COLLABORATIVE DESIGN AND LEARNING

Competence Building for Innovation

João Bento, José P. Duarte, Manuel V. Heitor, William J. Mitchell

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This book includes a set of original contributions aimed at discussing and capturing new trends in design education and practice in a way that fosters creative communities through joint efforts and integrated actions on innovation and competence building. It was prepared and edited following a meeting organized in the Portuguese Pavilion at the Hannover 2000 World Exhibition, on September 11, 2000, which was conceived under the theme *Collaborative Design and Learning: Competence Building for Innovation.* Then, the work associated with the preparation of the book brought together many experts in leading universities and design studios worldwide who have committed to explore new forms of design education and practice.

The experiences considered throughout the book are usually provided through global classrooms, which consist of a learning environment in which multiple sites distributed around the world share an educational experience with the ultimate goal of creating new architectural or engineering designs. This has been possible due to advances in information and communication technologies, and the technologies used include video-teleconference and other Internet-based groupware. In this context, "virtual teams" have been associated with the emergence of distributed cross-organizational arrangements, which involve people from different organizations who work in different places. The result is a process of entrepreneurial learning, through which the acquisition of new knowledge is followed by living and experiencing entrepreneurial environments, in order to facilitate the creation of new knowledge.

Thanks are due to many individuals and institutions that helped in various ways to bring this project to fruition. We thank the chapter authors for sharing their insights and perspectives on a range of important topics regarding collaborative design. We are grateful to our colleagues, members of the Hannover conference's Organizing and Programme Committees for planning the conference and for having made possible such a high-level forum. A special acknowledgment goes to Simoneta Luz Afonso and colleagues at the Portuguese Pavilion, who made the conference possible. The support of Luís Magalhães, President of the Portuguese Science and Technology Foundation at the time of the Hannover Exhibition and of the Portuguese Ministry of Science and Technology, are much appreciated. And we are grateful to those who so effectively managed the event, in particular the staff at the Centre for Innovation, Technology, and Policy Research, http://in3.dem.ist.utl.pt, Lisbon, Portugal. Finally, we are especially grateful for the dedicated and excellent publication effort of Miguel Silveiro, also at the Centre for Innovation, Technology, and Policy Research, at IST, Lisbon and of Katie Chase, Project Editor at Greenwood Publishing Group.

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Introduction:
...in the Way of a *Manifesto*: Competence Building for Innovation

Manuel V. Heitor

This book is based on the presentation and discussion of new perspectives aimed at creating and promoting design capabilities and new skills on engineering, architecture, and construction leading to creative communities and taking advantage of new information and communication systems. The analysis is based on long-distance design education and practice, including the discussion of case studies on collaborative learning and virtual teaming, with emphasis on transdisciplinary projects. The mechanisms used are networks that link people, and students in particular, with different backgrounds, aiming at increasing their ability to cope with emerging challenges through collaborative learning.

It should be noted that we normally think about knowledge as personal and individual. But it can also be embedded in regions and organizations and, as noted by Conceição, Heitor, and Lundvall (2003), the shared routines, the common communication codes and the formation of social relationships within teams may be regarded as different ways of embodying knowledge in collective units. This concept is examined in this book in the shape of long-distance learning networks, the existence of which will contribute to building new attitudes and will, as we contend later, definitively transform universities and education in general.

BUILDING A VISION: ENABLING THE FUTURE OF ENGINEERING DESIGN FOR HUMAN DEVELOPMENT THROUGH DISCOVERY, LEARNING, AND INNOVATION

At the onset of the twentieth century few could have guessed the importance that the then-nascent technological disciplines would have in the improvement of the quality of life over the ensuing century. As we enter the twenty-first century, the promise of further improvements based on new and deeper applications of information and communication technologies, and engineering systems in general, is a reason for optimism. Although it is difficult to forecast the exact shape and form that the technical disciplines of the future will assume, it is safe to say that there are a number of challenges for which engineering design can provide at least a partial response. The vision supporting this book is based on an identification of some of those challenges that, although specific to engineering, architecture, and construction, must be understood within a context in which the integration of collaborative learning procedures in an increasingly open and interconnected world cannot be ignored. The assumption is that several now-disjoint disciplines must join efforts to provide new solutions to mobilize *people*, *ideas*, and *tools* to help to catalyze the strong progress in information and communication technologies needed to secure the necessary creativity for a sustainable future worldwide.

DEVELOPING A CONCEPTUAL FRAMEWORK: INNOVATION AND COMPETENCE BUILDING

The scope of this book is all about programs aimed at creating and fostering new design and communication skills through the establishment of networks that link students and practitioners with different backgrounds and increase their ability to cope with emerging challenges. The object of most of the tools and projects described throughout the book was the design and construction of complex products or systems requiring particular precautions and specific production expertise in a way that has provided unique learning challenges and opportunities. The goal of creating bridges across disciplines, namely between architecture and engineering, to achieve these objectives is emphasized during the design process described in most of the chapters of parts II and III of the book and conceptually analyzed in the chapters of part I. This introductory chapter defines the scope of the book and attempts to clarify the boundaries of its intervention.

Learning as Knowledge Accumulation

The analysis presented in this chapter builds on previous research into the contemporary role of education based on recent conceptual approaches to economic growth, namely in terms of the accumulation of knowledge being the fundamental driving force behind growth (Conceição & Heitor, 1999). The process of knowledge accumulation is complex, however, and requires continuous adaptation if the "places of inquiry" described by Burton Clark (1995) are to be fostered.

The question that does arise is how education can be effectively oriented, transmitted, and assimilated to allow societies to move toward a sustainable and entrepreneurial world. Ehrenfeld (1998), for example, calls for a broad and deep design exercise that goes far beyond the positivist, disciplinary framework in which human beings create, categorize access, and apply knowledge today. Because the university is perhaps the major player in maintaining the current disciplinary structure, thinking and acting differently will indeed be the challenge to face. For example, as in the leading experiences in design process at the Southern California Institute (e.g., Reeve & Rotondi, 1997), exploring the relationship of ideas to systems thinking and modes of action should be central to engineering education.

Taking Pine and Gilmore's contentions (1999) about what they termed "the experience economy" and the role that experiences play in building stronger and more personal relationships in the corporate world, our argument is that universities must deliver authentic experiences to build and encourage sustainable and entrepreneurial growth. Pine and Gilmore explored the idea of experiences as a fourth economic offering, as distinct from services as services are from goods, but one that has until now gone largely unrecognized. Although services may be considered as a set of intangible activities carried out on behalf of a person, experiences are memorable events that engage that person in an individual way, so that they determine and guide transformations. Experiencing entrepreneurial processes at the university thus sets the stage for the societal transformations required to progress successfully toward entrepreneurship.

The formal evidence presented in the various chapters of this book and the general perception that ideas and knowledge are becoming more important than material things has, naturally, been the focus of several conceptual studies. Several issues have been analyzed, from the definition of knowledge, to its economic impact, to the processes by which knowledge is created, diffused, and used (e.g., Ancori, Bureth, & Cohendet, 2000; Conceição et al., 1998; Foray & Lundvall, 1996). Common to all these approaches is the idea described earlier that learning is vital to growth because it consists of the process of new knowledge accumulation.

The concept that the ability of human beings to learn is at the heart of development is not new. In fact, it can certainly be said that human competence in creating knowledge has been the crucial factor for development in any society, at any historical moment, as extensively discussed by Conceição et al. (1998). These authors remind us that knowledge has very specific characteristics that make it economically different from physical objects. Taking individual human beings as the unit of analysis and considering knowledge as all that is nonphysical (i.e., all that is human and intangible in nature, as defined by Nelson & Romer, 1996), it can be divided into two categories:

- *Software*: knowledge that is codified and is stored outside the human brain, in, say, papers, CD-ROMs, computer hard-drives, papers, blueprints, and so on
- *Wetware:* the knowledge stored in the wet computer of the human brain, including beliefs, skills, and talents, among other things

The key distinction between *wetware* and *software* is that the latter is codified, whereas the former is tacit. Foray and Lundvall (1996) proceed to establish a finer classification of these two broad categories. Within *codified software,* they distinguish between

- Know-what: knowledge about facts, in the sense that is normally associated with the word *information* (How many people live in New York? When was the Battle of Waterloo fought?)
- Know-why: knowledge about scientific principles and laws of nature, underlying technological progress, and product and process development

Within the more *tacit wetware,* more difficult to measure and to codify, Foray and Lundvall differentiate between

- Know-how: knowledge associated with *skills* or the *capacity to execute something,* which is typically developed and maintained within an individual's brain (a skilled worker, an experienced businessman)

- Know-who: knowledge about *who knows* what and *who knows* how to do what, being associated with the formation of special *social relationships* that give access to experts and use their knowledge effectively

It is clear that, as recently discussed by Malerba and Orsenigo (2000), although the distinction between *tacit* and *codified* knowledge is indeed very important, what is interesting to consider is the interaction between the various pieces of (tacit and codified) knowledge. This must consider complementary learning processes, namely bringing together formal processes of teaching and research, with informal processes of learning-by-doing and learning-by-interacting. These processes are those particularly considered within the scope of the various projects described in this book, through the experience of implementing design strategies (i.e., learning-by-doing) together with the facilitation of interactive networks (i.e., learning-by-interacting).

The role of different mechanisms for learning about new designs and the challenges facing new product development have recently been subject of increased attention by both research communities and major consultant firms, leading to a common result about the need to enhance and foster information flows and interactive skills among designers and practitioners. For example, Salter and Gann (2003) have looked at project-based firms in the construction industry and shown that engineering designers involved in complex, nonroutine design processes rely heavily on face-to-face conversations with other designers for solving problems and developing new innovative ideas. Also, Holman, Kass, and Keeling. (2003) argue that product-development companies must now turn their attention to building a more "nimble and flexible product-development organization." Their analysis has included medical equipment and other complex product-based companies and has shown the need to focus on information flows through improved information management rather than processes.

It should be noted that we consider knowledge beyond its personal and individual characteristics, and as noted by Lundvall (2002), the formation of social relationships within teams may be regarded as different ways of embodying knowledge in collective units. This concept is important because the production of intellectual capital (learning) is strongly dependent on social capital—"the social capability of citizens and workers to collaborate to allow a country or region to move forward in the process of development" (Coleman, 1988). In fact, how new forms of social capital can be created and accumulated is a major issue in the emerging learning societies, as Putnam (1993), Conceição et al. (2000), OECD (2000), and others have argued.

Learning for Change: Innovation and Competence Building

The process of learning, as the process of knowledge accumulation mentioned earlier, is based on the hypothesis that over recent decades, an acceleration of both knowledge creation and knowledge destruction has taken place (Conceição et al., 2003). The analysis calls for the need to promote innovation as the way in which firms and entrepreneurs create value by exploiting change (Conceição & Heitor, 2000). Change can be associated with technological advances, but it can also be linked to new organizational forms, modifications of the regulatory framework of industry, shifts in consumer tastes, changes in demographic makeup, or even in major alterations in global geopolitics. In this context, McKnight, Vaaler, and Katz (2000) build on Schumpeter's concept of "creative destruction," whereby innovations would destroy existing technologies and methods of production only to be assaulted themselves by imitative rival products with newer, more efficient configurations. The rapidly accelerating pace of regulatory, technical, and business innovation, which is "destroying" old regimes and creating in their place more exciting though less-predictable scenarios, accentuates the topic's importance.

In addition, learning for change implies that individuals as well as firms need to update their skills more often than before, because the problems they face will be changing more rapidly than before. Therefore, what constitutes success is not so much having access to a stock of knowledge as, rather, possession of the ability to learn and forget rapidly, for old ways of doing things sometimes get in the way of learning new ways.

In this context, the work of Lundvall and Nielsen (1999) shows that there is a strong synergy between the introduction of new forms of organization and the performance and innovative capacity of firms. Establishing the firm as a learning organization, as characterized by decentralized responsibility and teamwork, among other aspects (e.g., mobility of employees, investment in training), has a positive impact on a series of performance variables and innovative capacity in terms of new products. Their research also shows that success in terms of innovation is even greater when such a strategy is combined with active networking in relation to customers, suppliers, and knowledge institutions.

Our conclusion is that a new kind of integrated *innovation and competence-building* strategy is needed, and that such a strategy should take into account how to combine formal processes of teaching and research with the development of new skills through the experience of implementing design strategies and network positioning.

The chapters included in this volume clearly highlight the link between competence (skills, education) and innovation (technological change) toward inclusive learning. The connection between education, skills, and competence, on the one hand, and the learning society, on the other, must consider the manifold interconnections between competence and the learning society and links them with the broader context of the anxieties and concerns, hopes and expectations that we live with today.

An important issue is to know what it takes to be part of the learning society. We may not know exactly what the learning society is, but we do know that there are requirements to be part of it. We need, in particular, to build competence, of which skills are a part. However, for some cases, the need for new skills is not associated with technological change, but with an organizational change, and the new skills provided are not particularly intensive in specialized knowledge. It is important to stress this point because the discussion can easily be drawn into the skill-biased technological change discussion. Naturally, technological change does indeed play a role in increasing the demand for a higher order of skills, but there are other elements of change driving this demand. What is hardly questionable is that those that do not possess the skills nor the ability or possibility to acquire them become excluded.

Carneiro (2003) is particularly effective in presenting a clear definition of competence: "Instead of requiring a skill, which they see as still too narrowly linked to the idea of practical know-how, employers are seeking competence, a mix, specific to each individual, of skill in the strict sense of the term, acquired through technical and vocational training, of social behaviour, of an aptitude for teamwork, and of initiative and a readiness to take risks." Many instances can be given about the importance of building competence. Carneiro chooses a few, from the resurgence of the "human capital" literature—which has percolated to the language of everyday life—to the very idea of the knowledge-based economy—the commonplace concept that we referred to earlier in this introductory chapter.

Carneiro also explores the implications of the importance of competence building to the individual and to the dynamics of innovation and presents the idea that it is important to nurture vocational identities. Vocational identities include, but are not limited to, the individual knowledge base and the portfolio of competencies. These include attitudes revealing a preference for learning, in which competence building also considers aspects such as the strengthening of identity and a foundation of emotional stability and self-esteem. Thus, the idea of competence building is, in this context, viewed in a much more comprehensive and deeper way, encompassing the individual in several dimensions. The link with innovation is made through the distinction between adaptive and generative learning, which are connected with the Schumpeterian cycle of creative destruction.

THE STRATEGY: PROMOTING CREATIVITY FOR INNOVATION

The preceding analysis recognizes the great importance of the tacit dimension of the learning process, examined in this book in the context of taking part in the design of complex products and systems and making use of learning networks. The importance of designing discovery approaches that go beyond scientific method has been widely discussed, and in this book, we attempt to emphasize strategies for stimulating a creative attitude toward innovation. For example, consumer products with complex, idiosyncratically curved surfaces are becoming increasingly common in the marketplace. It is now usual for designers of products such as cars and electronic consumer goods to use free-form surfaces that cannot be adequately represented in two-dimensional drawings. As a result of this, computers, three-dimensional CAD systems in particular, have become essential design tools.

Current software allows designers to quickly create flawless, styled shapes and surfaces. Interactive shape deformation functions enable users to match, smooth, and trim curves and surfaces intuitively. Real-time quality checking is possible through extensive curve and surface dynamic diagnosis. Because the systems generally offer a math-free representation, designers can directly manipulate the bodies and associatively reproduce the surface changes on other geometry.

Geometry is not merely a collection of shapes, but also a strict technical discipline with its own historical development and logic. For example, in architecture today there is an explosion of new geometries available to designers, yet these are being understood critically as just another set of the same shapes we have seen before. In the words of Frank Gehry (as cited by Van Bruggen, 1997), "To say that a building has to have a certain kind of architectural attitude to be a building is too limiting, so the best thing to do is to make the sculptural functional in terms of use. If you can translate the beauty of sculpture into the building... whatever it does to give movement and feeling, that's where the innovation in architecture is." And in his view, it was Le Corbusier who explored innovation in materials and techniques "in a plastic sense beyond architecture, taking it out of its limits."

In fact, shifting from an ideal space of inert coordinates to an active space of interactions implies a move from autonomous purity to structural, programmatic, material, and contextual specificity. To quote Frank Gehry again: "Solving all the functional problems is an intellectual exercise. That is a different part of my brain. It's not less, it's just different. And I make a value out of solving all those problems, dealing with the context and the client and finding my moment of truth after I understand the problem."

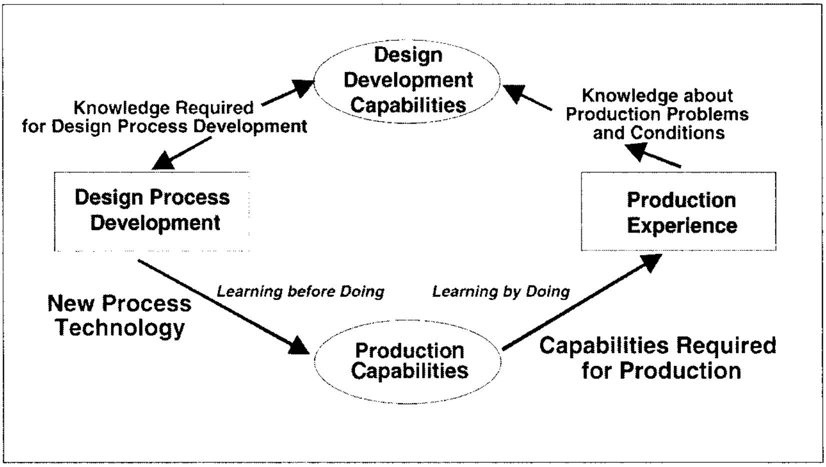
In general, the analysis shows that in the emerging learning economies, the secret of success is a combination of expertise in a productive manner. This breaks with existing concepts of time, space, mass, and behavior. In fact, current technological systems are complex and carry many levels of cultural meaning, which per se bring new challenges and opportunities for innovative design processes.

In this context, the positioning of innovative education and research institutes is extremely interesting. This is based on the idea that technological innovation is chiefly a social activity and that a technical university with a multidisciplinary orientation provides an "important democratic function in the critical acceptance and social embedding of the many products of technical innovations," according to Ed Taverne (1998).

The building up of design capabilities involves multiple learning routes, including formal and informal processes, where the roles of design development and production experience are simultaneously important, as schematically represented in Figure 1. The lower half of this diagram considers avenues through which production capabilities evolve. They include development projects, which are associated with the launch of new products, and production experience, which provides capabilities for new product development.

The diagram is symmetric because both development projects and production experience have dual roles as both users and producers of capabilities. This framework raises interesting issues in the development of design and production capabilities, and here our attention is focused on "learning before doing" in terms of the product development process itself. However, the learning-by-doing component is particularly important in the process of network building, through experiencing long-distance interactions with students from different backgrounds.

Figure 1
Capabilities development for complex product design.



IMPLEMENTING THE LEARNING ENVIRONMENT: ANYWHERE, ANYTIME

Although we are still in a very early and limited stage of what Mitchell (1995) called "cities of bits," it is clear that we should use the opportunity to start establishing long-distance learning networks, which will help build a new attitude for entrepreneurs and will definitively transform universities (e.g., Sullivan, 2000). It is also clear that the increased integration of the world economy—globalization—not only facilitates this process, but also creates new challenges and expectations (Conceição et al., 2000).

In this context, this book reports on the development of various joint educational programs that have successfully implemented the idea of learning networks through the establishment of a learning environment in which multiple sites distributed around the world share an educational experience. In general, we consider fully distributed systems, in which learning is provided anytime, anyplace, and beyond a single organization, as schematically described in Figure 2. In this context, virtual teams have been associated with the emergence of distributed cross-organizational arrangements that involve people from different organizations working in different places. This has been made possible due to advances in information and communications technologies that have increased the ability of networking, and here we consider learning networks that lead to self-reinforcing learning cycles. In most of the cases reported in the chapters of

Figure 2
Teaming perspectives showing the "distributed cross-organizational" virtual teams used throughout most of the examples reported in this book.

SPACE/TIME	ORGANIZATION *Same*	ORGANIZATION *Different*
Same	**Collocated**	**Collocated Cross-Organizational**
Different	**Distributed**	**Distributed Cross-Organizational**

parts II and III of the book, the various sites were linked using Internet-based groupware and video-teleconference, different information technologies and telecommunications capabilities.

It should be noted that classical virtual teams combine people in different places and organizations with some need to function at the same time (synchronously), though not all of the time, of course. Most work combines a pattern of individual tasks and group tasks with time spent working alone and time spent working with others. For most virtual teams, synchronous interaction—shared time—is a scarce resource. Time creates a complication that not even instantaneous communication can solve. As the distance increases and more time zones are crossed, the window of synchronicity in the workday narrows.

The most extreme type of virtual team is one that is cross-organizational and that rarely, and in some cases never, meets in the course of its work. Without face-to-face time, this type of team tests the limits of dealing with contentious issues, but may shine in information-sharing and technical problem-solving tasks. As George Metes noted (1999): "... we see the balance of work shifting from stable, physically collocated functions to dynamic, competency-based, electronically collocated business networks: virtual teams that create value by synthesizing information and knowledge across geographies and organizations." The result is a process of entrepreneurial education, in which the acquisition of new knowledge is followed by living and experiencing entrepreneurial environments to facilitate the creation of new knowledge. The goal is to establish a learning triangle, integrating academic, vocational, and experimental activities.

In this context, and following Schmidt (1998) and others in the Lectures Notes edited by Ian Smith (1998), Bento (1999) identified the need to understand the cognitive needs of designers by focusing on the way information and knowledge are perceived, acquired, stored, and processed. Bento suggests the various modes of operation of an ideal virtual design studio as a function of time, space, and shared content, providing the evidence for considering diversified tools. In fact, as Manuel Castells (1996) suggested, "It is precisely because of the diversification, multimodality, and versatility of the new communication system that it is able to embrace and integrate all forms of expression, as well as the diversity of interests, values, and imaginations."

INTRODUCING THE MATERIAL INCLUDED IN THE BOOK

This book brings together experts from leading universities and design studios worldwide who aim to promote new design capabilities through collaborative and distance learning. The rationale for the book, as presented in this introductory chapter, derives from the fact that in the emerging knowledge economies, the required combination of expertise in a productive manner breaks with existing concepts of time, space, mass, and behavior. In fact, current technological systems are complex and carry many levels of cultural meaning. In this context, the renewal of both design education and practice systems is based on the idea that technological innovation is chiefly a social activity and that technical education with a multidisciplinary orientation provides an important role in the critical acceptance and social embedding of technical innovation outputs.

To overview the various challenges required to better understand these objectives, we have organized the remainder of this book into four parts. First, we discuss the conceptual background by including two chapters dealing with key ingredients that transform learning into creativity and on the major challenges that technical education is facing. Second, we present recent practices on the development of advanced tools and logistics for collaborative design, dealing with different applications in architecture, engineering, and construction in five chapters. Third, we present and discuss six different case studies, revealing a diversified range of experiences on collaborative design. Then the book concludes with a final chapter exploring new ideas for design studios to allow expanding our horizons about collaborative design.

Throughout the book, it is clear that the building up of design capabilities involves multiple learning routes, including formal and informal processes, in which the roles of design development and production experience are simultaneously important. Both development projects and production experience have dual roles as users and producers of capabilities. This framework raises interesting issues in the development of design and production capabilities, and the focus is on "learning before doing" in terms of the product development process itself. However, the "learning-by-doing" component is particularly important in the process of network building, through experiencing long-distance interactions with individuals with a different background.

The living environments considered throughout the book are usually provided through global classrooms, which consist of a learning environment in which multiple sites distributed around the world share an educational experience. This has been possible due to advances in information and communications technologies, which have increased networking capabilities. In this context, most of the experiences reported consider *learning networks*, that is, networks that lead to self-reinforcing learning cycles, with the ultimate goal of promoting new architectural and engineering designs.

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PART I
BUILDING A CONCEPTUAL FRAMEWORK

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Introductory Note

Manuel V. Heitor

The two chapters included in part I provide insight into the conceptual understanding of new perspectives aimed at creating and promoting design capabilities and new skills leading to innovation through creative communities. William Mitchell argues for the progressive establishment of creative communities and discusses key ingredients that transform learning into creativity. Then, Pedro Conceição and Manuel Heitor focus on major challenges technical education is facing and discuss university functions in light of new theoretical developments about the knowledge economy. These two chapters allow us to build on current understanding of the emerging *learning society*,[1] in that technical advances promoting network communities targeted to develop complex projects lead to new "reliable knowledge,"[2] but this requires a timely process of constant inquiry, involving individuals and organizations beyond the necessary infrastructures.

William Mitchell, in chapter 1, starts by discussing that the most obvious advantage of electronic remote collaboration is that it provides an efficient way of "aggregating specialized expertise" through "common access to project databases, compatible software tools, and advanced telecommunication capabilities." But he emphasizes that "it does little about the problems of creating trust and confidence, and of building intellectual and social capital for the long term," requiring the development and maintenance over weeks and months of "project-based learning communities" looking at a common and complex target. Long-term collaborations can provide a more permanent framework of online resource sharing, and the *ArchNet* community does provide a clear example of such an initiative, which brings *scale* and *diversity*, beyond *time*. Based on this example, Mitchell concludes by arguing that we should look beyond the popular idea of *learning communities* and seek to produce communities that "motivate and sustain creative discourse yielding original intellectual products such as architectural and engineering designs," the so-called *creative* communities.

Pedro Conceição and Manuel Heitor, in chapter 2, focus their attention on current challenges technical education and research is facing to help accomplish the communities discussed by William Mitchell. Their analysis shows that universities should foster an environment in which the results of learning-by-living can have economic impact, although one must not forget that the mission of the university must be preserved. Among the various organizational and strategic arrangements that universities have exhibited in the recent past, the unifying characteristic of those different arrangements is provided by the unique characteristics of "the university" as a societal environment for *exploration and interpretation of knowledge*. Exploring and interpreting knowledge are two sides of the learning process. Therefore, the authors attempted to look at the university as a *learning organization*, exploring its role in the broader context of the learning economy. Under this context, they describe a conceptual understanding of the relationship between *learning* and *economic prosperity*, emphasizing the critical role in understanding the complementary roles of research and development (R&D) and research and learning (R&L), the latter being accomplished through the systematic implementation and maintenance of design practices.

NOTES

1. See, for example, Conceição, Heitor, & Lundvall (2003).
2. As initially discussed by Ziman (1991).

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1

Challenges and Opportunities for Remote Collaborative Design

William J. Mitchell

Consider a typical scene from a traditional design studio, as illustrated in Figure 1.1. The participants in a discussion stand within a circle that is about two meters across. A drawing laid out at the center of the circle forms the focus of their discussion. Surrounding them, in an area maybe twenty meters in diameter, a large quantity of reference material is available for consultation. If any of the participants wish, they can break free from the discussion and retire to their private desks to work individually. This homely scene neatly poses the problem of remote collaborative design. What if the distances between participants are not a meter or two but thousands of kilometers? What if all the participants are not available to meet at the same time? What if reference materials and other resources are not gathered near at hand but are scattered across the entire globe? How can we make a studio work effectively under these conditions?

Early attempts at solving this problem through electronic telecommunication provoked reactions much like that of Dr. Johnson, when he encountered a dog walking on its hind legs. The amazing thing was not that the dog did it well, the crusty old critic remarked. It was that the dog did it at all. Similarly, it seemed sufficient accomplishment to overcome the numerous technical difficulties and to demonstrate that geographically distributed teams could work effectively with the support of new digital technology. But now the technology has matured, and we need to ask what it means to do it well. What are the advantages we should seek? How can we achieve them? What can we do that's not possible through more conventional means?

Figure 1.1
Typical scene from a traditional design studio. MIT Rotch Library Visual Collection.

AGGREGATING SPECIALIZED EXPERTISE

The most obvious advantage of electronic remote collaboration is that it provides an efficient way of aggregating specialized expertise. If you have a complex and demanding problem to solve, it is most unlikely that all the world's best specialists in every aspect of the problem are close at hand and ready to work on it. You must therefore devise some strategy for identifying relevant specialists and bringing them into the team. In addition to these human resources, you may also need access to highly specialized tools and equipment, production machinery, and so on.

One traditional strategy for providing the necessary human and material resources is to build a large-scale cross-disciplinary organization that covers all the relevant areas. This has been pursued by large architecture/engineering/construction firms. It also underlies, the very idea of the modern research university. It has been successful, but it also has some fundamental limitations. It requires an enormous investment of resources, it is not particularly flexible, and it becomes very inefficient when some of the specialties are not required on current projects but still must be kept in place. And, no matter how large, powerful, and prestigious an organization might be, it cannot be the world leader in *everything;* successful organizations learn to focus on what they do best, and flexibly tap into additional expertise by hiring consultants, forming strategic alliances, participating in multiorganization project teams, and so on.

Another common strategy is to create cross-disciplinary project teams. These are common in architecture and construction, in film production, and in other fields that require collaboration of experts for relatively short periods. This format is extremely flexible, and from that viewpoint is very attractive, but it has its own limitations. It takes time to build trust and mutual confidence among members of a new team. You cannot be certain of getting all the team members you really want, and it may be difficult and expensive to bring team members together in a suitable working environment. (That's why architects and consultants spend a lot of time traveling to meetings.) Furthermore, this simple strategy creates few opportunities to accumulate intellectual and social capital for the long term.

An obvious alternative to co-locating members of a project team is to link them together remotely through common access to project databases, compatible software tools, and advanced telecommunication capabilities such as videoconferencing. The associated research problems are mainly of a basic technical character, and most are not specific to the domain of design collaboration. They mostly focus on issues of achieving sufficiently speedy, reliable, and inexpensive linkage, of organizing online databases, of structuring interfaces, and of coordinating standards and conventions.

Electronic remote collaboration reduces the friction of distance, potentially provides access to a global talent pool, and will be increasingly efficient as digital telecommunications infrastructure and groupware software continue to improve. But, in itself, it does little to solve the problems of creating trust and confidence and of building intellectual and social capital for the long term. Furthermore, it creates some new problems of its own; how, for example, do you locate, contact, and enter into a working relationship with someone out there in the global talent pool?

PROJECT-BASED LEARNING COMMUNITIES

To overcome some of these difficulties, it is useful to look beyond merely aggregating expertise (which turns out to be insufficient) and to create project-based learning communities. This has, in fact, been the focus of most efforts to run virtual design studios—including the MIT/Portugal glass chair design studio.[1]

Generally, in these projects, the teams are initially put together by making use of existing personal contacts and established institutional relationships. Motivation to interact intensively is effectively provided by the need to solve a challenging problem in a short time—a task that is well beyond the unaided capabilities of any individual participant. E-mail, videoconferencing, and the Web provide the means of electronic interaction. Extension of the project over weeks or months creates the opportunity (though usually not without some pain) to build trust and effective working relationships among team members who have never met face-to-face. And participants that collaborate to solve design problems in these sorts of projects have certainly succeeded in learning a great deal from remote team members who bring different expertise and cultural backgrounds and approach problems in different ways.

Over the course of such projects, databases of relevant background information and design proposals accumulate and can be made conveniently accessible via the Web. But because of the short-term project orientation, there is little opportunity to build durable intellectual and social capital. The content storage and community interaction facilities are typically ad hoc and without institutional support for long-term maintenance once the project has ended.

LONG-TERM, LARGE-SCALE LEARNING COMMUNITIES

Many of these limitations of project-based collaborations can be overcome by providing a broader, more permanent framework of online resource sharing, community support, and collaboration facilities. The ArchNet system—based at MIT and serving the needs of architects and planners in the developing world—is now a well-developed example of such a framework.

ArchNet is an online, Web-based community in which members have personal workspaces that provide individually tailored entry points to the system and storage for personal work and resource collections (image collections, bibliography entries, and so on). Associated with each personal workspace is a self-created and self-maintained member profile that provides a means of self-representation within the community (in as much or as little detail as one might wish). This profile may include a photograph, contact information, biographic and publication details, and a list of interests. In addition, fairly sophisticated access controls allow members to make personal material publicly available within the community or to specified subsets of the community. You can think of one of these workspaces as a personal studio desk at which reference materials and projects in process are stored; some materials are locked up in drawers and files and others are pinned up on public display, and everyone knows they can find you there.

Besides personal workspaces there are also similarly structured institutional workspaces. These provide the opportunity for schools, research institutes, design offices, and the like to represent themselves and to put their creative output on display.

The core attraction of ArchNet, and the focus of the ArchNet community, is a large-scale digital library containing a great deal of valuable material—most of which would otherwise be difficult to access, particularly in the context of developing countries. This library contains texts (papers, journals, books), digital images, digital audio and video, and CAD files. One part of it is created and maintained centrally under tight editorial control that guarantees a high level of quality and integrity; the major sponsoring organizations stand firmly and visibly behind this part. A second part is created and maintained in a more decentralized way by participating institutions operating in bottom-up, open-source fashion; these institutions are responsible for the quality and integrity of their own contributions, and they put them out from their own workspaces, under their own names. A third part of the digital library is created and maintained in an even more highly decentralized fashion, with only the most minimal central editorial controls, by individuals operating from their personal workspaces. Material may migrate from level to level within this structure; a text might begin as a working paper residing at a personal workspace, develop into a research report offered by an institutional workspace, and eventually be accepted by one of the centrally edited online journals.

Thus the ArchNet community is much like the ancient Library of Alexandria—a diverse, cosmopolitan community of scholars attracted by and clustering around a unique and continually growing collection of intellectual resources.

ENCOURAGING AND SUSTAINING COMMUNITY LIFE

Just as Alexandria provided public spaces and social events to bring scholars together to interact and participate in community life, so ArchNet provides the online equivalents. By searching member profiles, you can discover and contact members who have interests that match your own or capabilities that you may need to access. By posting to and accessing various community notice boards—job listings, event calendars, and so on—you can conveniently remain abreast of what is going on. And, by participating in online forums, you can directly engage in the discourses that animate the community.

Of course, it would be technically possible to offer all these capabilities within the context of a short-term project. But the investment required to do this well would rarely be worthwhile. By taking care of the overhead of sustaining an active online community, ArchNet attracts the ongoing attention of members, makes knowledge and resources visible, creates the conditions of trust and accountability, and thus establishes firm ground for successful online collaboration.

Scale and diversity matter here. If an online community is to be culturally vital and mind-expanding like a big city, not constricting like a dull provincial town, it needs to attract and engage sufficient breadth of talent. The more active members ArchNet attracts, the more valuable it becomes to all the members.

SUPPORTING COLLABORATIVE PROJECTS

ArchNet not only supports accumulating and accessing knowledge, it also encourages active *use* of that knowledge for creative purposes by providing online collaborative workspaces. These are much like the Web-based, collaborative workspaces that have been built for many collaborative design projects in the past. They incorporate a standard, robust set of capabilities for posting and organizing design work and for critically discussing it.

By making collaborative workspace facilities available to a large community and by sharing the cost of software tools and reference databases over many projects, ArchNet can justify a higher level of investment in collaborative workspace capabilities than is normally possible within the framework of budget-constrained individual projects. More importantly, the long-term life of ArchNet allows collaborative workspaces to remain online and available permanently, and thus to become part of the community's growing stock of intellectual capital.

The long-term view suggests that membership of the community should not be affected by changes in status such as graduation from a degree program, relocation to another city, or movement to a new job. At MIT we are planning to address this through a new project—ArchNet.MIT—through which architecture students will acquire "lifetime" personal workspaces on ArchNet. They will create these workspaces when they enter a degree program, use them to store their ongoing studio and other work, utilize them to present online portfolios when they look for a job, retain them throughout their careers as alumni, and continually employ them as entry points to the expanding ArchNet community.

In many ways, then, ArchNet.MIT recaptures the ancient idea—exemplified by the Cambridge and Oxford colleges in their original, semi-monastic form—that entry into a community of scholars was a lifetime thing. In the old days it meant living within the college walls for the rest of your years. Today that is no longer desirable or possible for most people, but the new, electronic equivalent provides many of the key advantages without the disadvantages.

FROM LEARNING COMMUNITIES TO CREATIVE COMMUNITIES

You can describe ArchNet (fashionably) as a learning community, and that sounds satisfying.

If you hang around universities long enough, you might start to believe that learning is an end in itself. But it's not, of course. At one level it's a strategy for coping with the exigencies of daily life and adapting to change. At another level it's a way of achieving the capacity to be creative. So, I would argue, we should look beyond the popular idea of learning communities and seek to produce *creative* communities—that is, communities that motivate and sustain creative discourse yielding original intellectual products such as architectural and engineering designs, works of art and literature, scientific discoveries, and so on. How can we accomplish this?

I doubt whether anyone knows for sure, but we can at least articulate some plausible ideas that can form the basis for experimental implementations. Creativity seems to depend on the capacity to discover and exploit unexpected connections. Thus a creative community should support vigorous discourse that makes a multitude of ideas and viewpoints known. It should provide convenient, low-risk ways to identify and contact people with relevant interests or capabilities to offer. It should allow ideas to be challenged and debated. It should not be constrained by rigid expectations, role definitions, procedures, and customs. These are the sorts of structural characteristics (not those of rigid e-commerce systems) that we must pursue and support, especially in communities such as ArchNet, if we want creativity to flourish.

CONCLUSION

The greatest opportunity and most exciting challenge of remote collaborative design is not merely the successful completion of some exciting projects (worthwhile though that may be), but the establishment and maintenance of ongoing creative communities that are even more vibrant and successful than the great examples of the past. This will require a foundation of excellent computing and telecommunication infrastructure and software tools. It will demand the continued maintenance of large-scale, long-term learning communities such as ArchNet. It will depend on our ability to create vigorous discourse within these communities and to discover and exploit unexpected fruitful connections among participating individuals and organizations—the key ingredients that transform learning into creativity. And it will support a growing number of remote collaborations that connect expertise in new ways to produce surprising and beautiful results—such as the MIT/Portugal glass chair.

NOTE

1. See chapter 9. Other case studies of many such projects are provided in part III.

2

Learning through Interaction: Perspectives for the University

Pedro Conceição and Manuel V. Heitor

The unique characteristics of "the university" as a societal environment for exploration and interpretation of knowledge are discussed in this chapter to better frame the need to rethink technical education and to better accommodate design training and collaborative practices into current university activities. We begin by describing traditional perspectives on the impact of universities for economic growth, focusing our attention on the research university. Secondly, we discuss recent conceptual advances that shed new light on the importance of learning processes for economic development. Based on these conceptual advances, we propose a model for economic development based on learning, broadly defined as the process through which knowledge can be accumulated. Under this context, we describe a conceptual understanding of the relationship between *learning* and *economic prosperity*, emphasizing the critical role in understanding the complementary aspects of research and development, R&D, and of research and learning, R&L, the latter being accomplished through the systematic implementation and maintenance of design practices and interactive routines. Finally, we derive implications and identify main issues to be considered for university renewal. They clearly consider a better compromise between design and science practice, preserving the institutional integrity of the university, in order to safeguard the existence in society of an institutional place where the exploration and interpretation of knowledge drives, sometimes in concealed ways, the process of social and economic development through competence building.

INTRODUCTION

Which limiting factors are conditioning the role of the university as a major driver of innovation in the current socioeconomic context? This is the main question we attempt to address in this chapter on the basis of the empirical evidence and analysis presented throughout this book. The analysis encompasses the understanding of the mission of the university, which is considered here in the context of the "Research University."

Traditionally, universities have been considered to be primarily part of an educational system (Rosenberg, 2002). In the nineteenth century, Humboldt developed in Germany a new paradigm of university, where not only teaching, but also research, was performed. The idea of a research university was exported to other countries, namely the United States, where it has had an outstanding impact on industrial development (Rosenberg & Nelson, 1996). Nowadays, the university is an integral part of the science, technology, and innovation system (Conceição & Heitor, 1999). In this context, the first aim of this chapter is to argue that research and teaching activities should be given equal weight, especially at a time where knowledge creation is increasingly important to the immaterial-based economies that are emerging. Although this may seem like a platitude, the fact is that in countries such as those in catching-up phases (Portugal being a clear example), the social standing of research in universities is still undervalued in comparison with education.

However, the second and most important aim of this chapter is to argue that it is not enough to consider a better compromise between education and research, but to better understand the different research functions and to argue for the need to broaden the scope of learning routines based on design training and practices. The practical implication of this point for technical education includes the need to integrate science- and design-based credits into current curricula, making a better use of the opportunities made available by information and communication technologies and groupware methodologies.

Our analysis is based on the way organizations deal with knowledge to foster innovative attitudes, that is, the way organizations promote "learning," where learning is understood as the mechanisms through which knowledge is produced and diffused. In this context, Salter and Gann (2003) have sown that engineering designers involved in complex, non-routine design processes in project-based firms in the construction industry rely heavily on face-to-face conversations with other designers to solve problems and develop new innovative ideas. Also, Holman, Kaas, and

Keeling (2003) have analyzed medical-equipment and other complex product-based companies and shown the need to focus on information flows through improved information management rather than processes, arguing that product-development companies must now turn their attention to building more flexible organizations. In fact, the role of different mechanisms for learning about new designs and the challenges facing new product development have recently been the subject of increased attention by both research communities and major consultant firms, leading to the common result about the need to enhance and foster information flows and interactive skills among designers and practitioners.

We start by presenting in the next section anecdotal evidence on the complexity of the university's contribution to development. We show that it is important to go beyond the linearity of the standard models of analyzing university impact, and we make explicit our understanding of learning as a process of knowledge accumulation by discussing, in the third section, a new model of economic development. In the fourth section we discuss the application of the model to the context of the research university and suggest new policy orientations that will lead to university renewal. Finally, in the concluding section we summarize the main arguments of the chapter in terms of the critical issues facing universities to allow them be considered critical actors fostering competence building for innovation.

PERSPECTIVES ON THE CONTRIBUTION OF UNIVERSITIES TO SOCIAL AND ECONOMIC DEVELOPMENT

Universities have as their primary role to provide higher education and to develop research activities (Caraça, Conceição, & Heitor, 2000; Lucas, 1996). The recent university investments in establishing closer links with the surrounding community, namely by seeking to exploit its scientific and technological potential (Brooks, 1993), has led to the recognition that beyond the university's traditional roles in education and research, a wide range of other activities, usually grouped together under the classification of "provision of services" or "links to society," are now part of the university's mission (Rosenberg & Nelson, 1996).

Nonetheless, the contribution of universities to economic development has been studied within the context of what we will call the "standard model," for which ideas and human capital flow linearly to society, which in return finances universities and provides feedback information. Linear models are both powerful and dangerous. They are powerful because they are simple and parsimonious. Mathematical modeling is easily developed as an input-process-output set of equations, which in economics results in production functions. Their danger, ironically, stems from the power they provide: This kind of modeling necessarily leaves out much of the complexity of the social and economic processes.

The evolution of theories of innovation is illustrative of both the power and limitations of linear models. Schumpeter's understanding of innovation is implicitly linear. The entrepreneur—or a large corporation, in a later refinement—captures ideas that are introduced in the market as innovations. This perspective still informs much of the modeling done in economics.[1] The linear models of innovation were also powerful in influencing policy making because they legitimized huge public and private investments in R&D as a way to achieve innovations. However, the interactive models of innovation made more justice to the complexity of the innovation process, proposing that R&D is just part of a complex process, and innovations do not necessarily come linearly as a result of research efforts. This revision called for integrative policies joining R&D, industrial, financial, and other aspects to achieve innovation.

Nevertheless, the standard model of the contribution of universities to economic development is rarely explicitly acknowledged, but is implicit in most studies. In the following paragraphs we illustrate this point by showing how the model is implicit in mainstream economic analysis, and how new theoretical advances try to go beyond the linearity of the "standard model." Then, we extend the insights provided by these new advances and propose a framework toward the establishment of a new model of economic development, based on learning, broadly understood as a process of knowledge accumulation.

The Impact of Education

Increased participation in university education is a valuable asset for economic growth. Most studies defend this position by following the growth decomposing strategy first developed by Solow (1956, 1957). This strategy implicitly follows the linear model, and scholars who use it rarely acknowledge it as an assumption. Our aim will be to illustrate how the linear perspective on the impact of university education came to be incorporated in models of growth. We start with an example of an empirical application in the realm of growth accounting.

Solow departs from an aggregate neoclassical production function, representing the way an economy produces output by processing physical capital, labor, and other factors of production. The contribution of these "other factors" was initially named the residual and was identified by Solow with technological change. But this was an arbitrary claim by Solow, as he acknowledged. More generally, one can argue that the residual is associated with increases in productivity that contribute to the economic growth unaccounted for by the accumulation of the factors of production capital and labor.

The human capital theorists (Becker, 1993; Schultz, 1960) suggested a further refinement of the Solow model. These theories argue that the impact of labor on economic growth depends on the quality of the workforce. The better qualified the workforce, the higher its human capital, the largest the impact of the workforce. Using these arguments, the Solow production function can be expressed (choosing an explicit Cobb-Douglas type functional form, following Mankiw, Romer, & Weil, 1992):

$$(1) \quad Y(t) = A(t) \cdot [K(t)]^{\alpha K} \cdot [L(t)]^{\alpha L} \cdot [H(t)]^{\alpha H}$$

where Y is output, K capital, L labor, and H human capital. The exponents indicate the shares of income. Most accounts attribute $\alpha_K = 0.4$ to capital, and, consequently, $\alpha_L + \alpha_H = 0.6$ to wages. The challenge is to determine the part attributable to human capital in the share of wages, or in other words, to determine the impact of human capital on economic growth.

An example on how the impact of human capital on growth can be computed is taken from Lant Pritchett's (1995) provocative paper. The assumption is that there is a 10 percent wage increase for every additional year of education. This estimate is based on studies on the impact of education on individual people's income (Psacharopoulos, 1993).

We are more interested here in the thought process through which the impact of education is extracted in the economic growth literature than in the specific assumptions, that are, themselves, the subject to a large literature.

Table 2.1 illustrates the way the computation of the shares of return from human capital is performed. Assuming that there is a wage increment to education, the share of human capital is a function of the wage premia for successive levels of education. Thus, people with no schooling set the standard (there is no wage premia), and for each additional year of schooling there is a wage increase. Under the assumption of the study by Pritchett, people with some primary education earn 1.4 times what those with no schooling do. For complete primary the ratio is 1.97, some secondary 2.77, secondary 3.9, some tertiary 5.47, and tertiary 7.69. With the relative wage

Table 2.1
Share of Return to Human Capital by Region

Share of Workforce by Educational Attainment 1985

	Developing Countries	Africa	Latin America	South Asia	OECD Countries
No Schooling	49.7%	48.1%	22.4%	69.0%	3.3%
Some Primary	21.3	33.2	43.4	8.9	19.4
Primary Complete	10.1	8.5	13.2	4.8	18.3
Some Secondary	8.7	7.7	8.4	8.8	20.7
Secondary	5.9	1.6	5.5	5.3	20.1
Some Tertiary	1.4	0.2	2.5	0.9	7.7
Tertiary	3.0	0.8	4.6	2.3	10.5
Average Years of Schooling	3.56	2.67	4.47	2.81	8.88
Share of Return to Human Captial	0.36	0.26	0.43	0.30	0.62

Source: Pritchett (1995)

premia by educational attainment and having the partition of the workforce by years of schooling (Barro, 1993), the shares of human capital can be easily calculated, as indicated in Table 2.1. Additionally, average years of schooling are also included. The shares vary from .26 to .62. Because the contribution for growth of total wages is .6, then the contribution of human capital is between .16 in sub-Saharan Africa and .37 in the OECD.

From Table 2.1 we can see that university education provides an almost eight-fold increase premium in wages. As a policy implication, a way to maximize the impact of human capital would be to increase the proportion of the workforce with tertiary education. Although this policy prescription is welcomed, it is unlikely, per se, to solve the developmental problems of, say, sub-Saharan Africa. This is an example of the limitations of a direct reading of the analysis just presented.

More than the substantive conclusions, we stress again that we are interested here in discussing the conceptual understanding underneath these studies. First, we should note how the departure point is a production function, implying an underlying model of the type input–process–output. Inputs are human and physical capital and labor. The process is represented by the production function, which transforms the inputs into the output of the economy.

Even accepting a production function framework, note that human capital production is exogenous to the process of growth. The institutions that provide human capital, namely schools and universities, not to mention the learning-by-doing activities, are absent. In this framework, representing the economic impact of universities is only a measure of the graduates and registered students. This takes us back to the standard model, which is, implicitly, the model that guides these studies.

The use of a production function, however, extends also to microapproaches. Examples include Brovender (1974), Verry and Layard (1975), Hanushek (1986), Hare and Wyatt (1988), and Dundar and Lewis (1995). These references provide a rich sampling over time, journals, and even academic fields, on microstudies on the economics of education and, particularly, the way schools in general and universities in particular function. In all of these references, a depiction of the standard model as the conceptual framework underlying the analysis would have been most appropriate. In its absence, it is clearly implicit in the discussion.

The Impact of Research

When trying to determine the impact of research, most mainstream studies use a modified form of the Solow production function, as in education. Again using a recent example from the literature, Sakurai, Ioannidis, and Papaconstantinou (1996) took a production function of the form:[2]

$$(2) \quad Y(t) = A(t) \cdot [R(t)]^{\lambda} \cdot [L(t)]^{\alpha L} \cdot [K(t)]^{\alpha K}$$

Here the meaning of the variables is as in (1), and R represents the stock of research. The way the impact of research is measured from (2) is slightly less direct and intuitive than in (1), except for the trained economist. The key is also in the exponents, more specifically in λ, which is the output elasticity of R&D. Therefore, λ gives the percentage change in output that results from a percentage change in research. Table 2.2 summarizes the estimates that resulted from a number of studies, which show typically that a 1 percent increase in research leads to an increase in output ranging from 0.05 percent and 0.1 percent in output. Although it is clear that this mathematical analysis is misleading and the formula above reductionistic, the evidence from Table 2.2 is also that policy issues have been currently raised based on this type of data.

An alternative way to look at the impact of research is by determining rates of return to research after computing costs and benefits. Rates of return are useful because they differentiate between public and private

Table 2.2
Estimates of Output Elasticity of Research

Nation	Study	Elasticity (λ)
US	*Griliches (1980)	0–7%
	+Patel and Soete (1988)	6%
	*Nadiri and Prucha (1990)	24%
Japan	*Mansfield (1988)	42%
	+Patel and Soete (1988)	37%
France	+Patel and Soete (1988)	13%
West Germany	+Patel and Soete (1988)	21%
United Kingdom	+Patel and Soete (1988)	7%
	*Cameron (1995)	0–27%
G7	Coe and Helpman (1993)	23%

Source: Cameron (1996). Scope of the studies: * industry, + national level.

returns. Table 2.3 summarizes the results of studies dealing with private research investments.

As before, we are more interested in the thought process by which these studies are performed than in their content. However, Table 2.3 presents evidence of substantive importance: although private rates of return are in the vicinity of 20 to 25 percent, social returns tend to be closer to 50 percent or more, even when we are dealing with private research investment. This results from the large spillovers involved with private research efforts.

At the university level, assigning a social rate of return is difficult and almost meaningless. It is known that there is a reinforcing relation between university research, on the one hand, and private research and innovation on the other (e.g., David, 1992), but computations of the social rate of return seem hopelessly to underestimate the social impact of university research.[3] Perhaps more revealing is the finding that without university research, 11 percent of new products and 9 percent of new processes would have not been possible in the United States, according to a survey of 76 manufacturing firms (Mansfield, 1995).

The conclusion of this subsection could be almost exactly replicated in a number of studies in the literature: Research is always modeled as an exogenous input into a production function. Implicit once again is the standard model mentioned earlier. In the next subsection we present recent

Table 2.3
Private and Social Rates of Return to Private R&D in the United States

Study	Rates of Return (%)	
	Private	Social
Nadiri (1993)	20-30	50
Mansfield (1997)	25	56
Terleckyj (1974)	29	48–78
Sevikauskas (1981)	7–25	50
Goto and Suzuki (1989)	26	80
Bernstein and Nadiri (1988)	10–27	11–111
Scherer (1982, 1984)	29–43	64–147
Bernstein and Nadiri (1991)	15–28	20–110

Source: Council of Economic Advisors of the President of the U.S. (1996).

theoretical advances that have broadened the perspectives by which the contribution of universities to growth is perceived.

Endogenous Growth and the Economics of Knowledge

In this section we will discuss recent theoretical developments that have improved some of the shortcomings described earlier. The production functions (1) and (2) showed that the sources of growth were exogenous, as if they would fall from heaven. One must not, however, neglect the accomplishment of the framework previously described, namely the differentiation between conventional inputs (capital and labor), on the one hand, and technology and human capital, on the other (Mankiw, 1995; Romer, 1996).

Our inheritance from the neoclassical models can be summarized in three key points:

a) knowledge (of which technology and human capital are part) is either

- a public good, in the case of technology or research results, largely exaggerating the social returns resulting from spillovers;
- a private good, in the case of human capital, largely neglecting the huge externalities associated with education;

b) knowledge is exogenous, determined outside the economic context, that is, knowledge creation is not subject to economic incentives, but results exclusively from luck, genius, and other serendipitous events and characteristics.

c) growth is a process that exhibits diminishing returns to the private inputs.

The first point, although seemingly a technical one, is very important, and we will see why later. However, the really disturbing shortcoming that had been bothering economists for a long time is related to the second point. As Romer (1994) clearly analyzed, knowledge is clearly associated with things that people do, and having the main drivers of growth coming from outside was clearly a nuisance.

The first effort to endogenize the role of knowledge is due to Arrow (1962), who formalized the positive effect of experience on a firm's production: workers learn-by-doing, increasing their productivity. Arrow chose to formalize this contention by assuming that knowledge creation (the result of learning) is a side product of physical investment, or capital accumulation. Mathematically, this has been expressed by stating that each firm exhibits a neoclassical labor augmenting the production function of the form

$$(3) \quad Y_i = F(K_i, A_i \,.\, L_i)$$

where A_i can be understood as the index of knowledge available to the firm. Two more assumptions were considerable:

Learning-by-doing increases with the firm's investment. Therefore, increases in the firm's capital stock have a parallel increase in the firm's level of knowledge A_i, that is

$$(4) \quad \dot{K}_i / K_i = \dot{A}_i / A_i$$

Knowledge at each firm is a public good. Knowledge spills over from one firm to the economy instantly, and any other firm can access this new knowledge at zero cost. It is important to note that this assumption means that all new knowledge is an unintended result of investment; it does not result from purposive actions of the firm. This assumption leads to

$$(5) \quad \dot{A}_i = \text{const.}\ \dot{K}$$

that is, the increase in knowledge in one specific firm is reflected in the increase of capital of the whole economy (K represents the capital stock of the entire economy).

Combining assumptions (1) and (2), we can replace A_i by K and express the production function as

$$(6) \quad Y_i = F(K_i, K \, . \, L_i)$$

or with more generality as

$$(7) \quad Y_i = A(K).F(K_i, L_i)$$

This development leads to the so-called AK model of economic growth, in which growth is endogenous and, in this case, results exclusively from learning-by-doing (Solow, 1997).

Following Romer (1994), the basic framework included in (7) provided the inspiration for the resurgence of endogenous growth theories in the mid-1980s. Lucas (1988) gave more emphasis to formal learning and assumed that the spillover effect came from investments in human capital, rather than physical capital. Following a similar line of reasoning, he suggested

$$(8) \quad Y_i = A(H).\mathrm{F}(K_i, H_i)$$

where H stands for human capital (at the firm level with the subscript, and the total stock, without it).

Romer (1986) proposed that spillovers from private research would increase the stock of public knowledge, which led him to write

$$(9) \quad Y = A(R).F(R_i, K_i, L_i)$$

where R stands for the stock of research results. The important point is that all models exhibit potentially increasing returns, with the source of these returns being endogenous to the model. The engine of this endogenous growth is, in all cases, the creation of new knowledge through a specific learning process. Table 2.4 indicates what type of learning is associated with each of these three theories of growth.

These models clearly go beyond the linearity implied in the standard model described earlier, although they still do not resolve the first of the shortcomings of the neoclassical model pointed out. Romer (1990) and Grossman and Helpman (1991), among others, proposed other perspectives in which the impact of research does not merely spill immediately to the entire society, allowing for temporary monopolistic rents. These models address the first point mentioned at the beginning of this subsection. Further discussions by Romer (1993a, 1993b) and Nelson and Romer (1996) have shown the importance of the nonrivalry of codified knowl-

Table 2.4
Endogenous Theories of Growth

Study	Source of Growth	Activity
Arrow (1962)	learning-by-doing	experience
Lucas (1988)	learning-by-learning	education
Romer (1986)	learning-by-researching	research

edge, and the relevance of the possibility of excludability in knowledge products, something we will explore extensively in the next section.

Finally, an emerging literature deals with even broader aspects relating to the importance of knowledge creation and diffusion for economic development. Barro (1990) studied the impact of public infrastructures; Putnam (1993), among others, launched the idea of social capital; whereas knowledge networks are a fast-growing focus of research (e.g., Economides, 1996).

If there is a message after the story told in this section, Pasinetti (1981) articulated it most clearly more than two decades ago. He defended that learning is the source of growth, observing that because man is able to learn, advancement occurs because the next society always has a better departure point than the previous. The learning ability of human beings is the ultimate key to economic growth, a perspective that is of the utmost relevance in the knowledge-based economy in which we live. In the next section, we explore more deeply how we can construct a conceptual framework based on this insight, towards a new model of economic development.

LEARNING AS THE ENGINE OF GROWTH: TOWARD A NEW MODEL OF ECONOMIC DEVELOPMENT

To explore a model of learning-driven economic development, where learning is understood broadly as knowledge accumulation, we need to elaborate on the economic importance of knowledge. This aspect has been analyzed in various academic disciplines and from various perspectives but here we will follow Nelson and Romer's (1996) differentiation between ideas and skills, or software and wetware, to use these authors' nomenclature. These two kinds of knowledge differ in the way they are used, diffused, and produced. However, they are strongly interdependent in the learning processes that lead to the accumulation of knowledge, the basis for our proposed model in which learning is the main driver for economic development.

We explore in a later subsection the differences between software and wetware identified in the introductory chapter of this book, and then we propose a unifying model of economic development, centered on the interactions between software and wetware. These interactions lead to the accumulation of knowledge through learning.

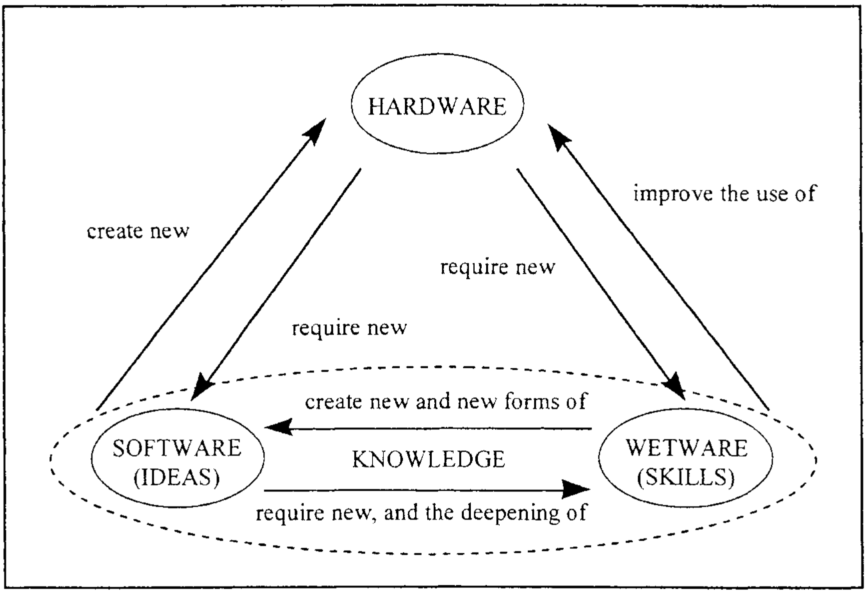
Software, Wetware, and Hardware: Understanding the Economic Behavior of Knowledge

We begin by exploring the differences between software and wetware and move on to show how they relate with hardware.[4] Further differences are explored toward the end of this subsection. The conceptual difference between software and wetware (i.e., ideas and skills) lies in the level of codification. Although ideas correspond to knowledge that can be articulated in words, symbols, or other means of expression, skills cannot be formalized, but always remain in tacit form. Under this taxonomy, knowledge is divided into two worlds: the world of codified ideas and the world of noncodified skills, the world of software and the world of wetware. The world of physical objects can be called simply hardware. It is evident that economic growth is a complex process involving the interaction of knowledge (software and wetware both) with hardware. After all, we still are very much in need of physical things. Figure 2.1 presents a stylized depiction of the complexity of these interactions.

Loyal to our claim that knowledge accumulation is at the heart of economic growth, we need to explore the process through which more knowledge is created, diffused, and used. This corresponds to better understand the circled part of Figure 2.1, encompassing the knowledge part. We begin, therefore, to analyze how our two kinds of knowledge may be used.

Ideas have the remarkable quality of being potentially usable by any number of people simultaneously. The fact that someone is reading a novel in no way prevents someone else from having access to it at the same time. The ideas in the novel and the benefit derived from its use may be shared at the same moment in time. Skills, on the other hand, can only be used by those who possess them, because skills are inextricably linked to that individual person. And it is only this person who can use them, when, how, and where he or she sees fit. In terms of their use, skills are perhaps deceptively similar to objects, which also can only be used by one individual at a time.

Figure 2.1
Interactions between knowledge (software and wetware) and hardware (objects).



Formally, this difference is related to a category used in public finance to classify goods: rivalry in use. A good is termed rival if only one person can use it at a time.

Moving on to an analysis of the processes involved in distributing knowledge, the distribution of ideas (i.e., software) is, as a rule, easy and inexpensive. Because the knowledge underlying software is codified, it is easily articulated and reproduced by simple, inexpensive means. In general, the costs of disseminating ideas are extremely low, especially in comparison with the costs of producing them. Indeed, the ease, speed, and low cost of distribution are characteristic of virtually all codified knowledge. By contrast, the transmission of skills (i.e., wetware) is complex, expensive, and slow. Skills result from a combination of factors, ranging from their largely innate quality, through individual experience, to formal training.

The issue that now is that of consequences is of the differences between ideas and skills, with particular reference to their production. As already stated, the rivalry associated with skills implies that, on the level of economic classification, they are similar to objects. As a consequence of this rivalry, it is clear who possesses a given object or ability and simple to assign the corresponding property rights. On the other hand, objects and skills are scarce, being limited by material and energy resources for the former and by people for the latter. These two properties (ease of assigning property rights and scarcity) mean that the market functions as an efficient means of producing objects and skills, as it is argued later.

In well-functioning markets, production incentives are generally associated with the benefits that the producer foresees he or she will enjoy as a result of the production. As long as property rights are adequately protected and the goods are scarce, the market provides the incentives that are necessary and sufficient for production. Indeed, with rival goods, the producer can keep all the economic benefits that result from the sale of those goods.

In the case of knowledge production, the distinction between software and wetware is crucial. The nonrivalry of ideas and their low distribution costs mean that it is very hard to assign property rights to them and to protect those rights, on the one hand, and on the other that ideas tend to be abundant, especially given advances in information technology and telecommunications, which enable codified knowledge to be easily and inexpensively used and transmitted. In contrast, the "thing-like" rival character of wetware means that in principle, the market provides the necessary and sufficient incentives to produce this type of knowledge, at least when it is analyzed in isolation.

From this perspective, what types of incentives exist for the production of ideas? David (1993) and Dasgupta and David (1994) suggest that there are basically two alternatives. The first consists of *intervention by the state* in the production of ideas by means of direct production (such as occurs, for instance, in state-controlled research laboratories) or by subsidizing production, such as funding of university research. The second alternative consists of granting property rights for the creation of ideas, that is by defining regulations for *intellectual property*—specific instruments that include patents, registered trademarks, and copyright. Therefore, the production of ideas requires more complex institutional mechanisms than those provided by the market. As for skills, it has been noted that they behave in a similar way to objects, and for this reason, the market provides a large proportion of the incentives needed for their production, at least when these are analyzed in isolation.

The situation changes when each of the categories of knowledge ceases to be seen in isolation. In fact, this is what we must do, because it is the accumulation of knowledge as a whole that leads to economic growth, which means that the way ideas and skills are related to each other needs to be explored. This analysis is found in the next section, in which we propose an innovative model of economic development.

A Knowledge-Based Model of Economic Development

As discussed earlier, learning, which is the accumulation of knowledge, appears as the driving force behind the increases in efficiency, which leads to economic growth. In this context, the differentiation between software and wetware allows us to reexamine the new growth theories discussed earlier under a new light. Arrow (1962) chose to model an informal way of learning, learning-by-doing, as the basis for his reasoning. Learning-by-doing leads to an accumulation only in the form of skills. Lucas (1988) also analyzed the accumulation of knowledge in the form of skills, but this time putting forward education as a formal learning process. In turn, Romer (1990) and Grossman and Helpman (1991) constructed models in which the accumulation of ideas results from effort put into research, another formal learning process.

The crucial aspect of the accumulation of knowledge is the interaction between ideas and skills, which gives rise to the learning processes. Indeed, ideas and skills are no more than two sides of the same coin, two essential aspects of the accumulation of knowledge. Many good ideas are useless if the skills needed to use them do not exist. Nelson (1997) described various circumstances in which individuals, companies, universities, and other institutions have made use of their skills to increase their accumulation of knowledge, acquiring further skills as well as ideas. The main implication of this argument is that the interdependence between ideas and skills casts doubt on the idea that the market supplies the necessary incentives for the production of skills, as was concluded before, where these were analyzed in isolation. It seems, therefore, that there is greater scope in the knowledge-based economy for institutional arrangements and public policies that go beyond the logic of the market.

Although to a great extent skills result from the innate characteristics of an individual or from the history of an institution or a country, they also depend on the learning processes (education, research, design, experience, social interaction) in which these entities are involved. Without skills, ideas may be irrelevant, and without ideas, there is no need for new and better skills. Analysis of the interaction between ideas and skills understandably brings us to explore learning processes in a more integrated and dynamic way, beyond the mere individual accumulation of ideas and skills.

To illustrate the close and complex interdependence between ideas and skills, Figure 2.2 seeks to enlarge the oval encompassing knowledge in Figure 2.1, showing the interactions between these two kinds of knowledge that lead to overall knowledge accumulation. This is a comprehensive model of knowledge accumulation that simultaneously accounts for the types of learning explored in the new growth theories (Conceição & Heitor, 1999).

It can be seen that although skills appear as a cluster of small ovals, reflecting the individual nature of the skills of people and of institutions, ideas appear as a single oval. This represents the indivisibility of ideas, meaning that, once created, an idea remains at least potentially accessible everywhere, and there is no need to rediscover it—hence the common expression "There's no need to reinvent the wheel." Figure 2.2 identifies the following main learning processes:

Cycle 1—codification of knowledge, the result of progress in information technology, telecommunications, and the scientific and technological base; that is, the great number of existing ideas that are the starting point or "feedstock" for new ideas to be constructed using existing skills.

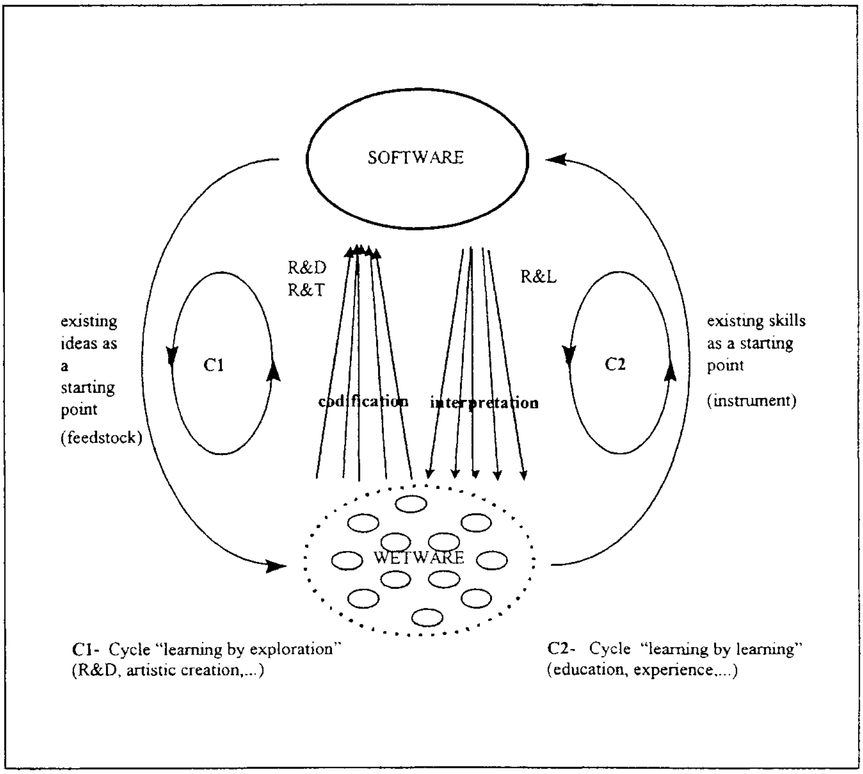
Cycle 2—interpretation of codified knowledge, using existing skills as a starting point or instrument to decode the ideas that are being studied or used, leading to improved skills.

Cycle 1 covers learning processes that result in the codification of knowledge, which is the generation of new ideas. Specific examples include research and artistic creation. In both cases, ideas are generated as a result of a process of exploration, in science or in search of a form of expression. This type of learning is *convergent*, meaning that on the basis of different and unique skills, ideas are generated that have the potential for common use.

Cycle 2, on the other hand, relates to learning by assimilation of knowledge, which results from activities such as education, experience, and social interaction. Through interpretation of these ideas, different skills emerge. Imagine a mathematics class: All the students are using the same book, they attend the same classes, they do the same exercises. However, the ways in which they assimilate and interpret these are different, meaning that the learning process is *divergent*.

The main conclusion of this section, as shown in Figure 2.2, is that the accumulation of knowledge, which is the basis for economic growth, is basically the result of a complex set of learning processes in which there is

Figure 2.2
Diagrammatic representation of learning processes: The accumulation of knowledge through the interaction of ideas and skills.



considerable interdependence between the accumulation of ideas and of skills. It is necessary to examine the role of the principal institutions of contemporary society and to attempt to determine how they fit into these processes.

The tendency, in what concerns the university, has been to emphasize the formal processes of education and research. In the following section we argue that the contribution of universities to economic development, through generalized learning processes, goes much beyond the important role played by these formal activities. The informal processes of learning are also very important because they can be translated into competence building for innovation (e.g., Conceição, Heitor, & Lundvall, 2003). In fact, there are many instances in which the contribution of universities to economic development has gone much beyond the standard model and has even surpassed what the three formalized ways of learning would lead us to expect. For lack of a better term, we group these instances as "learning-by-living," reflecting the fact that their common feature is that they are developed by people living at universities. Universities provide an environment that allows people to learn just by the fact they are there, in an institutionally unique and special setting, a societal space for creativity, experimentation, risk taking, intellectual venturing, and human interaction.

THE HIDDEN CONTRIBUTION OF DESIGN TRAINING AND PRACTICE: LEARNING AS REFLECTED IN NEW ATTITUDES TOWARD INNOVATION

Considering the scope of technical education and the requirements to promote learning skills, namely in research universities, we put forward in this section an argument favoring the need to identify and understand the different components of university research. It is clear that we intend to stimulate an interest for future research, rather than presenting accomplished research results.

Our hypothesis is based on the fact that expanding the modes by which research is performed at universities is the way to intensify the learning skills that people are required to have to sustain a societywide learning culture. Research can be viewed as various subfunctions, not always clearly defined, but that should be the subject of separate public policies and forms of management, as follows:

1. R&D, Research and Development, which aims at the accumulation of ideas and is usually associated with processes of knowledge codification. This is the commonest form of research, particularly in the context of economic development and from the standpoint of the relationship between universities and companies.
2. R&T, Research and Teaching, in which research functions as a way of developing teaching materials, as well as of improving the teaching skills of the teaching staff, and which is also associated with processes of knowledge codification.
3. R&L, Research and Learning, in which the value of the research is not necessarily in the creation of ideas, but in the development of skills that enhance opportunities for learning.

According to the definitions of the learning processes of Conceição and Heitor (1999), R&D and R&T are aimed to create ideas and require the selective choice of individuals with suitable skills for these types of activities. In turn, R&L seeks to develop learning skills through the experience of doing research and of inquiring, namely at the design level. It is important to disseminate these opportunities, presenting research as a cultural factor. In addition, it will facilitate promoting the entrepreneurial culture so well identified by Castells and Hall (1994) and Clark (1995), among others in the literature, as a critical role for technical universities.

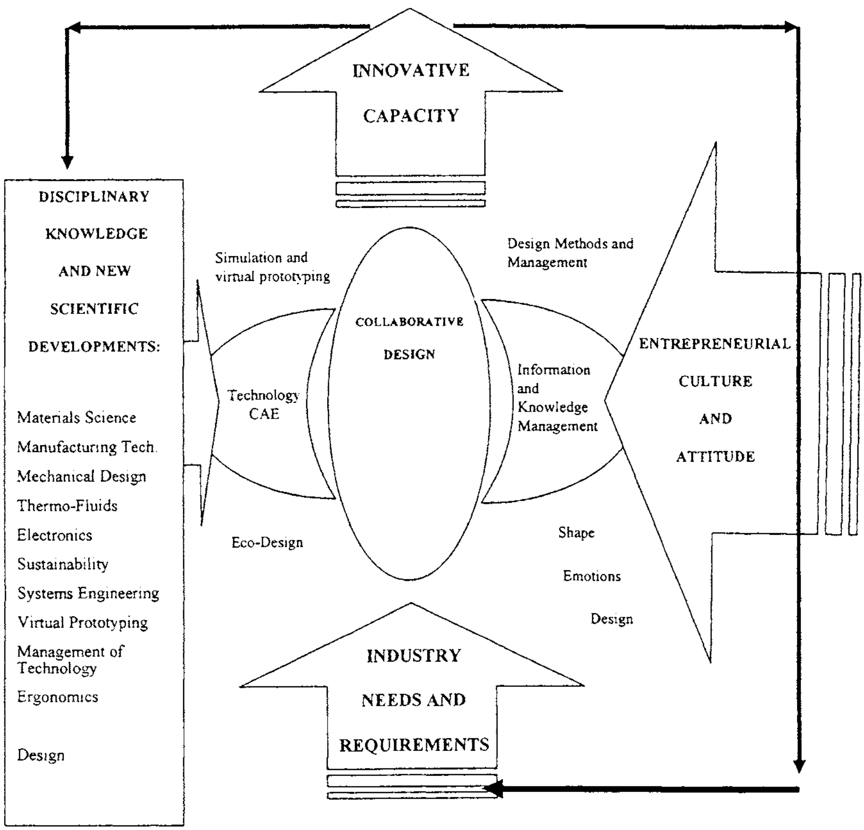
Following the analysis of Castells and Hall (1994), "It takes a very special kind of university, and a very specific set of linkages to industrial and commercial development, for a university to be able to play a role it often claims to play in the information-based economy." Definitely, those technical universities that are pure teaching factories, or work under a bureaucratic structure, are unlikely to act as generators of an advanced technological milieux.

In these circumstances, it is clear that a diversified system could respond effectively to the different demands in the emerging learning society by being selective in R&D and R&T and comprehensive in R&L. Indeed, the selective nature of R&D and R&T require fundamentally autonomous institutions, able to set up their own research agendas and establish their own criteria for scientific quality and career promotion (as clearly discussed by Castells and Hall, 1994).

On the other hand, the comprehensive nature of R&L requires establishing problem-oriented programs, including the implementation of design practices and product development strategies. It should be noted that major changes are currently taking place in industry all around the world. Changes in products, the design process, the marketplace, relationships with business partners, and environmental demands have all placed new demands (both managerial and technological) on the entire product development process. Following other international practices, the importance of integrating advanced methods and tools from the field of engineering design with the management of engineering (i.e., adopting a holistic approach to the product development process) has become apparent, as schematically represented in Figure 2.3.

To sum up, rather than presenting a detailed plan of public policy options and forms of management for technical universities, our analysis sets out to show how our conceptualization of learning as knowledge accumulation can be used to analyze the challenges facing technical education and the university in general. Among our substantive conclusions are the importance of maintaining the academic character of teaching and research, but in a way that promotes a new milieu of discovery, learning,

Figure 2.3
Systemic approach to collaborative design routines.



and sharing through the implementation of design practices and a better compromise of science- and design-based activities.

But Which Are the Questions to Be Raised?

The vision and strategies considered in this book and discussed in the preceding paragraphs bring a series of new questions particularly important in terms of the need to constantly rethink technical education and the positioning of the design studio for innovative practices. Even though some of the ideas are specific to engineering design, architecture, and construction education, the value and implications of the analysis are likely to be of importance for most technical universities around the world: engineering education must adapt to the emerging knowledge-based economy, in which new demands and new expectations present significant challenges but, most importantly, great opportunities. In our view, the key challenge and greatest opportunity for technical universities is to find a balance between striving for more social and economic relevance, while keeping the fundamental ability of being a place for new technical discoveries and free intellectual inquiry. Following Conceição and Heitor (2002), this discussion is particularly central to the processes discussed in this book, but require the correct questions to be asked.

This is because we may want to ask: WHAT will the new technologies be like? WHICH research we should invest in? WHAT engineering courses should we teach in our schools and universities? These are, however, the wrong questions: Our impatience with the future and our pragmatism demand that we do ask these questions, but to get answers may be a hopeless task. If we were to take a lesson from looking back, with the hindsight of having observed the evolution of so many new technologies and their economic and social impact, we could learn that it is, indeed, difficult to guess the outcome. It is difficult to know for sure which specific technologies will be important and what engineering courses we should teach.

But there is an alternative to attempting to guess the future in this precise way. We can look, instead, at the process. At HOW all the many important technologies were created and at HOW they have impacted on our societies and on our economies. The WHAT and WHICH become irrelevant; it is the HOW that matters!

If we take this approach, we need not lose ourselves in the details of the existing technologies drafting hopelessly complex possible paths and detailed recipes for the future evolution of what we have today. This is, in our view, what technical education should give priority. It should be focused on the process through which human intervention changes our world. And the process of creativity is the only way through which we can invent the better and the sustainable world!

But "HOW" to Renew Technical Education?

Our vision is that of a new milieu of discovery, learning, and sharing, in which people learn-by-doing, interacting and consulting widely, being able to readily access vast storehouses of knowledge, anytime and anyplace. Engineered learning systems should be promoted to achieve this vision. Such systems must emphasize active learning experiences, such as simulation, creation, and collaboration, in a learning environment enhanced by technologies for accessing global resources, real-time and asynchronous distance interaction, self-directed exploration, self-assessment, and authoring.

To achieve these goals, we have listed a few critical concepts to be considered in renewing engineering education. It is not a detailed program and should not be used as a recipe, but rather sample topics for reflection and for promoting the debate facing technical education at the onset of the twenty-first century.

Constructionism. A design challenge within technical curricula is considered as a critical aspect in renewing technical education. Following Piaget's (1973) view of knowledge construction by using "active methods which require that every new truth to be learned be rediscovered or at least reconstructed by the student," Seymour Papert (1991) added the idea that the knowledge construction "happens especially felicitously in a context where the learner is consciously engaged in constructing a public entity." This constructionism viewpoint facilitates the "new milieu of discovery, learning, and sharing" mentioned earlier, and leading experiences (e.g., Bucciarelli, 1994; Frey, Smith, & Bellinger, 2000; Riis, 2001) suggest that it allows to

- Expose students to a multidisciplinary design/product development experience
- Prompt participants to think about systems architecture
- Raise issues of organizational processes in an engineering context
- Build learning communities of students, faculty, and staff

Following the practices, skills, attitudes, and values described by Horgen et al. (1999) for process architecture, technical education must consider that learning a new practice requires moving through discovery, invention, and production not once, but many times, in different contexts and different combinations. Looking at the leading experiences in design process at the Southern California Institute (e.g., Reeve & Rotondi, 1997), we must realize that technical education has the potential to incorporate the humanities and sciences into a complex system of experiences. The objective is to integrate systems of knowledge and ways of practicing because "without knowledge, practice is limited and without practice, knowledge will never be fully realized."

Interaction. Although we are still in a very early stage of Mitchell's (1995) "cities of bits," it is clear that we should use the opportunity to start establishing long-distance learning networks, which will contribute to build a new attitude for entrepreneurs and definitively will transform universities. The diversification, multimodality, and versatility of the new communication system are enabling us to embrace and integrate all forms of expression, as well as the diversity of interests, values, and imaginations, as described by Castells (1996). Fully distributed systems are to be considered, in that learning is provided anytime, anyplace, and beyond a single organization. In this context, "virtual teams" have been associated with the emergence of distributed cross-organizational arrangements, which involve people from different organizations who work in different places. It is also clear that the increased integration of the world economy—the globalization—not only facilitates this process, but also creates new challenges and expectations. Our proposal is that dynamic, competency-based, electronically collocated networks of students will sustain virtual teams that create value by synthesizing information and knowledge across geographies and organizations. Leading examples include the various experiences described in parts II and III of this book, which integrate educational frameworks and theories that support collaborative, distant, and project-based learning. The result is a process of entrepreneurial education, in which the acquisition of new knowledge is followed by living and experiencing entrepreneurial environments to facilitate the creation of new knowledge.

Diversity. Diversity enriches the educational experience and improves the practice of engineering. We learn from those whose experiences, beliefs, and perspectives are different from our own, and these lessons can be taught best in a richly diverse intellectual and social environment. Increasing diversity in technical education and profession can be achieved by promoting greater participation of people, which is critical to sustain a larger knowledge base. In addition, following the analysis of Conceição and Heitor (2000) based on the way organizations deal with knowledge, that is, the way organizations are promoting "learning," there is a need to promote a diversity of organizational arrangements, which per se could be a major contributor to ensure the institutional integrity of the university.

Scope. The scope includes changes in the culture of technical education and research to provide a team-based, interdisciplinary arena for research for undergraduate and graduate students, in partnership with industry. Research activity lies at the interface between the discovery-driven culture of science and the innovation-driven culture of engineering, creating a synergy between science, engineering, and industrial practice. Following Schuetze (2000), among others, technology transfer as it has been conventionally understood is only a part of a larger system of knowledge creation and application, involving many forms of communication and interaction between university and community. Knowledge transfer must involve opportunities for learning of all kinds, requiring technical universities to consider cooperative research and organized learning as twin activities. In this context, the leading Aalborg experience (Fink, 2001; Kersdam, 1994) provides evidence of problem-oriented project-organized type of education, which is emerging as a new paradigm for engineering education. Riis (2001) argues about the need to combine this approach with other methods, and we emphasize the need for diversified and multifaceted learning environments, able to stimulate individual creativity and foster collective efficiency. To facilitate achieving these goals, a focus on design/build or product development experiences for students should be promoted.

Integration. Engineers and technology experts need frameworks and methodologies that view technology as part of a larger societal whole and that follow a historical path. For example, Lundvall (2002), among others, found that firms that introduced new information and communication technologies without combining them with investment in the training of employees, with change in management, and with change in work organization got a negative effect on productivity growth that lasted several years. Related findings on negative correlations between technological innovation and productivity growth rate have recently led many authors to argue about the need for alternative perspectives to the "new-economy hypothesis," but clearly calls our attention to the need to consider technological innovations together with proper institutional and organizational frameworks. In the context of engineering education, this requires integrative educational strategies that complement traditional engineering science strengths and enable students to better understand complex systems. Following the leading experiences on "technology, management and policy" education reported by De Neufville and Heitor (2001), our perspective is that of the need to broaden technical education with emphasis at the postgraduate level to clearly integrate engineering policy and management of technology as an emergent engineering discipline. We refer to engineering because it involves solid understanding of the technical aspects of issues, but: (1) it is focused on systems design, that is, major complexes of technological design and implementation; (2) is multidisciplinary and requires a strong grounding in applied social sciences, economics, management, and policy analysis in particular; and (3) is directed toward applications, toward dealing with, if not solving, major issues.

Sustainability. The new generations must be prepared by their education to use sustainable engineering techniques in the practice of their profession and to take leadership roles in facilitating sustainable development in their communities. Studies of economics and ethics are necessary to understand the need to use sustainable engineering techniques, including improved clean technologies, but models of reflexive learning in practice (living) may facilitate building of the "sustainable" university. In particular, we refer to the development of norms as part of the learning process and tying this to a concept of sustainability in which responsibility is central (e.g., IISD, 1999; ULSF, 1999). The analysis based on sample initiatives in progress in many universities shows that the importance of learning sustainability through the experience of living requires radical changes in the university. Interdisciplinary research and curricula are critical but face well-established resistance to change. Integrative concepts such as industrial ecology (e.g., Ehrenfeld, 1998) can guide the design of new institutional structures.

Ethics. As the result of the accelerating pace of scientific and technological change, which is rapidly transforming society and the economy, issues of ethical choice have taken on an increasing importance for all professions, especially for engineering. Ethics education in engineering should endeavor to equip students with the skills to confront ethical problems and exercise their ethical responsibilities as engineers.

The preceding analysis is a contribution for an ongoing discussion on how universities, and engineering education in particular, can play a more effective role in contributing to promoting wealth creation. A significant stream of that discussion has regarded American research universities as a reference and has resulted, within the diverse range of institutions in the worldwide higher education system, in various organizational and strategic arrangements that go much beyond the traditional roles ascribed to education and research. The unifying characteristic of these different arrangements is provided by the unique characteristics of "the university" as a societal environment for exploration and interpretation of knowledge.

And about Institutional Integrity?

The concluding analysis in this section aims to show that although the role of the university needs to be reexamined, the institutional integrity of universities must be preserved (Conceição & Heitor, 2000). The analysis also shows that the variety of demands and the continuously changing social and economic environment surrounding higher education organizations, and technical universities in particular, is calling for diversified systems able to cope with the need to produce policies that nurture and enhance the learning economy.

In fact, the important strategic role that universities can play in helping nations to meet public goals has been extensively recognized. These roles have a multifaceted nature, including such diverse aspects as public safety, quality of life, health care, environmental protection, and economic development and growth (e.g., Clark, 1995; Lucas, 1996; Noll, 1998). The specific ways in which universities have played these roles are dominated by activities associated with the creation and distribution of knowledge (Rosenberg, 2002). The generation and diffusion of knowledge is translated, for example, in improved competencies and skills in the labor force and in the development and commercialization of new technologies. However, in the face of continuous public funding restrictions and ever more demanding public scrutiny, traditional suppliers of knowledge—such as schools, universities, and training organizations—as well as businesses and knowledge-based organizations in the public sector (growing users of knowledge) are urgently seeking fundamental insights to help them nurture, harvest, and manage the immense potential for their knowledge assets for capability to excel at the leading edge of innovation.

To a certain extent, it can be argued that, at least for the most industrialized societies, a trend is emerging leading to a breakdown of the institutional boundaries that separated companies and universities. This process of "institutional convergence" can be understood as a result of two forces that come together to impose an ever-closer identification of firms and academic institutions, and vice versa. The first force results from the fact that the creation of added value and wealth is increasingly associated with the production of knowledge, so it is natural that companies look to the way universities function for inspiration on how to perform creative tasks. Secondly, the universities find themselves facing difficulties in obtaining sufficient funds for their basic tasks of teaching and research (see Caraça, Conceição, & Heitor, 2000), so it is also natural that they look to companies to learn how to derive commercial benefits from their intellectual assets and endeavors.

On the other hand, it can also be argued that in most late industrialized societies and catching-up countries, there is still a large gap in industry-science relationships with technical education.

As various studies have shown, although this convergence is, to a certain extent, to be welcomed, it can also be dangerous. Rosenberg and Nelson (1996), Dasgupta and David (1994), David (1993), and Pavitt (1987) argue that this convergence is "acceptable" as long as it does not harm the institutional integrity of the university. Companies and universities have evolved in a social context to the point of attaining what these authors call "institutional specialization." Thus, whereas companies are concerned with obtaining private returns for the knowledge that they generate, universities have traditionally made it public. By means of this specialization, or "division of labor," the accumulation of knowledge has taken place at a rapid pace, as is shown by the unprecedented levels of economic growth since the end of the Second World War (Rosenberg & Nelson, 1996). These authors show that the universities we know today, despite their long historical inheritance, are relatively new institutions, namely in the way they relate to their surrounding social and economic context. And universities have defined themselves almost as nonfirms, in the sense that they produce knowledge that is publicly available. To do this effectively, a complex set of incentive structures and organizational features emerged, which are relatively easy to destroy, despite the long time it took for these to evolve.

In other words, an evolutionary metaphor could, with some liberties, be used here. Both firms and universities have evolved over time as institutions adapted to an environment in which different types of knowledge were generated by each institution for mutual benefits. Thus, in a simplified way, although firms were able to commercialize and diffuse technologies, universities specialized in advancing the knowledge frontier at the forefront of the unknown. No insurance mechanism or system of private rewards could possibly lure investors into this most risky of ventures. Universities assumed this role, with a structure of incentives that never penalizes too much for failure, but that also does not reward exceedingly for successes. This is particularly true in Europe, where university professors are, to a large extent, civil servants, and their salaries are rigidly structured by the civil servant system in which seniority carries a very heavy weight, and there is not much possibility for competition along the salary dimension (Rosenberg, 2002). The danger addressed in this chapter is in the "extinction" of one of knowledge creating "institutional species" identified earlier. If universities become, at least in the way they deal with knowledge, very much like firms, we will be in fact witnessing the death of an institution!

CONCLUSIONS

Over the past decade there has been an increased discussion on how universities can play a more effective role in contributing to promotion of wealth creation. A significant stream of that discussion has regarded American universities as a reference and has resulted, within the diverse range of institutions in the European higher education system, in various organizational and strategic arrangements that go much beyond the traditional roles ascribed to education and research. The unifying characteristic of these different arrangements is provided by the unique characteristics of "the university" as a societal environment for exploration and interpretation of knowledge.

Exploring and interpreting knowledge are two sides of the learning process. Therefore, in this chapter we attempted to look at the university as a learning organization, exploring its role in the broader context of the learning economy. Under this context, we described a conceptual understanding of the relationship between learning and economic prosperity. Our analysis led us to suggest that although the role of the university needs to be reexamined, the role of informal learning activities must be promoted, namely through the systematic implementation of design training and practice, together with collaborative projects. The analysis also shows that the variety of demands and the continuously changing social and economic environment surrounding higher education organizations is calling for diversified systems able to cope with the need to produce policies that nurture and enhance the learning economy, as well as for systems that promote the institutional integrity of the university.

To achieve these conclusions, we have argued that that those living in the university—students, faculty, and staff—are immersed in an institutional setting that provides them with unique perspectives and opportunities. In fact, this book presents anecdotal evidence that shows that "learning-by-living" in universities is expected to develop new competences for innovation, namely when encompassing well-structured design activities and collaborative actions.

Policywise, we argue that, as a hidden dimension, the contribution of design training and practice within the institutional dimension of universities has not been fully recognized. It is up to university management to give visibility to this hidden dimension, creating the mechanisms that nurture and encourage design practices and a better compromise between science- and design-based activities to take full advantage of "learning-by-living" in the university. This effort, however, must not endanger the fundamental mission of the university or the rules of engagement of the academic community. Again, we must reinforce the important idea that the institutional integrity of the university has to be preserved. Threatening this institutional integrity would be like killing the golden egg goose. It would destroy the features that make learning-by-living at universities have an important, yet still hidden, impact on economic development.

Finally, theoretically, we defend that there should be an approximation of the formal and appreciative (or institutional) theories on economic growth in order to better understand new challenges facing the research university and the role of design training and practice fostering competence building for innovation. This task, though difficult, may be key to illuminating the process by which economic growth occurs in the knowledge-based economies and emerging learning societies.

NOTES

1. However, Schumpeterian competition is much more complex than the competition normally modeled in neoclassical economics. Several efforts have been made to model Schumpeterian competition, but these do not change the fundamentally linear process implicit in Schumpeter's reasoning.
2. The authors also include a term M(t), which stands for intermediate inputs. This is not significant for the discussion.
3. Mansfield (1991) estimated it as 28 percent.
4. Most of the discussion in this section is based on Conceição and Heitor (1999, 2000).

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PART II
ADVANCED TOOLS AND LOGISTICS

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Introductory Note 2

José P. Duarte

Collaborative design and learning have emerged as important research topics over the past decade, partially because developments in technology succeeded in creating computer-aided tools for individuals, and advances in information technology made it technically and financially feasible to undertake experiments in collaborative design. The various chapters in Part II describe a series of efforts to develop advanced tools and logistics for both design education and practice. Sancho-Gil stresses that although the focus has been on technology, the financial and organization investments required for creating virtual learning environments is critical, and that the ultimate drive for creating virtual learning environments should be to help people developing skills in effective ways. Peña-Mora provides a model to follow in the implementation of effective distance-learning environments, and Duarte suggests the use of grammars as a protocol for collaborative design. Anumba envisions a system formed by separate components in which communication is made effective by technologies such as information exchange standards, whereas Scherer proposes the development of a system that specifically ties different components together.

Chapter 3, "Expanding Learning Experiences: Possibilities and Limitations of Virtual Learning Environments," by Juana M. Sancho-Gil, points out that despite all the enthusiasm for the use of information and communication technology for learning, little has been done to understand in depth how the use of technology can contribute to enhancing teaching/learning environments.

Sancho-Gil defines virtual learning environments (VLEs) as online domains allowing both synchronous and asynchronous exchanges among teachers and learners used both in face-to-face and distance courses. VLEs have different goals, as well as technological, pedagogical, and institutional frameworks, and they can be used in primary, secondary, and higher education. VLEs are tightly related to the development of information and communication technologies (ICT), but its roots can be traced to different forms of distance education, such as correspondence courses. Sancho-Gil points out that the drive for conducting VLEs relies on two contradictory interests: one is the educational desire for improving learning, and the other is the economic drive for making profit. For Sancho-Gil educational demands are not only related to the need for managing information using the most advanced tools, but also particularly to the need for individuals to find educational settings in which they can develop their various skills. Accordingly, she rejects the vision of technology alone as the essential factor behind human evolution, and she stresses the need for developing a new teaching and learning architecture that makes VLEs better or, at least not worse, than face-to-face environments.

Sancho-Gil relates a personal experience in distance learning as a basis to analyze the pros and cons of VLEs. She concludes that VLEs can be conceived as new learning settings in which students can find an enlargement of their learning experience. VLEs solve accessibility problems and provide people in remote locations with a wider range of educational opportunities. However, VLEs also challenge people and institutions with the need for transforming their roles, as they require an investment in technology and knowledge acquisition; updated, more demanding organizational schemes; and increased workloads for students and teachers.

Chapter 4, "MIT-Miyagi 2000: An Experiment in Using Grammars for Collaborative Design," by José P. Duarte, reports an experiment that partially simulates a framework for providing customized mass housing. The framework includes design and production systems, but the experiment is focused on the design system, which is based on the concept of grammars. The idea is that a grammar captures the rules for designing houses in a certain style, and these rules are manipulated to generate houses that fit specific contexts. The ultimate goal is to have an automated system to search for the right house within the universe of solutions, but experimental subjects were asked to apply the rules by hand to test the concept.

The experiment took the form of a course taught simultaneously in the United States and in Japan using various forms of electronic communication. After being introduced to shape grammars, teams of American and

Japanese students used a specific grammar to design houses for a panel of international clients. The specific grammar was based on the rules followed by the award-winning architect Álvaro Siza for designing patio houses at Malagueira, a 1,200-house development in southern Portugal. Experimental results confirmed the need for a tool to avoid using the grammar manually and suggested changes to the grammar to make it feasible. Duarte argues that the grammar was helpful in overcoming communication barriers between members of the design teams and between the design teams and the client, while providing the means to generate customized Malagueira designs. The city block produced in the experiment looked very much like other blocks at Malagueira, and Siza agreed that the houses were in the correct style. Results suggest that grammars can function as a protocol to enable design collaboration.

In chapter 5, "Supporting a 'Real-World' Project-Based, Technology-Supported, Collaborative, Distance-Learning Environment," Peña-Mora et al. describe a collaborative effort called DiSEL aimed at preparing students for "the realities of working in the era of globalization." DiSEL implements the DaVinci initiative of the MIT Intelligent Engineering Systems Laboratory, which seeks the use of computer and communication technologies for supporting distributed collaboration in engineering projects. The DiSEL effort has taken the shape of a course simultaneously taught at MIT and at CICESE, a Mexican research center, although several institutions from different countries are expected to participate in the project over the next few years. In the DiSEL courses, both real-world experience and educational theory are used to set up the curriculum. The task that students are expected to accomplish is the development of a synchronous communication system. The simulation of a real-world framework is expected to facilitate the future integration of students into the industry. At the end of the course, students are expected to master complex systems and ill-defined requirements.

The DiSEL lab incorporates a combination of pedagogical theories and learning methods. The pedagogical theories are Teaching for Understanding (Wiske, 1998) and Theory One (Perkins, 1995). The learning methods are project-based learning (De Grave et al., 1996) collaborative learning (Slavin et al., 1985), distance learning (Simonson, 1995), and metacognitive (Jay et al., 1995). The process of combining these theories has led to the development of a distance-learning model that outlines clear guidelines for both students and instructors who work in such environments, called Five Critical Moves (FCM). This model was developed after Lipnack and Stamo's virtual team model, as well as after the implementation of the DiSEL project.

In chapter 6, "Information and Communication Technologies to Facilitate Collaboration in Architecture, Engineering, and Construction," C. J. Anumba is concerned with the current disintegration of the architecture, engineering, and construction (AEC) sector. He proposes to overcome this disintegration by fostering collaboration among the various participants, both at the design and construction stages. He sees enabling effective communication as being crucial to this goal.

Anumba, thus, briefly characterizes the current changing environment of the AEC sector. Then he identifies the main interfaces between the various AEC participants, including people and tools, where communication problems might arise. Finally, the chapter discusses existing information and communication technologies that can be used to overcome such problems. These technologies include information exchange standards, net technologies, distributed object models, modelling tools, virtual reality techniques, distributed artificial intelligence agents, and groupware tools. The view is that current and future advances in these technologies will lead to increasing collaboration and, ultimately, to the integration of the AEC sector.

Anumba states that his listing of the communication interfaces will permit an understanding of the communications issues in the AEC sector, and that it will constitute a framework for developing an appropriate infrastructure for collaborative work. To illustrate this idea, Anumba mentions two projects that have successfully used the framework for developing such an infrastructure. He concludes by stressing the social benefits that can be brought about through collaboration of the AEC sector.

In chapter 7, "Information Logistics for Supporting the Collaborative Design Process," Raimar J. Scherer argues that a system of concurrent engineering components linked together, rather than separate tools, is necessary to cope with the complexity of the information flow in collaborative design. Scherer considers that in AEC design there is both innovative and routine design. Although the bulk of design work is routine design, to guarantee cost effectiveness and the quality of design products, both from the aesthetic and functional viewpoints, and to achieve a high degree of client satisfaction, both kinds of design need to be enabled. Therefore, Scherer considers that collaborative design applications should be permited to switch back and forth between innovative and routine design work. Innovative design mostly requires synchronous communication, whereas most routine design work proceeds asynchronously, due to cost effectiveness. Consequently, in a concurrent engineering environment, both modes of collaborative work, synchronous and asynchronous, should have their place.

Then Scherer describes an application developed with theses ideas in mind, but mainly developed for asynchronous collaboration. This system coordinates the design information flow to facilitate discussion and decision making. The information logistics of concurrent engineering components are addressed in the context of collaborative design. The system has proven highly effective for synchronous collaboration, but it presents some limitations regarding the support of synchronous work and innovative design, mainly because it relies on the exchange and manipulation of material in computer data structures. Scherer suggests that these limitations might be overcome by developing tools to convert speech into written protocols and tools to analyze the content of such protocols. This would make it feasible to use the tools developed for asynchronous collaboration in synchronous work and innovative design.

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3

Expanding Learning Experiences: Possibilities and Limitations of Virtual Learning Environments

Juana M. Sancho-Gil

> The justification for a university is that it preserves the connection between knowledge and the zest of life, by uniting the young and the old in the imaginative consideration of learning... At least, this is the function which it should perform for society. A university which fails in this respect has no reason for existence.
>
> Alfred North Whitehead

INTRODUCTION

One of the possible accounts of the history of education could be done through the moments when new information technology tools were made either available to society or commercialized. The use of the printed text had a dramatic impact on the way formal education was conceived and implemented in the Modern Age (McClintock, 1993). The paperback revolution was presented as a way of liberating teachers and learners from texts, lectures, and recitation (Cohen, 1988). Cinema, radio, television, computers, and nets had been periodically announced as the new panacea for educational problems (Cuban, 1986; Gates et al., 1995; Papert, 1993; Perelman, 1992; Sancho et al., 1998; and Saettler, 1990; among others).

For many years educators and also technoenthusiasts without a real expertise in education and training[1] have been trying to implement and use new information and communication tools (from cinema, video, and computers to Internet) in the teaching and learning processes. The explicit agenda had been the search for any means to communicate, transfer, or deliver knowledge in simpler, cheaper, and less time-consuming ways. Alfred North Whitehead's idea that "the best education is to be found in gaining the utmost information from the simplest apparatus" (Cuban, 1986, p. 3), despite all evidence challenging it, seems more and more alive. However, for many practitioners, scholars, and authors (MacDonald, 1993) the hidden agenda of the permanent concern for new users of the newest device lies in the urge of industry for customers ready to absorb any modern gadget and keep alive the idea of endless "progress" alive.

With the growth of computer-based interactive technologies, the educational techno-optimism has found in digital or virtual learning environments (VLEs) one of its latest devices. The growing interest for digital or virtual learning environments flourished in the open and distant-learning field. Little by little these new learning milieus are being considered as a way of widening teaching and learning experiences, even in face-to-face institutions, both for adults and children. Over the past few years, the interest for designing and implementing VLEs for open and distance education related to the potential application of information and communication technologies (ICT) has experienced a remarkable increase. Countries with large geographical dimensions and population, such as Australia, New Zealand, Brazil, or Mexico, do have a long tradition in distance education, even at compulsory schooling level. Some other countries, such as European Union ones, are investing an important volume of funds on R&D projects to promote the use of the newest technologies in this teaching modality.[2]

The impressive development and application of ICT in practically all fields of human endeavor and the unbelievable power, wealth, and glamour netted by some companies and people related to ICT have aroused a great amount of interest and excitement in the realm of education. However, lessons learned through more than forty years of research on the application of different media to improve teaching and learning processes have made well-informed educators and scholars aware that the use of any new tool does not automatically mean

- The development and implementation of new approaches to school or academic knowledge[3]
- The transformation or improvement of existing teaching and learning methods or the development and implementation of better ones
- The solution to all educational problems

For practitioners, educators, and researchers, the real meaning of the social transformations due to political, economic, and technological changes and the appearance of new tools is the need to meet new educational challenges, new kinds of practical issues, and new research topics. Political, economic, and technological transformations have an impact in the construction of society and shape the inclusion/exclusion processes with related consequences for people's learning opportunities. And tools alter the structure of our interests (the things we think about); change the nature of symbols (the things with which we think); and modify the nature of the community (the area in which we develop our thoughts).

This new scenario faces primary, secondary, and higher education and training with the necessity of deeply rethinking teaching and learning processes as a whole. This means not only to reconsider the content to be taught, the way to teach it, and the way to assess students' learning, but also the characteristics of the learning environments provided and the quality of the learning experience. In this context, virtual learning environments can be conceived as new learning settings where students can find an enlargement of their learning experience.

This chapter offers a broad definition of VLEs, discusses the complexity of the roles and functions of education, approaches the characteristics of collaborative learning environments, and finishes with a practical example to analyze the pros and cons of implementing VLEs in higher education.

AN APPROACH TO VIRTUAL OR DIGITAL LEARNING ENVIRONMENTS

In the educational literature we can come across with different ways of nominating the new learning environments made available by using and implementing ICT in education and training. When speaking about virtual[4] and digital learning environments we refer to very different kinds of reality. They relate to a material nature that does not have a physical presence, but has an inherent power to produce certain effects and to represent reality itself in an accurate and somehow enriched manner (McClintock, 1993; Negroponte, 1996).

From this perspective, when we talk about VLEs, we are adding a certain quality, certain new proprieties to traditional learning environments.[5] Primarily a learning environment or setting (Barker, 1968) is a place arranged specifically for learning purposes. Traditionally learning environments that provided a social organization for teaching and learning had

- A given physical structure[6]
- A given way of selecting and structuring knowledge
- A given way of understanding the nature of teaching and learning
- A practical arrangement of time, place, and pedagogical rituals
- A clear normative behavioral system for students, teachers, and the rest of the school staff

Virtual learning environments have basically the same structure but

- The physical structure has been highly transformed and almost made invisible.[7]
- The selection and structuring of knowledge even if evident and highly fixed gives an impression of openness and flexibility that hardly resists an accurate revision.[8]
- The way of understanding the nature of teaching and learning is highly influenced by the growing "collaborative and interactive mystic" persona awarded to ICT.
- Practical arrangement of time and place seems one of the more differentiated aspects of VLEs. In relation to pedagogical rituals, even if a superficial approach could give the impression of significant change, a deeper exam shows that, as in face-to-face learning environments, they still depend on teachers' beliefs and backgrounds.[9]
- The clear normative behavioral system for students, teachers, and the rest of the educational staff might be deeply transformed, but it is also there.

So, the most distinctive characteristic of VLEs is being an online domain allowing both synchronous and asynchronous exchanges among teachers and learners. The collaborative interaction is a potentiality that, as we will see in the last part of the chapter, is highly related to the pedagogical model. ICT, as any technology, is made up of empty tools that permit or inhibit certain actions. Users, in this case, educational designers, teachers, and students, will grant the final meaning of these actions. Meanwhile, VLEs provide learning resources to be used by students at any time. For ICT enthusiasts, compared with traditional learning environments, the key role of different technologies, especially those related to the Internet, has dramatically enlarged educational opportunities of VLEs.

The concept of VLEs, tightly related to the impressive development of ICT, has its roots in the evolution of different forms of open and distance education. Oilo (1998) identifies teaching and learning modalities used since the nineteenth century that can be considered as both predecessors and a semantic field of VLEs:[10]

- Correspondence courses: which used postal services to overcome distances
- Distance education: existed long before the development of the new ICT
- Distance teaching, distance learning, distance-teaching university: characteristic of the audiovisual (televised) stage of distance education.
- The open universities: emphasis is placed on access and global aspects
- The collaborative or cooperative university: stresses the collaboration, between teachers and learners and between education partners
- Asynchronous education: takes advantage of the fundamental aspects made possible by ICT (i.e., studying at one's own pace with no time constraints)
- The global university: with a clear geopolitical vision
- Computer-mediated education and distributive learning: used by technology specialists
- The Internet university: technological and commercial

Dynamic advances in global digital communications and increasingly sophisticated learning technologies are accelerating major organizational changes and new developments in higher education.

> These technical advances are an additional driving force for change in traditionally organized universities in the twenty-first century. Emerging competitors to traditional colleges and universities see opportunities in: 1) increasing costs of university tuition; 2) growing demand for learning; 3) demand for content that can be applied in work settings; and 4) new technologies. These new organizations are competing directly with traditional universities and with each other, and through this competition they are beginning to cause significant change in traditional universities. (Hanna et al., 2000, p. 19)

Universities and colleges are using VLEs both in face-to-face and distance courses. However, the big boom in the last few years has been the dramatic increase in the number of courses and activities offered on both an open and distance basis. In the United States, the National Center for Education Statistics found that one-third of higher education institutions offered distance-education courses in the fall of 1995. Another one-quarter planned to offer such courses in the next three years, and 42 percent did not offer and did not plan to offer distance-education courses in the next three years (Primary Research Group, 1997).

VLEs are also being used in primary and secondary schools. Both developing and developed countries are engaged in the design and implementation of VLEs to diversify, enrich, and enlarge students' learning experiences.[11] In this educational stage VLEs are seen more as a complement to face-to-face schooling than a substitution.

EDUCATION IS MORE THAN INFORMATION PROCESSING

The powerful discourse on the convenience of designing and implementing VLEs subsists on two often-contradictory interests. The first one of an educational nature refers to the potential of any new information and communication tool for improving leaning. The second, with a clear economic flavor, sees VLEs as another big business in the field of education.

Regarding the first interest, when thinking of the possible ways of improving teaching education by using VLEs, we should not forget the complex tasks and functions of this endeavor.

The set of highly complex and demanding roles performed by education over the years goes beyond the mere exchange of selected and organized information. Now, more than ever, an educated person is not only an erudite, somebody able to repeat facts and concepts generated by others and solve already solved problems. Today a democratic citizen, with full rights and duties, needs to understand the keys of a global society. This means to be able to face uncertainty and change, to cope with unforeseen problems, to have criteria to select and interpret information, to be ready to go on learning along the whole life span, and above all, to develop an ethical approach to social, political, economic, and environmental issues.

If this is the case for primary and secondary education, the demands for higher education are not less challenging and complex. The traditional role of universities and colleges of "deliver information in an organized manner" is being questioned by

- The exponential growth of information production, transmission storage, and accessibility. At this moment, the biggest question for higher education is not information access, but the need for teachers and students to have criteria for selecting information, cognitive tools converting information into knowledge, and the ability to transfer meaning and understanding to different learning settings and activities. Knowing how to select information, being able to establish links and meaning, using it to solve unknown problems and situations, and going on learning along the whole life seem fundamental matters for higher education.

- The deep changes taking place in the productive world structure, the professional profiles and knowledge, the labor demands, and the workers' involvement. Nowadays, intelligence does not imply only cognitive capacities, but also noncognitive ones, such as emotions, imagination, and creativity. This trend confronts higher education with the need of revising the most instructional and reproductive teaching practice, which does not take into account more holistic, systemic, and procedural approaches. In this respect, higher education (virtual or not) should analyze the coherence between the kind of educational training provided to students and the kind of situations they will find in the workplace.
- The significant changes in the scientific, technical, and social knowledge. At this moment, disciplinary divisions do not respond to either the market needs or the production of knowledge needs. For Delors (1996) the institutions with better results are the ones that have been able to establish, with flexibility and in a collaborative mood, ways of teaching that transcend discipline-based knowledge borders.

In relation to the second interest based on the contradictory idea of saving money and energy and being more effective while generating big business, we have to take into account two fundamental concerns. In the first place, any educational system intending to update its performance by infusing ICT and expanding students' and teachers' educational experience knows the amount of extra material and human resources needed. New ICT infrastructure is expensive, much more so if it has to be used by a considerably high number of people (students, teachers, administrators, etc.).[12] Educational systems have to maintain the previous structure (teachers, advisors, experts, administrators, etc.), have to provide them with the suitable training to perform new tasks and operate new tools, and have to consider new roles and professions (ICT specialists, computer system administrator, educational software developers, etc.).

In the second place, we should not forget that education is a field in which its multiple benefits are not to be found in the production of material wealth, but rather in social and cultural terms. Let's think of a society that could count on educated people to perform the required tasks in the productive sector. People are environmentally aware, so that waste and destruction of the habitat could be prevented. People are respectful to other cultures and ways of living, so that social peace could be assured. People are socially responsible, so that democracy could be deepened and enlarged. People are emotionally balanced, so that personal relationships could be gratifying. If such a society could exist, it seems clear that the benefits of its educational system could also be enumerated in economic terms.

Finally, even if today's education can be a big business for some people (textbook publishers, teaching materials and software developers, assessment agencies, etc.), it seems to be intrinsically contradictory to find ways of reducing the cost of education and training and, at the same time, thinking that the way to do it would mean big business for some people.

A NEW ARCHITECTURE FOR TEACHING AND LEARNING

In the educational and corporate world there is a tendency to establish a rather mechanistic relationship between the fast evolution of ICT and the emergence of new educational and training needs. This restricted vision invests technology with an independent existence and has several implications. The most important one is the reinforcement of the technological imperative as the vision that sees the production of physical tools (machines) as an essential factor of the human evolution. This view implies that individuals and even groups cannot direct change and progress.

This approach strips people and countries of one of the most fundamental democratic rights—the right to decide the kind of environment and life they would like for themselves and their children. A second, but not less important, consequence is that it does not consider the set of fundamental economic and political decisions that shapes society and individuals' lives and guides the evolution of technology itself.[13]

As a matter of fact, ICT can be used and is being used for many different purposes. On the other hand, its effective use both demands specific, sometimes new, knowledge and skills and provides new learning opportunities and experiences. This fact has significant implications for education and training. One of the most important implications relates to the need to enlarge students' learning experience and enrich their cognitive, physical, and emotional processes. This new reality represents an enormous challenge for the current educational institution, from kindergarten to university. And, as it happened in the sixteenth and seventeenth centuries with the generalization of the printed text (McClintock, 1993), it could lead to a totally different conception not only of teaching and learning but also of the physical and symbolic organization of the official learning milieus (schools and universities).

As we have seen in the previous paragraphs, explicit educational demands of contemporary society are not only related to the necessity of managing and processing information using the most advanced tools. They also refer to the need for individuals to find educational settings in which they can develop, in the best possible way, their cognitive, artistic, social, personal, and emotional knowledge and skills.

From this perspective, the design and development of VLEs, to be used as the only mode of education delivery or as a complement for face-to-face education, confronts the educational challenge of any educational planning. To this already large task, add the fact that all advanced ICT-based environments must meet the economic problem of making the needed infrastructure (including updates) accessible to all students and teachers.

For the purpose of this chapter, the most important issue refers to the challenge of making VLEs better or at least not worse learning places than face-to-face ones.

For Hanna (2000), student learning frequently occupies a secondary position in internal assessments of higher education, which are often focused on establishing institutional accountability using measures such as faculty teaching loads, cost containment, revenue generation, program assessment, and research outcomes and productivity. However, widespread concern about the skills and proficiencies of university graduates has caused an external reassessment of the entire educational process. To this respect, understanding the emerging approaches for creating more effective learning environments in an interconnected world is central to addressing the future challenges facing universities and colleges.

As pointed out earlier, a major challenge to educational systems and to institutions is to enable students to have the experiences necessary to develop knowledge and skills appropriate for living and working in a rapidly changing, technology-based and unbalanced society. The second fundamental requirement is to enable students to develop the habits and attitudes that will enable them to be lifetime learners. Critical to this change is the systematic creation of new models for learning environments, models that support the development of active, engaged learners.

In the engaged-learner classroom (virtual or not), the teacher provides the environmental framework and context but is also a learner and coinvestigator with the students. The teacher is not the primary source of all information relevant to the content of the course or even the primary interpreter or integrator of such knowledge and information. That role becomes the learner's. The teacher's role becomes one of modeling effective learning behaviors, coaching and guiding, and mediating among possible classroom activities and pursuits within the framework of overall course content.

Chickering and Gamson (1991) and Chickering and Ehrmann (1996) define seven principles of good teaching practice as a framework for organizing these new learning environments.

1. Encourage student-faculty contact.
2. Encourage cooperation among students.
3. Encourage active learning.
4. Give prompt feedback.
5. Emphasize time on task.
6. Communicate high expectations.
7. Respect diverse talents and ways of learning.

For Palmer (1998, p. 90), "to teach is to create a space in which the community of truth is practiced." Such a teaching and learning space, which engages learner and teacher collaboratively and communicatively, should

- Be bounded and open; be hospitable and charged.
- Invite the voice of the individual and the voice of the group.
- Honor the "little" stories of the students and the "big" stories of the disciplines and tradition.
- Support solitude and surround it with the resources of community.
- Welcome both silence and speech.

From these perspectives, Hanna (2000, pp. 53–59) considers that four major approaches to creating active and engaging learning environments are

- Collaborative and cooperative learning
- Problem-based learning
- Learning communities
- Communities of practice

Collaborative and cooperative learning, which is more a personal philosophy than teaching technique, suggests a way of dealing with people that respects and highlights individual group members' abilities and contributions. This approach underlies a set of basic assumptions about learning (Matthews et al., 1997):[14]

1. Learning in an active mode is more effective than passively receiving information; the teacher is a facilitator, coach, or midwife rather than a "sage on the stage."
2. Teaching and learning are shared experiences between teacher and students.
3. Balancing lecture and small-group activities is an important part of a teacher's role.
4. Participating in small-group activities develops higher-order thinking skills and enhances individual abilities to use knowledge.
5. Accepting responsibility for learning as an individual and as a member of a group enhances intellectual development.
6. Articulating his or her ideas in a small-group setting enhances the student's ability to reflect on his or her own assumptions and thought processes.
7. Developing social and team skills through the give and take of consensus building is a fundamental part of a liberal education.
8. Belonging to a small, supportive academic community increases student success and retention.
9. Appreciating (or at least acknowledging the value of) diversity is essential for the survival of a multicultural democracy.

Problem-based learning can be defined as a form of cooperative learning that organizes group learning around a structured problem created by the instructor. It shares many fundamental assumptions with both collaborative and cooperative learning, including the idea that learning is a constructive process and that social and contextual factors influence learning (Gijselaers, 1996).

According to Wilkerson (1995), high-quality problem-based learning environments are led by teachers who

- Balance student direction with assistance
- Contribute knowledge and experience
- Create a pleasant learning environment
- Stimulate critical assessment of ideas

Learning communities are intentionally created environments for learning that bridge courses, programs, academic departments, or living facilities to create a joint quest for learning among members and participants. Through the intentional creation of a safe psychological climate or a space for learning, learners with different backgrounds, ethnicities, religions, or other characteristics are able to learn from each other intensively and cooperatively.

Communities of practice are increasingly created and utilized by professional associations and others interested in fostering access to new knowledge emerging from practice. Within a community of practice, the processes of learning and membership are intertwined.

Most higher education teaching practices (even primary and secondary) are far away from meeting the requirements of this new way of understanding teaching and learning. And the role of ICT in creating collaborative environments is still in its first stages:

> With no more than twenty-five years of experience in the use of technology to create collaborative learning environments (Woolley, 1994), we are only beginning to explore how technology can build more effective collaborative learning environments. Recent developments with computer conferencing software linked to the Web environment are especially promising in their possibilities (Gilbert, 1995). To restate the task before us in relation to learning technologies, the challenge is not simply to incorporate learning technologies into current instructional approaches, but rather to change our fundamental views about effective teaching and learning and to use technology to do so. (Hanna, 2000, p. 61)

For Privateer (1999, p. 68), to be truly a revolutionary force in higher education, academic technologies should

- Be deployed in new kinds of academic environments driven by a real understanding of change
- Reflect an understanding of the underlying catalysts for this change
- Be driven by an understanding of how new digital technologies require radically new and different notions of pedagogy

These principles are rather difficult to meet in existing VLEs, no matter whether they are designed and implemented as in institutions going through expansion or transformation processes or in brand new ones.

LESSONS LEARNED BY TEACHING IN A VIRTUAL CAMPUS

The last part of this chapter will critically analyze an experience of teaching in a virtual environment. This will contrast, in practice, most of the pros and cons of designing and implementing VLEs and elaborate some consequences.

THE BACKGROUND

Since 1995, the "Instituto Tecnológico de Enseñanza Superior de Monterey" –(ITESM), in Mexico, has been converted into a virtual institution with 26 sites distributed in the whole country, by using a sophisticated interactive technology. Courses and learning activities are broadcast via satellite, and lecturers get immediate student feedback on a text screen. This interaction can continue by e-mail and discussion in a news group.

The combination of different technologies, as shown in Table 3.1, allows lecturers and students to perform synchronous and asynchronous teaching and learning activities.

The use of different means of communication places the courses into a real multimedia environment. Video, audio, text, and graphic are mostly used in the synchronous sessions. In these sessions all students are able to see the lecturer. However, the lecturer can only receive "virtual" student feedback through the text messages they send online. In the asynchronous interaction, texts, images, and graphics can be used both in the print course materials and the Internet exchanges (e-mail, discussion group, and Web pages).

As well as implementing this distance education model, the ITESM is also in the process of putting into practice a new teaching and learning paradigm to develop in a planned manner the skills, attitudes, and values established by the new institutional "Misión" and increase staff commitment levels. In pedagogical terms this implies moving from a fact- and lecturer-based instruction to a more problem-solving student-based approach to learning. Staff is invited to participate with in-service activities both on a face-to-face and a distance basis to foster this change of mentality.

Table 3.1
Learning Activities

Technology	Synchronous Interaction	Asynchronous Interaction
• Print course material		X
• TV broadcasting (plus online messages and quick opinion checker device)	X	
• Internet (e-mail, discussion group, Web pages)		X

In 1997 the ITESM offered a set of in-service courses within the "Development of Teaching Skills Programme." I was invited to participate in this program by giving a course on Assessment and Self-assessment of Learning Processes and Results. The course was attended by over 100 lecturers of all disciplines (from engineering to Spanish language) scattered in 24 sites across the country. The course was implemented using the technological system mentioned previously.

THE IMPLEMENTATION: CHANGING THE VIEW ABOUT ASSESSMENT NEEDS MORE THAN NEW SKILLS

A common feature of the positivist approaches to knowledge, science, teaching, and learning is the conviction that implementing changes in the way people perform their jobs simply means to deliver them ready-to-use tools or a set of steps to be followed. As the important existing volume of studies on innovation and change has shown (from Lewin, 1946, 1951 to Bodilly, 1998; Fullan, 1993, 1999, 2001; Hernández & Sancho, 1995; Sarason, 1990; Stoll & Fink, 1996; Stringfield et al., 1996; and Tyack & Cuban, 1996, among others), this view misses all the complexity of people thinking, people interaction, and institutional constraints. It does also ignore the inevitable stress of the first moments of any situation in which an important number of people do not have experience—like references about how to behave, what to expect from the others, and how to cope with the emergent circumstances.

Taking into account this late viewpoint and being highly aware that the perspective teachers used to assess students plays an important role in modelling students' learning experiences, the course I was about to teach could not be a mere transfer of concepts and procedures. The proposed activities should challenge the existing views of lecturers on their institutional and teaching role, the students' roles, the ways of understanding academic knowledge, and the ways of understanding society demands for people as professionals and citizens.

According to this perspective, the main purpose of the course was "to enable lecturers to conceive teaching and learning activities that would allow the students to develop understanding, interpretation and metareflection (learning to learn) capacities, in order to better prepare them to cope with current and future challenges as individuals and professionals."

It does not seem difficult to argue that such an aim is not a "measurable" outcome to be achieved by providing lecturers a set of tools, but an ongoing process in which important discussions, negotiations, and compromises between lecturers themselves, as individuals and as a part of a community, should take place.

From this point of view, aims, content, methods, and assessment should be coherent. So, the main course activity should allow participants to carry out

- A reflection on different conceptions and practices of assessment
- An analysis of the coherence between educational aims and assessment procedures
- A deliberation on issues related to the assessment of a kind of learning that cannot be only understood as a short-term outcome

Such activities require a good deal of discussion, pointing out paradoxical situations and negotiation among and with students. So, lecturing is not the best way to carry them out. However

- The course should be done within given dates: from Monday to Friday
- In a given time: from 9:00 to 11:00 A.M.
- Using given basic technology: TV satellite broadcasting, a text-based interactive device, and Internet

These teaching conditions had a lot of advantages for both the participants and the institution:

- More than 100 people could attend the course without leaving their locations or the lecturer having to travel around the country. This saved a good amount of material and human resources and energies.
- Students could "see" the teacher, so they had the "impression" they were in a "real" class.
- Students could send their impressions and comments whenever they felt like, so if the teacher wanted to take them into account, the "interactivity" could be much higher than in a traditional class.
- After the direct teaching period, students could send the teacher their comments and reflections. They could also share them with the rest of the students through the news discussion group.

Nevertheless, this teaching modality also presented some inconvenience and raised several basic points such as

- The anxiety lecturers can feel and generate by thinking they are speaking to a TV camera when, far away, a group of students they cannot see are watching and listening to them.

- The awareness of time by lecturers and students. As the broadcast is booked for a certain time and it is expensive, everybody thinks it should be used as much as possible. This can result in teaching activities heavily based on lecturing.
- Students' participation is mostly carried out in a written form. During the synchronous sessions students use an "emergent" type of writing as the key tool of communication. Emergent writing, as pointed out in research (Guitert, 1995), tends to spoil the use of written language, although it can also mean the development of skills to synthesize thoughts.

These fundamental issues are related not only to the technological infrastructure but also to the pedagogical model, the students' roles and activities, and the teacher's roles and involvement. I will deal with each of them by raising several questions.

COULD SOME VLES REINFORCE INSTRUCTIVE MODELS OF TEACHING?

When planning the course, I realized that, although I already knew this distance-education technology, I had never used it myself to teach a course. I was highly aware of the use of time (satellite broadcasting is expensive) and the fact that students were used to "listening" to a teacher. On the other hand, even if technology allowed some kind of interactivity, the teacher is, in fact, the one who monitors the process. While the teacher is lecturing or proposing activities, students can send him or her messages that she or he will receive almost immediately through a screen placed in the studio. However, it is the teacher who decides whether to use this input or not. I shall further point out how taking into account this kind of input means new commitments for lecturers.

Under these conditions, the big danger of using this technology lies in the reinforcement of the more instructional aspects of teaching. Those aspects that educational research has pointed out as less suitable to develop higher-order thinking skills and the understanding of complex knowledge. If facing complex and controversial aspects of "knowing what" and "knowing how" takes time and deep discussion, this kind of distance-education technology can reinforce the production of highly structured-prescriptive knowledge. So, facing them with simple problems or questions with already-made answers can simulate interaction with students. In fact, in this context, as it has been mentioned, one of the tools teachers can use for quick student interaction allows the students to answer "yes," "no," and a range of "highly agree-disagree" answers.

To overcome this situation without feeling that the pedagogical model suitable to achieve the course goals could be swallowed up by technology, I had to pay more attention to the kind of proposed activities that implied the need for more feedback. On the other hand, as students used the computer as their communication tool, they explored new communication ways.

HOW DO STUDENTS USED TO ORAL INTERACTION COPE WITH VIRTUALITY AND THE NEED FOR USING WRITTEN TEXTS?

In a highly based oral culture, using the written text as the basic way of communication is a really important change. Written messages were of two types, one that could be called "in hot" and the other one "in cold." The first ones were written during the broadcast session. Their contents referred to punctual questions suggested by the teacher or by other students, and they were comments found pertinent by one or more participants. Such messages were short and did not pay much attention to linguistic issues.[15] Being in a higher education context, this can be a minor point. However, it would be important to assess its impact on a Spanish language modality heavily eroded by the influence of the United States.

The second kind of messages, containing the proposed tasks and activities and all those reflections and comments participants found pertinent, usually related to the controversial issues of the course, were produced in a more reflective manner. Linguistic and expressive issues were taken into account and, if the computer system did not prevent them, they all used the Spanish signs.

However, the most interesting side of this mode of communication was that participants had to express their views on rather complex concepts in a structured way so as to make them understandable. This meant much more work for them, but also the possibility of expressing themselves in a more thoughtful way, using different channels.

WHAT DOES THE USE OF THE FULL POTENTIAL OF INTERACTIVE TECHNOLOGIES MEAN FOR A LECTURER IN TERMS OF TEACHING EXPERTISE AND WORKLOAD?

Experienced lecturers have a professional background that allows them to develop their duties in a highly effective way with a reasonable expense of energy. They can interpret classroom situations, use different resources to ensure students' motivation, and take into account students' contributions. However, it could be the case that lecturers know very little about the way their students think, by allowing their students only to participate at certain times and through certain ways: classroom questions, exams, essays, or assignments.

Because I am a lecturer who wants to know how students think, how they express their views, knowledge, emotions, and positions, especially on an issue as controversial as assessment, making use of the potential of interactive technologies was too good an opportunity to pass up. This meant proposing to the participants in the course a set of activities that would allow them to express themselves. By doing that, as a lecturer, I had to perform the same kind of activities I normally do when preparing my teaching, though, in this case, it was not enough. I had to add some activities that were highly demanding and time consuming to the ones I normally do when I plan and implement my teaching.

Every day, while performing in front of the TV camera and the nine on-site students, I had to be aware of

- Looking at the TV camera, so that students attending the course in other campuses had the "impression" I was looking at them
- Looking at the on-site students, so that they could feel I was paying attention to them
- Taking into account contributions made by on-site and other campuses' students, that one assistant was filtering[16] and putting on a screen next to me
- Being aware of not leaving too much or too little time for students' activities (see Table 3.2)

Table 3.2
Characteristics of Teaching Activities

Face-to-face teaching activities		Interactive distance teaching activities
• Prepare course content. • Prepare course materials. • Decide pedagogical models. • Take into account students' contributions in classroom or tutorial sessions. • Decide assessment model. • Read and assess student productions.	+	• Preview the time necessary for students activities. • While speaking in front of a camera and a few students, taking into account the rest of students' inputs written on a screen. • Read and answer all the messages sent by participants. • Give global feedback of the kind of questions and issues raised by participants.

Every day, when the synchronous part of the course was over, I carefully went through all the messages received during the session and composed a feedback message for all the participants. I also added comments on their assignments and questions students sent to me by e-mail. If necessary, these messages were also answered individually. Most contributions were taken into account in the broadcast session the following day.

I can assure that this way of working has been one of the most interactive I have ever experienced. However, the workload was also considerable. Apart from the previous preparation for the course, I spent between four and six hours a day to complete the rest of the tasks for this format.

CONCLUSIONS

Not all VLEs share the same technological and pedagogical framework. Not all of them have the same aims and functions. So, the experience of teaching and learning for users could be very different. However, there are a few aspects that seem common to most of them. VLEs used in distant education can solve access problems and provide people who live in remote places access to a wider range of educational experiences. In face-to-face institutions they can enlarge students' learning experience. However, they do not immediately solve teaching and learning problems. In fact, they face people and institutions with the necessity of transforming their roles and performance. This transformation implies technological choices and periodical updates that have substantial impact in the mode of delivery, a deep redefinition of organizational issues, an increase in the workload for both students and teachers, and the necessity for everybody to develop or acquire new knowledge, attitudes, and skills.

NOTES

1. It's interesting to see how people with any kind of specialized knowledge about education seem to find a panacea in any new tool provided by the Information and Communication Technology industry.
2. The Telematics Application Programme (TAP) was an important chapter of the European Union IV Framework Programme. Between 1994 and 1998, the TAP invested more than 50 million euros for R&D projects to develop applications to promote the use of telematics in education and training. In the V Framework programme (1998–2002), through the Information Society Technologies-KA3 programme (Content, Multimedia Tools and Markets), a considerable amount of resources has been allocated to calls such as the flexible university, the schools of tomorrow, or the learning citizen. All of them have the task of developing and implementing digital or virtual tools and content to promote better or different

ways of learning, in tune with today's resources and necessity both for higher, primary, and secondary education and lifelong learning. Other European initiatives such as Socrates (Minerva) also deal with the development and use ICT-based courses and digital teaching materials.

3. Gibbons et. al (1995), Simó (1996), and Sancho (1998), among others have pointed out the gap between the way knowledge is created, disseminated, and legitimized and how knowledge becomes institutionalized and made available to students.

4. Virtual is defined as being such in power, force, or effect, though not actually or expressly such. Opposite to real (noting in an image formed by the apparent convergence of rays geometrically), but not actually, prolonged, as the image formed by a mirror. Having an inherent power to produce certain effects.

5. Only a few years ago much more was written about teaching than about learning. At the moment, even if most educational practice is still highly teacher centered (Cuban, 1993), there is an increasing interest in finding ways to promote students' learning.

6. Most educational buildings for primary, secondary, and higher education followed the same pattern in the last 100 years. As it happens with other kinds of infrastructure, educational buildings have deeply influenced teacher and student interaction and, very often, are one of the most important obstacles for educational change.

7. Schools or universities can be "contained" in a computer system and students and teachers can be scattered all over a city, country, or the whole world.

8. The analyses of any teaching material used in most "virtual universities" shows the same problem of selection and articulation of knowledge than that of any curriculum.

9. Even if the technological structure of some VLEs can represent a loss of teachers' autonomy, their role is taken by the system administrator, the teaching materials designers, etc.

10. The first distance-education course was offered in 1728, when Caleb Phillipps, shorthand teacher, announced his course in the *Boston Gazette*, offering the possibility of distance delivery.

11. All European countries have educational ICT programs to promote the use of computers and electronic networks. The European Commission has launched different initiatives for the same purpose. The latest one has been the Information Society Technologies named "The School of Tomorrow" and the "Learning Citizen," as a significant effort for blurring school and community learning barriers, reconceptualizing the meaning of "learning environments" and fostering lifelong learning attitudes.

12. Perelman "calculated that the average job in the American economy requires $50,000 of investment in plant and equipment for every employee. For schools the figure is a mere $1,000. If you go along with the notion that the real 'worker' in the teaching and learning processes is the student, that figure drops to

$100. While the rest of society goes through a technological revolution, schools are lingering in the Stone Age—not only in the way they deliver information but in virtually every other activity in which they engage" (Fiske, 1991, p. 146). Even if this calculation and the comments were than more than a decade ago, it is difficult to find evidence of any substantial change.

13.The decision to invest in a given field of study and not in another, the promotion of a certain research program and not others, the infusion of funds to develop a given technology and not others, are fundamental steps in the configuration of a given environment and way of life to the detriment of other possible ones.

14.Cited by Hanna (2000, p. 53).

15.To the rush of the moment it has to be added that the technical system developed in the United States did not allow other alphabetical signs than the English ones.

16.In a two-hour session students in distant campuses could send over 90 messages. More than 50 percent of them were related to technical problems; the rest dealt with the proposed activities or their own worries and views about the topic.

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4

MIT-Miyagi 2000: An Experiment in Using Grammars for Collaborative Design

José P. Duarte

This chapter reports on an experiment that shows the feasibility of a grammar-based framework for the mass customization of housing and the value of grammars in collaborative design.

INTRODUCTION

This chapter describes in depth an experiment that partially simulates an envisioned framework for the design of customized mass housing. This framework includes computer-aided design (CAD) and production systems. The design system (Duarte, Ferreira, & Cruz, 2000) encompasses a Web site and the use of rapid prototyping techniques and virtual reality environments. The Web site provides the user with a catalog of existing designs and an automated tool to generate new designs online. The catalog provides prospective dwellers with a way to understand the available housing solutions and a way to structure their needs. The automated design tool allows a thorough exploration of the space of design solutions in search of an adequate solution. Rapid prototyping and virtual reality techniques are used to convey solutions to clients. The production system makes use of Computer Numerical Control (CNC) assembly line equipment to efficiently produce thousands of unique products. The goal is to customize housing and increase user satisfaction.

The automated design tool uses a shape grammar as the main formalism to encode architectural knowledge and to define the space of design solutions. The experiment described in this chapter was part of a set of experiments designed with the goal of developing and testing this grammar. After being introduced to shape grammars by lectures and by a series of hands-on exercises, students used a particular grammar to design a set of houses for given clients. This Malagueira grammar captured the rules followed by Álvaro Siza (Pritzker Prize '92) for designing patio houses at Malagueira, a 1,200-dwelling development still being designed and constructed today. Taught simultaneously in two different countries and with the participation of a panel of international clients, the workshop was also an opportunity to experiment with distance teaching and collaboration models between local and remote students. Electronic communication—videoconferencing, electronic mail, and the World Wide Web—held collaboration together and enabled the work to be done quickly and efficiently.

Results showed that the grammar was helpful in overcoming communication barriers between members of the design team and between the design team and the clients, while providing the means to generate customized housing. In the end, the city block produced after the experiment looked very much like other blocks at Malagueira, and the original architect, Siza, agreed that the new houses were stylistically compliant. Therefore, results suggest that the design system of the envisioned framework is valid.

The second section provides the necessary background on grammars, distinguishing between analytical and original grammars, and explains how the Malagueira grammar spans between these two types. The third section introduces a methodology to use in the development of such grammars. The fourth section briefly describes the Malagueira grammar. The fifth section describes the experiment, including goals, participants, Web resources, settings, tasks, and procedures. The sixth section presents the results and discusses its implications, considering aspects such as the potential of the developed grammar for generating goal-matching designs, for improving collaboration among designers, for balancing variety and unity in urban environments, and for mediating client participation. A small concluding section closes the chapter.

GRAMMARS

Grammatical design studies had its beginning in a seminal paper by Stiny and Gips (1972), in which they laid the foundation of what was to become the most important algorithmic approach to design. Since their discovery, the field has grown to encompass a number of technical devices and research issues. A shape grammar specifies how designs can be generated from an initial shape through the recursive application of shape rules.

Shape grammar studies can be grouped into two different categories: analytical and original. Analytical grammars have been developed to describe and analyze historical styles or languages of designs by architects that are no longer living. In fact, after the first grammar was developed to explain a corpus of architectural artifacts, the one for Palladian villas (Stiny & Mitchell, 1978), others have been developed with the same purpose over the past 20 years. Among them are Wright's Prairie Houses (Koning & Eizenberg, 1981), Buffalo bungalows (Downing & Flemming, 1981), Japanese tearooms (Knight, 1981), and Queen Anne houses (Flemming, 1987), to name an important few. Analytical studies use a set of existing designs to represent the language—the corpus—and to infer the rules of the grammar. The grammar is, then, tested by using the rules to generate designs in the corpus, as well as new designs in the language.

Original grammars are concerned with the creation of new and original styles of designs from scratch. The use of grammars for creative design has not been explored as deeply as the use of grammars for analytical studies. Although implicit in Stiny and Gips (1972), such use of grammars was only explicitly addressed in Stiny (1980), where he proposed a program for developing new grammars that is illustrated using Frederick Froebel's kindergarten method of education. Stiny's program was implemented by Knight, who introduced grammars in the design studio. From this experience, Knight highlighted some of the difficulties in using grammars for creative design, which are connected to the "translation of abstract, experimental forms into architectural designs that fit particular design contexts or programs" (Knight, 1992). Solving this difficulty was central to the work described in this chapter, which is focused on the design of goal-matching designs.

The grammar for Siza's houses at Malagueira is in the footsteps of the analytical studies mentioned earlier. Nevertheless, it is a grammar developed for an evolving project by a living architect. To the extent of author's knowledge, there has been only one other grammar of this kind: the one on the work of the architect Glen Murcutt (Hanson & Radford, 1986). However, unlike the Murcutt grammar, the Malagueira grammar was developed with Siza's support, and therefore, it can be seen as a natural extension of Siza's work at Malagueira. The impact of such a novelty is twofold. First, it is possible to use the original architect and the dwellers in addition to existing designs as sources of information to derive the rules of the grammar. Second, it is possible to use the grammar to generate and build new houses in the language. Therefore, the grammar is more than a mere analytical grammar aimed at describing a family of designs. But it is not a full grammar developed from scratch to generate entirely new designs. It is reasonable to consider that it spans between analytical and original grammars.

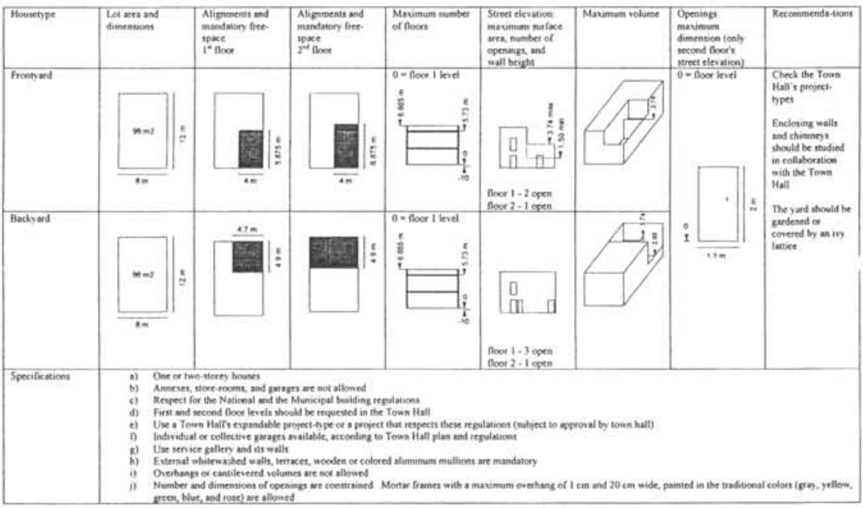
The experiment described in this chapter is part of the methodology used to develop such a grammar, and although it takes advantage of the possibility of using the original architect and the dwellers as sources of information, the objective is to solve the problem of generating new, goal-matching designs.

METHODOLOGY

Stiny and Mitchell (1978) listed three tests to confirm whether a grammar has any explanatory or predictive value. First, it should reveal the common, underlying features of designs in the corpus. Second, it should provide the criteria to determine whether a design is in the language. And third, it should specify how to generate new designs in the language. We called these tests descriptive, analytic, and synthetic tests. Given the goal of generating customized designs, we propose an additional test called goal test. This new test states that a grammar should possess the means to generate designs that match given criteria. These four tests were formalized as experiments in the methodology followed in the development of the Malagueira grammar.

In Experiment 0, the grammar was iteratively sketched after the analysis of designs in the original corpus until it was possible to describe their generation using its rules—descriptive test. In Experiment 1, the same rules were applied to a design not considered in the original corpus to verify their capability to account for its generation—analytic test. Experiment 2 addressed the generation of random new houses, which were checked by Siza for stylistic compliance—synthetic test. In both Experiments 3 and 4, experimental subjects grouped in design teams derived designs for given clients out of the grammar rules—goal test. However, they differed in some important aspects. In Experiment 3, subjects in the same design team were collocated, and teams were given the same client and the same land plot. In Experiment 4, subjects in the same design team were remotely located, and teams were given different clients on adjacent land plots. The idea in Experiment 4 was to further test the collaborative value of grammars. The experiment described in this chapter corresponds to Experiment 4.

Figure 4.1
Malagueira design regulations.



THE MALAGUEIRA GRAMMAR

The Malagueira development was a large development planned as an extension of the city of Évora, in Portugal. The development considered the possibility of different types of housing promotion, with Siza in charge of designing houses for public and cooperative promotion. Private promotion foresaw the possibility of hiring other designers. Therefore, Siza included in the plan a set of regulations to control the outcome of designs by other designers (Figure 4.1). Siza also devised a scheme that allowed for the generation of different houses in an attempt to incorporate into public and cooperative promotion the users' desire for a unique house. The scheme was composed of a set of rules that could be used by him or his collaborators to design customized houses. However, he never laid them out in an explicit way, and to develop the grammar, a corpus of 35 different houses designed over a period of two decades was used to infer the rules (Figures 4.2 and 4.3).

To make it possible for the reader to understand the formal properties of the Malagueira grammar and to understand the experimental context, we show a very simplified set of shape rules and the partial generation of a layout using such rules in Figure 4.4.

Figure 4.2
Main types and variations considered in the corpus.

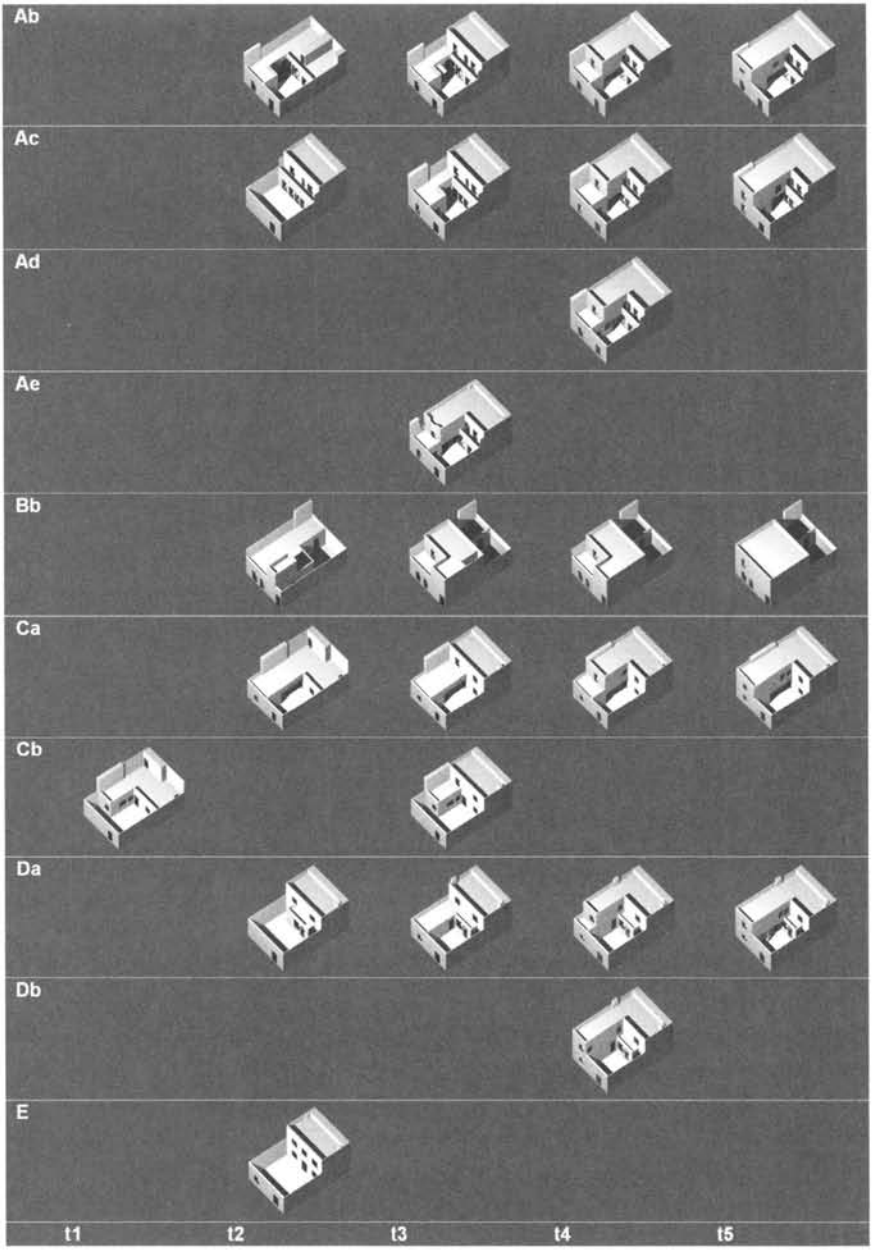


Figure 4.3
Plans, sections, and elevation of types Ab and Ba included in the corpus.

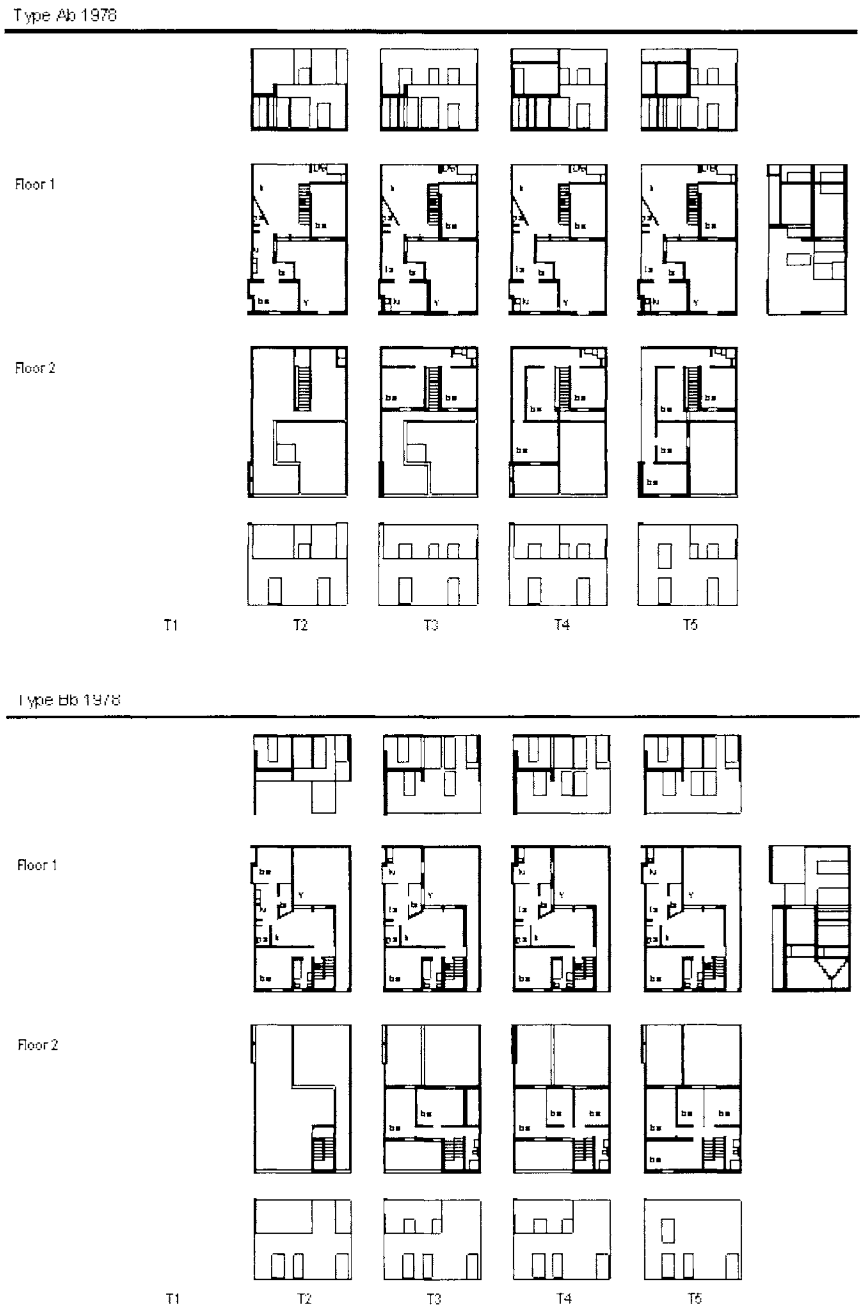
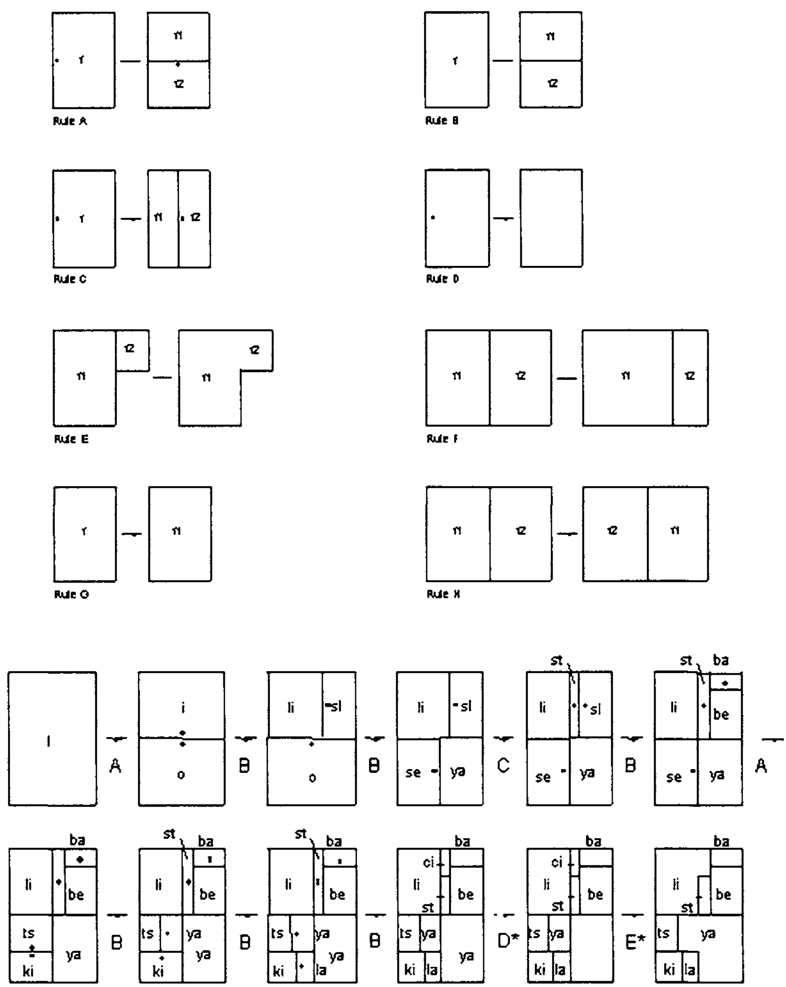


Figure 4.4

Simplified Malagueira shape rules (a) and partial derivation of an existing layout (b). *There are rules for dissecting (A, B, and C), connecting (E), and extending (F) rectangles. The remaining rules are for deleting a marker (D), assigning a function (G), and permuting functions (H). Legend: l—lot, i—inside zone, o—outside zone, li—living zone, sl—sleeping zone, se—service zone, ya—yard zone, be—bedroom, ba—bathroom, ki—kitchen, ts—transitional space, la—laundry, pa—pantry, ci—circulation, st—stairs. The asterisk means that the same rule was applied several times.*



In brief, the generation of a Malagueira design is based on the manipulation of rectangles using rules for dissecting, connecting, and extending rectangles, as well as rules for assigning and changing the functions associated with them. The generation of *basic layouts* with these rules comprises two

Figure 4.5
Partial tree diagram showing the partial derivation of the house types in the corpus, as well as new types produced in Experiments 1 (F) and 2 (New).

steps. In the first step, the lot is first divided into the four functional zones—patio, living, service, and sleeping—thereby obtaining a *basic pattern,* and then a staircase is added thereby defining a *stair pattern* and the house type. In the second step, these zones are divided into rooms to obtain the layout. The labels "fn" denote the functions of the rooms that the rectangles represent. The dot • is a label that identifies the last line placed and indicates on which side the next dissection may occur: on both sides (Rule A) or only on one side (Rule B). In Rules A and B, dissections are perpendicular to the bigger side of the rectangle, whereas in Rule C it is perpendicular to the smallest one. Rule D deletes the label •, preventing further dissections. Rule E concatenates two adjacent rectangles to form a larger room. Rule F extends a room at the expense of an adjacent one. Rule G assigns a function to a room. Finally, Rule H permutes the function of two adjacent rooms. The actual grammar is more complex, and it included many more rules, including some for making openings and other details.

Figure 4.5 shows the partial derivation of houses in the corpus, as well as new houses produced in Experiments 1 and 2. An important problem faced in the development of the grammar was to decide which patterns it could generate. For instance, if one considered all the possible ways of dividing a rectangular lot into four functional zones, 192 different basic patterns can be obtained, but Siza only used 6 of them (Figure 4.6). Should one follow a broad interpretation of Siza's rules and have the grammar generating all the 192 patterns, or should one be strict and consider only those used by Siza? We followed an intermediate approach, by having the grammar generating patterns that seemed closer to Siza's intentions, and the idea was to confront such a decision with the experimental results.

EXPERIMENT

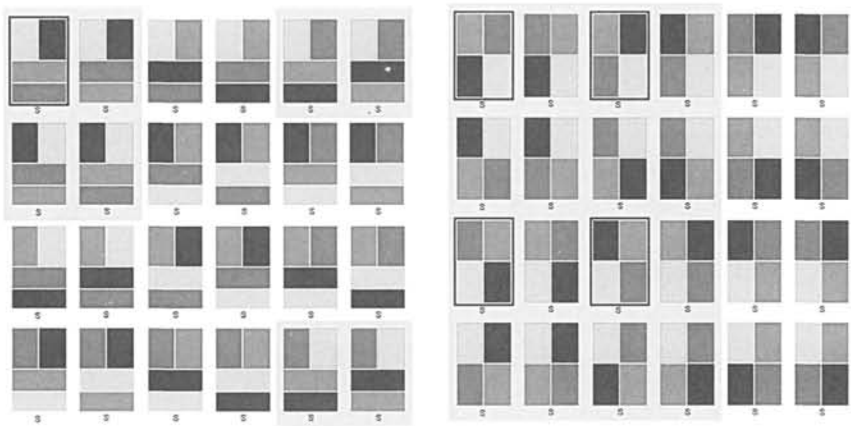
Goals

The main goals of this experiment were threefold. First, it was to test whether the grammar could be used in the generation of designs that were in the Malagueira style and matched given functional requirements. Second, it was to find whether using the grammar improves design communication, despite a variety of cultural backgrounds. The third goal was to verify whether the grammar provided the means to solve the variety/unity paradox faced by designers when they are asked to customize houses and to integrate them into a whole. The experiment had other goals, such as to find out how designers find their way through the maze of solutions to generate a particular one and to test ArchNet, a Web environment being developed at MIT to support collaboration, but these aspects are only briefly mentioned here. The experiment took the form of a workshop offered to students.

Course Description

The MIT-Miyagi workshop was offered as a graduate course in the Department of Architecture at the MIT School of Architecture and Planning in the spring of 2000 within the context of the MIT Design Studio of the Future project (http://loohooloo.mit.edu/people/WJM/DSOF.htm). It was the first course to use grammars in remote collaboration, and it was set

Figure 4.6
Forty-eight of the 192 basic patterns that can be obtained by dividing a rectangular lot into four functional zones. *Patterns bordered by black lines correspond to houses designed by Siza. Shaded patterns are patterns considered in the version of the grammar used in the experiment.*



up as an intensive four-week workshop conducted in collaboration with Miyagi University in Sendai, Japan. Students were asked to explore issues in shape grammars, rapid prototyping, and remote collaborative design. Students were introduced to concepts in shape grammars through a grammar developed for Siza's Malagueira houses. Teams of participants were asked to design a housing block composed of units, for a given set of clients, both by following the grammar rules and by changing these rules. Rapid prototyping techniques were used in the process of design. The project required students at MIT and Miyagi University to work collaboratively through Web and videoconferencing technologies. The MIT students visited their teammates in Japan at intervals during the workshop.

The workshop was held from February 3 through March 3. The four weeks were organized in the following way. In the first week, the fundamentals of shape grammars were introduced using abstract grammars. In the second week, the Malagueira grammar was described in detail. In the following two weeks, the clients were introduced, and design teams were asked to generate houses for them within the Malagueira grammar. The whole class met twice a week on Mondays and Fridays from 18:00 to 20:00 at MIT (Tuesdays and Sundays from 9:00 to 11:00 at Miyagi). The Monday session was a lecture, and the Friday session was a presentation session in which students showed their solutions to the assignments handed out in the lecture. In between the lecture and the presentation sessions, there were working sessions on Tuesdays, Wednesdays, and Thursdays booked by the teams at their convenience (Wednesdays, Thursdays, and Fridays at Miyagi).

Participants

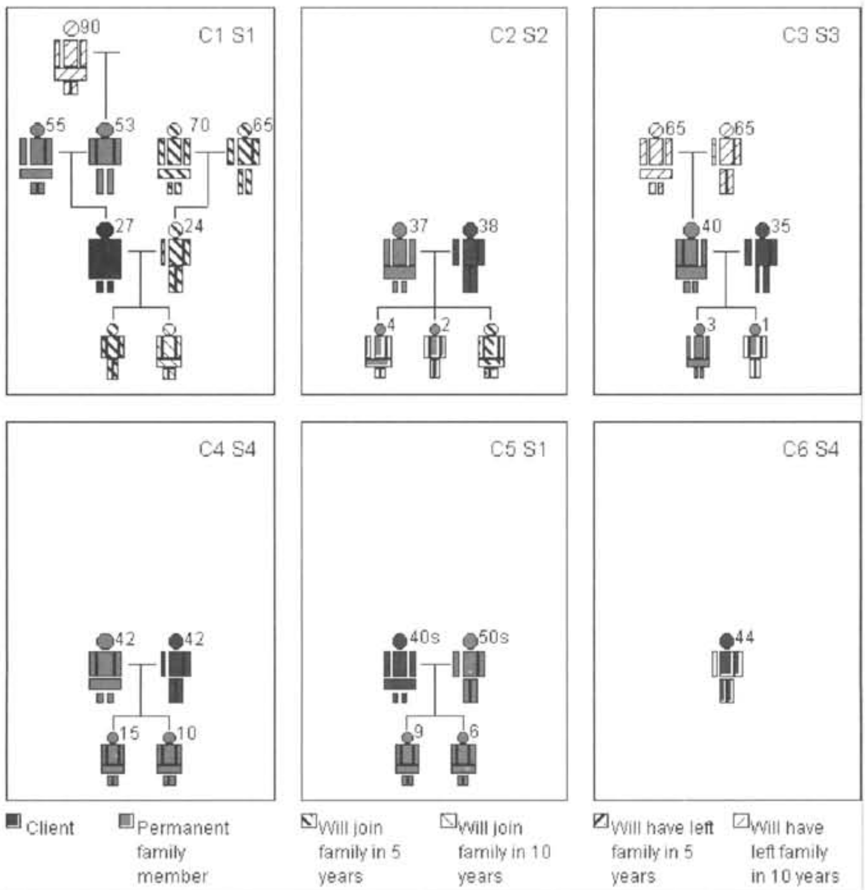
Five sets of participants were in the experiment: instructors, observers, students, clients, and reviewers.

The instructors were José P. Duarte, who had a formal education in architecture and experience in architectural teaching and practice and was a Ph.D. candidate in Design Technology at MIT. He was the author of the Malagueira grammar and Web site and planned the course structure. Terry Knight, associate professor at the School of Architecture and Planning at MIT, has taught Shape Grammars for many years. She has advised many students in the use of shape grammars in architectural design projects. Professor Knight supervised the planning of the course structure and briefed students on the fundamentals of shape grammars. William J. Mitchell, professor of Media Arts and Sciences, has been a pioneer in the field of design and computation and, particularly, in the use of shape grammars in architecture. Professor Mitchell supervised the course. Susan Yee was a Ph.D. candidate at MIT, developing research on remote collaborative design. Susan developed the course Web site as well as coordinating the development of ArchNet. She also devised the remote collaborative apparatus used in the course and helped planning the course structure. At Miyagi University, Professor Riusuke Naka, who has had the initiative of the remote collaborative program since 1998, coordinated the class with the help of Professor Soichiro Okishio.

The course also had the participation of two observers at MIT: Hiroto Kobayashi, a Japanese scholar who helped with the translations, and Birgul Colakoglu, a Ph.D. candidate at MIT, who commented on the use of grammars for designing.

The set of clients was formed by four Japanese and two North American families who volunteered to perform the role of clients (Figure 4.7). These families were represented by one or two family members who were university professors at Miyagi University (Akihiro Fujii, Eiji Keyamura, Ryusuke Naka, and Kumi Tashiro), at MIT (George Stiny), and the Chinese University of Hong Kong (Andrew Li). These families were selected from a larger pool using as criteria the need to obtain varied social profiles (members, age, gender, activity, interests, lifestyle, etc.) thereby providing

Figure 4.7
The families of the clients who participated in the experiment. *The clients are identified by the letter C, followed by a number, whereas the designers of their houses are identified by the letter S, also followed by a number. In each frame, each level represents a generation; in top-down fashion: great-grandparents, grandparents, parents (the client's generation), and children. The numbers next to family members indicate their ages.*



a variety of design problems. The clients participated in the presentation sessions and were available to students through e-mail, chat, or videoconference. Many also posted their comments on ArchNet.

The students, the true subjects in the experiments, were organized into four design teams. These teams were formed by two MIT graduate students and three Miyagi undergraduate students according to the following criteria: (1) one of the MIT students had reasonable knowledge of shape grammars; (2) the other MIT student had basic knowledge of shape grammars; (3) two of the Miyagi students were architecture students with no knowledge of shape grammars: and (4) the third Miyagi student was a nondesign student whose role was to work as a language assistant. None of the design subjects were knowledgeable of the architectural and cultural contexts in which the Malagueira project was developed.

The reviewers were the author of the grammar and Álvaro Siza, the author of the original Malagueira houses. Both were in charge of reviewing the designs developed by students in the workshop to determine their grammatic and stylistic fitness.

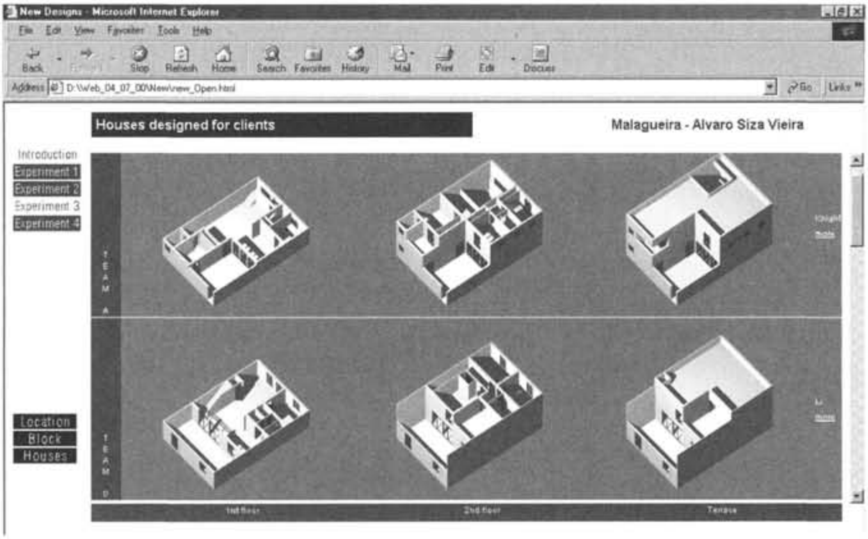
Web Resources

The required background information for students in the course was available on the Web from three different sites. The first site was ArchNet, an environment that was being developed at MIT aimed at creating an online community for architecture practitioners and scholars. This site can be viewed in the original version at (http://archnet.org/groups/mit-miyagi-design-workshop1/), and it possessed asynchronous and synchronous collaborative tools. As asynchronous tools, it included a Web-based workspace where participants could review each other's profiles, upload and download files, pin up design work, comment on such work, post questions, and retrieve the answers afterward. The synchronous tool was a chat system that permitted participants to communicate with each other when logged on. Because this environment was still under development, and its interface was not optimized for current tasks, a traditional Web site also was used for the course. As shown at http://architecture.mit.edu/~syee/MIT-Miyagi/, this site included the list of participants, the class calendar, copies of lectures and handouts, and the solutions to the assignments. The third Web site (Duarte et al., 2000) was the official Malagueira grammar Web site (now at http://www.civil-ist.utl.pt/~jduarte/malag), which included a description of the Malagueira development, catalogues of existing and new designs, and detailed information on the grammar (Figure 4.8). These Web sites were very important as online resources for all the participants involved.

Settings

Four experimental settings were used in this experiment. The first setting served to interview the client remotely. It included a computer with the following software: PictureTel (videoconference system connected to

Figure 4.8
One of the pages of the Malagueira Web site.



one ISDN line, including audio and video communication), NetMeeting (Internet-based videoconference with audio and video communication, as well as a chat system, a drawing board, and desktop and application-share features), ICQ (an alternative chat system), Internet Explorer (Web browser), and Camtasia (desktop recording).

The second setting was used in remote work sessions among team members. It was similar to the first setting, but it also included a document camera, a video recorder, paper with the Malagueira lot drawn over a millimetric grid, pencil, a list of rules, and a table summarizing the dimensional requirements of Malagueira houses. All these items were used for synchronous work. In addition, this setting included various e-mail applications and ArchNet. It also included a rapid prototyping system, namely the Fused Deposition Model by Stratasys. (A stereolithography machine was available at Miyagi University.)

The third setting was used in lecture and in presentation sessions attended by all the participants. It was equipped with an overhead projector connected to a PC and a PictureTel videoconference system. This system was connected to three ISDN lines, and it included two cameras for room views, one camera for document views, onitors for outgoing and incoming images.

The fourth and last setting used a chair and served to show the new designs to Siza.

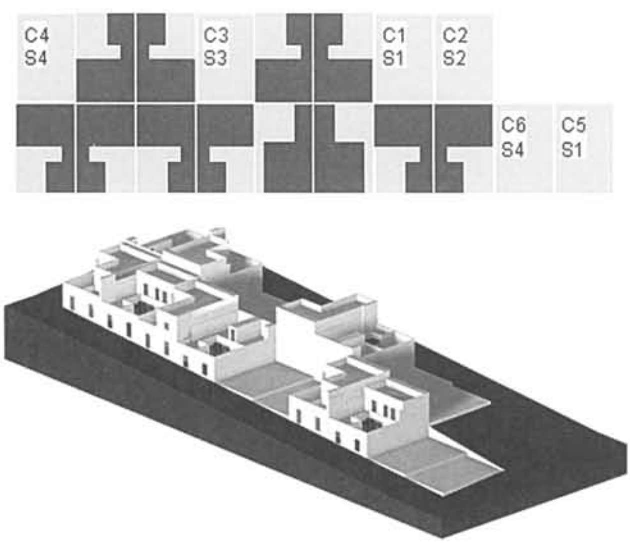
Tasks

The overall task of the experiment was to redesign one of the Malagueira city blocks, from which some houses had been deleted (Figure 4.9). Then specific tasks were assigned to the clients, the design teams, and the reviewers.

The clients had to visit the Malagueira Web site to choose a plot in the development and to describe the house that they needed. Then they had to comment on how the design solutions satisfied them.

The design teams were assigned four tasks of increasing difficulty to give students who were not familiar with grammars the opportunity to learn the basics and to allow all students to become familiar with the Malagueira grammar. In the first task, students were asked to read a paper on shape grammars (Knight, 1992) and then to complete an assignment that required them to look at three different ways of working with grammars: *using a shape grammar* to generate new and existing designs in the language, *changing a shape grammar* by modifying its rules, and *discovering a shape grammar* that generated given designs by constructing a step-by-step derivation of such designs using grammar rules. The second task required them to read a paper on the Malagueira grammar (Duarte, 2001), to explore the Malagueira Web site to see how existing designs were generated using the grammar

Figure 4.9
Plan and view of the city block considered in the experiment. The plan also shows the assignment of clients to lots.



rules, and to come up with the derivation of other existing designs, based on the same rules. The third task was to design a house that satisfied the clients' requirements by strictly following the rules of the grammar, and they were asked to show a step-by-step derivation of their designs. The subjects were, thus, put in the position of Siza's collaborators. The request for strictly following the rules aimed at clarifying whether designers did not respect the rules because they did not know them or because solving the design problem demanded so. The fourth task assigned to the design teams was to generate a house that satisfied the clients' requirements, but they were allowed to change the grammar rules by deleting, changing, or adding new rules, as long as they respected the building regulations defined by Siza. They were, thus, placed in the position of the designers who were not affiliated with Siza's office and had to design houses for the Malagueira development. In this fourth task, the design teams had to design a house for a new client or to redesign the house for the former clients, depending on whether their initial designs had been considered satisfactory.

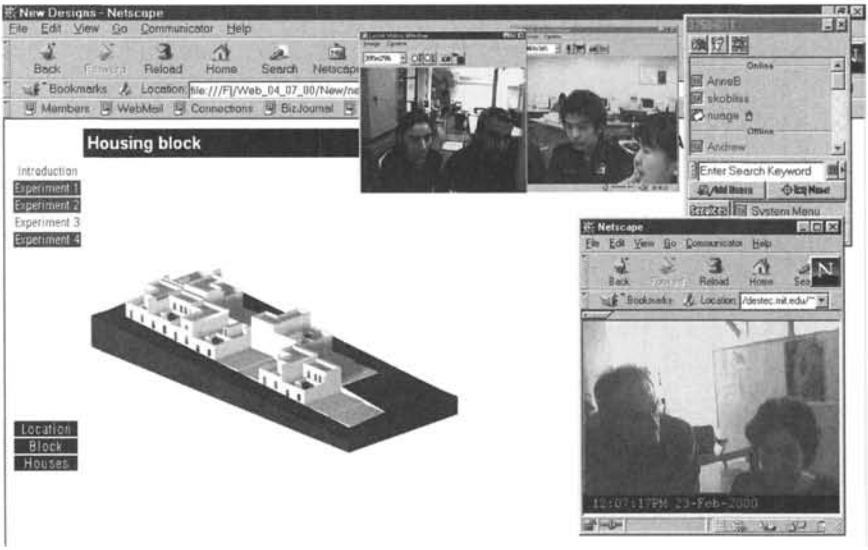
The author of the grammar had to verify whether the houses respected the grammar rules during the design process. Siza's task was to make the final comment regarding stylistic compliance.

Procedure

In the week before the workshop, the clients were asked to describe their desired house by filling in a form. This form was similar to the one used in Experiment 3. Then they had to attend a short interview (2 to 5 minutes) with the author of the grammar, who asked them to mention the important aspects about their house that were not covered in the form or to clarify the answers to some of the included questions. This interview proceeded through videoconference, and it was recorded.

In the last four weeks of the workshop, the design teams were asked to design houses for given clients, the tasks that formed the core of the experiment. Before starting these tasks, they were given online access to their clients' forms and interviews and provided with the list of rules, the area requirement table, and a plan with the location of the plots (Figure 4.10). Then, they were asked to start designing the house, using paper, pencil, and the document camera or a CAD application with the application-share feature turned on. This session was videotaped for posterior analysis (Figure 4.11). They were allowed to continue developing the houses after this session and to show them to the client and to the author of the grammar.

Figure 4.10
Screen snapshot of work session with members of the design team at MIT and at Miyagi University communicating through videoconference (*top, left*) and a chat system (*top, right*) while listening to the interview with the client (*bottom*) and looking at the Web page with site information (*background*).



For communicating with the reviewers, the design teams could post drawings and photos of the rapid prototyping models on the pinup page and then use e-mail or a chat system to communicate with them. At the end of the week, they had to present their housing solutions to the clients through videoconference, using 2-D and 3-D drawings, as well as physical models produced by rapid prototyping. Also, they were required to show the derivation of their designs, indicating the rules applied at each step, including any eventual new rules. The workshop terminated with a final presentation in which all the produced houses were gathered to form the housing block (Figure 4.12). At the end of the workshop, the design subjects were asked to fill in a questionnaire regarding their understanding of the grammar and Siza's architecture at Malagueira.

After the workshop finished, the individual houses and the city block were shown to Siza.

Collaboration Strategies

The MIT-Miyagi 2000 workshop experimented with using structured design problems to organize collaboration and with using technology to create reciprocal collaborative environments (Yee, 2001).

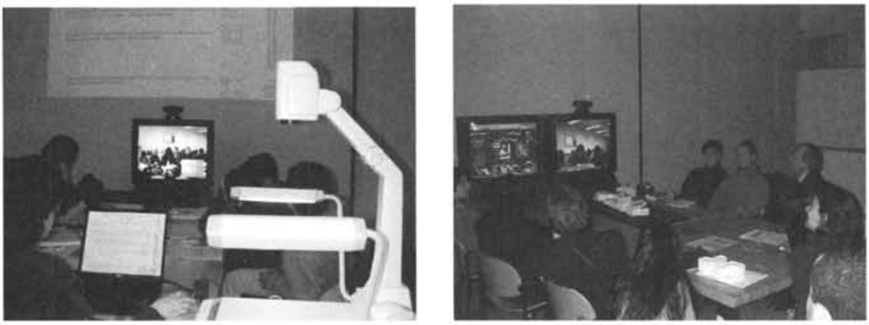
Figure 4.11
Snapshots of work sessions with videoconference at MIT, showing the design subjects working on the derivation of their houses together with their Miyagi teammates through the document camera. The video recording setup is shown on the bottom right image.

The MIT-Miyagi 2000 workshop was the first project in MIT DSOF project to integrate structured design problems with collaborative processes, and the results show that structured problems helped students to engage in peer learning, cultural exchange, and teamwork, thereby helping them to build a relationship that facilitated subsequent less-structured work. The workshop focused on learning the concepts of shape grammars.

Due to the significant differences in the backgrounds of the participants involved in the workshop, it was organized so that collaboration could take advantages of such differences. The diversity of the students in terms of design experience and shape grammar knowledge provided an opportunity to form teams that encourage peer learning. For instance, each team had an MIT student with deeper knowledge of shape grammars who would act as a mentor and a Miyagi student who was proficient in English and worked as a language translator to the remaining team members.

The diversity of the instructors was used to provide design teams with a diverse set of clients, thereby making it possible to test the potential of the Malagueira grammar to satisfy varied requirements. Moreover, the client

Figure 4.12
Snapshots of sessions attended by all the participants: lecture (*left*) and presentation (*right*).



roles helped to integrate Japanese instructors who were less familiar with shape grammars into the collaboration process. The diverse backgrounds of the instructors, also gave students a chance to engage in cultural exchange. For instance, while trying to satisfy client requirements within the grammar, design teams became acutely aware of the differences among the cultural contexts of the clients, the site, and themselves.

The workshop was organized so that each of the four MIT teams spent one week at Miyagi University. The visits to Miyagi added a social component to the workshop that encouraged trust building and team coherence. In the weeks prior to the visit, the prospect of meeting their teammates led students to cooperate intensively so as not to disappoint each other. While in Japan, MIT students became fully immersed in their teammates' world. Consequently, after the visit, they understood better each other's expertise and work methods, and remote work sessions became smoother.

The workshop was undertaken in the physical spaces of MIT and MYU and, to a certain extent, in the digital space of ArchNet. ArchNet allows members to work together in group workspaces. The participants in the workshop were made members of ArchNet, and several group workspaces were created, one for all the participants, and one for each design team. The group workspace provided spaces for real-time chatting in the chatting room; displaying and reviewing images on the pinup board; coordinating schedules in the group calendar; storing files, references, Web links, and other resources in the collections space; and assembling the team's final work in the portfolio. The participants used these spaces in synchronous and asynchronous work, and so an important part of the activity actually took place in ArchNet.

The use of ArchNet helped to integrate the two sites through the common group's workspaces, but the two schools were also integrated due to the use of compatible technologies for other synchronous interactions. For the large videoconference sessions at the beginning and at the end of the week, similar PictureTel videoconference systems were used at both ends. At MIT, the participants gathered around a seminar-style table with the PictureTel screen at the end, and with a screen displaying the class material above. At MYU, the participants were clustered in a classroom style facing two large screens displaying the class material and the remote site. The placement of a computer at the end of the seminar table at MIT and the use of a large screen at MYU represented an attempt to create a unique atmosphere between the two sites. In the synchronous teamwork sessions students were gathered around a computer. During these meetings, ArchNet functioned as a basis for discussion. In between the videoconferences, students used ICQ to keep track of their teammates' presence online and NetMeeting to work from home whenever they liked.

Another aspect of the working environment was the use of 3-D printed models. A common feature of remote collaborative studios is that physical models are either on only one side, or they are built differently on both sides, thereby making evaluation and discussion difficult. The use of 3-D printers in the workshop made it possible to have similar models on both sides and facilitated discussion, particularly with the clients.

Despite the organizational and technical difficulties encountered during the workshop, the human, technical, digital, and physical setup used in the workshop enabled the development of successful collaborative strategies during the workshop. There were difficulties caused by the language barrier, time difference, and varied administrative protocols. There were also difficulties related to file transfer among different CAD platforms, poor sound transmission over the Internet, and malfunctioning of ISDN lines. However, these difficulties were overcome, and the setup used in the workshop can be seen as a prototype for collaborative endeavors carried out with similar goals. Moreover, as technology evolves, some of the encountered difficulties might be avoided. For instance, the future might bring real-time artificial translators with speech recognitions and voice synthesizing, wider Internet bands, and better ISDN connections. For a more detailed discussion on the collaborative and social aspects of the workshop, and particularly of ArchNet, please read Yee (2001).

RESULTS AND DISCUSSION

The plans, sections, and elevations of the houses designed by subjects in the experiment are shown in Figure 4.13, and the schematic derivation of these houses is shown in Figure 4.14.

Generating Goal-Matching Malagueira Designs

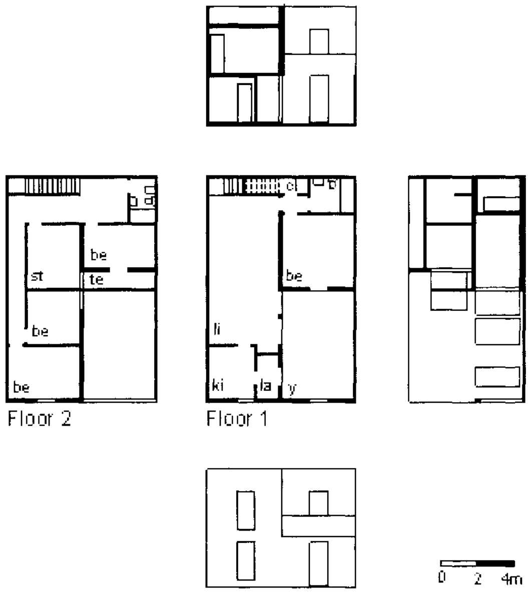
Verifying whether the grammar could generate criteria-matching Malagueira designs—the first goal of the experiment—was a matter of checking how it performed in the analytic, descriptive, synthetic, and goal tests. This was accomplished by analyzing client, subject, and reviewer data, as described below.

Analytic Test: Are the Designs in the Language?

The analysis of the derivations in the third task, when designers had to respect the rules, revealed that they did not follow the rules of the grammar. In Design C1S1, the patio was smaller on the second floor. This feature also was found in Malagueira houses that were changed by their users after moving in. Design C4S4 disrespected the rules for making openings regarding their number, location, and size. Analysis showed that the subjects concentrated on the rules for generating the layout and did not go into the detail of understanding how windows were placed. Nevertheless, these designs were functionally acceptable, and according to Siza, if one accepted the smaller patio and corrected the openings, they could be considered in the language.

The other two designs were a different case. Design C2S2 had a small living room without windows, and Design C3S3 had a studio without windows. Analysis revealed that designers became entangled by the dual need for satisfying the clients' requirements and respecting the pattern generating rules, and they did not find their way to a satisfactory solution. Consider, for instance, Design C2S2. Early in the derivation process, the subjects decided to locate the patio on the side of the lot without neighboring houses to make it look wider, as desired by the client. Because the rules of the grammar could only generate patterns with the living room diagonally opposite to the patio, it was located on the side with neighboring houses. Consequently, it could only have windows to the patio. Later, the subjects enlarged the dining room at the expense of the living room to make it adjacent to the kitchen, as also desired by the client. However, such an enlargement caused the living room to lose its windows, and the

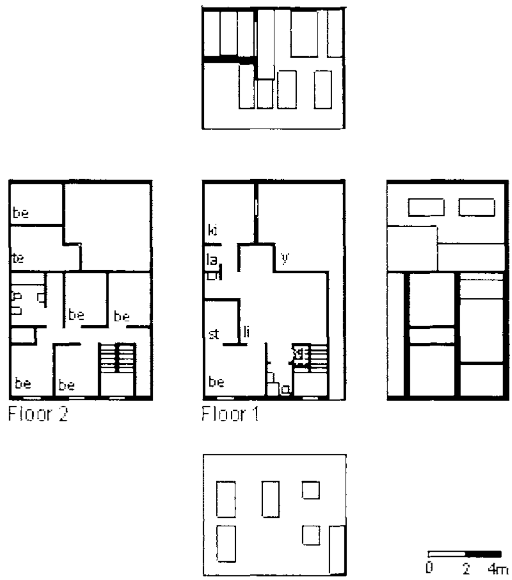
Figure 4.13
Plans, sections, and elevations of the designs generated in Experiment 4, task 3 (respecting the rules). The openings were corrected after the experiment. Design C2 S2 I was considered nonsatisfactory (please refer to text discussion).



C1S1

C2S2I

Figure 4.13 (continued)
Plans, sections, and elevations of the designs generated in Experiment 4, task 3 (respecting the rules). The openings were corrected after the experiment. Design C3 S3 I was considered nonsatisfactory (please refer to text discussion).

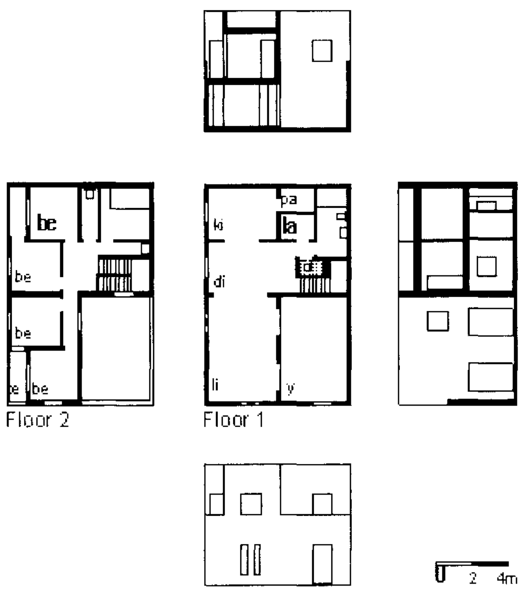


C3S3I

C4S4

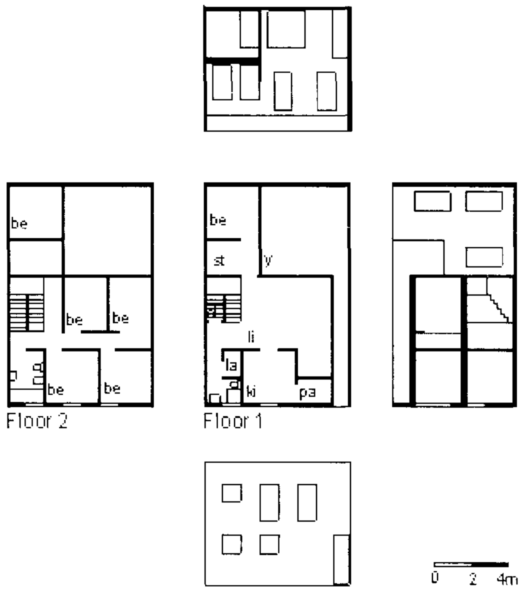
Figure 4.13 (continued)
Plans, sections, and elevations of the designs generated in Experiment 4, task 4 (changing the rules). The openings were corrected after the experiment.

C5S1

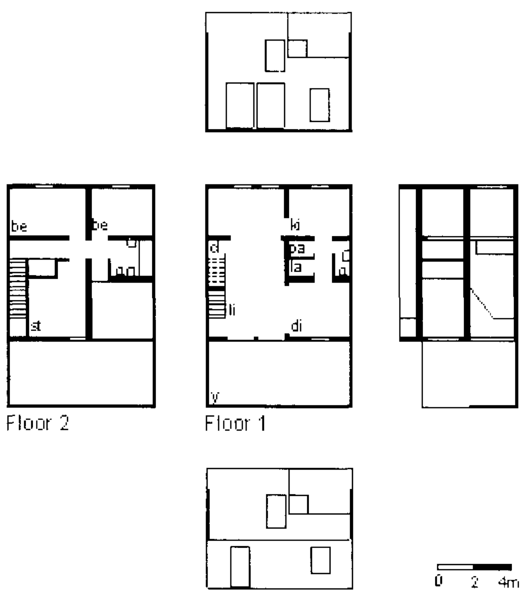


C2S2II

Figure 4.13 (continued)
Plans, sections, and elevations of the designs generated in Experiment 4, task 4 (changing the rules). The openings were corrected after the experiment.



C3S3II



C6S4

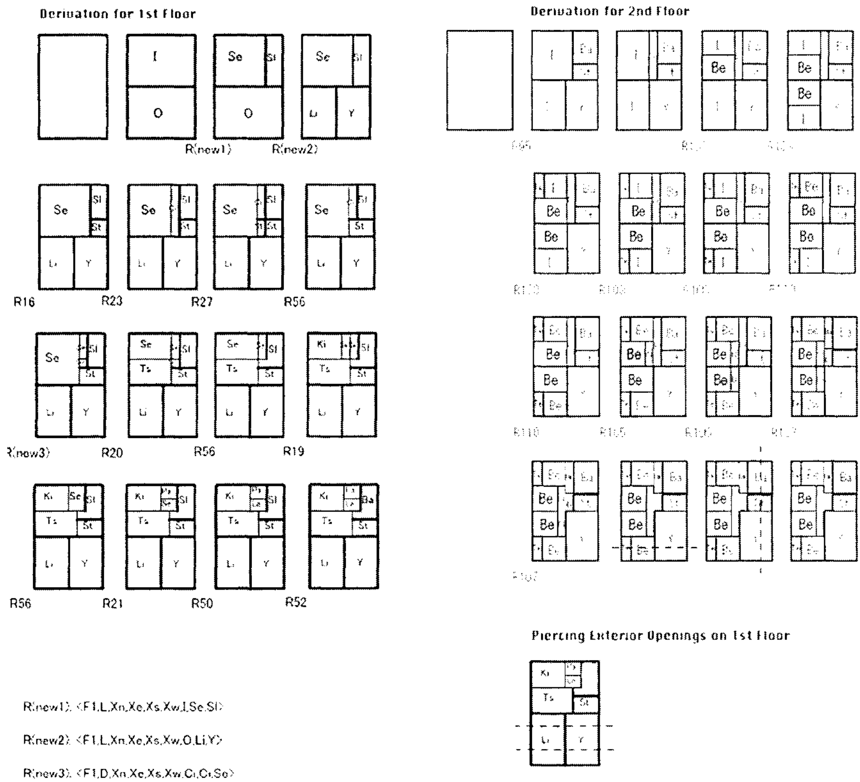
Figure 4.14
Partial tree diagram showing the derivation of the designs produced in Experiment 4, tasks 3 and 4. (Compare with Figure 4.4.)

client was not happy with the solution. In the fourth task, when the rules could be changed, the subjects added rules to generate new patterns and were able to satisfy their clients' requirements. (Figure 4.15) Siza accepted the new designs, thereby suggesting that the grammar could be changed to encompass all the patterns that could be inferred from a broad interpretation of his design rules.

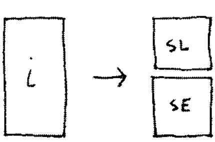
The subjects also introduced other rules in the fourth task. The great majority was aimed at satisfying functional requirements set by the clients: a skylight (Designs C2S2 II, C5S1, and C6S4), a double-height room (Design C5 S1), a detached room (Design C3 S3 II), a Jacuzzi (Design C2 S2 II), and a laundry next to a bathroom (C2 S2 II). The introduction of such rules confirmed the conflict between client requirements and the grammar. The conflict was largely due to cultural differences between the Japanese clients and the Portuguese tradition reflected in the grammar. "Our client wanted her laundry area close to the bathroom, but we couldn't do that. It is difficult to make a Japanese house using the shape grammar because we have a different culture," said one of the subjects. In Portugal, the laundry is close to the kitchen. Siza accepted the introduction of rules for satisfying functional requirements because they did not cause visible stylistic discrepancy. Therefore, results suggested the need for changing the grammar to increase client satisfaction and the possibility of making such changes while maintaining stylistic consistency.

Surprisingly, despite complaining about the limitations to creativity posed by the grammar during the third task, the subjects introduced few rules to express their formal preferences in the fourth task: a rule for making two thin windows next to each other (Design C2 S2 II) and another for creating an overhang (Design C5 S1). It seems that they accepted operating within the formal framework defined by the grammar once they became more familiar with the rules: "Using the grammar, we could not make original design, but I could understand its benefits," acknowledged one subject. Another concluded: "We did design in the 'style' of a particular architect. It could be likened to working in his office. This instance of grammar application seems to have opened up an intermediary position for a group of professionals, who will connect the more specific requirements of the client and a master of design. The process may not be 'design.'" The process may not be designing in the strict sense of the term, but it could be used with success to guarantee designs in the language.

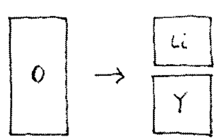
Figure 4.15
The derivation of design C2 S2 II and two of the new rules presented by the design subjects team in the final presentation.



R (new 1): Dissecting the inside zone into sleeping and service zones.



R (new 2): Dissecting the outside zone in living and yard zones.



Descriptive Test: Does the Grammar Explain the Common Underlying Features of Designs?

The design subjects indicated two difficulties in working with the grammar: to understand its rules and to apply them. In their opinion, the large number of rules, the symbolic notation used to specify the conditions for rule application, the lack of a "procedural clarity," and the short time available made it hard to understand the grammar. The Japanese subjects also mentioned the language barrier. Most of the subjects said that they eventually understood the grammar, but were then faced with the rule application problem. They said the process was counterintuitive, and that an engine to help finding the rules that could be applied at each step in the derivation could have helped.

The design subjects also mentioned that the grammar constrained design creativity by not allowing designers to express formal preferences and to satisfy clients' functional requirements. Nevertheless, they acknowledged that the grammar helped structuring decisions in the design process and described how to generate houses in Siza's Malagueira style. Not surprisingly, the subjects who were not architects or architecture students (the Japanese language assistants) were more enthusiastic about the use of the grammar and considered that they had learned a lot about architecture. As one of the architects acknowledged, "The rules do not require a trained designer to generate an acceptable outcome."

Siza stated that "these houses are much better than most of the houses designed by other designers [nonaffiliated with his office] at Malagueira," who only followed the building regulations. Therefore, the grammar succeeded in explaining the essential underlying features of Malagueira houses, thereby overcoming the descriptive test.

Synthetic Test: Does the Grammar Tell How to Generate New Designs in the Style?

Considering that designs generated by the design subjects were, to a considerable extent, in the Malagueira style, it is reasonable to accept that the grammar also overcame the synthetic test.

Goal Test: Do the Designs Meet the Given Requirements?

Experimental results showed that two changes were required for allowing the generation of functional features not foreseen in Siza's initial designs and confirmed the possibility of making such changes while maintaining stylistic coherence. The first change was to enlarge the universe of solutions by incorporating all the design patterns that can be inferred from Siza's designs, including those that Siza did not use. The second change was to rewrite the rules in a general format to diminish the number of rules, to highlight the algorithmic nature of Siza's approach to the Malagueira design problem, and to permit the satisfaction of spatial configurations based on user requirements. The variety of the designs generated in the experiment confirms the potential of the grammar for satisfying varied requirements if such changes are incorporated. In conclusion, the designs met the requirements, but it is advisable to change the grammar to increase the possibility of satisfying diverse requirements.

Improving Collaboration among Designers

The design subjects' opinion regarding the collaborative value of grammars can be summarized as follows. First, they stressed the need to have a solid understanding of the grammar before collaboration could take place and mentioned that they were too concerned with learning the grammar in the workshop to take effective advantage of its eventual collaborative potential. Second, they acknowledged such a potential. As one designer put it: "Since the basic rules are already established by the grammar, it provides a good platform to begin collaborative design. Much of the ground is already covered, value judgments are already made, and one can focus on finer points."

The analysis of the design processes confirms the potential of using grammars for collaborative design. The design teams took advantage of such potential in different degrees, depending on the working strategies that they adopted. Some teams used a strong division of labor, with some members generating the plans, others making the 3-D model, and others preparing the presentations. On a first glance, these teams took less advantage of the collaborative potential of grammars. However, results suggest that their division of labor was successful exactly because the use of the grammar limited conflict. When they had to evaluate their design before switching shifts, their discussion was focused because the grammar made decisions less arbitrary, diminished the importance of authorship, and focused the discussion around the satisfaction of user needs. Thus, they could easily come to an agreement. Other teams followed a weaker division of labor with all its members involved in each task. The role of the grammar in limiting conflict was even more useful in these cases. Discussion was centered on what existing rules permitted, on which rules should be used, on how they should be applied to satisfy the clients' requirements, or on what rules needed to be created. In conclusion, independent from the working strategy adopted by design teams, the grammar provided the common thread that guided their members through the design process.

Balancing Variety and Unity in Urban Environments

Collaboration among the different design teams was low. In fact, interaction among members of different teams was restricted to the exchange of information regarding the location and size of the yard and the number of floors in their houses. However, by looking at the 3-D model of the city block (Figure 4.16), it is reasonable to state that it possesses stylistic unity. There are no striking differences among the different houses in terms of color, proportions, the size and location of openings, or in any other visible stylistic aspect. On the other hand, it does present some formal variety. Moreover, the houses that form the block are tailored to their users and were derived by designers with varied backgrounds. Therefore, results suggested that it was possible to attain a balance between the satisfaction of individual requirements and the collective aim for a formally coherent urban environment. We argue that balance was possible because the grammar provided a formal protocol, a common architectural language that permitted the expression of individual requirements without jeopardizing the whole.

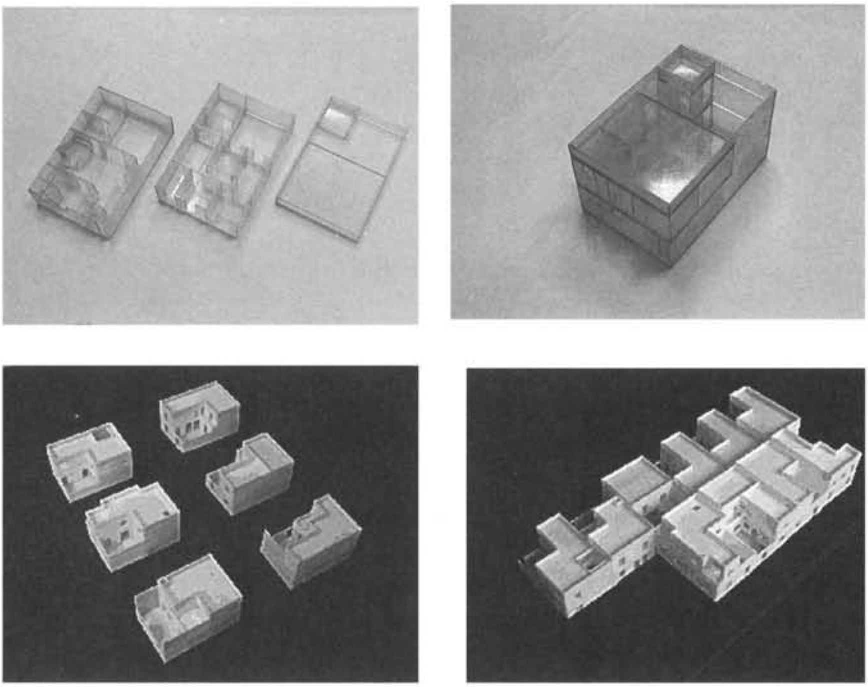
Mediating the Client/Designer Interaction

The analysis of experimental results showed that the use of the questionnaire provided to clients was useful but insufficient to mediate the client/designer interaction.

Results show that *the design problem often was overconstrained.* In some cases, this was because the client specified too many requirements to satisfy within the Malagueira framework. For instance, the area to allocate exceeded the available area in design problem C1S1. In other cases, the problem also was that the client specified contradictory requirements. For instance, the client wanted a sunny backyard house, in a lot surrounded by houses on three sides in C1S1. The approach used by design subjects to solve overconstrained problems was to talk to the client, proposing alternative solutions: "Hi, this is your client [C1S1]. First of all, thank you for your design in spite of my tough request. I like it very much [with] only one exception. Could you connect the bathroom directly to the Grandma's bedroom? It will be easier for Grandma and somebody who helps her to access... it. About [the] yard, I agree with your idea; in this case, [a] frontyard looks much better than [a] backyard because of sunlight, wind, and other environmental aspects. I got you."

Experimental results also show that *the problem often was ill-defined.* Clients seemed not to have a very clear idea of what the needs were until

Figure 4.16
Physical model of a house generated in the experiment produced by stereolithography at Miyagi University (*top*) and physical models of all the houses and the city block produced by Fused Deposition Model at MIT (*bottom*).



they saw a solution: "Hello! I just look[ed] at 'my' house. It is looking good, though of course now that I see it I have second thoughts about my requirements." The design subjects' approach in such cases was to go through a design-show cycle with the client, until the solution eventually became stable.

Results also showed that, even when the problem was not overconstrained or ill-defined, designer subjects made qualitative judgments about the requirements set by the client. For instance, in design C6 S4, designers deliberately chose to connect the dining room to the patio, instead of to the kitchen, although the client had specified otherwise and both were possible.

Therefore, results suggest that the interface between the client and the designer should support a dynamic interaction between the client and the designer. Namely, it should announce when the problem becomes overconstrained, while the client is specifying the design brief, for instance, by telling him that the available area has been exceeded. It should also provide the means for the client to assess a solution, to change the requirements, and to generate a new solution.

CONCLUSION

Grammars were invented more than 25 years ago, but their use in design teaching and practice has been rather limited. This chapter reports an experiment that actually tests the validity of shape grammars for building a framework for the design and production of customized housing.

Results show that when design subjects had to respect the grammar rules, it was not possible to satisfy some clients' requirements, mainly due to the clash between the cultural background of clients and that of the tradition encrypted into the grammar. Results also show that when design subjects could change the grammar, it was possible to satisfy such requirements by introducing a few rules while maintaining the style. Therefore, results show the need for unrestricting the grammar to enlarge the universe of design solutions, thereby increasing customization.

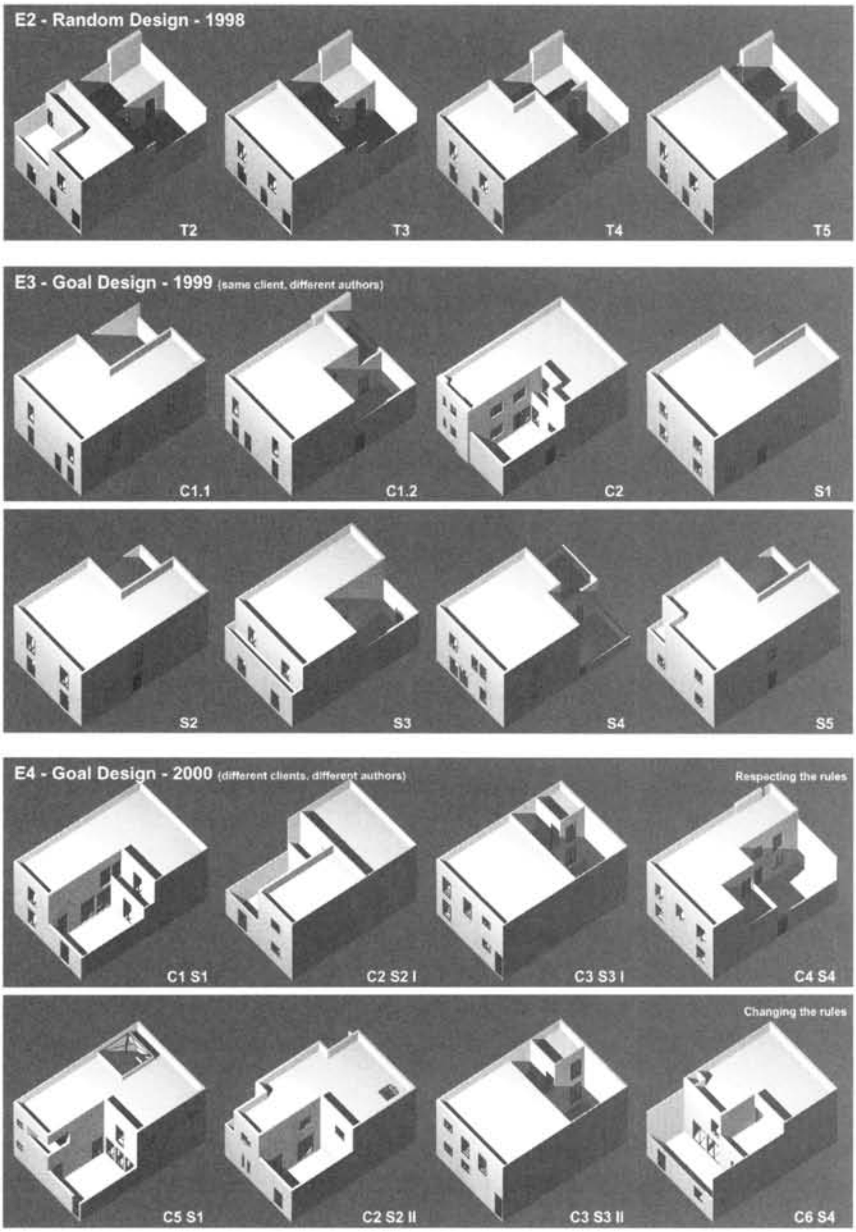
Results also show that designers who were not familiar with Siza's work could use the grammar to generate customized Malagueira designs. Nevertheless, results suggested the need to rewrite the rules as an algorithm to generate spatial configurations based on given functional requirements, in order to develop an automated design tool with the same capability. Results showed that design problems are overconstrained—the client specified too many or contradictory requirements—and ill-defined—the clients did not have a clear idea of their needs before they saw an actual solution. The strategy used by designers to overcome these problems was to engage in a dynamic interaction with their clients—present them with a solution, collect their opinion, and go back to design—which stresses the need for an automated tool that can support and speed up such interaction.

Results showed the potential of using grammars to improve design communication. Because the basic framework is established by the grammar, it provides a good basis for design collaboration. Value judgments are already made, and designers can focus on finer points. Results confirmed that using the grammar helped to prevent conflicts among team members whether they had divided the tasks among them or had been involved in all of them. The grammar made decisions less arbitrary, diminished the meaning of authorship, and restricted the discussion to which and how rules should be applied to satisfy the requirements. The discussion was, thus, focused on user needs.

Figure 4.17
The set of Malagueira designs by design subjects in Experiments 2, 3, and 4.

New Designs

Malagueira - Alvaro Siza Vieira



Results also showed that the use of the grammar by different designers could guarantee a balance between the satisfaction of individual requirements and a formally coherent whole in the design of urban environments. Interaction among design teams was restricted to the exchange of information regarding the location and size of the yard and the number of floors in their houses. The variety of clients agreed that the houses satisfied their needs, but by looking at the resulting urban block, one can observe that there are no striking stylistic differences, despite the existence of some formal variety.

In summary, the results of a set experiments that simulated an envisioned framework for the design of customized housing (Figure 4.17) confirmed the feasibility of such a framework, despite the need to fine-tune some technical aspects. Subsequent work addressed such aspects. The success of the experiment, however, raised the issue of whether designing with grammars in the way proposed in the experiment could be considered designing. If using an existing grammar is not "design" then where in this process is "it" located? As Siza asked: "Who is the author? Is it the person whose 'style' is captured into the grammar [i.e., the person who created the corpus of designs]? Is it with the person who infers the style from the corpus? And the person who uses the grammar, what is he or she doing?" According to Andrew Li: "Perhaps, the grammar user is a kind of apprentice. Would then there come a time when the apprentice assimilates the grammar and begins to alter it in subtle ways, effectively developing his or her own 'style'? Could we see this whole recent experiment with grammars as an apprenticeship with Siza?" Future work will be able to provide more precise answers to these questions, but the experiments showed the potential of using grammars in architectural design. For additional and updated information on the project please refer to the Web site: http://www.civil.ist.utl.pt/~jduarte/malag/.

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Supporting a "Real-World" Project-Based, Technology-Supported, Collaborative, Distance-Learning Environment: The MIT-CICESE Distributed System Engineering Lab

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The Distributed System Engineering Lab (DiSEL), located in Mexico and the United States, is an experimental practicum designed to prepare graduate engineering students for the realities of working in the era of globalization. DiSEL was created to help students learn about the development life cycle of systems while designing and developing a marketable, innovative, and reliable product in a distributed setting. Assessments of student learning, interactions, and motivations in this setting provide insight into the efficacy of this collaborative environment as well as valuable lessons for comparable endeavors. To ensure that this type of laboratory setting does, in fact, help students gain real-world experience and support them throughout the learning process, DiSEL integrates educational frameworks and theories that support collaborative, distant, and project-based learning. This chapter profiles the applications of real-world experience and educational theories into the DiSEL curriculum and evaluates the implementation of the course. In addition, based on the lessons learned from the implementation of DiSEL, this chapter presents the Five Critical Moves (FCM) model needed to conduct a distributed, collaborative, and project-based course effectively.

INTRODUCTION

The course described in this chapter is an initial stepping-stone for a larger effort, led by the Intelligent Engineering Systems Laboratory

(IESL) at Massachusetts Institute of Technology (MIT). The objectives of IESL are threefold: (1) study major challenges in the civil engineering industry, (2) conceptualize solutions to those challenges, and (3) use information technology to implement those solutions with the support of organizational change and process redefinition. One of the current flagship projects of the laboratory, the Da Vinci Initiative, is the application of computer and communication technologies in support of distributed collaboration in engineering projects. To test some of the hypotheses developed in the Da Vinci Initiative, the Distributed Systems Engineering Lab (DiSEL) was established between MIT in the United States and the Centro de Investigacion Cientifica y Estudios Superiores de Ensenada (CICESE) in Mexico.

This classroom collaboration between MIT and CICESE was developed as an initial test environment. Cotaught by an MIT instructor and a CICESE instructor, the DiSEL course lasted nine months and served different purposes at each university. At MIT, the course was required for master's civil engineering students, whereas at CICESE the course was optional—students did not receive credit for their work—but their work was recognized as part of their master's thesis. To further test this environment, several other research, educational, and industrial institutions are expected to participate in this collaboration consortium over the next five years. Currently, the following institutions are considering participation in the collaboration: the University of Sydney, Australia; Ecole Polytechnique Federale de Lausanne (EPFL), Switzerland; Pontificia Universidad Catolica de Chile (PUC), Chile; four corporate entities—Kajima and Shimizu Corporations in Tokyo, Japan, and InteCap and Modern Continental in Boston, Massachusetts; and two public agencies, the Massachusetts Highway Department and the Massachusetts Turnpike Authority.

To support this collaborative effort, the course combines collaborative and pedagogical methodologies with communication tools in a distance-learning environment. This course structure was developed to test the limits of computer-based, multicultural collaboration while providing graduate engineering students with an opportunity to get "real-world" systems development experience in an academic setting. Recognizing the need to prepare students to be active participants in industry without too much retraining from companies, the DiSEL instructors designed their course to better prepare participants for their transition from "engineering student" to "engineering professional."

Given the similarities between the systems and civil engineering design and construction process, the use of simulation engines and visualization tools, the complexity of the products, and the time-and-cost uncertainty associated with delivery, the same type of course could effectively be used for teaching traditional civil engineering product development processes.

The yearlong project that students are required to complete in DiSEL is the building of a synchronous communications system that other distributed communities would want for themselves. Through this project, students learn about new communication technologies, develop entrepreneurial and collaboration skills, and create a collective memory repository. By the end of the class, students should have developed a working version of the system efficiently and on time according to a schedule they set for themselves within the constraints of an academic year. Thus, after completing their course work, the DiSEL students should have learned to master some complex systems and ill-defined requirements while working in different time zones and cultures. These challenges provide class participants with a real-world experience in organizing their work to accomplish tasks that may at first seem nearly impossible. Such efforts are critical for the type of innovative engineers that the future demands. According to Dr. Joseph Bordogna, "U.S. colleges and universities are facing information-age transformations with virtual centers and institutes, shared infrastructure, and long-distance learning. The future portends even more...We cannot graduate talented engineers and scientists with supremely specialized expertise that exists in a vacuum" (Bordogna, 1999).

Combining the teaching of system development skills with project management, collaboration, and learning skills can be arduous. To ease this process and ensure student understanding of the subject matter, DiSEL incorporates a combination of pedagogical theories that support the diverse requirements of the course. The pedagogical model unites the Teaching for Understanding (Wiske, 1998) and Theory One (Perkins, 1995) educational frameworks to organize the DiSEL curriculum and also incorporates project-based (De Grave, Boshuizen, & Schmidt, 1996), collaborative (Slavin et al., 1985), metacognitive (Jay, Perkins, & Tishman, 1995), and distance-learning (Simonson, Schlosser, & Hanson, 1990) methods in its implementation.

The process of bringing educational theories into such a complex technology-driven environment has led to the development of the Five Critical Moves (FCM) model—a distance-learning model that outlines clear guidelines for supporting students and instructors who choose to work in a technology- and project-based, collaborative distance-learning environment. The FCM model is based on Lipnack and Stamps's 1997 virtual team model already in existence, the implementation of the DiSEL classes, as well as the meetings, journals, interviews, and surveys of class participants. The instructors, as in any learning situation, are key to the success of the environment, and the FCM model encourages them to assume the role of facilitators or coaches who keep students motivated while guiding them through activities in which they thoughtfully explore and construct new knowledge. The FCM model also scaffolds how to begin planning a class such as DiSEL, which one student described as presenting "similar problems we will see when we start working.... Definitely a very useful experience." In order to explore the educational experience of students in this real-world experience, this chapter will detail the pedagogical and theoretical basis for the course and how these were realized in the curriculum (see section 2), what was successful, and what was not (see section 3). Further, in section 4, the FCM model that evolved from the evaluation of the curriculum, and that outlines how to conduct this type of course, is profiled.

THE PEDAGOGICAL FOUNDATION AND ITS IMPLEMENTATION IN THE DISEL COURSE

Distributed, collaborative projects are becoming the norm in industry. The instructors of the DiSEL course, therefore, decided that to well prepare their students for the realities of this work environment, they needed to create a comparable educational setting. However, there is a critical difference between an educational and industrial environment: in classrooms special considerations need to be made for guiding students through their work at a level-appropriate pace, assessing student performances based on their level of understanding, and supporting student reflection. This shaping of students' experience therefore requires more of a planned and controlled setting than a real-world, unpredictable development situation allows. To compensate for this discrepancy, the DiSEL instructors needed to develop a flexible course schedule and allow for variable grade requirements. With the aid of the pedagogical frameworks Teaching for Understanding (Wiske, 1998) and Theory One (Perkins, 1995), the instructors were able to articulate and prioritize their teaching goals, as well as students' expected performances, so the curriculum was cohesive and focused even though the project was ill defined.

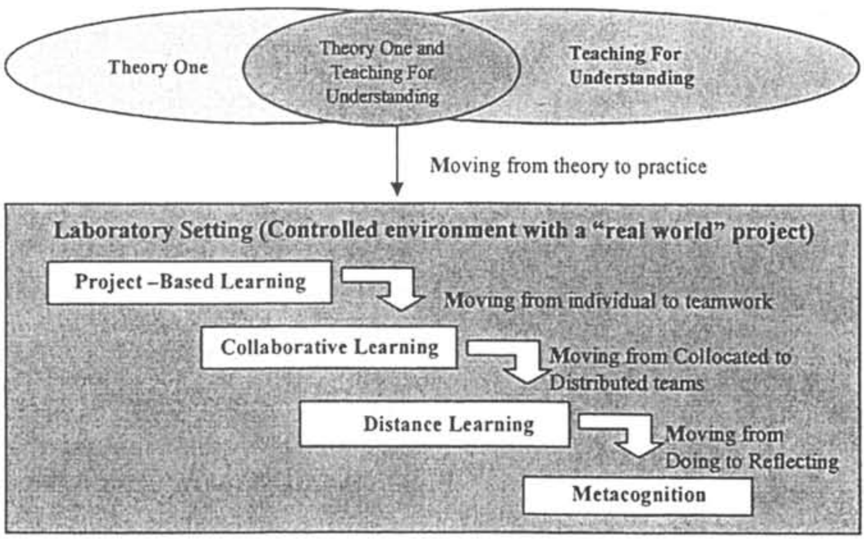
Once the Teaching for Understanding (TFU) and Theory One (TO) frameworks were integrated to form the foundation of the DiSEL pedagogical model, project-based (De Grave et al., 1996), collaborative (Slavin et al., 1985), and distance-learning (Simonson et al., 1999) theories, as well as the theory of metacognition (Jay et al. 1995), were utilized to plan specific course activities (Figure 5.1). These theories were chosen because they support the learning environment the DiSEL instructors created. In addition, they require learning by doing, and this adheres to the constructivist school of thought that believes students construct new ideas by "assimilating new information to pre-existing notions" (Strommen, 1991). In the process of integrating new information, learners "modify their understanding...and their ideas gain in complexity and power" (Strommen, 1991). Constructivism therefore encourages educators to design courses that challenge students' experiences, instincts, and understandings so they can develop their ideas in depth and detail.

Project-based, collaborative, and distance-learning theories and the theory of metacognition, were also selected for the way they complement each other in practice. Project-based learning stresses helping students work at their own pace on a problem of great relevance to the real world, and collaborative learning encourages teamwork over individual or isolated attempts to solve very complex problems. Given the distributed element of DiSEL, distance-learning theories help explain and support the collocated team dynamics of distance education. To keep the educational aspect of the course at the fore of the work, metacognitive practices were used to help students reflect on their learning and work experience. Finally, given the exploratory nature of the class, all work took place in a laboratory setting in which students were encouraged to experiment with their ideas and the system development process specifically. Each of these pedagogical aspects of the DiSEL course will further be explained in the following sections.

Teaching for Understanding and Theory One

Teaching for Understanding (Wiske, 1998) and Theory One (Perkins, 1995) together form the basic foundation of the DiSEL pedagogical model. These frameworks help educators organize their courses around what it is they most want students to understand. By asking instructors to consider their educational goals and subject matter in terms of the understanding they want students to gain, TFU and TO help them convey information to students in relevant and, ideally, interesting ways. The five organizing elements of the TFU framework are (1) *overarching understanding goals*, (2) *throughlines*, (3) *generative topics*, (4) *performances of understanding*, and (5) *ongoing assessment*. A worksheet for instructors using TFU has been developed by TFU researchers to help guide them

Figure 5.1
The Pedagogical Framework of the DiSEL Course



through these five planning elements (see Table 5.1). The worksheet highlights specific statements related to each of the elements of TFU. For example, to develop their overarching understanding goals, instructors are to finish statements such as, "The thing I most want my students to understand after this course…" or "Students will understand…." By completing these statements, instructors can identify exactly what they want students to be learning from them, and accordingly, they can organize their curriculum and assess student work based on their understanding goals.

Throughlines are questions that, when answered, should demonstrate an understanding of the overarching understanding goals. Some educators have students write their own throughlines to ensure student interest and commitment to the work, but regardless of who writes the throughlines, they should be interesting enough for both instructors and students to answer throughout an entire course or unit. Throughlines can therefore keep class participants motivated, as well as help keep classes relevant, as any lesson or activity should in some way help students answer the throughlines. Questions to consider when developing throughlines include: What type of experience do I want my students to have? and What do I want students to be thinking about throughout their work? Good throughlines should help bring to light the understanding goals as well as

Table 5.1
The Teaching for Understanding Framework (adapted from Wiske, 1998)

<table>
<tr><td colspan="2">Overarching Understanding Goals and Throughlines
To develop these overarching goals,
the instructor(s) complete the following statements:
The things I most want my students to understand after this course are ...
Students will understand...

To develop throughlines, the instructor(s) should ask the following questions:
What type of experience do I want my students to have?
What do I want students to be thinking about throughout their work?</td></tr>
<tr><td>Generative Topics
To develop these topics, the instructor(s) respond to the following questions:

What topics strike you as being the most interdisciplinary?
and
Which topics do your students find most interesting?
and
Which topics do you find most interesting?</td><td>Unit-Long Understanding Goals
To develop these goals, the instructor(s) complete the following statements:

Students will understand...
and
The questions I'd like my students to be able to answer are ...</td></tr>
<tr><td>Performances of Understanding
To develop these performances, the instructor(s) complete the following statement:

Students will build toward achieving the understanding of goals by ...</td><td>Ongoing Assessment
To develop the assessment for students' work, the instructor(s) complete the following statements and question:

Students will get feedback on their performances by...
or
How will students know how well they are doing?
and
The criteria for each performance will be...</td></tr>
</table>

the central, or generative, topics an instructor will focus on during a course.

Generative topics are "central to a domain or discipline, accessible and interesting to students, interesting to the instructor, and are connectable to students' previous experience (both in and out of the classroom), and to important ideas within and across disciplines. They often have a bottomless quality, in that inquiry into the topic leads to deeper questions"

(Wiske, 1998). Generative topics in the DiSEL course include "the roles involved in the system development process" and "the life cycle of system development." These generative topics were easily identified in the curriculum and emerged by answering questions such as: What topics strike you as being the most interdisciplinary? Which topics do your students find most interesting? and Which topics do you find most interesting? Often the topic to be taught is the only information an instructor has to begin preparing for a course, so the generative topics may be determined before any planning can occur.

Only in its second year, the DiSEL course is continuously changing, and its throughlines are slowly evolving based on the five generative topics of the class: the system development life cycle, collaboration, collective memory, technology, and entrepreneurship. During the 1998–1999 DiSEL course, five throughlines emerged in association with the generative topics of the class:

1. System Development: In what ways are the roles of the project manager, requirements analyst, designer, programmer, knowledge manager, quality assurance specialist, tester, and configuration manager interdependent, and how do they support the system development process?
2. Collaboration: In what ways can you collaborate and determine if your collaborations with colleagues were successful or unsuccessful?
3. Collective Memory: How can others best understand your work and the decisions you have made throughout the project?
4. Technology: How can you use currently available technology and push it in new directions?
5. Entrepreneurship: How can an idea be developed and marketed?

These throughlines help guide the inquiry and work of the students throughout the DiSEL course so that the knowledge gained in the class connects to a bigger picture that provides an integrated view of the subject matter. Therefore, smaller units' understanding goals should connect to the overarching understanding goals or throughlines. To this end, instructors can use the throughline questions as parts of assignments, as ways to shape students' work, or as ways to help students reflect on their work. In the DiSEL course, the system development throughline was, "*In what ways are the roles of the project manager, requirements analyst, designer, programmer, knowledge manager, quality assurance specialist, tester, and configuration manager interdependent, and how do they support the system development process?*" Accordingly, one of the overarching understanding goals was, *"Students will understand the different and necessary roles involved in system development."* Such an understanding goal indicates for students what is important to understand and how they should approach their learning.

How students are expected to demonstrate their understanding should be outlined for them by the instructor(s) in the TFU worksheet under "Performances of Understanding." These are the activities students participate in that require them to demonstrate their learning of the understanding goals. Once these performances are clearly explained, assessing student work becomes more straightforward, as students can discern for themselves whether they are generally meeting the performance criteria or not.

Performances of understanding are usually developed by finishing the statement: "Students will build toward achieving the understanding goals by..." When students in the DiSEL course, for example, built on each other's knowledge and resolved their own conflicts, they demonstrated collaboration, and this was in fact an expected performance of understanding. Accordingly, one of the DiSEL throughlines was, "In what ways can you collaborate and determine if your collaborations with colleagues were successful or unsuccessful?" and an understanding goal was, "Students will understand how to define when a group is working and when it is not." As shown here, all the TFU categories should support one another and reinforce the focus of the course.

Finally, considering how students will get feedback on their performances and by what criteria they are being assessed is the ongoing assessment aspect of the TFU framework. Assessments should be happening *continuously* from peers, instructors, and the students themselves. To define how assessment will happen for students, it is useful to answer statements such as, "Students will get feedback on their performances by..." and "The criteria for each performance will be...." By focusing on these two aspects of the students' learning experience, instructors can evaluate their feedback procedure as well as the frequency of their feedback and reconsider how meaningful their assignments are in the first place. Instructors should not stop there, though. According to Theory One (TO), instructors also need to provide meaningful feedback that helps students build on their ideas so they can take their knowledge to a higher, more flexible level of understanding. TO therefore enriches the TFU theory and pushes educators to further reflect on their teaching and its impact on students (Table 5.2).

"Clear information," "thoughtful practice," and "student motivations to learn" (Perkins, 1995), the other three parts of the TO framework, also

Table 5.2 Theory One (adapted from Perkins, 1995)

Theory One	Criteria of Theory One Components	Theory One Implemented in the DiSEL Curriculum
Clear Information	Descriptions and examples of the goals set, knowledge needed, and the performances expected.	The Expectations Rubric (See Table 5.3) is provided to students at the beginning of the year.
Thoughtful Practice	Opportunity for learners to engage actively and reflectively with whatever is to be learned (i.e., tracking different versions of reports to understand the complexity of document repositories).	The DiSEL students are engaged in the system development project as well as in entrepreneurial competitions.
Informative Feedback	Clear, thorough counsel to learners about their performances, helping them to proceed more effectively.	The DiSEL instructors meet with students weekly to review work-in-progress.
Strong Intrinsic or Extrinsic Motivation	Activities that are amply rewarded, either because they are very interesting and engaging in themselves or because they feed into other achievements that concern the learner.	Students participating in the DiSEL Lab have a great deal of autonomy on their projects. Further, they are encouraged to select their own project goals. Out-of-class assessment by prospective employers and entrepreneurial competitions also help to motivate students.

complement the TFU framework. "Clear information" means that students should be well aware of what they are going to learn and what they are going to do to learn. An instructor should articulate these aspects of the learning experience when he or she defines the understanding goals and performances of understanding within the TFU framework. Next, the TO framework stresses that students should be given opportunities to use new knowledge thoughtfully, in activities that require application of the ideas taught so that they "engage actively and reflectively with whatever is to be learned" (Perkins, 1995). Performances of understanding should provide such experiences, and feedback should help students reflect on their learning experience. Finally, TO stresses that motivation can be either intrinsic or extrinsic and is critical to the learning process. So, as students proceed with their work, their activities should be "amply rewarded, either because they are very interesting and engaging in themselves or because they feed into other achievements that concerns the learner" (Perkins, 1995).

Both TFU and TO stress that instructors should organize their teaching objectives clearly and share these with students. To do this in the DiSEL course, the instructors created an Expectations Rubric and handed it out within the first week of class. The Expectations Rubric clearly defined for students what was expected of their work throughout the course by identifying the learning categories the instructors planned to address, articulating the understanding goals, explaining the expected performances of understanding, and specifying the methods of ongoing assessment (see Table 5.3). This rubric was critical in the DiSEL implementation as it provided students with a type of job description such as they would receive in a real work environment.

By incorporating the TFU and TO frameworks via the Expectations Rubric, the DiSEL instructors could focus attention on what students do to learn as well as how they will be assessed. This is possible as both frameworks ask instructors to think about active, performance-based, hands-on learning that keeps learners motivated and engaged in the process of learning itself. One way to create such an environment in practice is to incorporate a project for the students to work on throughout a course. Project-based learning stresses that by keeping students focused on a project, they can best construct their own understanding of how to accomplish a given or self-defined goal.

Project-Based Learning

Project-based learning (PBL) is an instructional strategy designed to induce conceptual change through cognitive conflict (De Grave et al., 1996) produced during a learner's active (re)construction of knowledge (Gijselaers, 1995). The cognitive conflict or puzzlement that arises when one's conceptual view is challenged by new information is the stimulus for learning and determines the organization and nature of what is learned (Savery, 1995). The "problematic," according to Dewey, is what leads to and is the organizer for learning (Dewey, 1916; Rochelle, 1992). Along these lines, Gibbs (1992) asserts that motivational context, learner activity, interaction with others, and a well-structured knowledge basis result from posed problems. Such problems are the "problematic" that is the foundation for PBL.

The challenge of solving problems in a learning environment should also be motivating and authentic to the instructor as well as to the students

Table 5.3
Expectations Rubric

Learning Categories (Generative Topics)	Understanding Goals Students will understand…	Performances of Understanding and Ongoing Assessment
1. Life Cycle of System Development	• How to reengineer or upgrade a system already developed. • How to see what similar products are already out there. • The different system development models. • The problems inherent with distributed system development. • The different and necessary roles involved in a team of system developers.	• Students show an appreciation for all the roles of the system development process in their course work and participation. • Students can identify and explain which role is responsible for which jobs and why in their course work and participation. • Students show an ability to identify the various types of system development cycles.
Requirements Analysis	Students will understand how to develop: • Good questionnaires for users and/or good interview questions. • Case scenarios of what users would want. • Measurements for those functions the users want, to establish priorities. • Ways to determine user satisfaction. • A requirements document.	Performances: • Develop a questionnaire/interview questions for market experts. • Develop case scenarios. • Develop good measurements of the requirements and user satisfaction. • Develop a requirements document. • Performs technical review.
Design	Students will understand how to: • Take the requirements of the system (developed by the Requirements Analysis team) and develop a model of how those functions are going to be represented and how they should perform in a program. • Evaluate the trade-offs of the various system functions (storage versus time of execution versus network distribution and load time). • Create a flexible and open model that can easily be expanded extensively. • Define the architecture of this system for implementation.	Performances: • Develop a viable model of how the requirements will be a part of the design. • Determine the trade-offs of system functions. • Create a flexible model. • Define the system architecture.

Project Management	Students will understand how to: • Develop a good working plan for the execution of the whole system development process. • Determine resource requirements (including time and software/hardware). • Analyze risk — foresee implementation problems. • Set realistic milestones. • Work to coordinate team member efforts (create team harmony). • Raise flags before problems become nightmares. • Present the product being developed to an external audience.	Performances: • Develop a working production plan as well as a business plan • Determine resource requirements. • Analyze risk and foresee implementation problems. • Set realistic milestones. • Facilitate harmony between team members.
Knowledge Manager	Students will understand how to: • Create a framework for documentation and product production. • Check for facts and assumptions. • Create a good repository for product memory. • Maintain the evolution of documents. • Develop a good searching mechanism of the final product and all associated information.	Performances: • Create a framework for documentation, product production, and tracking • Review documents well for facts and assumptions. • Produce a memory repository. • Develop a search mechanism of the final product and associated information.

Table 5.3 (continued)

Learning Categories (Generative Topics)	Understanding Goals Students will understand…	Performances of Understanding and Ongoing Assessment
Quality Assurance	Students will understand how to: • Monitor both product and process compliance to good practice and standards (relevant information is recorded properly, and assumptions documented.) • Create cases that test the product process to assure that good development practices happen • Highlight problems in the early phases • Produce statistical results of problems and provide guidance for solutions • Develop a good plan for resolving problems, identifying by when and whom a problem should be resolved • Assure that the system is compliant to user requirements • Assure that the process and the product can be extended • Maintain a low overhead during the development process and production of the system • Differentiate and prepare technical reviews (walkthroughs, audits, peer reviews, and inspections), recognize when to use which, and the advantages and disadvantages of each.	Performances: • Monitor the product process and assures compliance to good practice • Create cases to test the product process and thereby identifiy problems in the product • Use statistical analysis to suggest ways to resolve identified problems • Assure low overhead costs during the development of the system • Set-up and participate well in product and process walk-throughs, inspections, audits and peer reviews
Programming	Students will understand how to: • implement design plans and develop an executable system that satisfies the design • devise a plan by which code can be developed by multiple programmers in distributed locations • handle code versioning • develop good incremental integration plan • comment in the code so anyone can follow it • create good documentation regarding the code	Performances: • Implement design plans • Develop executable system • Code from distributed programmers are well integrated and can be easily modified • Create documentation of and comments on code that are understandable • Use a reliable programming language

Configuration Management	Students will understand how to: • Identify the configuration of a production system • Control all configuration changes • Record and trace all changes in a system • Verify all changes via auditing and reporting	Performances: • Make sure production processes are successful and repeatable • Track and control all versions of the system during the development process so all project members can get up-to-date information on the product's status • Minimize production costs • Ensure product testing and compliance with specifications • Improve quality of the final product
2. Entrepreneurial Skills	Students will understand how to: • Design, develop, and sell an idea in nine months • Define their local and global market niche • Determine their revenue source • Determine product maturity to establish the time for venture capitalists' involvement and second phase support (when money needs to be coming in, when money needs to be going out) • Define their product • Define their market share • Present a business idea to funders • Create a product portfolio that shows the service plan • Organize themselves so creativity flows • Develop a business plan	Students will demonstrate their understanding by: • Correctly applying for funding (1K or 50K) • Presenting their business plan

Table 5.3
(continued)

Learning Categories (Generative Topics)	Understanding Goals Students will understand…	Performances of Understanding and Ongoing Assessment

3. Collaboration	Students will understand how to:
	• Define when a group is working and when it is not
	• Discern when:
	  • Tasks need to be done by divide and conquer
	  • Tasks need to be done with everyone's' participation
	  • One person needs to champion some task through completion
	• Know peers' faces and names
	• Create a good mental model of what their fellow group members can do and can't do well and how reliable they are
	• Create trust in the group
		Students will show their understanding by:
		• Appropriately working together by building on each other's ideas
		• Knowing when a group is working and when it is not (appropriately addressing situations where the group is functional and when it is not functional)
		• Appropriately determining when a task needs to be done by dividing and conquering, everyone participating, or when one person needs to champion some task through to completion
		• Knowing peers' faces and names
		• Creating a good mental model of what their fellow group members can do and can't do well and how reliable they are
		• Creating trust in the group
		• Setting up the expectations of the group

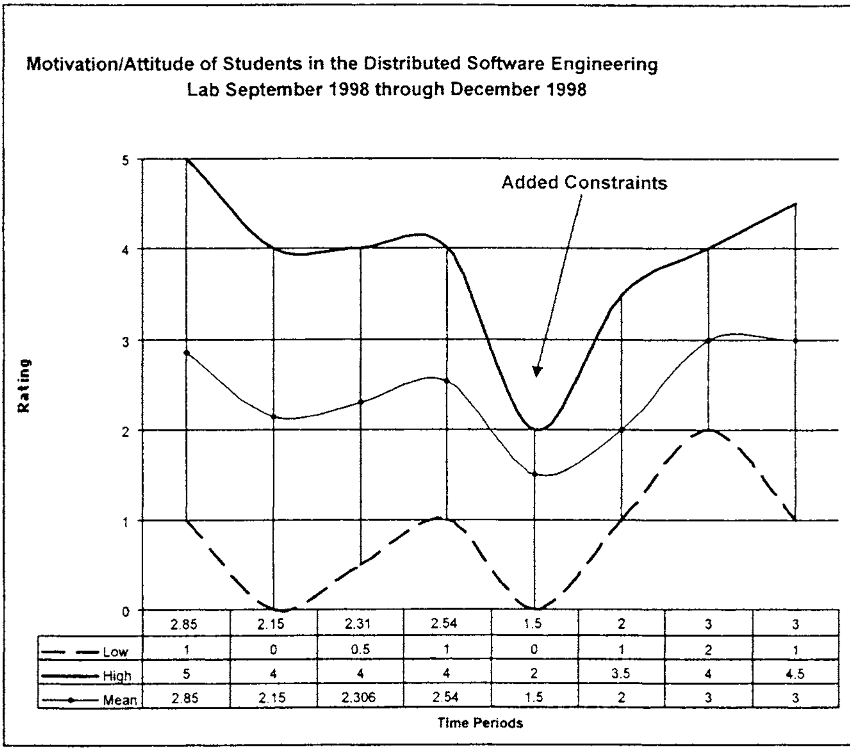
4. Collective Memory	Students will understand how to: • develop a memory of the system development process so that others can understand the experience and build on it • recognize benefits and limitations of overhead costs • amortize project costs • reflect on past experience and other projects that have taken less time	Students will show their understanding by: • Storing their work in ways that are understandable and sharable • Developing a database of work completed • Using a repository of the work completed in the class for the project
5. Technology	Students will understand that: • technological tools are mechanisms that without the other elements of support (physical setting and organizational process) will fail • technology is evolving at a fast pace and that we can't allow limitations to tell us what we can or can't do (new technologies present opportunities to do what once couldn't be done) • sometimes it is critical to learn from the engineers of the past — the inventors of the technology used are often the best sources of information • technology won't solve all the ills of the world • there are times to question when to use technology	Students will show they understand by: • How resourceful they are in solving technology problems (Are they complaining about things they could find their own solutions to?) • Discerning when technology becomes inefficient • Designing and using technology for their own purposes • Setting up the equipment in the lab • Demonstrating ability to introduce technology • Keeping a log of communications and media they use to accomplish their work

(Goodrich et al., 1995). Motivation for learning, a common result of PBL according to Albanese and Mitchell (1993), comes from choosing topics, tasks, and goals that everyone truly cares about (Goodrich et al., 1995) and by providing students with an opportunity to create and have ownership of their creation (Jones, Rasmussen, & Moffitt, 1997). In the DiSEL course, students are able to request an engineering role, and based on their preferences as well as a Pre-Course Skills Assessment, they are assigned the role they will work in for the duration of the course. Keeping with the PBL method, the students are then assigned a project in which they are asked to review a synchronous communications system designed by previous classes and commercial institutions and to create their own goals for how to improve the system during the project.

In PBL scenarios, problems and projects must also be designed to simulate real-world contexts or actually involve students in real-world situations and conversations. The DiSEL course provides students with such an experience, as they must work on a tangible system project that outsiders to the class will eventually review. Further, the unpredictability of real situations is strategically brought into the DiSEL laboratory. For example, during the 1998–1999 course, new constraints of the system to be developed were added after the students had already developed a work schedule and had come to a consensus on how to proceed with the system project. Although this created the motivational low point in the class (see Figure 5.2, Period 5), the students soon adjusted and were able to proceed with their planning of their work. The lesson was pivotal, though, as an example of a complex system in which there are ill-defined requirements that system engineers have to cope with. Such a context helped students develop the skills required for working in a rapidly changing global economy and helps improve both the retention and functional use of knowledge, which in turn induces a deeper understanding of what is to be learned (Jones et al., 1997).

Albanese and Mitchell (1993) single out two other essential features of PBL that seem to impact students' learning significantly: the role of the tutor and the format of the problems. The tutor must focus on helping students acquire self-directed learning skills (Bereiter & Scardamalia, 1992) while finding a balance between allowing students to discuss and explore issues and intervening to enforce critical learning issues (Wilkerson, 1995; Williams, 1992). When the DiSEL instructors got involved with the planning and process of the group collaborations, they were often helping students articulate the alternatives they had before them individually as well as collectively. For example, when the students had to decide which features should be added to the preexisting system, the instructors led a class discussion in which students had to voice their opinion based on their role

Figure 5.2
Student Motivation in a Distributed Learning Environment, Year 2 1998–1999



	2.85	2.15	2.31	2.54	1.5	2	3	3
Low	1	0	0.5	1	0	1	2	1
High	5	4	4	4	2	3.5	4	4.5
Mean	2.85	2.15	2.306	2.54	1.5	2	3	3

within the system development process. Students then had to publicly vote on their preferences. The instructor(s) would often look for such opportunities to demonstrate how in industry, collaboration rather than individual problem solving is a better way to solve more complex problems. Students came to see this, as they would get feedback on how well their ideas compared to their classmates and then had the opportunity to brainstorm solutions to problems they were finding difficult to solve on their own. The DiSEL project consequentially became as much about collaborative learning as project-based learning.

Collaborative Learning

Based on the writings of Slavin (1979, 1983, 1989, 1990, 1991, 1992) and Slavin, Sharan, Kagan and others (1985), we know that unlike solitary learning, collaborative learning can heighten student motivation as well as catalyze social interaction and integration. Specific academic skills such as high-level reasoning, metacognitive thinking, and an increased willingness to take intellectual risks also evolve from collaborative learning because collaborating students "share the process of constructing their ideas, instead of simply laboring individually. The advantages of this collective effort are that students are able to reflect on and elaborate not just their own ideas, but those of their peers as well. Students come to view their peers not as competitors but as resources. Mutual tutoring, a sense of shared progress and shared goals, and a feeling of teamwork are the natural outcomes of cooperative problem solving, and these processes have been shown to produce substantial advances in learning (Strommen, 1991).

One example of how working collaboratively is better than working alone when solving conceptual and complex tasks comes from a study by Gauvian (1994). In this study, "pairs generated more attempts to solve the problem (an unsolvable spatial logic problem), less often erroneously believed that they had solved it, and more frequently attributed their lack of success to the 'unsolvability' of the problem than to the problem being too hard for them. The pairs that collaborated (rather than taking turns) made suggestions regarding each others' ideas and remembered and kept track of prior moves and attempts to a greater extent, monitoring and editing plans together, thereby supporting each other in developing novel solutions" (Rogoff, 1998).

To help students realize the benefits of collaborating, the DiSEL course required participants to work in teams on the planning and development of a new version of already existing meeting system. Thanks to Microsoft's NetMeeting, e-mail, chatting software such as ICQ, repositories, and threaded discussions such as in Lotus Notes, as well as meeting environments such as CAIRO (Peña-Mora et. al., 1996), students in Mexico and the United States were able to collaborate (share and build on each other's ideas), both synchronously and asynchronously. These communication systems were available at all times in the lab so students could access them whenever collaboration was deemed necessary outside class time. Further, once a week, during student-run labs, the instructors helped students collaborate with these communication tools by asking for clarifications on project decisions as well as by inquiring into how conclusions were drawn, much as managers would. In this way, students were able to develop collaboration skills as well as experience real-world work situations.

Such interaction between students and instructors required all DiSEL participants to communicate their ideas clearly and resolve controversies through attempts to understand and persuade (Webb, 1982; Rogoff, 1998). By explaining one's knowledge and summarizing another person's perspective, a learner's understanding and reasoning can be enhanced, and learners can build new knowledge together. Doing this effectively can be difficult, and when students are collaborating over significant geographical distances, special efforts need to be made to support their communication; this is why the theory of distance learning was integrated into the course.

Distance Learning

When an instructor is physically separated from his or her students, yet continues to plan the learning experience for students, this is called distance education or distance learning. More specifically, distance education is "formal, institutionally-based educational activities where the learner and teacher are separated from one another, and where two-way interactive telecommunication systems are used to synchronously and asynchronously connect them for the sharing of video, voice, and data-based instruction" (Simonson, 1995). According to the equivalency theory (Simonson et al., 1990), a new theory crafted to guide the implementation of distance education, "those developing distance education systems should strive for equivalency in the learning experiences of all students, regardless of how they are linked to the resources or the instruction they require" (Simonson et al., 1990). Crafting a distance-learning course that honors equivalency requires tremendous planning before the course begins, as equal access to all the course materials needs to be ensured for all class participants. Educators in distance-learning environments must subsequently utilize the features of virtual environments (i.e., discussion and information repository spaces) and allow for the technological and cultural challenges of connecting distributed participants. Further, the work should proceed in a fairly predictable manner. This "predictability" is critical for students to know where to find resources (people as well as readings or multimedia files) and schedules so they can do their work as it is assigned.

To assure that the virtual workspace and the syllabus of the class were accessible to all course participants, the DiSEL instructors made sure that the lab (and all its technology) was available to students outside class time. The syllabus as well as the Expectations Rubric (see Table 5.3) were available online and were handed out at the beginning of class so students could become well versed in the course guidelines and could easily gauge what participation was expected of them. According to Berge and Collins (1995), regardless of whether a course is face-to-face or computer mediated, there are nine resources students need access to, should they be expected to fully participate in the course:

1. Instructor and technical support contact information
2. Online hours (or course hours)
3. Course description
4. Objectives
5. Attendance (how many times students should be online to keep up with discussions)
6. Assignments
7. Schedule/calendar
8. Grading criteria
9. Evaluation

To be sure that students did review these aspects of the DiSEL course, the first DiSEL class was completely devoted to the presentation of this logistical information, just as the first day of work would be used to introduce these resources to a new employee. In addition to the conventional elements, there are features unique to online courses that instructors should also address with their students:

- Participation (how many messages must be posted to discussions)
- Computer mediated communication (CMC) learning strategies (how to utilize the online environment, how to cope with information overload, too many e-mails, and how to achieve an optimal level of interactivity)
- Conference structure (how the online system is structured)
- Computer use, training, and support (make sure students know how to help themselves with the technology)

Finally, there are appendices that Berge and Collins (1995) suggest:

- List of relevant Internet resources (listserv discussion groups, libraries, and database resources)
- Computer conferencing worksheet (a checklist of tasks students are asked to do to ensure familiarity with the technological infrastructure of the course)

The criteria Berge and Collins (1995) suggest lay the groundwork for well-organized virtual classrooms in which good pedagogy can thrive. An accessible and organized course Web site and syllabus, as well as protocols to guide student participation, are critical to promote a high level of academic success in a virtual environment. The COMMAND System (Williams et al., 1998) at MIT was developed for all courses throughout the Institute and provides the DiSEL course with a suitable online repository for student work. Papers, e-mail, threaded discussions, and other text-based communications, as well as lecture slides, demos, class videos, and white boards (all the artifacts of the class) can be stored in virtual form on COMMAND and accessed via a Web browser or through collaborative environments such as CAIRO (Peña-Mora et al., 1996).

CICESE and MIT students in the DiSEL course have equal access to these Web site resources, as well as the system needed to download various course materials. Having a reference guide with the details of how to access the technology and complete the work as expected by the instructors is another feature unique to a distance-learning environment, and a student handbook featuring this information will be developed for the next DiSEL course. Such a handbook is comparable to a company handbook that outlines the protocols and procedures employees are expected to follow. This element of the DiSEL course adds to the real-world aspect of the course and helps students gain an understanding of how an office within the system development industry may be organized.

Once the technology and scaffolding for the work is provided, a pedagogically sound distance-learning course (as well as face-to-face courses) should incorporate activities that require reflection. According to the TFU and TO frameworks that form the basis of the DiSEL pedagogical model, reflective practices help students become metacognitive, meaning that they gain insight on their own thinking skills, a skill needed in the professional world where teamwork and good communication skills are mandatory. Assignments that ask students to explain new knowledge, as well as their thinking process during or after a learning experience, are therefore significant features of the DiSEL course.

Metacognition

Metacognition, or thinking about one's own thought processes, requires higher-order knowledge, "knowledge about how to get knowledge and understanding" (Perkins, 1995). Mental management, another term for metacognition, is defined by Jay et al. (1995) as "the art of reflecting on and guiding one's own thinking processes." It is generally assumed that metacognition affects the use of knowledge (Glaser, 1991), as it requires learners to be aware of how information is relevant and useful to them and their experience—necessary skills for both the academic and professional worlds.

In the DiSEL course, metacognition helps students move from doing to reflecting—the instructors wanted students to reflect on their work to better understand their knowledge and where it was applicable to the system development process. Further, students who make reflection a part of their work processes are more likely to take the time to keep a record of their work, and this is one of the most important skills the DiSEL instructors wanted students to learn—collective memory (see Table 5.3). Another benefit of reflection is that students would be less likely to repeat their mistakes as, to a considerable extent, the good thinker in virtually any field has proven to be intellectually self-watchful, self-guiding, and self-assessing (Jay et al., 1995). Bruer (1993) further declares that learning is quicker for students in possession of these self-monitoring skills, generally referred to as metacognition.

Bruning, Schraw, and Ronning (1995) discuss several teaching strategies that can be used to teach metacognition:

- Encourage students to engage in deep processing.
- Focus on understanding rather than surface memory.
- Promote elaboration of new ideas.
- Help students become more metacognitively aware by demonstrating the kinds of questions they can ask themselves during problem-solving action.

The Teaching for Understanding framework that drives the course encourages questions of inquiry that are metacognitive in nature, such as "How can others best understand your work and the decisions you have made throughout the project?" Students answering these questions in DiSEL assignments including journals and a thesis, as well as in discussion, are articulating and sharing knowledge about their work explicitly to each other. This is important in a distance-learning environment, especially as students have no way to assess each other implicitly or through casual observations. Relationships between students living in different places and cultures and speaking different languages are difficult to build. By bringing metacognitive activities into the environment, students benefit twofold: by improving their thinking skills and by getting a better sense of each other's strengths and weaknesses.

Thinking skills are a key requirement of problem-based learning (PBL). PBL requires a demonstration of understanding as students must visibly solve problems, and it is this emphasis on the development of problem-solving skills that requires reflection on one's thought process. Sharan (1990) further emphasizes that collaborative student groups need mental management techniques and skills to reach their goals, as they need to be able to explain their thinking to each other. Beyond describing one's thinking, metacognition also requires goal setting, strategy selection, and goal evaluation (Gijselaers, 1995). Typically, metacognitive skills include the ability to monitor one's own learning behavior, that is, being aware of how problems are analyzed and whether problem-solving results make sense (Bruning et al., 1995). To incorporate mental management into education, Jay et al. (1995) suggest that educators should model mental management by

- Actively monitoring their own thinking processes and remarking about them in ways such as, "When I think about this, I first tend to..."
- Explaining key mental management concepts and practices
- Developing the habit of discussing and expressing in words their mental processes and encouraging students to do the same
- Organizing opportunities for student/student and instructor/student interactions around mental management. For example, students could be asked to diagram and then explain their diagram of the mental path they took in deciding on a solution to a problem.
- Being sure that students get feedback about their mental management practices
- Realizing that each thought process expressed or shared is a teaching opportunity
- Giving plenty of positive reinforcement for effective thinking
- Suggesting and alluding to alternative methods of attacking the problem

When the DiSEL instructors give feedback to students, these habits of mental management are brought to the fore of the commentary—and they have many opportunities to provide such feedback. Reflection journals and papers, surveys, and focus group discussions along with the DiSEL course project are assignments through which the instructors are able to reinforce metacognitive practices. By asking students to become more aware of their learning, the students theoretically should become more directed, articulate, and motivated in their work; the DiSEL course, as a lab, puts this to the test.

The Laboratory Method

Active and experiential learning comprise the Laboratory Method, and each has multiple definitions. Active learning could be defined either as self-regulation during various phases of the learning process (such as goal-setting, planning, monitoring, and assessment) or as the extent to which internal cognitive abilities are challenged by the instructor or the material itself (Simons, 1997). Active learning requires the student to actively monitor and assess his or her own learning processes, whereas experiential learning places such responsibility on the instructor, whose job it is to excite the mental processes. Experiential learning describes the general process of learning by experience. As an instructional method, experiential learning may describe either carefully structured learning experiences, where the student is expected to actively pursue knowledge and skills not presented directly, or through authentic real-world experiences in which all knowledge presented is relevantly contextualized. Active and experiential learning comply with Dewey's (1916) exhortation that knowledge should not be set apart in "abstract, bookish" forms divorced from life, but rather rooted in experience; education must be active and involved. The DiSEL course, with its system development project that should become a viably marketable project in the eyes of potential investors, presents such a real-world experience.

Hands-on activities foster true, authentic learning, encouraging students to apply and demonstrate their knowledge and skills in new situations (Gutloff, 1995). Lodewijks (1991) showed that students performed better when learning science concepts in a self-chosen sequence, rather than learning in a predetermined sequence. Likewise, Van der Sanden (1986) showed that some students performed better on a practical construction task without instructions than with detailed explicit advice. To provide students with the advantages of the hands-on and generally guided experiences, Gutloff, Lodewijks, and Van der Sanden suggest instructors should assign learning activities that need not be projects. The activities should therefore address one aspect of a problem (whereas a project is multifaceted). Doing this in a technology-based experimental learning environment requires innovative assignments that can provide educators with insight on student understanding throughout the work. The DiSEL course meets these challenges with its pedagogical model that stresses learning goals as well as a carefully scheduled project. Further, this course design inherently reflects the realities of the global industry that the students will be working in after completing their studies.

THE CHALLENGES AND SUCCESSES OF IMPLEMENTING THE PEDAGOGICAL MODEL IN THE DISEL COURSE

Implementing the DiSEL pedagogical model resulted in a course students agree prepared them well for the realities of global industry. When the system students proposed won the MIT Entrepreneurial Association's 1K Competition (MIT Entrepreneurial Association, 1998) in the software category, their understanding of entrepreneurship and systems was confirmed outside the class arena. As well, during job interviews, potential employers recognized that the problems students faced during the course were similar to the realities they faced in their work. Such affirmations helped students recognize that their efforts and lessons learned were relevant to the global industry in which they would be working. Based on student interviews and surveys, students also indicated a deeper understanding of entrepreneurial tactics and collaboration, new technologies, and the value of collective memory. The lessons the instructors gained from the challenges and successes of implementing each part of the DiSEL pedagogical model are explored in the following section.

The Success and Challenges of Implementing the Teaching for Understanding and Theory One Frameworks

The DiSEL instructors provided an Expectations Rubric (see Table 5.3) at the beginning of the 1998–1999 course so that students had an introduction to the instructors' teaching goals. However, keeping the expectations and assessments present throughout the work proved a challenge, and often students would not have a sense of what criteria was being used to grade them. By having the Expectations Rubric in a student handbook as well as by discussing it as the students develop their vision of the system project, students should be able to keep their work focused on their learning in the areas the instructors clearly stated they deem most important. Further the throughlines for the class evolved during the 1998–1999 year and were not available for students to use to help them stay on task. Now that they are established, the instructors can utilize them as students progress in their understanding of the subject matter being taught. For example, when giving feedback in the class about the technology students decide to use, the instructors can ask the students how they are pushing technology in new directions. This question clearly incorporates the technology throughline: "How can your ideas push technology into new directions?" and it encourages students to develop their system while learning what they need to in this course.

The DiSEL instructors, one in Mexico and the other in the United States, need to also coordinate their efforts to motivate students. The CICESE students were not getting credit for this course, which was required for the MIT students. Although the instructors were sharing the teaching responsibilities of the class and students would turn to the appropriate teacher for specific questions, the two student groups worked at different levels of commitment to the project. When one side is more dedicated to the work and the vision of the final product becomes disparate, resentments and distrust can result, and cooperation between teams becomes impossible. The instructors who alternate grading assignments therefore need to collaborate and send consistent messages to the students regarding their work, expectations, and requirements.

The Challenges and Successes of Implementing Project-Based Learning

Effective project-based learning situations make sure that the objectives of an assigned project are made clear at the start of the project with the understanding that the means to achieve the objectives may change. In the real world, resources and even the intended audience can greatly change, so system developers such as the students in the DiSEL course need to be prepared for such volatile variables. Accordingly, in DiSEL, constraints did change, forcing students to create a new version of a previously developed system instead of starting from the beginning of a concept. This reality proved difficult for the students and forced them to reorient their vision of the system after well into the second month of the course. The motivation levels of students significantly declined as a result (see Figure 5.2), and it took over two weeks to get students back on track.

Once students restructured their teams and reoriented to the new basis of the project, they were able to agree on features they would add to the existing system. Further, they were able to take their ideas and shape them into a business plan for the MIT Entrepreneurial Association's 1K Competition (MIT Entrepreneurial Association, 1998). The business plan was so strong that the DiSEL students won the 1K Competition in the software category and went on to submit a business plan for the 50K Competition, in which they became semifinalists. Inspired by their success, the students went on to submit their system project to other competitions, resulting in a second-place ranking in the Lynn Cyber Competition (Lynn Cyber, 2000) and a first place ranking in the University Angels Competition (University Angels, 2000).

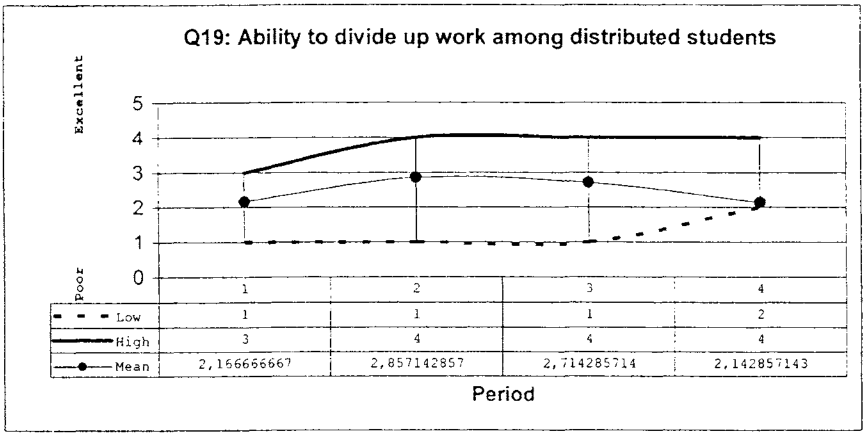
The students' ability to anticipate and cope with the multiple and changing variables of a project in a professional and productive manner is a skill the DiSEL instructors planned to teach, and the change in the project constraints provided an opportunity for such teaching and learning. Although the cost of successfully bringing the real-world project situation into the classroom was motivation, the gain was in the students' experience of adapting to a situation beyond their control. By developing their ideas into successful business plans, the students proved their understanding of how to adjust when unexpected changes happen.

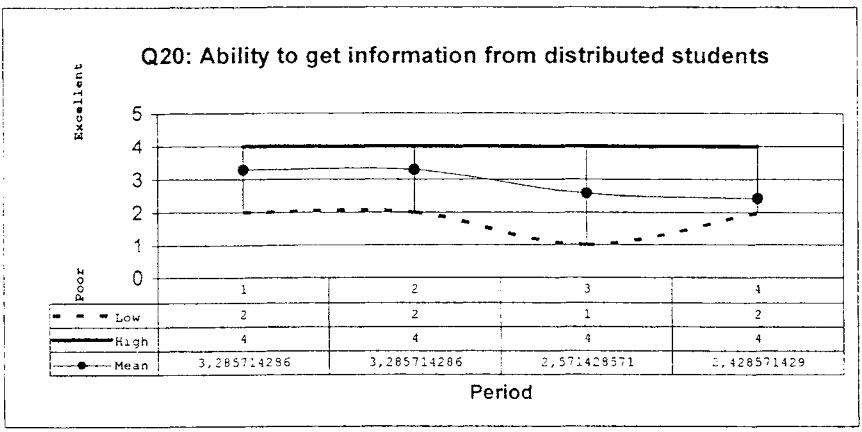
The Challenges and Successes of Implementing Collaborative Learning

In the second year of the DiSEL course, students needed to come to a consensus on the planning and development of the system they had to design for their project, as well as to develop a business plan with which to sell their project. To approach the work, students divided the work that needed to be done between them, and small groups of students were able to focus on identified tasks. To get to this point, meetings in the class were highly organized by the MIT instructor, who would get students to articulate where they were in the work and how they planned to proceed, either collaboratively or individually. Although there were pockets of collaboration between students on these projects, for the most part the CICESE students were isolated in the discussions and often couldn't follow what was happening in the MIT lab when decisions were being made. Due to both language and technology, and lack of communication outside scheduled meetings, there was no way to bring everyone into the discussions collaboratively. Consequently, there was little synergy between the remote and local students' ideas. During the first year of the course, student questionnaires reflected a similar experience. Students felt that it was difficult to divide work among distributed students, track progress of distributed teams, explain ideas to distributed students, and get information from distributed students (see Figure 5.3). These challenges were not insurmountable, and the work did get completed; however, the remote students never felt quite like classmates (see Figure 5.4), and collaboration always proved difficult.

The struggle to collaborate over a distance came to the fore during the second year, when the DiSEL students participated in MIT-sponsored

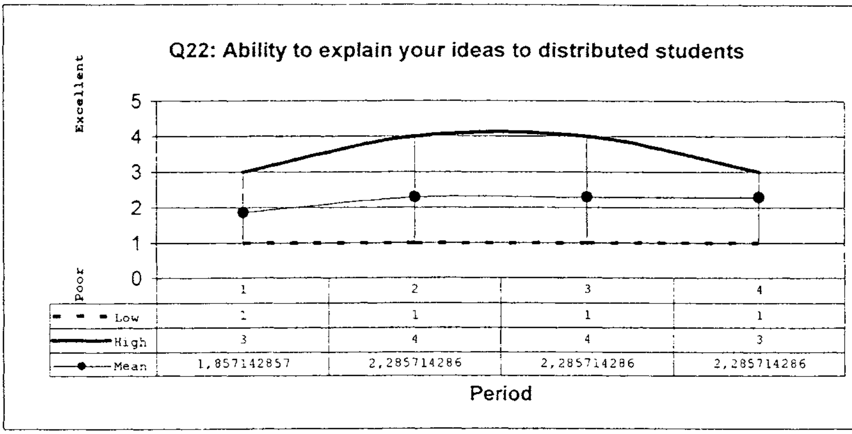
Figure 5.3
Effects of Distance on Collaborative Learning

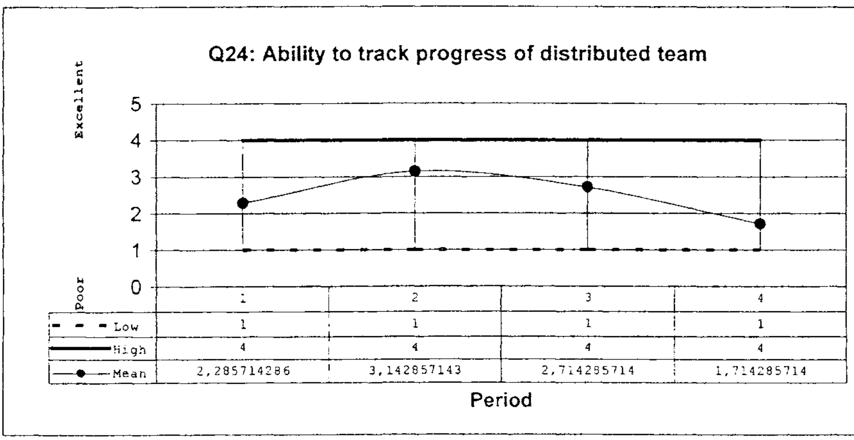




entrepreneurial competitions. The MIT students and the CICESE students were not able to collaboratively develop the required business plans, and the two classes became divided. The time requirements for the business plans were very restrictive, and as time became limited, the desire to collaborate declined. It became a matter of divide the tasks and conquer them as quickly as possible. The CICESE students were able to do some work, but for the most part felt like observers. During the first year of the course, the remote students on the whole were perceived as half observers and half classmates (see Figure 5.4). Individual collaborations varied greatly but on the whole, establishing a classmate experience with a remote partici-

Figure 5.3
(continued)

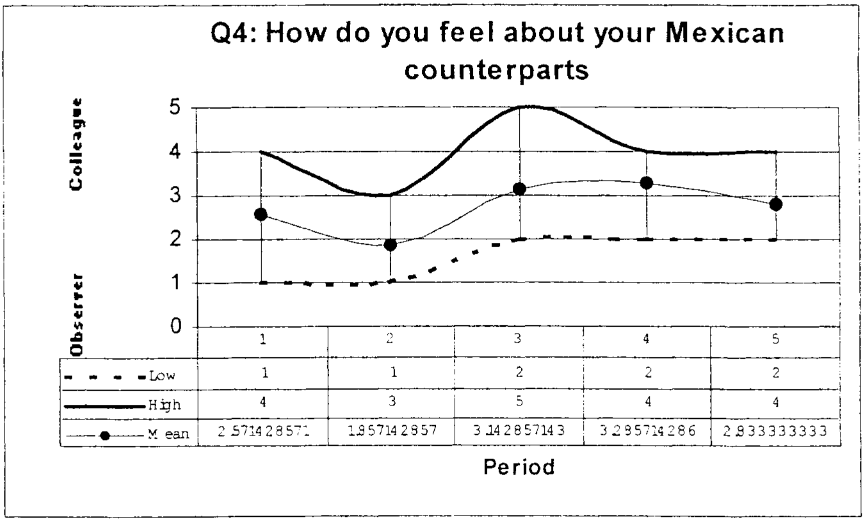




pant proved to be a difficult undertaking. Because one of the instructors' objectives is to unite the entire class, this remains a challenge for them.

One way the instructors plan to bring remote and local students together in collaboration is to have them make decisions with a decision pyramid. Scheduled for implementation during the next DiSEL course, the pyramid makes time during lab meetings for pairs of students to agree on a solution to a posed problem. Once a student pair has made a decision, two student pairs, then four, then eight, and so on must agree on a decision until the entire class comes to a consensus. By making important decisions this way, students can truly collaborate as a whole class, and valuable decision-making skills can be learned.

Figure 5.4
Perception of Remote Students

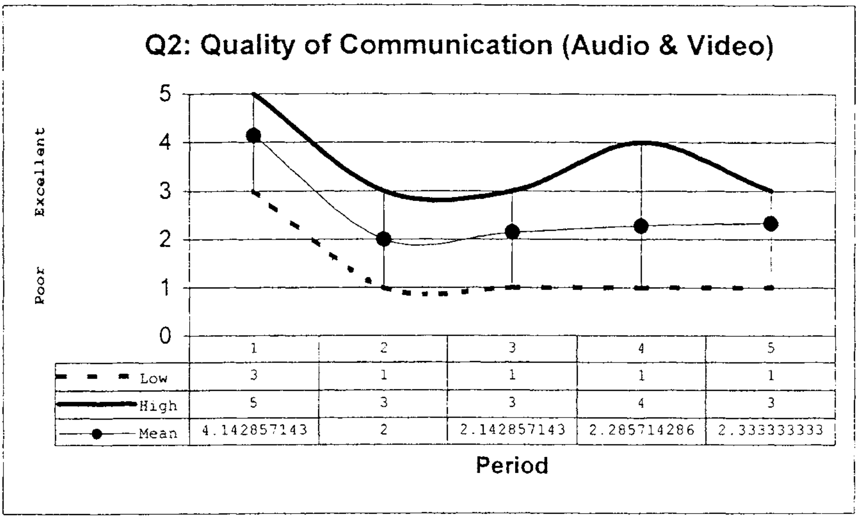


The Challenges and Successes of Implementing Distance Learning

Distance learning requires reliable technology. DiSEL used an Internet-based videoconferencing system to connect the MIT and CICESE students, and this meant depending on three hours of low Internet traffic for good connections. Rarely did this happen, and subsequently much of class and lab time was spent waiting for stable connections between the two universities. The technology in these instances interfered with the delivery of the course. In questionnaires during year 1 of the course, students confirmed that the quality of the audio and video was below average and that it was more difficult to understand the instructor lecturing from the remote location (see Figures 5.5 and 5.6).

Wanting to keep a low-cost distributed setting, the instructors did not change the Internet-based videoconferencing technology, and difficulty understanding what was happening at the remote locations during distributed labs and classes continued into the course's second year. At MIT, setting up the videoconferencing technology proved to be another distance-learning hurtle as lights, cameras, microphones, and a projector needed to be set up each time a meeting was held. This was in striking contrast to the scenario at CICESE, where a room dedicated to the class had

Figure 5.5
Quality of Audio and Video Communications, Year 1, 1997–1998

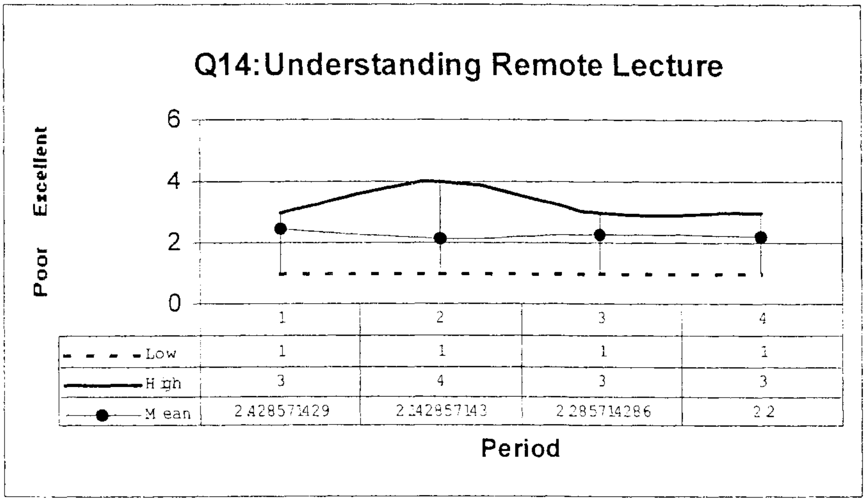


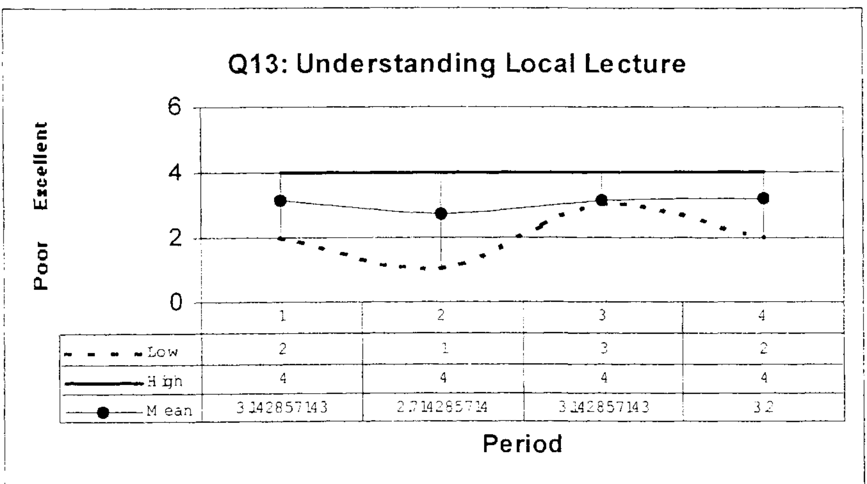
been built. To meet these challenges during the next DiSEL course, an Internet2 (Internet 2, 2000) level connection will be used as the main link between the schools, and a room with videoconferencing technology permanently in place will be set up for the MIT students.

Another important piece of a distance-learning environment is the infrastructure. MIT has a university-wide course Web site system called COMMAND (Williams et. al., 1998) that was utilized in the DiSEL course for all asynchronous communications. Students also developed a Web site of their own that complemented COMMAND, but this proved more confusing than helpful, as students were not sure where to find each other's work. During the next DiSEL course, only one dedicated server will be introduced to the class (i.e., COMMAND) so students will be able to store all their communications in one location.

Once the technology becomes reliable, relevant, and easily accessible to students working in a distributed learning environment, explicit communication becomes the key to a successful collaboration. Whenever a quiet comment is made or someone just rolls their eyes, that information is only shared with the local students, and this happened quite often between students. Consequently, the implicit understanding of each other that evolves between local students bonds them and further isolates the remote students. Although this can never be completely avoided, using the chat or

Figure 5.6
Understanding of Local/Remote Instructor, Year 1, 1997–1998





other features available on the system should be used to keep the entire group of students—remote and local—treated as one unit.

The Challenges and Successes of Implementing Metacognitive Activities

Activities that require reflecting on one's work alone or with others, working through a mental block, or reviewing another's work are metacognitive in nature. At the end of the first class of the second year, students took a Pre-Course Skills Assessment Exam so the instructors and the students themselves could get a sense of what understandings and experiences students had on entering the course. The advantage for the instructors was that they could direct their lectures accordingly while students could start to reflect on and gauge their own knowledge. The exam also provided the instructors with insight on the experiences and understandings the students brought to the class so they could reference them and students could then make connections between their past and present work. The issues with a Pre-Course Exam is that students felt that they were put on the spot the first day of class, that knowledge rather than skills were being tested, and that if the lecture overheads were already designed, the exam didn't make a difference. By more carefully explaining the advantages and utility of such an exam and making the exams available for students as a reference throughout the year, the exam could be better put to use.

A second method used to help students think about their own thinking at the start of the course during the second year was the Learning Styles Questionnaire (LSQ), designed by Peter Honey and Alan Mumford (1995). The LSQ was implemented to help students identify if they tend to be pragmatic, reflective, theoretical, or active learners. Each type of learner has a preference in how they work and study, and awareness of one's or a teammate's style could help when planning to work alone or in collaboration with others. Though learning styles can change as we learn new thinking skills, the learning styles of each student at the beginning of the year, as well as a full explanation of the styles, was posted to the class Web site for easy referencing. The class as a whole did not find these categories helpful, however, and students did not refer to teammates' learning styles when discussing group dynamics. Further, they stated that although the LSQ was interesting, it was not always accurate, and it felt too restrictive even knowing that styles could change. As well, no time was made during class to further discuss the learning styles due to students' lack of interest and time constraints. In future DiSEL courses, more time needs to be spent on this so students can gain the advantage of getting to know their own and their classmates' learning styles.

Electronic journals were assigned to provide students with a space to explore their learning and thinking to find ways to better articulate their frustrations and successes with themselves, each other, and the course. From the journals the research assistant was able to glean how the class was progressing, how to improve the course, and in return, could raise questions about the students' thinking and ask students to explore ways to proactively address their frustrations. Unfortunately, the journal method was not well liked by the students, and some wanted more guidance than was provided. Rather than view the electronic journals as a useful reflection space, they saw it as cumbersome and additional work. During the second semester of the class, they elected to only have interviews and surveys to reflect on and assess their learning and the class experience. So that students have a chance to explore all these methods of reflection, journals, with more instruction and guidance available, as well as the interviews and surveys will be used again in the next DiSEL course.

Interviews and surveys were not the only ways students reflected on the second semester of the second year of the course. A thesis was required of the MIT students, and their paper topics had to build on the learning in the class. The interviews, surveys, and theses proved to be the most rewarding for the students, according to interviews and the surveys themselves, and proved to the instructors that students were understanding the subject matter presented in the course. These activities will therefore be implemented again, though the surveys will be shorter and administered in electronic form. The reason for the electronic survey is that paper surveys proved cumbersome and difficult for data collection. Perhaps even more significant, though, is that electronic surveys can be reviewed again and again by students, so their reflections are not turned in and never seen again. Thus, students will have space to reflect on their work and the progress of their learning. Further, students (and not the instructors) will be able to review their thinking as the surveys will be accessible to them at all times. Anonymous summations and graphs of the survey outcomes will also be generated so that a collective review of the class *will* be available for both students and professors.

The Challenges and Successes of Implementing a Laboratory

Laboratories are generally places to experiment with new ideas and explore possibilities. In the DiSEL course, students are discovering new ways to collaborate and communicate. To this end, two labs were implemented during the 1998–1999 course. The labs required students to use chat boards and white board space to agree on a list of questions and design a Use-Case Diagram, respectively. Providing feedback to students proved the greatest challenge with these labs, but they were successful in bringing students together and giving students a chance to explore the technology. The instructors are therefore planning on implementing more instructional labs with specific feedback procedures during the next DiSEL course. Perhaps the most important one will be the online retreat.

Proxy, reputation, recommendation, and resume are often the initial ways we get to know strangers (Wilson, 1999). During the 1998–1999 DiSEL course, students in Mexico and the United States did not get to know each other very well, though they had to work together. To address this problem, future DiSEL courses will have each student make a home page for another student in the class as a point of introduction. Each home page will need to address motivation (How is this student motivated by the class? Why is this person in the class?), personality (Who is this other student? What are his or her interests? How would this person's friends describe him/her? Where does this student see himself/herself in 5 years?), experience (What is this person's educational and professional background? What work is he/she most proud of having done?), and work style (What are this person's perceived strengths and weaknesses? How does this person prefer to work—alone or in teams? Why?) During the online retreat, the students will introduce each other by presenting the home pages during a synchronous meeting. Such an activity gives students a chance to meet one another and to start exploring the technology.

Another way students will familiarize themselves with the technology will be to set up the videoconferencing system before each meeting and to take it down at the end of the meeting. This system was effectively implemented throughout the 1998–1999 DiSEL course and gave students the opportunity to learn the tools and the configurations of videoconferencing system. The major advantage of this is that students can set up meetings without instructors and can find ways to organize the interface to help them communicate better. Often chatting was used as much as video and audio for such communications, and the laboratory environment gave students the freedom to play around with the technology and discover better practices.

From trying new metacognitive approaches such as journals and the Learning Styles Questionnaire in an engineering class, to connecting classrooms distributed in Mexico and the United States with the Internet, to requiring collaboration as a course goal, the DiSEL course experimented with nearly every aspect of its learning environment. All these activities were developed to support the learning theories of the DiSEL pedagogical model (project-based learning, collaborative learning, distance learning, and metacognition) and to meet the instructors' learning goals around the system development life cycle, entrepreneurial skills, collaboration skills, collective memory, and technology (see Table 5.4).

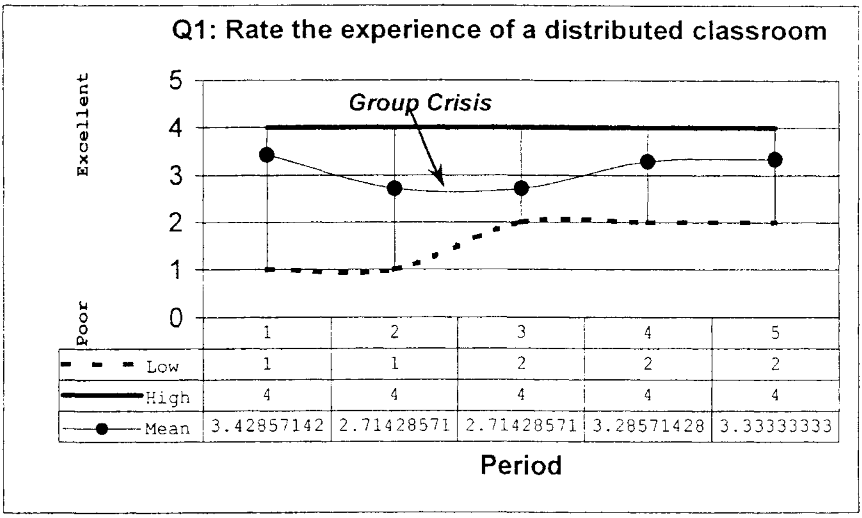
Table 5.4
The DiSEL Course Pedagogical Structure and Implementation

Learning Goals	Learning Theories	DiSEL: Implementation
System Development Life Cycle	Project-Based Learning Collaborative Learning Distance Learning	On-line retreat Team/role assignments Term team project
Entrepreneurial Skills	Project-Based Learning Collaborative Learning Distance Learning	MIT 1K Competition MIT 50K Competition Market Research to determine similar products
Collaboration	Collaborative Learning Metacognition	Distributed teams working on one system product
Collective Memory	Distance Learning Metacognition	Repository of working papers needed by all team members
Technology	Project-Based Learning Distance Learning	Videoconferencing system configuration Videoconferencing hardware set-up

Such a complex course demands continuous evaluation, and this was done via student interviews, focus group discussions, journals, and questionnaires during the first two years of the course. At the beginning of the course in both years, enthusiasm was high on starting something new and different with people distributed geographically (see Figure 5.2 and Figure 5.7). In both years there was a crisis felt by the students when reality set in on the difficulty of the process. By the end of years 1 and 2, though, enthusiasm and motivation had risen to initial ratings because, according to student comments and interviews, they learned how to function in that environment and could adapt their work habits accordingly.

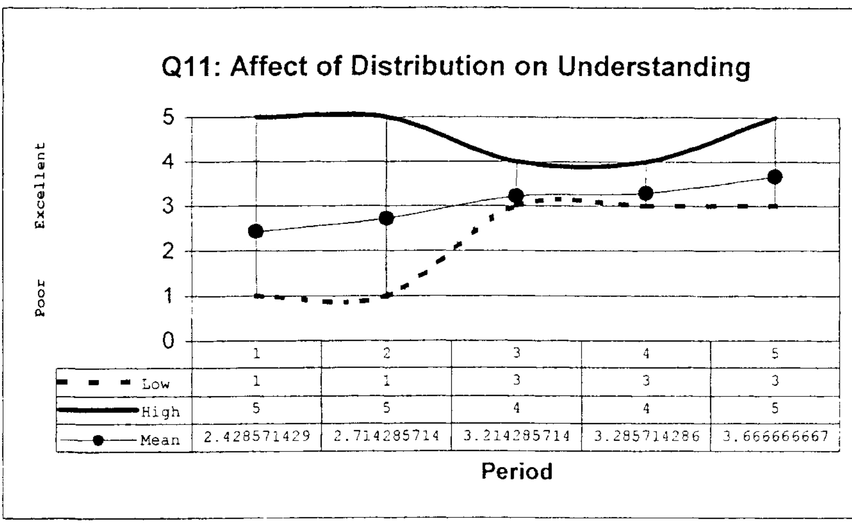
Based on the questionnaire in year 1, the effects of the DiSEL environment on student understanding of the course material was positive (see Figure 5.8). At the end of the course's second year, student interviews revealed that students felt they understood more through their work in the distributed environment than they would have in a traditional classroom. However, in questionnaires from the same time period, their assessment of their understanding overall didn't increase significantly, if at all (see Figure 5.9).

Figure 5.7
Enthusiasm for Distributed Collaboration, Year 1, 1997–1998



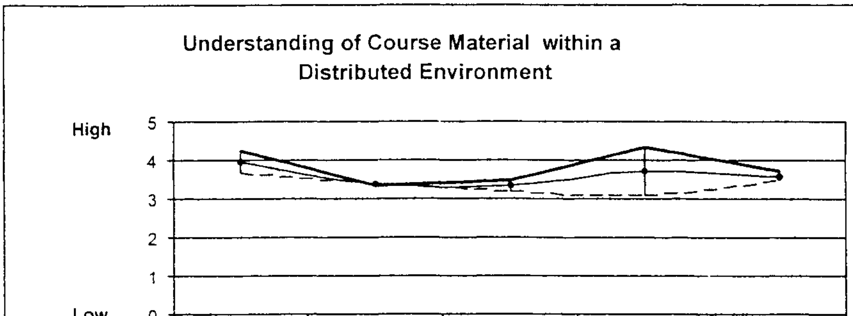
	1	2	3	4	5
Low	1	1	2	2	2
High	4	4	4	4	4
Mean	3.42857142	2.71428571	2.71428571	3.28571428	3.33333333

Figure 5.8
Effect of Distribution on Understanding, Year 1, 1997–1998



	1	2	3	4	5
Low	1	1	3	3	3
High	5	5	4	4	5
Mean	2.428571429	2.714285714	3.214285714	3.285714286	3.666666667

Figure 5.9
Understanding of Course Material, Year 2, 1998–1999



	System Life Cycle	Entrepreneurl ship	Collective Memory	Technology	Collaboration
Jan-99	4.25	3.33333333	3.5	4.33333333	3.71
Mar-99	3.66666667	3.4	3.2	3.08333333	3.45454545
Mean	3.95833333	3.36666667	3.35	3.70833333	3.58441558

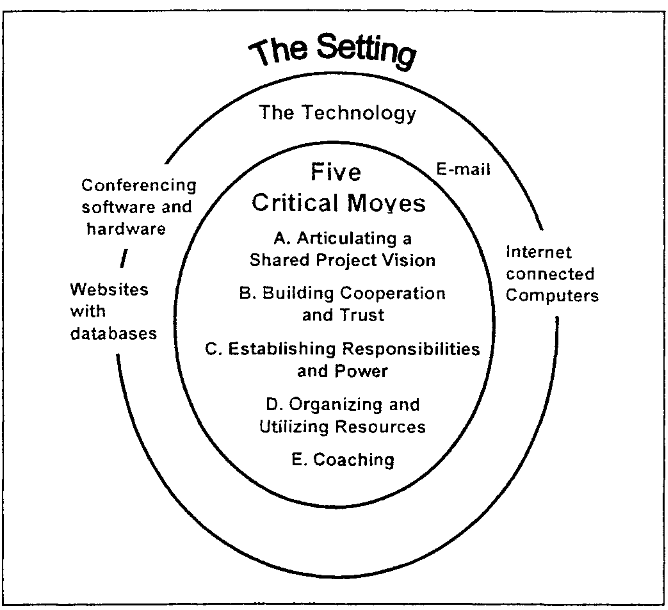
Reasons for the discrepancy between student interviews and questionnaires during the second year seem to stem from students' experience in the first half of the course versus the second. During the first half of the course, students benefited from a significant amount of instructor guidance—they heard lectures and completed assignments to build their understanding of the course material—and therefore were confident in their understandings. During the second half of the course, though, students were to put into practice what they learned without as much instruction; with the lack of direction, their confidence dropped. Support for this conclusion stems from the fact that at the end of the year, when students were receiving significant instructor support developing a business plan for their systems project and were focusing on their entrepreneurial skills, their rating of their understanding of entrepreneurial methods increased.

Thanks to the research completed in both years of the course, necessary changes could be identified, and a system for setting up this type of course could be developed. This system, called the Five Critical Moves (FCM), should help educators commit to the amount of preparation and implementation work required for a successful distributed learning course. The FCM model will be tested during the next DiSEL course.

THE FIVE CRITICAL MOVES (FCM) MODEL

Careful analysis of the Lipnack and Stamps (1997) virtual team model and the elements of the DiSEL pedagogical model has lead to the development of a model for supporting learning and doing project collaboration in distributed or virtual teams. This new model is called the Five Critical Moves (FCM) model, and it brings attention to the critical steps needed to facilitate a virtual learning environment (Figure 5.10). Before taking these first steps, though, there are two elements that facilitators need to consider: (1) the setting where the learning will take place, and (2) the technology with which the coursework must be completed. These factors are important to recognize as inhibiting or supporting the virtual teamwork that must get done. The setting, whether a laboratory or classroom, should be one in which experimentation is encouraged so that distributed teams can explore new ways of using communication systems and can push the evolution of new technologies. Among some of the technologies required by virtual teams are e-mail, Internet-connected computers, conferencing systems and hardware, and Web sites with databases. In the DiSEL course, students use e-mail, Microsoft's NetMeeting, ICQ, and CAIRO when communicating with each other. (Due to the importance of archiving and

Figure 5.10
The Five Critical Moves Model



sharing documents as well as comments, telephones and faxes were not deemed appropriate in the DiSEL setting.)

Once the setting and the technologies have been set up and defined, there are five critical moves (FCM) to consider that bring the major features of virtual team interactions to the fore. Implementing these five moves could be done during the first week or two of a course and could be thought of as the guidelines for an online retreat:

- Articulating a shared project vision
- Building cooperation and trust
- Establishing responsibilities and power
- Organizing and utilizing resources
- Coaching

Articulating a Shared Project Vision

At the beginning of any course, there needs to be a clear introduction to the learning and work to be done. This was provided in the DiSEL course with the TFU rubric (see Table 5.3), which was handed out at the beginning of the course. To ensure commitment to the class and to keep motivation of participants high, there also needs to be a process of developing a shared vision of the most important priorities in the learning. The main advantage of this is to avoid some of the problems students in the DiSEL course faced when some of the project requirements were changed during the course. In a virtual setting, this is especially critical for participants to keep in mind as they work physically separated from each other. Thus, the two most important considerations when working toward such a shared vision in a distributed, project-based learning environment are reflection and collaboration.

Negotiating a shared vision can be a complicated process and should be ongoing throughout a course. To begin, participants need to have a chance to develop and articulate their personal vision of what they will get from the course, identify risks in the work and learning, and hear each other's ideas. Taking the time to create an open environment in which participants can learn from their colleagues and become comfortable expressing themselves should be a priority for virtual teams. "A shared vision is strongest when it builds from the foundation outward, connecting local visions with their counterparts throughout the organization" (Senge, 1994). To actually do this in a course project, space needs to be made for everyone to think about what they really envision. They need enough information to build from, though, so there is a challenge for instructors to outline the project goals and still keep them flexible for members of the team to make their contribution. The criteria for which the team as a whole will be assessed should also be articulated so that participants can appropriately gauge expectations. A general outline of the project goals should therefore be made available. The outline should note the primary problems the group is trying to solve, acceptable behaviors, as well as the concrete results expected inside and outside the group. Any identifiable milestone dates should also be mentioned. This is essentially the Expectations Rubric established by the DiSEL instructors before the class started (see Table 5.3). Once the students' voices are considered, their vision should be added to this rubric—so the rubric should be flexible and editable.

Once the project goals are outlined and shared with the newly formed team, each participant needs to reflect on their vision of the project, identify problems that may not have been mentioned, and feel that they have space to articulate their conclusions to the group at large. By making room for this at the beginning, participants should feel free to express their feelings without reservation. If the time had been taken to do just this during the first two years of the DiSEL course, students would not have suffered such a drop in their motivation (see section 3.2) when the realities of the project came to light. Ensuring openness in the general outline of the project goals becomes critical for everyone to feel comfortable expressing their ideas and motivated to complete the work. Defining and supporting reflection becomes the pivotal step in this process.

"We undertake reflection, not so much to revisit the past or to become aware of the metacognitive process one is experiencing (both noble reasons in themselves), but to guide future action (the more practical purpose).... In other words, reflection-for-practice is in essence proactive in nature" (Brubacher, Case, & Reagan, 1994). Getting to the heart of reflection, means exploring the three elements of reflective thinking: cognitive, critical, and narrative (Brubacher et al., 1994).

Cognitively reflective thinkers review the knowledge they need to make good decisions in and about their learning situation (Brubacheret al., 1994). To create a grounded/practical vision of one's learning experience, one should identify (or approximate) what knowledge is needed to get the job done and figure out how to make that a part of the vision itself. Experience is often the best teacher of this; however, reflection can expedite the process by creating an awareness of needing resources and mentors as well as an openness to learning from both good and bad in-practice decisions (Brubacher et al., 1994). In the DiSEL course, the Expectations Rubric should play a significant role in helping students reflect on this level. By seeing what they are to be doing clearly before them, students can evaluate the decisions they need to make and can reflect on where they can go to get the information they need to make solid decisions. Again, there was no time taken during the first two DiSEL courses for this gauging of expectations to occur, and conflicts arose between students trying to collaborate. By getting the students as well as the instructors' expectations aligned, many levels of frustration can be avoided, and real teamwork becomes possible.

The second element of reflection focuses on issues of social justice and ethics. The distinction of what we want to achieve and the restrictions that exist on how our goals can be achieved are manifestations of the issues of social justice and ethics reflective researchers stress (Brubacher et al., 1994). Attending to these issues is like holding up a mirror to how we do coursework: Are we proud of the way we do our work? Are we upholding the values we claim to live by in our actions? By telling the story of one's experience in learning or work environments, we can give others insight on our understanding of what the future holds in the current learning space. This type of narrative reflection helps to contextualize our understanding and can prove valuable when developing expectation of others with whom we are to interact in such a focused environment (Brubacher et al., 1994). Accordingly, educators could share their experiences when they want to give students a sense of what they are expecting from them, and each class period offers such opportunities for the DiSEL instructor(s). During the first two years of the course, the instructors would have students speak about their work in the context of making a decision about the project but would then proceed to make the decision for them. By incorporating the decision pyramid, instructors would be able to discuss their experience and then let students work through their thinking to come to a decision on their own. In this way, students' sense of ownership would not be thwarted, and collaboration would be possible.

Collaborating, or building on each other's ideas, is difficult in person, let alone at a distance, and requires patience and space for everyone to participate. A Web site where everyone has been able to post his or her vision of the work is an important resource to this end, and COMMAND (Williams et al., 1998) can provide this space for the DiSEL students. Participants in geographically distributed environments should review each other's visions before a carefully planned synchronous meeting that brings basic goal constraints to the forefront, gives everyone space to contribute their vision, and sets up basic meeting protocols. A record of such a meeting needs to be carefully kept and visible to the entire group during and after the meeting so no ideas are lost and a consensus can be achieved on the issues at hand. Protocols for bringing attention to a lack of collaboration, for example, should be established and agreed upon. A document with the vision for the group will emerge in such a synchronous meeting, and this document should be accessible to all members of the group. In the next DiSEL course, there will be one assignment early on in the project that asks students to create their vision, share it with the group, and come to a consensus of what the class sees as its project objectives. Had this been done during the earlier DiSEL courses, it is possible that the remote students would have felt more like real teammates than observers to the local students (see Figure 5.4).

Building Cooperation and Trust

When we meet someone "face to face" (FTF), material goods, voice, body language, appearance, gender, age, even odors, as well as the location or context of the encounter, can greatly influence our perceptions, trust, and expectations of the other. How can we create a context for ourselves on the Internet to establish substantial relationships of cooperation and trust? Getting to know each other, finding ways to communicate feedback to each other, and seeing the need to cooperate are ways of building cooperation and trust in distributed classes. This was never established between the remote and local student groups during either year of the DiSEL course, and collaboration, as well as a truly codeveloped product, never emerged.

"We all know the basic moral and practical costs of dishonesty. More subtle are the tokens of trust and mistrust that people convey through competence, rewards, and information" (Lipnack & Stamps, 1997). Growing to trust a classmate's competence often comes from one's expectations of his or her performance and commitment to the work. How do we initially get these expectations? "Reputations, recommendations, and resumes loom larger when people must establish relationships quickly through narrow channels" (Lipnack & Stamps, 1997).

Whether our initial trust of "the other" is built on proxy, reputation, recommendation, or resume, it materializes as our prediction or expectation of what we will get from working with a specific person. Often what we expect or demand of someone becomes what we get from them, and this can become a self-fulfilling interaction for better or worse. According to

Perkins (1998), five ways to relate to people "with reflective trust, not tragic trust" so that we can work together without great disappointment are as follows:

- *Don't demonize.* If your distrust seems profound and sweeping, don't trust your trust model. Consider bringing your trust up a notch or making it more differentiated.
- *Don't angelize.* If your trust in someone seems idealistic, don't trust your trust model. Consider bringing it down a notch. Are your expectations idealistic or reasonable? You may be setting yourself up for a flip into profound distrust, the tragedy of trust.
- *Pygmalionize.* Trust a little more than you think you objectively should. Get Pygmalion on your side.
- *Objectivize.* If you feel that events keep confirming your deep trust or distrust, don't trust your trust model. Stand back and take an objective look. Are you processing evidence selectively? Are you creating the situation you see by the Pygmalion effect (which could be good) or reverse Pygmalion effect (not good)?
- *Clarify.* A person committed to reflective trust clarifies expectations. If expectations are vague, get them out on the table and negotiate conflicts in a positive win-win spirit.

Another significant issue associated with trust concerns how our peers, and those evaluating our performance, reward us. If our collaborative efforts go unrecognized, our best intentions can be undermined and seem a waste of time. "The second way that people generate trust is by their commitment to a unifying purpose with shared rewards. Conversely, nothing provokes mistrust faster than a mismatch between a team's goals and the system that rewards it. Many companies ask people to work toward cooperative goals then evaluate and reward them on the basis of individual performances. This often arouses suspicion and provokes people to act competitively" (Lipnack & Stamps, 1997). This is also true in educational settings where rewards are grades. The issues here again revolve around expectations. Are those who grade or manage you committed more to the group or to the individual? What do you expect from them? How did you come to these conclusions? Being able to predict another's behaviors is to trust that you know something about them and can then learn and work with them. The instructors of the DiSEL course developed the Expectations Rubric (see Table 5.3) to avoid just this type of miscommunication but still struggle with communicating their expectations during class time.

Often students were struggling to figure out what they were actually being graded on and where they stood with the instructors. Until they scheduled a face-to-face meeting with the instructors to get perspective on their work and how they were being assessed, students were often left in a quandary.

A third issue of trust within distributed environments is with the technology itself. How reliable is the technology? Will information be accessible? The value of information in the virtual environment shouldn't be underestimated, as this is the glue that keeps each person in a group connected. If participants cannot access the information they need due to faulty technology, the entire distance-learning endeavor is futile. The DiSEL course demonstrated this as student frustrations mounted when synchronous meetings were slow, full of static, and took more time than expected to set up. Although students could access the written materials, the personal connection promised was painfully lacking. Using Internet2 and the most advanced communication technologies during the next DiSEL course, the instructors hope to ensure more reliable technology for synchronous transmissions to avoid frustrations that could inhibit the success of the course.

Reliable technology along with a reward system and cooperative colleagues are a great combination for a successful distance-learning environment, but the glue that really keeps it together is the communication itself. In virtual teams, this requires developing protocols for interaction. One example of such a protocol is called The Ladder of Feedback (Wilson, 1999). Created to help shape feedback in a way that would honor the presenter(s) ideas, ensure understanding of these ideas, encourage constructive advice, and depersonalize the critiques, the feedback ladder has four rungs: clarification, valuing, concerns, and suggestions.

- *Clarification*

  Ask questions first before any other discussion to be sure that the topic is well understood.
- *Valuing*

  Honor the good points of the work. This not only benefits the person whose work is being evaluated, but it also helps you to clarify the value of what is before you.
- *Concerns*

  Identify concerns you may have with the ideas or actions presented. What difficulties do you foresee? Statements that start with: "Have you considered...?" "What I wonder about is..." "Perhaps you have thought about this, but..." are all ways of framing concerns in non-threatening ways.

- *Suggestion*

  Work through your concerns with the presenter. What alternative approaches or solutions could you think of to help the person in his or her work? Statements that start with "Perhaps you could try..." or "Maybe you thought about this, but what about...?" are ways of opening a brainstorming session around identified obstacles to the work. (Wilson, 1999)

Using the Ladder of Feedback for both written as well as oral work allows for ongoing assessment of one's self as well as others. Further, this clear, predictable approach to communicating feedback can ease tensions around criticism and concerns and helps to build cooperation and trust between members of a team. Such an open and accepting approach to feedback can also help team members see each other as resources and mentors. In a distance-learning environment, this is especially important, given the fact that one bad communication can lead to significant mistrust that cannot easily be resolved. This was discovered during the DiSEL course when collaboration broke down between the two participating schools because students at CICESE felt excluded from the decision-making process around the MIT 1K and 50K Competitions. To avoid such rifts, e-mails between the DiSEL students should reflect this Ladder of Feedback.

Establishing Responsibilities and Power

Once resources are identified, participants introduced, and visions of the work articulated, a process for determining participant responsibilities and interests should be established. To begin with, the shared vision outline created by the team needs to be accessible to all participants. The outline should highlight project goals, the primary problems the group needs to solve, and acceptable behaviors, as well as the concrete results expected inside and outside the group. Further, the milestone dates and obvious tasks should be noted. Once the problems, expected results, and deadlines are identified, the team learning and work can be prioritized appropriately, and participants can claim the work they want to take responsibility for. In the DiSEL course, student roles are assigned, but the students primarily articulate their responsibilities so they can begin to see the interdependence of tasks and the behaviors others expect of them within their roles.

This is done after the instructors have lectured on each role in the system development life cycle.

Another move that will prove helpful is to develop a responsibility chart based on what each participant sees as her or his responsibility. Questions each participant should consider are:

- What are the concrete results expected of the participant inside and outside the team?
- What task will the participant take responsibility for in the work? When do they see his or her task leading the overall project? Who will share the responsibility for the named task?
- Who inside and outside the team will need/want information about the task? Who can benefit from this work? How will the leader of the task make sure these interested parties are included in the reporting of the work?

Those assessing the team participants, as well as the team as a whole, should answer these questions for themselves. Clarifying expectations on all fronts can help bring conflicting agendas into discussion. Such dialogue should be encouraged at all levels to assure participants that their views are respected and considered. This should be done after the shared visions outline is complete, but before the meeting planned to establish responsibility and power over tasks and deadlines. Students in the DiSEL course can fill out a responsibility chart once they are assigned their roles midway through the first semester. Once they agree to fulfilling the tasks on the responsibility chart, students can then take ownership of their work and can be graded accordingly. This did not happen during the second year of the DiSEL course as the CICESE students' course work was not weighed as heavily as the MIT students'. Further, any confusion around what students need to be doing should be eliminated with a responsibility chart so even if communication between participants breaks down, as was the case during the 1998–1999 DiSEL course, the breakdown will not inhibit the students from getting the work done.

Organizing and Utilizing Resources

For teams to do project work, participants need to know the tools at their disposal and how to use them. Computers, software, and communication tools may be some of the equipment available to get the work done, and these items, as well as their characteristics, should be compiled into an inventory list or database. In the DiSEL Student Handbook, such a list has been developed so that all students can find resources efficiently. In a virtual team, knowing what is available at each location also keeps communication between team members flexible as they can determine if e-mail, chats, or threaded discussions are the best ways to stay in touch with each other. Further, keeping IP addresses for computers in the lab on such a list ensures that everyone knows how to reach each lab computer without too much of a hassle, as was the case during the DiSEL 1998–1999 course.

Databases with this information can also be developed, and the first week of a virtual team's online retreat schedule should include getting to know each other as well as each participant's resources. The available resources may be categorized as hardware, software, multimedia, human, and text. (There may be other categories, and the database should allow users to add them.) The database should be continuously updated with access from each location where participants are based. This resource database may be considered a user's manual and should be as complete in detail as possible concerning resource nuances or annoyances.

Coaching

Throughout the work, those ultimately held accountable for the deadlines and quality of the project need to be connected to the work processes of the virtual team. To this end, instructors become coaches who are responsible for the initial outline of project goals and for providing feedback and points of reflection throughout the work cycles. As well, the instructor/coach should resolve conflicts that may arise and reward both individuals and the team as a whole.

Through focus group discussions, interviews, meetings, and questionnaires, coaches can simultaneously provide the feedback and reflection points virtual teams need to thrive. Within the DiSEL setting, focus group discussions and interviews were effectively used to encourage reflection on the teamwork and addressed how well team members were collaborating. Meetings gave the class opportunities to update everyone on the progress of the project and what the next steps were in the work, and questionnaires were used to assess the success of the work at a particular point in time. The questionnaires were critical in determining causes and effects within the environment. When coaches assist with decisions or raise questions about the project or coursework in these types of interactions, they are helping the virtual team improve on their performance while giving them a chance to review what they have accomplished. As well, each one of these interactions should draw attention to how the coach can further help the virtual team, the individuals, the project, and the process. The DiSEL instructors made time for this at the beginning and ending of every class to ensure numerous coaching opportunities.

To well connect with team members in focus group discussions, interviews, and meetings, the coach also needs to consider ways of honoring those on his or her team and encourage their ability to think critically about their work. Critical thinking allows for members of the team to be metacognitive by assessing their situation and then improving it for themselves without necessarily needing the coach to tell them how to proceed; it is a basis for individual development and understanding of the situations in which we live and learn. Such critical thinking is actively fostered in dialogues that may emerge between team members in focus groups and meetings.

"True dialogue cannot exist unless the dialoguers engage in critical thinking…thinking which perceives reality as process, as transformation, rather than as a static entity—thinking which does not separate itself from action, but constantly immerses itself in temporality without fear of the risks involved" (Freire, 1970). Such dialogues can foster progress within a collaborative learning environment as participants are required to fully engage themselves with each other's ideas and opinions. Such dialogue is easiest when there are very few dialoguers, though protocols such as the decision pyramid make it feasible with dozens of participants. In distributed learning environments miscommunications can also easily occur as observed in the second DiSEL course when information shared with body language or as a quiet comment was only available to local students. Coaching dialogue can therefore be tricky, as the coach must be willing to honor student opinions fully, make sure everyone hears the opinion, and keep the conversation on a productive track so decisions can be made and next steps planned. This is not entirely different from a face-to-face class, but more attention needs to be paid to making things explicit.

The DiSEL setting provides the space for focus group discussions, interviews, and meetings that can become good reflection and feedback points that can be difficult to make time for. In such an open space, team members may feel comfortable enough to bring sensitive topics into the limelight. Such a move may prove taxing for the coach and demands careful communication of ideas. If the technology, and the audio in particular, were to go bad in such a situation, the encounter could be counterproductive, as carefully crafted comments may need to be repeated and then clarified and then may still be incomprehensible. Consequently, group cohesion can dissolve as conclusions may be inappropriately drawn. In such situations, the coach can prove ineffectual and may resort to telling people what to do rather than helping them figure out solutions to the problems they have either discovered or created. Utilizing text-based chat systems at such moments becomes imperative to keeping messages clear, and the DiSEL participants relied heavily on this medium to clarify events. By allowing for a shared vision and an open discussion on responsibilities and power at the beginning of the project, coaches are off to a good start supporting dialogue and collaboration within the team so true learning can take place and trust between participants can evolve.

CONCLUSION

The Five Critical Moves (FCM) model described here is designed to create a meaningful learning experience in a virtual environment. Articulating a shared project vision, building cooperation and trust, establishing responsibilities and power, organizing and utilizing resources, and the coaching elements of the FCM model bring participants into a project in ways rarely articulated in a traditional classroom. These moves actively integrate learning and motivation as participants become vested in shaping the processes and outcomes of the real-world coursework. Together with DiSEL's constructivist pedagogical model, the FCM model forces clear articulation of expectations and rewards by participants as well as leaders, and this fosters a democratization of work also rarely found in traditional education settings.

"Now in any social group whatever, even in a gang of thieves, we find some interest held in common, and we find a certain amount of interaction and cooperative intercourse with other groups. From these two traits we derive our standard...These two traits are precisely what characterize the democratically constituted society" (Dewey, 1916). And these traits can certainly be found in a carefully crafted distributed environment as described in this chapter.

To do their work and build cooperation and trust, virtual team members are encouraged to interact freely with their coaches (i.e., instructors) and classmates. Therefore, they should be able to create new associations between the course and their interests. By merging the diversity of their interests into one outline of the shared class goals, the students have a remarkable opportunity to consciously bring to light any connections between them. A distributed classroom that integrates the FCM and DiSEL pedagogical model in these ways, then, has numerous opportunities to be true to the democratic principles Dewey describes.

The settings and technologies of the different locations participating in a distributed class or virtual team should support participants in these democratic and educational endeavors. To this end, a technological infrastructure such as accessible computers, e-mail, Web sites (servers), and a videoconferencing system need to be in place. In the DiSEL course, the technology is equally available at all participating locations, however, connections could often be frustratingly slow, and communication was often poor. The addition of a server that will host the course Web site and Internet conferencing and feature the Pre- and Post-Skills Exams will help. This server will also host the monthly surveys and evaluation forms, as well as the data repository so students can locate the resources they need to do their work and fulfill their project vision.

A student handbook, an online retreat, and an online decision pyramid protocol are also in development to bring the Five Critical Moves model into the DiSEL course structure. The student handbook will include the syllabus, complete course schedule, introduction of the instructors, the Expectations Rubric, the technological information of the participating labs/classrooms, and protocols for meetings. By consolidating all the elements of Teaching for Understanding and Theory One, as well as project-based, collaborative, and distance learning into one reference, students can better make connections from their daily activities to the course's objectives.

The DiSEL instructors, by implementing the FCM model, are working hard to create a learning environment that fosters good pedagogical theory in practice and utilizes technology in innovative and meaningful ways. Further, they are giving students a unique environment that should help them cope with real-world system development decisions. As an experimental laboratory carefully crafted to help students become more metacognitive in their work, the DiSEL setting should also help students ultimately become better learners. And learning how to learn, many would agree, is the purpose of education in the first place.

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6

Information and Communication Technologies to Facilitate Collaboration in Architecture, Engineering, and Construction

Chimay J. Anumba

Effective communication is vital for collaboration in the architecture, engineering, and construction (AEC) sector. This chapter reviews the key communication issues that need to be addressed in a collaborative design and construction environment. In particular, the key communication facets (or interfaces, such as those between project team members, and between inter- and intradiscipline design tools) that are applicable are presented and the enabling information and communication technologies that are necessary to address them are discussed. It is argued that these are vital for facilitating collaboration in the AEC sector.

INTRODUCTION

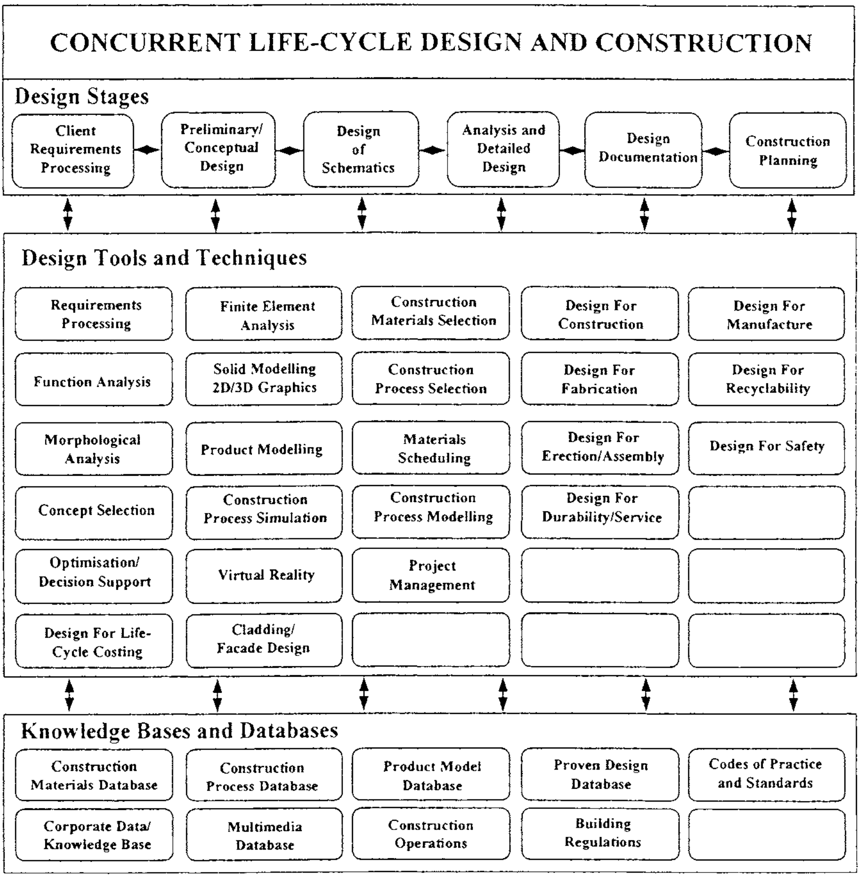
Communication may be defined as "the imparting, conveyance or exchange of ideas, knowledge or information" (Clark, 1991). It is considered central to any relationship (Briggs, 1996), and the establishment of effective communications protocols between collaborating parties is therefore essential. This is particularly true of the construction industry, which is severely fragmented, with each construction project involving several disciplines collaborating for relatively short periods in the development of a facility (Popple & Towndrow, 1994; Wheeler, 1986). Communication under these circumstances currently takes the form of paper-based 2-D drawings, supplemented with periodic face-to-face (FTF) project team meetings. This combination of fragmentation and inadequate communication protocols has made the industry inefficient, with numerous problems (Evbuomwan & Anumba, 1996a, 1996b).

There is growing interest in the adoption of collaborative and concurrent engineering as a means of addressing the construction industry's problems and enhancing its competitiveness (Anumba, Evbuomwan, & Sarkodie-Gyan, 1995). This involves the integration of all project team members, as well as all the stages in the project life cycle, with a view to ensuring that all key life-cycle issues are addressed early in the design process (Evbuomwan & Anumba, 1996a). An integrated framework for concurrent life-cycle design and construction (CLDC) has been developed and is illustrated in Figure 6.1. Within the framework, the integrated design and construction process is underpinned by a variety of design tools and techniques and by appropriate databases and knowledge bases. An important aspect of the adoption of concurrent engineering in construction on the basis of this framework is the need for effective communication of project information at all stages in a project's life cycle. This is recognized as vital for virtual organizations (such as construction project teams) to achieve their goals (Rogers, 1995). Bowles (1994) goes further to identify the primary objectives for IT and communications to support concurrent engineering as follows:

- To reduce the effect of distance so team members can interact as if co-located
- To enable cost-effective, flexible applications to have a visual object representation
- To manage the generation, storage, and distribution of data
- To facilitate the integration of applications so the man-machine interface solves the business problem and not vagaries of implementation—in particular, to provide smooth transfer between design, modelling, test, and production

In fulfilling these and other business process objectives, therefore, it is of paramount importance to understand the nature of communications in a collaborative and concurrent engineering environment. A key aspect of this is the identification of the facets of communication that have to be provided for. This chapter contributes to this understanding by presenting a taxonomy, or classification framework, for these communication facets. First, the changing nature of the construction environment is discussed.

Figure 6.1
Integrated CLDC Framework



THE CHANGING CONSTRUCTION ENVIRONMENT

Before discussing the range of communication facets in a collaborative and concurrent engineering setting, it is pertinent first to review the changing environment within which the construction industry operates. Some of the key issues include the following:

- Concurrency in an integrated design and construction process requires greater discipline in the production, manipulation, storage, and communication of project information.

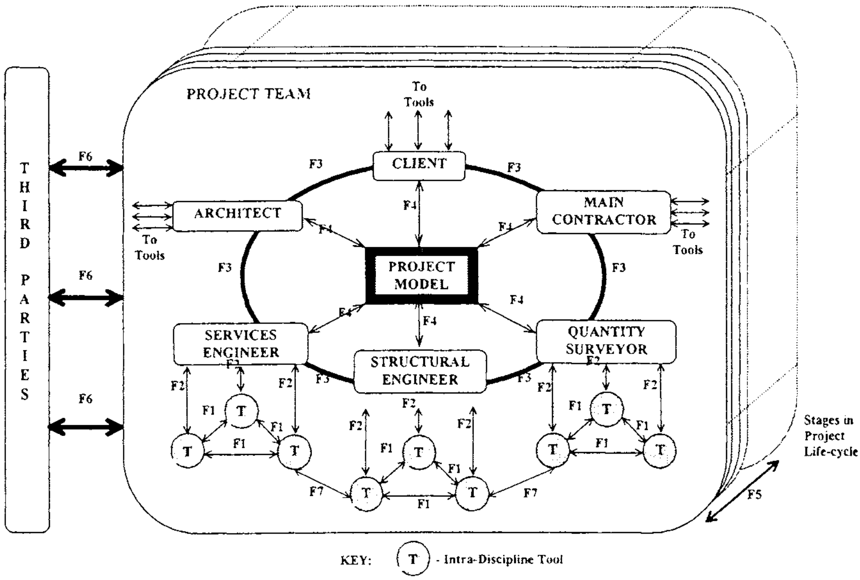
- Project information necessarily consists of both graphical and non-graphical information, which must be communicated between members of the project team.
- The greater the level of concurrency in a process, the greater the level of coordination required. This entails an increased level of communication between the various stages and activities in the process, as well as between the project team members.
- Paper-based communication of project information is now inadequate to cope with the high level of functionality (in terms of speed, accuracy, usability, ease of modification, enhanced visualization, improved coordination, etc.) required in a collaborative working environment.
- The increasing globalization and complexity of construction projects means that project teams often involve partners from widely distributed geographical areas, sometimes on different continents (Madigan, 1993). Face-to-face meetings in such circumstances are expensive in terms of time, money, and personal inconvenience (Rogers, 1994); effective communication protocols able to collapse time and distance constraints are therefore necessary.
- The very fast pace of technological development, particularly in computing and telecommunications, dictate that for the construction industry to remain competitive, it must take advantage of new and emerging information and communication technologies such as the Internet, multimedia, virtual reality, and broadband communication networks.

KEY COMMUNICATION FACETS

The classification of communication facets is based on a clear identification of distinct groups of people, tools, and project phases across which communication has to take place. As illustrated in Figure 6.2, there are seven main facets of communication that need to be addressed in concurrent life-cycle design and construction. These are

- Communication between intradisciplinary computer-aided engineering (CAE) tools (F1)
- Communication between each project team member and his/her design tools (F2)
- Communication between project team members (F3)
- Communication between each discipline and the common project model (F4)
- Communication across the stages in the project life cycle (F5)

Figure 6.2
Facets of Communication in CLDC



- Communication between the project team and third parties (F6)
- Communication between interdisciplinary CAE tools (F7)

Intradisciplinary Tool-to-Tool Communication

This refers to the communication between the various design and other software tools within each discipline. For example, the structural engineer's finite element (FE) analysis model needs to be able to communicate with the elemental design and detailing packages or with a knowledge-based conceptual design system. This facet of communication is essential to integration within a given discipline and will, in addition to minimizing data input and rework, ensure that all design information from each discipline is mutually consistent.

Designer-to-Tool Communication

It is important that the designer be able to communicate effectively with the design tools at his/her disposal. This facet of communication is often a function of the user-interface design, and is necessary for the effective deployment of the tools. In this regard, it is essential that CAE tools are designer oriented (Anumba & Watson, 1992), providing the designer with the flexibility to structure design information in accordance with individual, project, and/or corporate requirements and to configure the user interface to suit individual preferences. This will entail taking advantage of emerging technologies such as multimedia, voice/motion recognition, and virtual reality.

Project Team Communications

This relates to communication between the various members of a given project team. There is a need to provide for an appropriate communication infrastructure that will facilitate multilateral communication involving all members of the project team or a subset thereof. Concurrent project development requires that all appropriate team members participate in meetings, agreeing on the basis for design decisions, and resolving potential downstream safety, buildability, or other problems. This facet of communication should provide support for both synchronous and asynchronous meetings, as well as both co-located working (such as within a multidisciplinary practice or in a face-to-face meeting) and distributed working (within a single organization and/or between an extended network of partners). In addition, enhanced visualization tools based on the "What You See Is What I See" (WYSIWIS) philosophy (Maher, 1994), but also allowing for multiple views of design information (Anumba & Evbuomwan, 1996) is necessary to support concurrent project development.

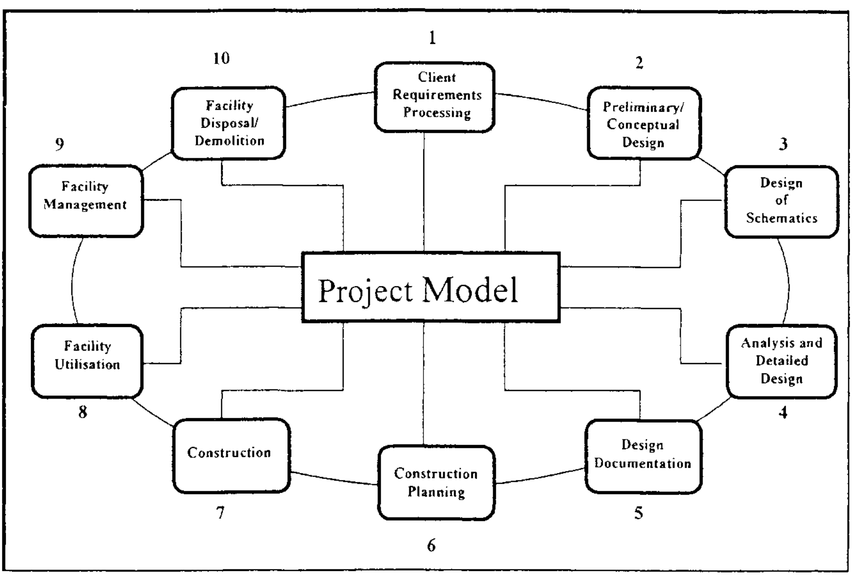
Discipline-to-Project Model Communication

At this level, each discipline should be able to communicate interactively with a common project model, which is considered vital for seamless interworking between several disciplines. Each discipline should, therefore, have facilities to insert and abstract information from the project model, as well as view (and comment on) changes to the model instigated by other disciplines. It is also essential that, where appropriate, intradiscipline design tools are compatible with the hardware and software platforms on which the common project model is based. This will facilitate bidirectional coordination. The common project model also needs to support concurrent multiuser access and provide appropriate mechanisms for integrity and consistency checking.

Communication between Stages in the Project Life Cycle

The integrated framework for concurrent life-cycle design and construction provides for six key design stages—client requirements processing, preliminary/conceptual design, design of schematics, analysis and detailed design, design documentation, and construction planning. There is need for communication of both design information and design rationale between these stages as well as the subsequent stages of construction, utilization, maintenance, and disposal (Figure 6.3). It should be born in mind that the configuration of the communication facets shown in Figure 6.2 will change from one stage of the project life cycle to another, as the communication requirements (and project team composition) are liable to change from one stage to another. Ensuring effective communication between stages in the project life cycle will not only facilitate the reuse of project information at the later stages of a project's life cycle, but also ensure the traceability of design rationale and decisions to explicit and implicit client requirements. This can be provided for within the common project model and will prevent ill-advised late changes and limit disputes and claims.

Figure 6.3
Communication across Stages in the Project Life Cycle



Project Team-to-Third Party Communication

In construction, third parties are often introduced into a project, and although they are not full-time project team members per se, there is a need for adequate communication links between the project team and such parties. Third parties may include specialists (e.g., geotechnics experts), regulatory bodies (e.g., local authority building inspectors, health and safety executive safety inspectors), or others. The involvement of some third parties, although transient, may involve a high level of communication with the project team. In such cases, it may be necessary to allow third parties limited access to the project model (or parts thereof) and/or the project team's communications network.

Interdisciplinary Tool-to-Tool Communication

This is the communication between the CAE tools used by the different disciplines. For example, there may be a need for the structural engineer's CAE system to exchange information directly with the architect's CAD modelling system or the services engineer's design system. This level of communication is sometimes useful and can readily be undertaken where the relevant disciplines utilize the same or mutually compatible systems. However, where disparate systems are in use, necessitating numerous interfaces, this level of communication would be best carried out via the common project model.

ENABLING INFORMATION AND COMMUNICATIONS TECHNOLOGIES

There are several information and communications technologies that have implications for the development of an effective communications infrastructure that supports the preceding communication facets and, hence, facilitates collaboration in the AEC sector. These are briefly described below.

Information Exchange Standards

For many years the DXF file format developed by Autodesk has been the de facto standard for file transfer between CAD and other design software. The file format is an ASCII text definition of drawing entities, and this can lead to very large text files, which are slow and verbose. Recently, the native AutoCAD DWG format has been used increasingly instead of

DXF; it is a binary format similar to DXF and as such is much quicker. Although Autodesk has not published the format of the DWG file, Bentley Systems and other CAD vendors have acquired the ability to read and write to files in that format. Both DXF and DWG formats remain proprietary, and Autodesk can change them without notice.

The development of neutral formats for the exchange of CAD data started in the 1960s with the Initial Graphics Exchange Specification (IGES) and led to the development of STEP (STandard for Exchange of Product model data). STEP is concerned with defining product data, only some of which is geometrical. It is intended as an international standard that covers all applications and has been adopted by the ISO. In STEP, the ISO 10303 Part 225 standard deals with building elements using explicit shape representation. STEP uses the standardized computer language, EXPRESS, to describe the data structures in the application.

A more recent initiative in the development of data exchange standards is led by the International Alliance for Interoperability (IAI), which is developing the Industry Foundation Classes (IFCs)—a common set of intelligent building design objects that will enable the sharing of information at all stages of the construction process. Unlike the pan-industry approach taken in STEP, the IAI's initiative concentrates on building construction. Although the two initiatives are separate, STEP has been fundamental in making available technologies that support computer-integrated construction (CIC) to the IAI, which has had the advantage of active industrial involvement (Wix, 1997). These have had limited impact on the construction industry to date because the models that are required by software implementers to develop the applications software are not yet fully developed. However, both the STEP and IAI initiatives are expected to have major impact on interoperability in the future by facilitating seamless interchange between construction project team members using heterogeneous CAD systems.

Internet and Intranet Technologies

The Internet. The Internet is an international network of computers that are geographically distributed but are able to exchange and communicate information. It is certainly the fastest-growing repository of information available. Several browsers are available to enable users to navigate the Web; examples include Microsoft Internet Explorer and Netscape navigator. Organizations and individuals have the facility to create their own Web sites (also known as home pages) containing whatever information they wish to place in the public domain. Access to certain types of information may be controlled by the use of passwords. Most Web sites often have hypertext links to embedded information within the site or to other related sites. These are based on 2-D environments created using HTML (Hyper-Text Mark-up Language). However, new 3-D environments based on the use of VRML (Virtual Reality Modelling Language) are becoming available (Bjork & Penttila, 1989) and will facilitate interaction within a more realistic 3-D world using text, images, animation, sound, and video. Using appropriate plug-ins, it is also possible to import and view 2-D or 3-D CAD models within the browser. This has significant potential for information delivery between construction project team members across wide geographical locations.

Intranets. It is sometimes necessary for groups of people to communicate and share information in such a way that only members of the group have access to the information. This is achieved through the use of intranets, which are business information networks that are firewall protected and link members of the group together. The group could consist of people within a single organization or members of a virtual organization set up to collaborate on a specific and time-limited project. It may be necessary to provide access to the Internet (or other networks) from an intranet. This is normally unidirectional and permits members of the group to access external information but denies third parties access to the intranet.

Potential

Both the Internet and intranets offer major scope for enhancing collaboration between members of virtual construction project teams. They have the capacity to serve as an inexpensive means of communication between geographically distributed project team members. The current trend toward the use of Web-based portals for project management exemplifies this. They also could, with appropriate controls, provide the link between individual disciplines and an integrated project model.

Distributed Object Models

Distributed object models employ, as the name suggests, object-oriented techniques in software that are distributed among different machines over networks. The two main protagonists, DCOM and CORBA, are discussed in detail next.

CORBA

The distributed object model known as CORBA (Common Object Request Broker Architecture) is the core part of the architecture developed by the Object Management Group (see http://www.omg.org/corba/corbiiop.htm). It relies on object request brokers (ORBs) that are aware of objects that are location, language, and operating system independent. The brokers intercept calls, find suitable objects, pass the parameters, invoke methods, and return results. Legacy systems such as databases can be integrated into software architectures via the process of wrapping. This provides a level of abstraction around the legacy system and allows other systems to access its functionality. Wrapping involves mapping an existing system interface to another (e.g., replacing a proprietary interface with a CORBA one) so that client software can use CORBA to access the system. Wrappers can also be used to collect a number of related objects and thus simplify the calling process. Additional functionality can also be defined in the wrapper code (e.g., to provide extra information about the legacy system) or to allow seamless access to a number of related systems or databases.

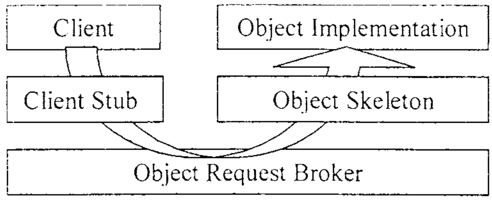
Programmers can use the Interface Definition Language (IDL) to define interfaces for objects. This is then compiled to generate source code for an object skeleton and a client stub. This code is integrated into the object and client respectively and handles all the intercommunication. A (simplified) request process using this approach is shown in Figure 6.4.

DCOM

The Distributed Component Object Model (DCOM) is Microsoft's distributed object model. COM (on which DCOM is based) was originally designed as an enabler for Microsoft's application interoperability concept OLE (Object Linking and Embedding). This would, for example, allow users to edit a spreadsheet from within a word processing application. DCOM is intended to provide a single programming model for creating objects within a process, between processes, or across a network—allowing object redistribution without changes.

DCOM uses its own form of IDL to handle interprocess communication and create a proxy and a stub. The client communicates with a proxy, which mimics the component. The proxy then communicates with the stub associated with the relevant component and coordinates the appropriate interaction. The client is not aware whether the component is remote or

Figure 6.4
CORBA Request



local—it just wants its call to be handled. The proxy and the stub are registered with a Globally Unique ID in the Registry—that integral part of Microsoft Operating Systems. The Registry information allows client processes to invoke both local and remote COM components via the proxy. A simplified call process is shown in Figure 6.5.

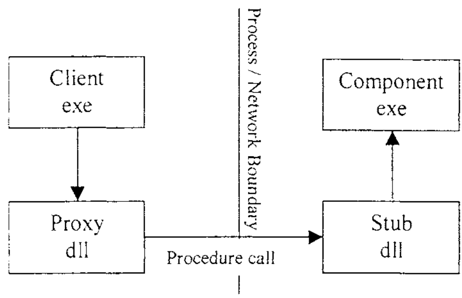
Both CORBA and DCOM are essential for integrating (legacy) intradisciplinary CAE tools with the integrated project model.

Modelling Tools

Java. The term *Java* is commonly used to describe the object-oriented programming language. It also refers to the bytecode that the compiled source code generates and the Virtual Machine that interprets the bytecode. The raison d'être of Java has been well publicized, but in summary, it provides a way of developing "write once—run anywhere" code that can run without any direct access to the operating system or hardware of the machine and is thus inherently safe. Such features make Java ideal for network download and execution and was originally designed to enable household appliances to periodically update their internal software over a network.

The Java infrastructure is one of lightweight clients, high bandwidth networks, and powerful, reliable servers. When coupled with distributed object models such as DCOM and CORBA, there is great potential for the development of portable, manageable applications that can invoke network services and data access as needed (Orfali & Harkey, 1997). In a construction project model scenario, any Java-enabled machine with network access could be used to interact with the model data without needing any preinstalled client software. A downloaded Java application (or applet) enables the relevant interaction. The applet would call distributed objects, allowing access to the relevant parts of the model data. Because

Figure 6.5
DCOM Call



applets are downloaded from the network, the need to maintain software on many and varied machines is removed.

Technologies that make wide use of networks are, of course, heavily dependent on their resilience and bandwidth and, clearly, an increased level of investment by construction sector firms is required in this area before distributed technologies can be used in earnest. These technologies will facilitate communication between members of a construction project team irrespective of their geographical location.

Object-Oriented CAD. Many see object orientation as the future of CAD. This paradigm allows for the use of libraries of components (or objects) that are put together in modular fashion to form a design. Currently, most CAD systems are used to generate 2-D drawing files or 3-D models. Many claim to be object oriented, but this is only true to a degree, in that they employ predrawn component objects that can be imported into a drawing. Fully object-oriented CAD would employ more complex objects with attributes in addition to geometric ones (e.g., costs, structural qualities, manufacturer). A design that utilized these objects would exist as a body of data that could be used to produce detailed views in 2-D, 3-D, and 4-D, bills of quantities, simulations, and architectural fly-throughs. Changes in the design would not require changes in all the affected discrete drawings, just in the underlying designed entity.

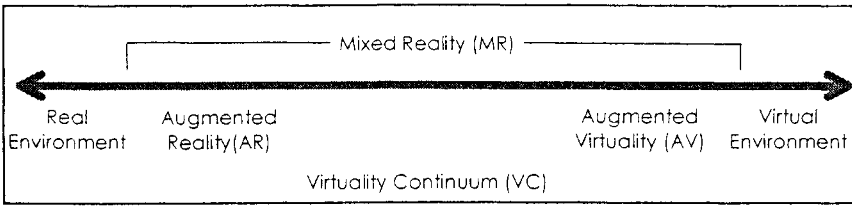
Such systems are beginning to emerge; however, they are heavily dependent both on the adoption of industry standard objects and on computing power (for buildings are complex and the number of objects required to fully define them is large). These two factors also explain why the use of 3-D and virtual reality (VR) has largely been restricted to a simulation and marketing tool. The generation of the virtual environment is a separate, appending process to design. Much of the detailed design information is stripped out in favor of smooth interaction and improved frame rate. This laborious process has to be carried out each time a different scenario is required or each time the design is changed significantly. The integration of fully fledged VR functions into traditional CAD packages or the smooth transfer of CAD data to VR would greatly facilitate the adoption of virtual reality by the construction industry. This is key to delivering the benefit of enhanced collaborative visualization of project information.

Virtual Reality. Virtual Reality (VR) is a medium that provides participative 3-D visualization and simulation of virtual or computer-generated worlds. Unlike animation, where previously created images are simply replayed in sequence, virtual reality environments can be freely viewed and examined in any way from an infinite number of perspectives without noticeable delay—that is, in real time.

Virtual Reality in Design and Construction. Architectural design has been the main driving force for developments in virtual reality. As a design tool, VR has many advantages for the architect. By allowing architects to immerse themselves in the their design, VR allows a much clearer understanding of both the qualitative and quantitative nature of the space they are designing. VR allows designers to evaluate proportion and scale using intuitive interactive modelling environments (Kurmann, 1995) and simulate the effects of lighting, ventilation, and acoustics in internal environments (Nimeroff et al., 1995; Pilgrim et al., 2001). The use of VR in this area also includes the simulation of egress from buildings for the design of fire escape routes (Spearpoint, 1994). As a visualization tool, VR is also used to communicate design ideas from designers to clients by generating walkthrough models to test the design with the clients in a more direct manner (Ormerod & Aouad, 1997). VR can also be used to model the construction sequence to simulate and monitor site progress. This is done using a preprepared library of 3-D graphical images of building components, facilities, and their related activities and generating VR models representing views of the construction sequence at any given time of the process (Adjei-Kumi & Retik, 1997).

Mixed Reality. Mixed reality (MR) environments seek to combine the best features of real environments with those of virtual environments. There are perceived benefits in this mixture, with the two main types of mixed reality environments being augmented reality (AR) and augmented virtuality (AV). Figure 6.6 illustrates the relative position of these environments in what Milgram and Kishino (1994) termed "the virtuality continuum."

Figure 6.6
The Virtuality Continuum (Milgram & Kishino, 1994)



Augmented Reality. Augmented reality (AR) is a technology in which the user's view of the real world is augmented with additional information generated by a computer (Klinker et al., 1997). It is complementary to virtual reality (VR) and enables users to interact with an integrated virtual and real world with ease. AR involves superimposing information in the form of a 3-D computer-generated image on top of a real-life visual scene. The scene may consist of still photographs and/or video images. It is possible, for example, to superimpose a 3-D CAD model of a building onto a picture of its proposed site to show what the finished building will look like on completion. In the case of video images, real-time processing is essential to ensure currency of the information being relayed.

Augmented Virtuality. This is the converse of augmented reality on the virtuality continuum. It consists primarily of a completely computer-generated graphical display, which has been augmented by the use of video reality (Milgram & Kishino, 1994). This involves superimposing a real scene on an aspect of a virtual reality model. An example could be integrating a video display of an outdoor scene with the view through a window in the VR model of a building. The key difference with AR in this case is that what is being augmented is primarily virtual rather than real. In the future, however, it may be more difficult to make this distinction.

Mixed reality environments could be useful for site exploration, the visualization of proposed buildings within the context of their locations, and the planning and monitoring of construction and refurbishment projects (Anumba & Duke, 1997a; O'Connor & Retik, 1998).

Collaborative Virtual Environments

Virtual reality has given birth to collaborative virtual environments (CVEs) within which users are virtually co-located and can interact with one another. One example of this is the virtual meeting room (VMR), which represents an extension of the concept of desktop videoconferencing. In a virtual meeting room, team members are able to interact intuitively in 3-D space and feel as though they were all in the same room. This is considered to be more realistic than desktop conferencing but requires the use of appropriate metaphors to represent both real-world objects and the collaborating parties. It is essential in VMR that normal meeting room decorum is observed and that all members of the team can see and hear one another (Madigan, 1993). This technology is still in its infancy and does not at present support realistic pictorial representation of the parties present in a meeting. Collaborative virtual environments can also be a medium for the remote collaboration of urban designers and the discussion of urban proposals by the general public.

At present the benefits that VR can bring to the construction industry are fully appreciated by the majority of practitioners. However, despite the continually falling costs associated with the hardware and software, there remains a big obstacle to its full uptake; this is the low compatibility of between VR and the existing CAD infrastructures, making its implementation costly due to the resource-intensive task of creating the models.

Telepresence

Telepresence may be defined as "the ability to operate a device by remote control, including perceptual data and sensory feedback transmitted from the operator, such that it appears to the operator as if the operator were present at the site of the remote device and operating it directly" (Morris, 1992). This is a rather broad definition, and it is important to define more clearly the context within which the term is used in this chapter. Within a collaborative communications setting, telepresence can be viewed as the facility that enables collaborating parties to be virtually located within a given (3-D) environment, in which they are able to interact with one another or with virtual objects that are also present in that environment (Anumba & Duke, 1997b). The intended aim of this is to create the illusion of being there (Cochrane et al., 1993). This is perhaps telepresence in its purest sense. Another definition—"Telepresence is enabling human interaction at a distance, creating a sense of being present at a remote location" (Walker & Sheppard, 1997)—implies that technologies such as the telephone (by extending human speech and hearing) or video conferencing (by also extending vision) provide telepresence to a degree. The other end of the spectrum is embodied by technologies such as the VisionDome[1] (Traill, Bowskill, & Lawrence, 1997). This immersive projected display technology (shown in Figure 6.7) can be used to provide a high degree of telepresence.

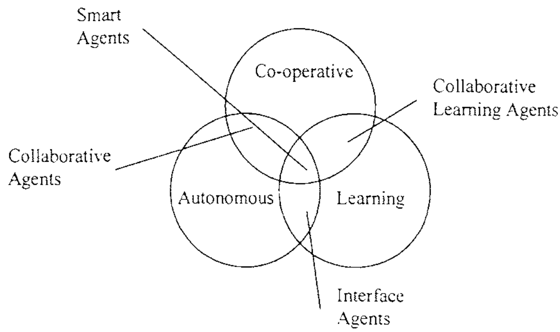
It is evident from the preceding definitions that telepresence systems have significant potential for improving communications in a variety of settings. Equipment maintenance/installation, mobile news-gathering, telemedicine, and remote surveillance are just a few of the emerging applications (Cochrane et al., 1993). There is major scope for enhancing construction project team communications through the use of telepresence. Duke, Bowskill, and Anumba (1998) have identified specific areas in which telepresence could be of use in a concurrent life-cycle design and construction setting. These include facilitating multidisciplinary teams, integrating communications facilities with design tools, and supporting project team communications with the use of collaborative virtual environments.

Distributed Artificial Intelligence

Distributed artificial intelligence, which is commonly implemented in the form of intelligent agents, involves systems that consist of self-contained knowledge-based systems that are able to tackle specialist problems and that can interact with one another (and/or with humans) within a col-

Figure 6.7
Architectural Review Meeting inside the VisionDome. Used by permission of Dr. Alistair Dune.

Figure 6.8
Taxonomy for Agents



laborative framework (Anumba & Newnham, 1998). Agents are expected to have a number of core attributes, including autonomy, cooperation and learning (Nwana, 1996). Figure 6.8 presents a taxonomy for agents, based on the degree to which they exhibit these attributes.

Agents are considered particularly useful for tackling large-scale, real-world problems involving multidisciplinary perspectives. They are currently applied to a variety of application domains, including workflow management, telecommunications network management, air traffic control, business process reengineering, information retrieval and management, electronic commerce, personal digital assistants, e-mail filtering, command and control, smart databases, and scheduling/diary management (Ndumu & Nwana, 1997). The distributed approach inherent in the use of agent-based systems allows for the decomposition of a complex problem into several smaller tasks. In construction, for example, it will allow individual areas of expertise to be encoded into particular agents, thus modelling the real-world problem of collaborative and concurrent design development in an intuitive, modular, and hence expandable manner. In such an agent-based system, as compared with a centralized expert system, decisions can be taken locally according to local knowledge, allowing greater flexibility as changes take place.

There are very few agent-based systems currently in use within the construction industry. However a number of research prototypes (Anumba & Newnham, 1998) are being developed and will enhance communication between project team members, as well as between their tools.

Groupware

Groupware systems are software that recognize the significance of groups in organizations by providing functions and services that support the collaborative activities of work groups. The overall aim of groupware systems is to improve the effectiveness of the work group by providing electronic links between its members. Group activities supported include the scheduling and holding of meetings, communication, collaboration, document preparation, and the sharing of knowledge and information. In order to support these activities, it is important that the members of the work group are linked via a computer network—this may be a special group intranet/extranet or the Internet. Many software systems can be termed groupware. These include electronic mail, videoconferencing systems, and electronic document management systems. Many of these systems are in use within the construction industry, and examples of specific software applications include Lotus Notes and BT Construct. Groupware systems have the potential to address many of the communication requirements of construction project teams and can be integrated with an integrated project model. They are particularly applicable to enhancing communications between team members.

DISCUSSION AND CONCLUSIONS

The communication facets presented in this chapter have served to enhance understanding of the communication issues inherent in the adoption of collaborative and concurrent engineering in the construction industry. It also provides an important and coherent framework for the development of an appropriate communications infrastructure for collaborative working in the AEC sector.

The development of an appropriate communications infrastructure, which incorporates the communications facets and issues raised in this paper, has been undertaken as part of two major research projects. The first is the European Union-funded project on Collaborative Integrated Communications in Construction (CICC). The CICC project sought to integrate (and evaluate the use of) several new and emerging information and communications technologies (such as augmented reality, mobile communications systems, telepresence, people and information finder) on construction projects. One of the pilot projects was a multimillion-dollar retail complex in the south of England and involved up to 150 construction companies. The second project, Telepresence in Concurrent Life-cycle Design and Construction, was a collaborative research project between Loughborough University and British Telecommunications plc, which built on the CICC project. It aimed to develop, within a concurrent engineering framework, a virtual communications environment within which construction project information and personnel could be readily located. The virtual environment was designed to change in line with the stages in the life cycle of a construction project. The success of these research projects is expected to stimulate the uptake of these information and communications technologies within the construction industry.

In conclusion, it must be reiterated that an effective communications infrastructure is a sine qua non for the success of collaborative and concurrent engineering in the AEC sector. Providing adequately for the facets of communication described here contributes toward this and will enable Bowles's primary objectives for IT and communications support for concurrent engineering to be addressed. Secondary benefits in terms of productivity gains, quality improvements, time savings, cost savings, greater client satisfaction, and improved project team dynamics are also realizable. Additionally, project information will be freely available within an effective social environment (Bowles, 1994). As evident from this chapter, the information and communications technologies necessary to implement an effective communications infrastructure for collaborative project teams are in existence. The construction industry needs to take advantage of these as an integral part of the adoption of collaborative working practices.

NOTE

1. VisionDome is a registered trademark of Alternate Realities Corporation.

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7

Information Logistics for Supporting the Collaborative Design Process

Raimar J. Scherer

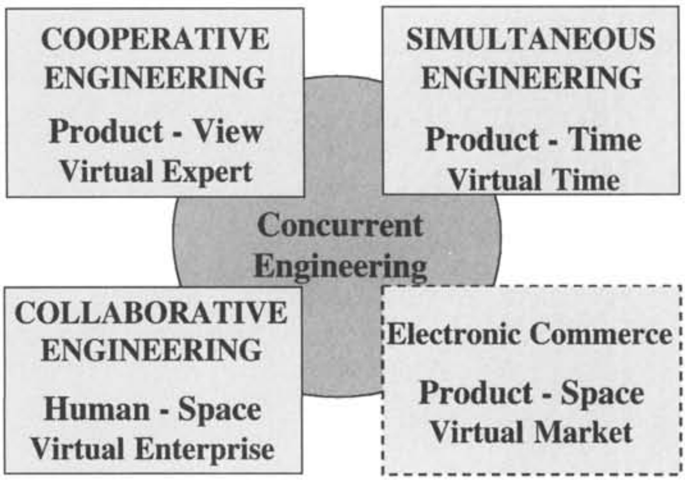
INTRODUCTION

Collaborative design is one of the new ways of working that belongs to the area of concurrent engineering. Concurrent engineering mostly has different aspects, which are often unclear. Concurrency can occur in four different basic ways: in time, in space, in domain, and in enterprise (Figure 7.1). Each corresponds to already defined and well-understood ways of engineering. These are simultaneous engineering, collaborative engineering, cooperative engineering, and—as an upcoming new branch—electronic engineering commerce (Scherer, 1998b).

Cooperative engineering is the synchronized work of different domain experts working on one and the same part of a product. This kind of concurrency, which represents the human-knowledge dimension, requires a virtual product model that allows different data views on one and the same part of the product and, moreover, needs functionalities for data management, such as transformation, consistency checking, monitoring, control, and notifications of the different engineers, so that a conflict-free synchronized design and manufacture of the product is guaranteed.

Collaborative engineering is understood to be the work of physically distributed teams working on one and the same product as if working at a roundtable, regardless of the location of the team members. This requires an extended or virtual enterprise organization to appropriately coordinate the work and streamline all participants toward one common objective, regardless of the different enterprises they belong to.

Figure 7.1
Aspects of Concurrent Engineering



Simultaneous engineering means that at any time in the design process, each product life state is appropriately taken into consideration (i.e., by applying the related expert knowledge by means of forecasting, prognosis, and simulation, either by tools or by involving the human expert directly).

The common goal of all aspects of concurrent engineering is concurrent access to the same data and concurrent synchronized objectives; just to form a team and provide teamwork, even if there is physically no team due to separation in time and space. Therefore concurrent engineering is strongly connected with virtual enterprising, with simultaneous access to and simultaneous modification of the same product items, and with the coordination of parallel streams of data, information, and knowledge flow in the virtual team and enterprise.

BASIC ORGANIZATIONAL REQUIREMENTS FOR DISTRIBUTED COLLABORATIVE WORKING

For distributed teamwork, we have to distinguish between two principle ways of collaborative working. These are

- Synchronous collaborative working
- Asynchronous collaborative working

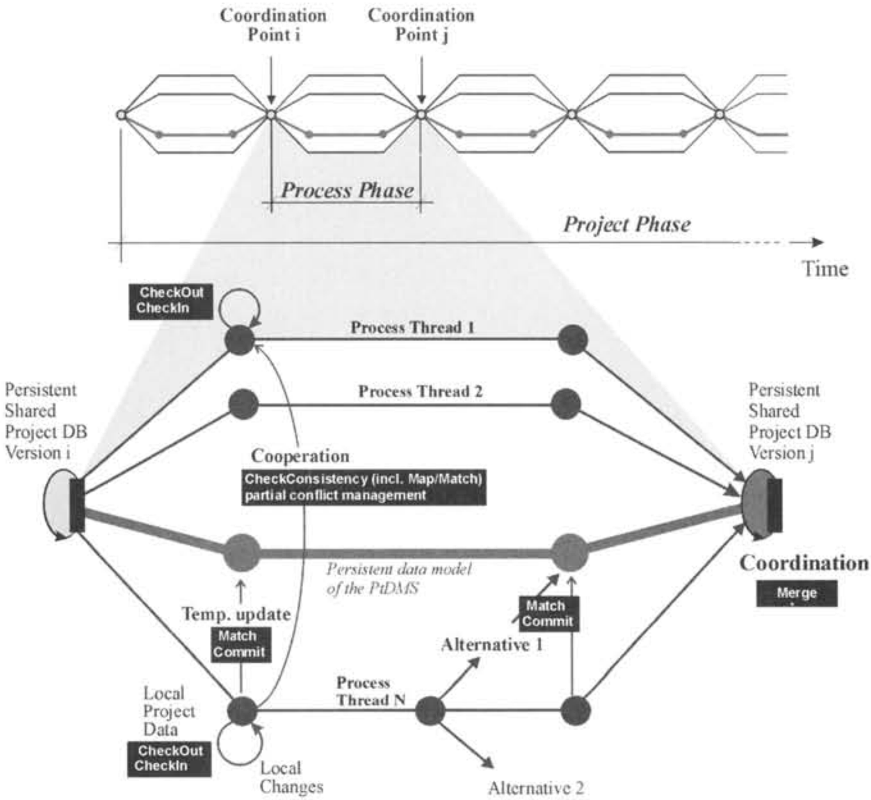
Synchronous collaborative working means that all members of a team are working on the same product at the same time for providing simultaneously their expert knowledge to problem solving. It can be either employed to search for a new innovative design solution or a routine design solution. The complexity of a design problem or the degree of novelty call for personal communication, discussion, and inspiration among the human experts. The communication stays in the human world.

Asynchronous collaborative working means that expert knowledge of all team members is necessary, but that each of them can provide and contribute a part, which is necessary for solving the problems without direct and immediate communication with other team members. Communication can be done via computer in a formalized way by exchanging the ideas and suggestions (i.e., the inherent knowledge in written and graphical representation and of course in product data model presentation). Communication is done in the computer world. This does not mean that the team members do not inspire each other, too, but usually this happens in a much lower level as for synchronous working. This kind of working is sufficient for most routine design tasks, which is the mass of design work to be carried out in the architectural, engineering, and construction (AEC) domain. The usual design process in AEC is parallel but independent work with—at specific time instances—coordination points (Figure 7.2) and roundtable meetings. These roundtable meetings should be preferably carried out by asynchronous collaborative design sessions to shield the team members from permanent interruption. These sessions would ensure a steady work environment enabling concentrated and efficient work for all team members.

Thus, the main difference is between the two kinds of teamwork is that the communication among team members is either in the human communication world or in the computer communication world (i.e., via information and knowledge representation in semantically high structured data as may be provided by product models). Computer communication may be understood as the representation of information and knowledge in data structures on a high semantic level and not as the application of computers and networks transferring multimedia content data like fax machines. Computer communication allows that the involved persons need not to be active and communicate to each other at the same time because the communicated content can be stored and retrieved later on and—as an additional advantage—can be repeatedly retrieved. It can be even conveniently retrieved with any time shift by each team member.

However, communication via computer world is only one of the two major aspects that are necessary to make asynchronous collaborative

Figure 7.2
Use of the Product Data Management Functions for Project Coordination



working happen. The second equally important part is contributed by the management of the time-stretched discussion process, because the main objective of collaborative working exists in adding value by discussion and not by simple information exchange. This can either be carried out—in a very time-consuming way—by a person, the work session leader, or by organizational teamwork tools supporting this person. They will remarkably reduce the organizational workload on the work session leader, the possible errors by overlooking or misunderstanding something, and the workload on every team member, who searches for necessary information to make his contributions to the right subproblems in the overall problem-solving process at the right time. Common teamwork or discussion panel tools can be beneficially applied and are already used in practice. Specifically adopted or newly developed tools would, however, show a much higher value for the collaborative working process due to the specific content of discussion and culture in AEC being even more specific in architecture as opposed to engineering and construction.

As a consequence, we will concentrate in the following on a tool particularly developed for AEC virtual teams working under the EU project ToCEE (Scherer, 2000). We will briefly introduce this client–server concurrent engineering environment, which provides the necessary capabilities and tools for asynchronous collaborative working of virtual teams. It will be demonstrated on an illustrative case example for the complex information flow and organizational processes supported by the ToCEE client sever system enabling virtual teams working on a highly effective level in reality.

INFORMATION LOGISTIC CENTERED CONCURRENT ENGINEERING ENVIRONMENT

Asynchronous collaborative working needs

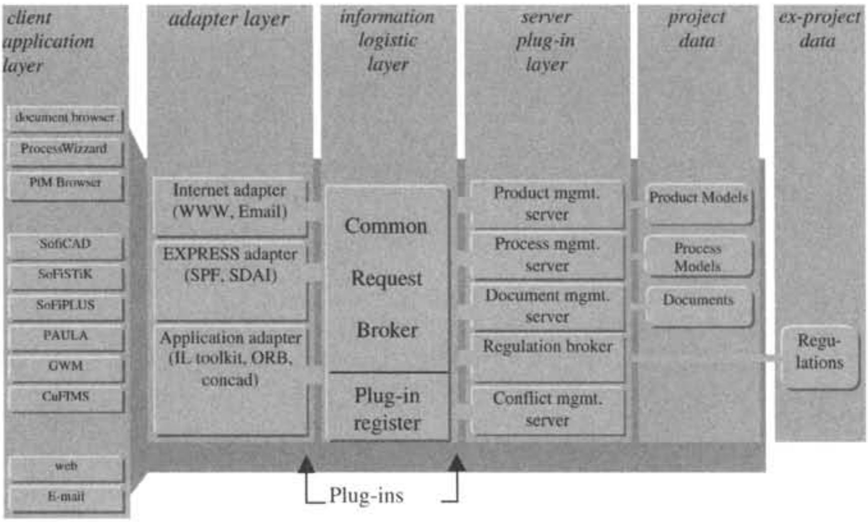
- Product data representation of design information and knowledge (i.e., Product Data Model Server)
- Textual and graphical representation of design information and knowledge (i.e., Document Management Server)
- Logistic support for managing the information (i.e., Information Logistic System and Server)
- Management tools to organize the discussion process (i.e., activity planning and workflow tools)
- Management tools to visualize the discussion process status (i.e., where and when approved, rejected or approved with concerns, and which design suggestion). In the ToCEE system we called this Conflict Management Server, because the original demand was focused on conflicts, but it is not restricted on conflicts in the narrow sense.

To make such a system work a common modeling framework is needed. It provides the necessary engineering ontology and subsequent interoperability methods (Katranuschkov, 2000; Scherer & Katranuschkov, 1997), which may be beneficially enhanced with agent methods (Scherer, 1998a; Scherer & Katranuschkov, 1999).

SYSTEM ARCHITECTURE

The ToCEE has a multilayered distributed system architecture. For the end-user perspective, the user basically interacts with workflow clients to perform tasks in the environment. Any tool or client application needed for

Figure 7.3
The ToCEE System Architecture



the execution of tasks shall be invoked through the information logistic system layer (Figure 7.3). The data can be distributed on several servers, which offer different services. The coordination of concurrent access of client applications to server-side data and services is achieved by an information logistic system layer, which is implemented as

- A common request broker, which is a uniform gateway to access data and services for process and workflow management
- A system component management system and server plug-ins
- Middleware adapters for client applications, which support different existing middleware standards, such as HTTP, Java RMI, or CORBA, and which are located in the adapter layer

Strongly connected with the information logistic system is the process and workflow management component, which is described in the following chapter.

The information logistic system comprises the following properties. First, it possesses a component registry, where all the concepts of every component of the CEE are described in a formal language, which is EXPRESS-C, and enriches secondly the information logistic system with system knowledge.

THE TOCEE ADVANCED PROCESS WORKFLOW MANAGEMENT SYSTEM

In ToCEE, the work of the members of a distributed virtual team is organized in terms of worktasks, which are globally identifiable (like other objects of the environment), linked to actor roles (e.g., architect, structural engineer, etc.), required input (documents, product data), expected or delivered output (documents/views of the product model/single objects of the product model), and the time schedule of a project.

Worktasks can be grouped and defined by means of two additional levels, namely activities and workflows:

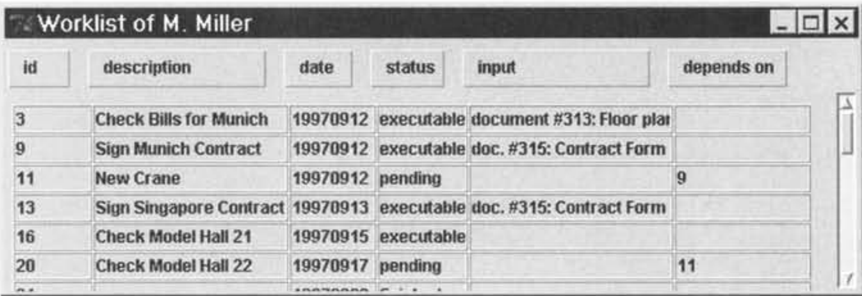
- Workflows are one or more activities. A project consists of one or more workflows. Several workflows of the same type may be performed in one project. The workflows themselves can be derived from generic workflow or process templates, declared by a project manager, or from predefined templates.
- Worktasks, which consist of one or more tasks and are to be carried out by one or more persons owning one and the same role.
- Activities, which are one or more worktasks and are to be carried out by one or more persons owning different roles.

During the overall work process, the process management tool continuously updates the worklists (Figure 7.4) for the different users, which contain exactly those worktasks that are relevant for one user. The user indicates that he or she wants to start the execution of a task by activating the according worktask on the worklist and then the system provides a list of all relevant documents and the corresponding tools from which to select an appropriate tool (e.g., a CAD, a structural analysis tool, or an office application or a document). When a user finishes a worktask, he or she assigns the results to the process management tool, and the tool updates the status of all possible follow-up worktasks for other users.

Each worktask can take on different status during its life cycle. They are as follows:

Initially, a task is *suspended* or—for some exceptional cases—also ready for execution. A task is suspended if it requires additional data to be executable (e.g., the task for calculation of loads may suspended, because data about the building geometry and the location of building elements is missing). As soon as all required input data is available, a task is *readyForExecution.* If the actor actually starts, the internal operation fetchForUnify is performed, ensuring exclusive access to this task

Figure 7.4
The Worklist for a User Provided by the ILS Client

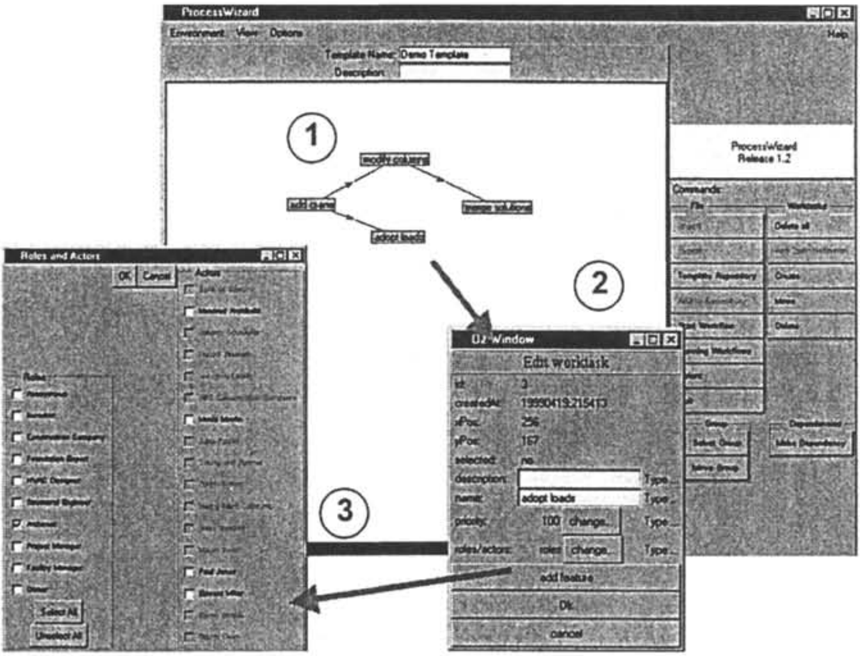


and changing the state to *inExecution.* Afterward the actor may switch the state between *inExecution* and *interrupted,* as often as he or she wants. The workflow system can be configured to check, if the actor performs tasks simultaneously and presents a notice. If the task is finished, the results are linked to the task (performed by the internal operation unify), and the state becomes *finished.* All tasks that are not finished can be *aborted.* Abortion can be performed for the workflow, which includes the task.

For a dynamic set-up of workflows, activities, and worktasks and their refinement on demand during runtime, a tool named ProcessWizard was designed that supports project managers in the coordination of the actors. A process definition methodology was developed to achieve a parametric description of worktask patterns, based on workflows templates as described earlier. Figure 7.5 shows a screen shot of an example session with the ProcessWizard. Each task of a user role is modelled as a worktask (a node in the process network), and the dependencies are represented as arrows. The main window (1) of the ProcessWizard shows the worktasks. By selecting a worktask, the properties of the worktask can be modified in a separate window (2). For each worktask, the actors and roles can be specified (3) by selecting them from overview lists, which are interrelated according to the actor matrix.

With the ProcessWizard, work templates may be created, edited, stored, and applied. Work templates can be applied. If a work template is applied, a new workflow is created. The worktasks of this workflow are immediately available on the worklist of all involved actors. The list of all workflows can be browsed with the ProcessWizard.

Figure 7.5
Process Management Tool in the ToCEE Environment



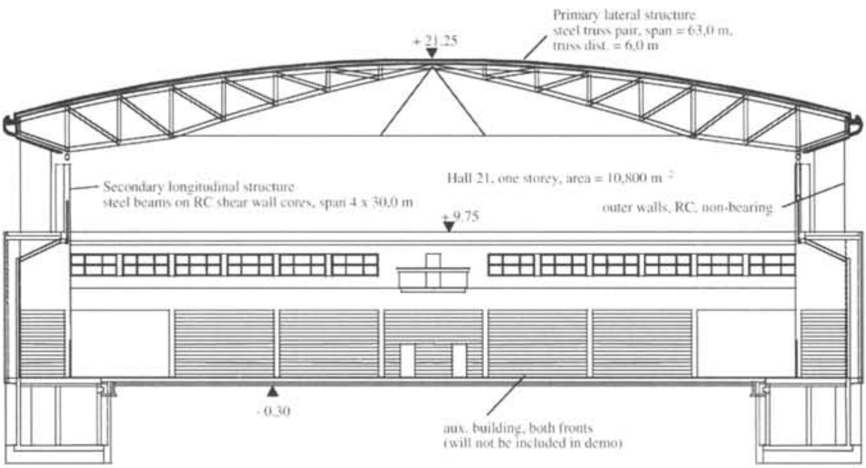
CASE EXAMPLE

The tools developed for design and for the computer-supported management of collaborative design in the ToCEE Concurrent Engineering Environment are demonstrated with the help of a small demonstration scenario, which is a cutout from the large demonstration scenario provided in the PPT show. As a case example, a simplified version of Hall 21 of the New Munich Fair recently designed and constructed is used (Figure 7.6). This example is taken from Scherer, 2000.

As a starting point, let us assume that the owner requests a change at a certain stage in the design of the building. The task is to provide light crane equipment with working area of the crane extending over the whole length of the hall.

Although the owner's order is given to the architect, this task cannot be fulfilled by the architect alone. Specialist knowledge of the whole design team (HVAC, electrical, structural, foundation engineer etc.) is needed to properly consider the possible consequences of the design change. Therefore, in parallel to determining the crane type and location, the architect

Figure 7.6
Front View of the Case Building (NMM—Hall 21)



sets up new workflow with several worktasks for the members of the design team with the help of the ToCEE ProcessWizard, as shown in Figure 7.7. Collaboration can hence start.

To focus on the description of the design and the conflict management tools, the cutout scenario is limited to the tasks of the architect and of the HVAC engineer in the following description.

According to the set-up workflow, the task of the HVAC designer is to redesign the duct system for ventilation and air conditioning so that it fits to the proposed change by the architect. However, this single worktask (from the point of view of the architect) involves a complex sequence of actions (from the point of view of the HVAC designer) requiring the use of a variety of tools, system services, and types of data. This expanded view of the worktask of the HVAC designer is shown in Figure 7.8.

At first the HVAC designer is informed of the new task through his workflow client (step H1), sometimes also called The Information Logistic System client, which continuously updates his individual worklist. After he started the worktask "Redesign ducts," he received a list from the Information Logistic System via the workflow client of all currently available documents and aspect product models, which contains the architectural redesigned element.

As next action (H2), he downloads the current, up-to-date product data from the architectural aspect model and then uses the virtual reality browser ProMoTe to obtain a fast impression of the changes made by the architect.

Figure 7.7
Initial Workflow for the Redesign to Add a Crane

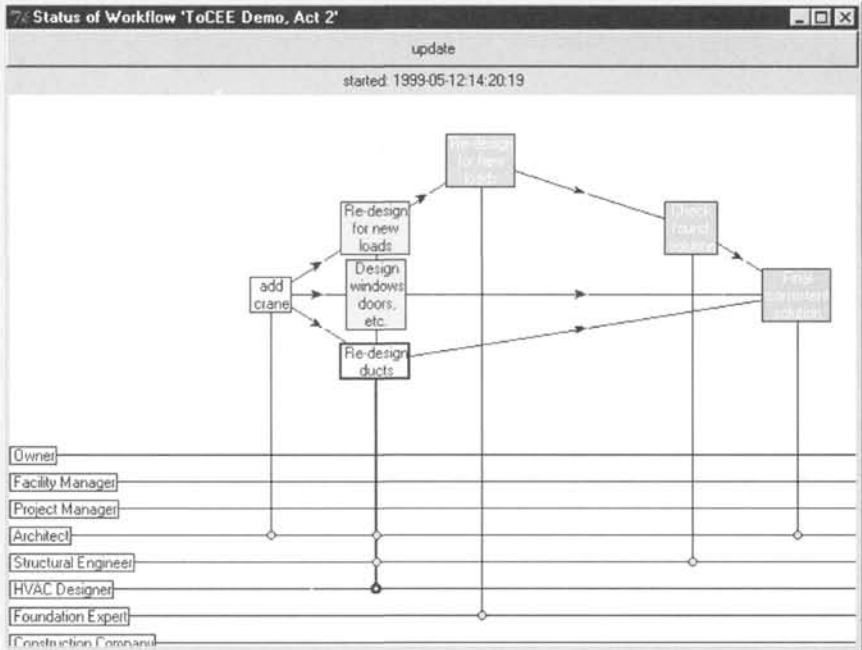
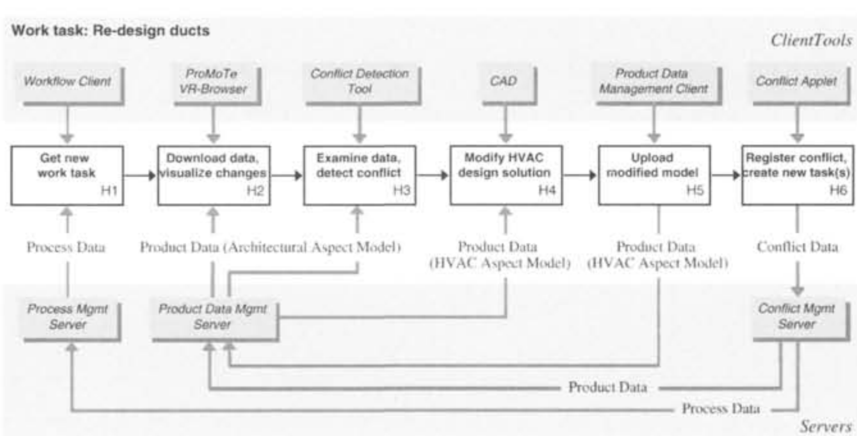


Figure 7.8
Sequence of Actions in the Worktask "Redesign ducts" of the HVAC Engineer; top: Tools, middle: Worktasks H1-H6, bottom: Servers and Dataflow



With ProMoTe, all new or changed objects with regard to some previous design state can be automatically highlighted and viewed in a VR model, and at the same time their nongeometric properties can be examined, as shown in Figure 7.9. From this quick examination with the ProMoTe tool, it becomes obvious that the crane presents a potential problem, because, when moving, it may collide against the ventilation ducts in the hall.

A detailed analysis with ToCEE's specialized conflict detection tool confirms the suspected problem (step H3). The conflict detection tool has been designed to detect geometric conflicts for objects moving along predefined working paths and is implemented on top of AutoDesk's Architectural Desktop. Figure 7.10 gives an example of its use, showing selected frames from the animation produced after the analysis of the crane path. Due to this now-obvious conflict, the HVAC engineer is not able to fulfill the requirements of the architect as suggested. Instead, he proposes an alternative solution, modifying, respectively, the product data as step H4 with the help of his CAD system (Figure 7.11).

In a conventional approach this would now complete the task of the HVAC designer. He would then notify the architect about the conflict with

Figure 7.9
Visualization of the Design Product Data with ProMoTe (new or changed data with regard to Previous Model Versions are highlighted and can be easily recognized)

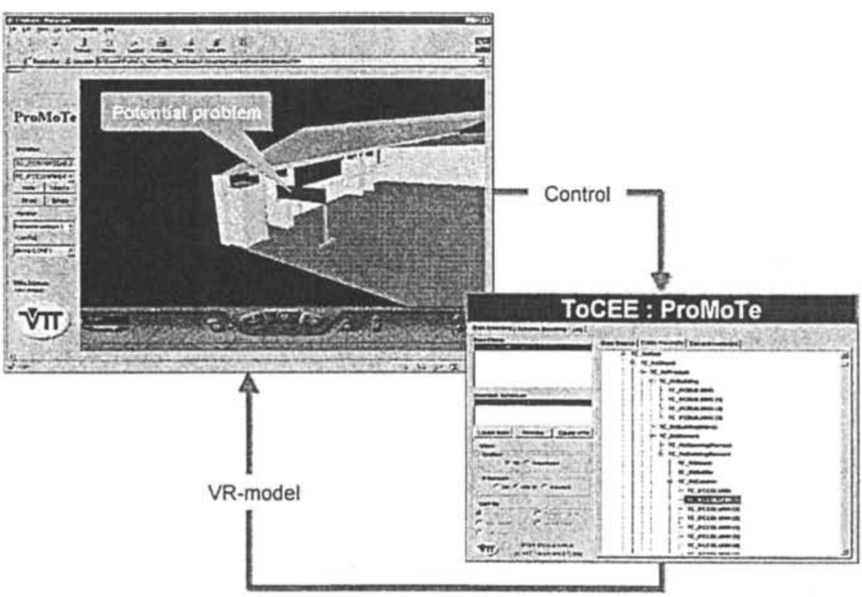


Figure 7.10
Detection of Geometric Conflicts with Moving Objects

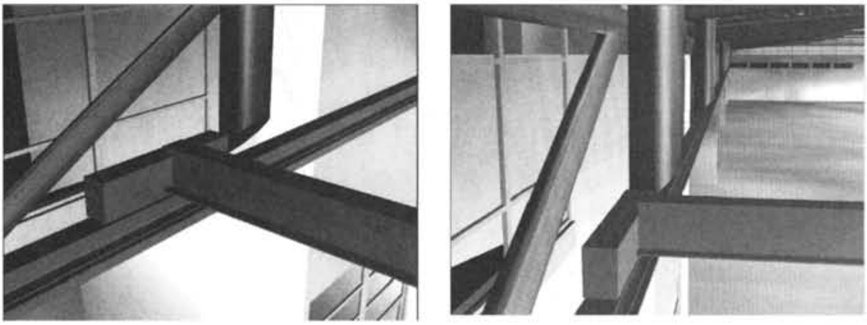


Figure 7.11
Change of the Design Data Due to the Geometric Conflict between Crane and Ventilation Ducts

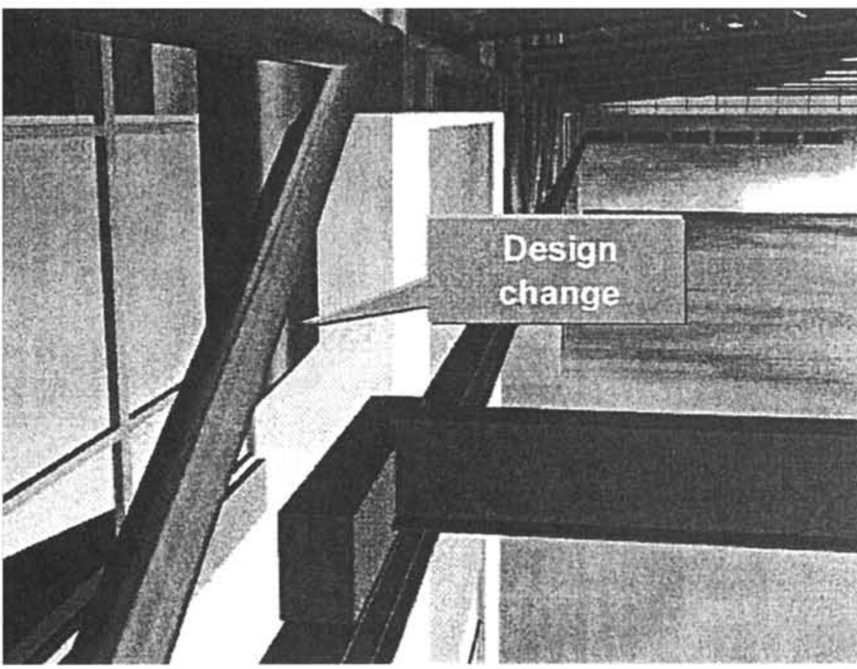
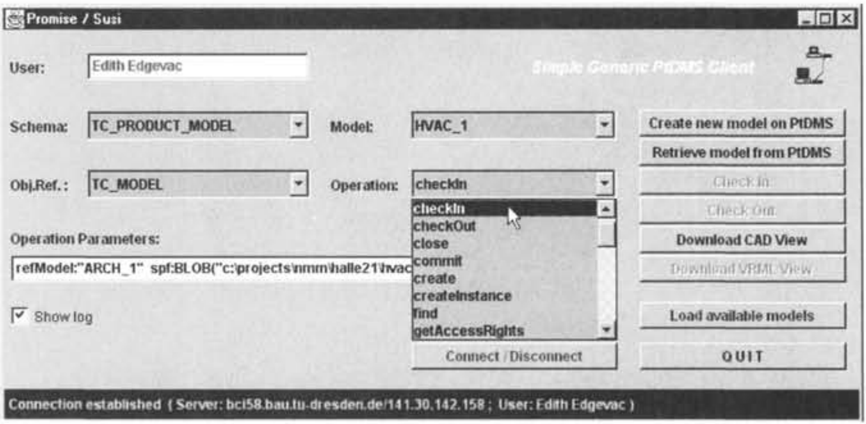


Figure 7.12
Uploading the HVAC Aspect Model Data to the Product Data Server with ToCEE's General Purpose Product Data Management Client PROMISE / Susi



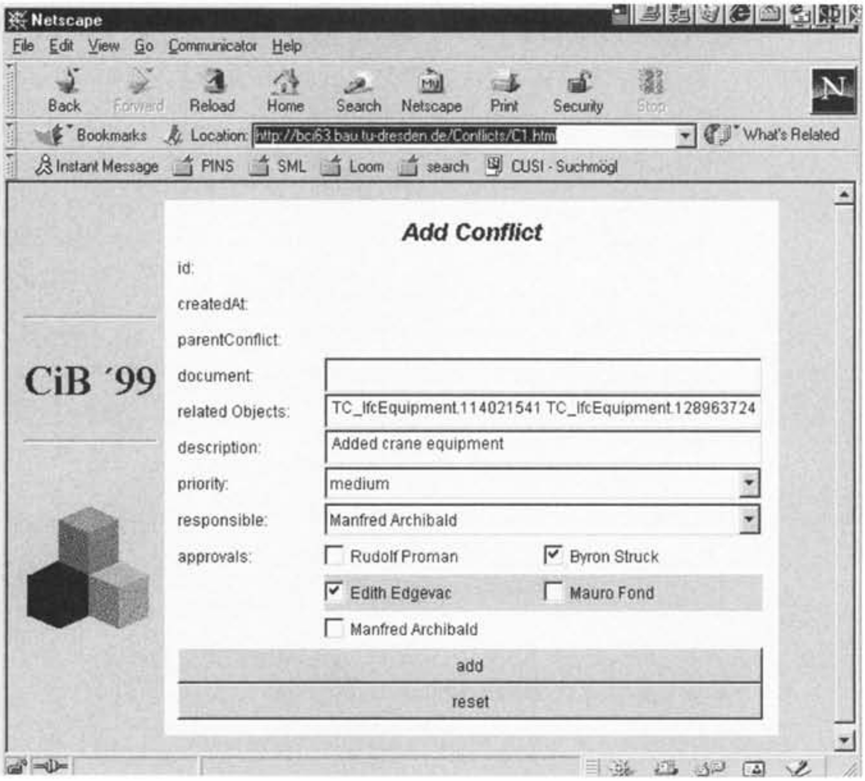
an informative message (by phone, fax, e-mail) and will either attach his alternative proposal as a drawing file to his message or, by more advanced organizational and IT infrastructure, he will store this file on the document management system used in the project.

It might also be possible to exchange the product data with the architect, but the coordination of the process of conflict resolution will still happen only in the heads of the designers, without notable IT support.

With ToCEE, however, a much more rigorous approach to change and conflict management becomes possible. Coordination of conflict solving and reaching agreement, status of conflicts projectwide, status of approval, status of development versions, and alternatives of the design solution, all this is maintained and managed by the ToCEE Concurrent Engineering Environment. All these boring and error-sensitive information logistics tasks are taken over by the Concurrent Engineering Environment, which keeps the users informed and up-to-date.

Therefore, in the next step in the Concurrent Engineering Environment after the product data are modified to represent the proposed new design alternative, the HVAC designer uploads the new version of the HVAC aspect model to PROMISE, the product data server of the ToCEE environment (step H5). This can be done either by the specialized client tool developed by SOFiSTiK or with ToCEE's general-purpose product data management client, PROMISE/Susi, shown in Figure 7.12. However, he

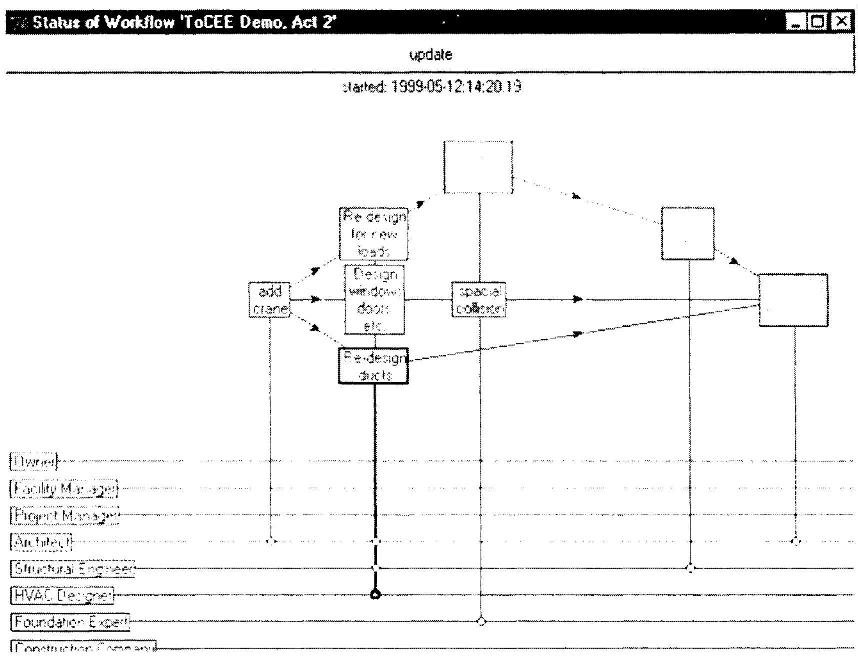
Figure 7.13
Applet for Reporting a Conflict



has now to indicate that this aspect model is not a new, valid version, binding for all, but that it is solely his suggestion for solving the design conflict concerning the newly added crane and the ventilation ducts. He will provide this notice in the next action (step H6).

In the next and final step (H6) the HVAC engineer registers the detected conflict via the conflict management client, a JAVA applet of the conflict management server (Figure 7.13) on the conflict management. The main objective there is to permanently store the information about the conflict in the Concurrent Engineering Environment and make it available whenever and for whomever it is of interest. When a conflict is registered without a proposed solution, only the person (or role) who is responsible to manage the solution has to be indicated. As default, the person who registers the conflict is taken.

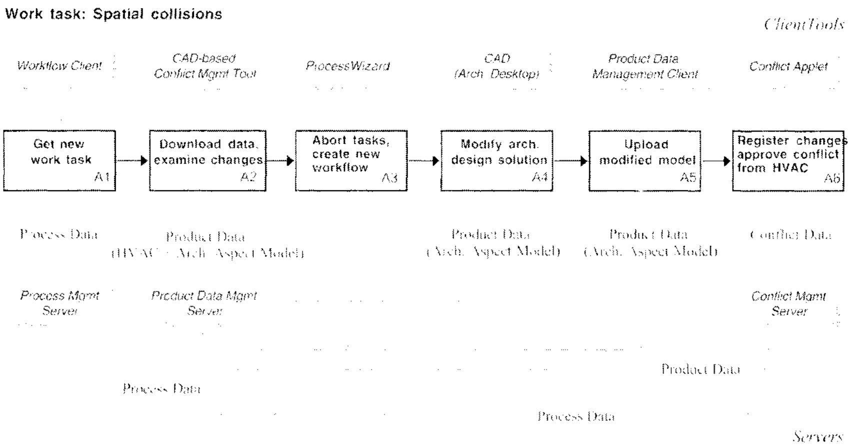
Figure 7.14
Workflow after the Spatial Conflict between Crane and Ventilation Ducts Are Registered on the CMS



In the present scenario, the HVAC engineer has already made a suggestion to solve the conflict and therefore already started the first step for the conflict resolution and has to indicate that he uploaded his proposed solution to the PtDMS, who has to approve his proposal (i.e., who are the participants of the virtual roundtable conflict solution meeting). These are in the present case the architect, the structural engineer, and the foundation (i.e., geotechnical) engineer.

The Conflict Management Server stores the conflict data, including all related references to processes, documents, and product model objects in a central conflict database, which enables the monitoring of the conflict status, the maintenance of the data consistency and integrity, and the notification of all actors involved in the conflict solution. Together with that, the system automatically creates a new worktask for the architect who has been selected as responsible actor for solving the conflict, which immediately appears on the workflow status window (Figure 7.14) and on the individual worklist of the architect, too. In this way robust coordination of

Figure 7.15
Sequence of Actions in the New Worktask of the Architect, Due to the Detected Conflict; top: Tools, middle: Worktasks A1-A6, bottom: Servers and Dataflow



data and processes with explicit consideration and control of responsibilities by the IT-system is achieved.

It has to be mentioned that this does not mean that the conflict has to be solved immediately before any other design step can be continued or started. It is solely the responsible person's decision (here the architect) when he is calling for the conflict resolution process. Nevertheless, any of the involved persons can work on the solution of the conflict whenever they consider it convenient for them. They have been informed personally about the conflict via the Concurrent Engineering Environment, due to their indication by the HVAV engineer as an approval person.

Today, conflicts are usually solved in roundtable meetings. The procedure of a "roundtable" consists in principle of two components, a coordinator and a controller. With the ToCEE Concurrent Engineering Environment the coordinator is the responsible person, whereas the controlling work is taken over by the Concurrent Engineering Environment. It controls the approvals. The start of a conflict resolution cycle has to be triggered by the responsible person by setting up the conflict resolution workflow. This worktask for the architect is named "spatial collision" in the present scenario. It consists of several actions, which are depicted on the expanded view of the worktask given in Figure 7.15.

Figure 7.16
Task for Conflict Resolution on the Worklist of the Architect

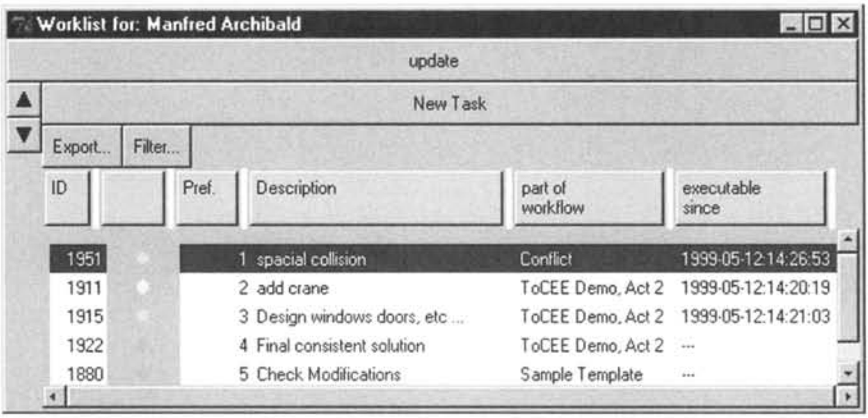
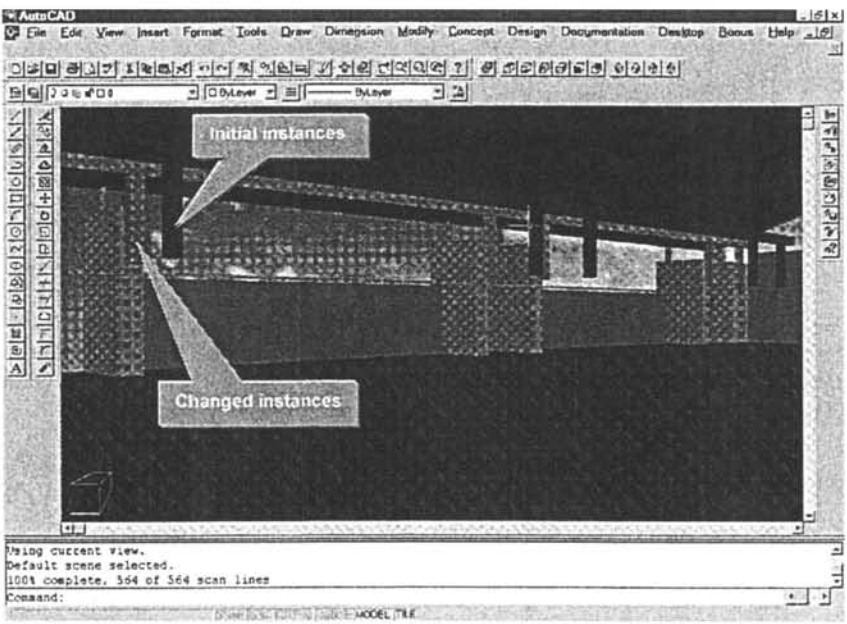


Figure 7.17
The ToCEE Change Management Tool Embedded in AutoDesk's Architectural Desktop



Immediately after the conflict is registered, it appears on the architect's worklist due to the automatic messaging system of the Information Logistic System. The architect starts his worktask "spatial collision" by selecting this worktask on his worklist (Figure 7.16), which is maintained by the Information Logistic System client (step A1).

The Information Logistic System provides the architect with all available information for this worktask as it was already explained for the step H1 earlier.

Usually the next step (A2) of the architect is that he informs about the conflict by downloading the architectural aspect model and the related HVAC aspect model as well as the proposed solution HVAC aspect model. He examines and compares them with the help of ProMoTe in a similar way as already described for step H2. Alternatively, the architect can use the CAD system to run the ToCEE change management tool on AutoDesk's Architectural Desktop, which allows him to view and compare the data of two aspect models right away, as shown in Figure 7.17.

With the change management tool, two models in STEP physical file format can be loaded on the Architectural Desktop in the same work session. The analysis of the differences between the two models relies on the centrally maintained object IDs for all product objects in all aspect models by the product data server.

The tool supports also direct queries to the product data server through the ToCEE information logistic client. In that case only the architectural model will have to be loaded completely, whereas the new and changed objects in the HVAC model can be obtained directly through a remote call to the knowledge-based server function *match*. From application point of view, this second procedure is much more efficient with regard to data storage and time, as it delegates most of the sophisticated model comparison work to the product data server. However, it is not interactive, and therefore the first, more explicit procedure might be preferred whenever more detailed control of the model matching process is felt necessary.

After examining the proposed changes, the architect must coordinate the solution of the conflict. From the workflow chart of the ProcessWizard, he can easily allocate all tasks affected by the proposed design changes. Assuming that he himself can agree with the modifications proposed by the HVAC designer, he must nevertheless take care that all other designers also agree with these modifications and rework their design solutions accordingly.

For this purpose, the architect stops the running workflow with the ProcessWizard as shown in Figure 7.18, and Figure 7.19 consequently sets

Figure 7.18
Aborting a Workflow

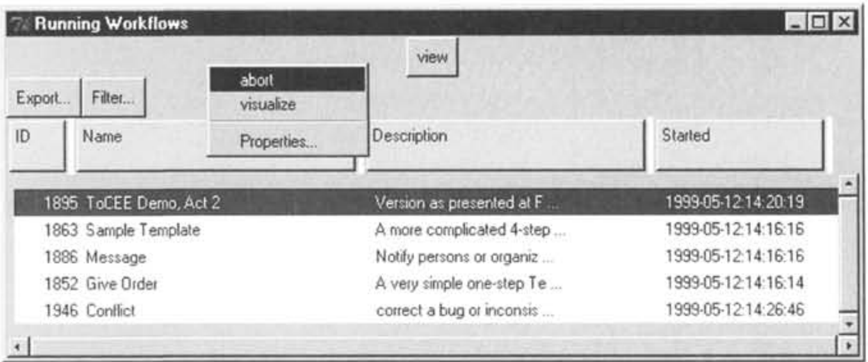


Figure 7.19
Workflow after Abortion (black boxes show aborted tasks, white boxes show already finished ones)

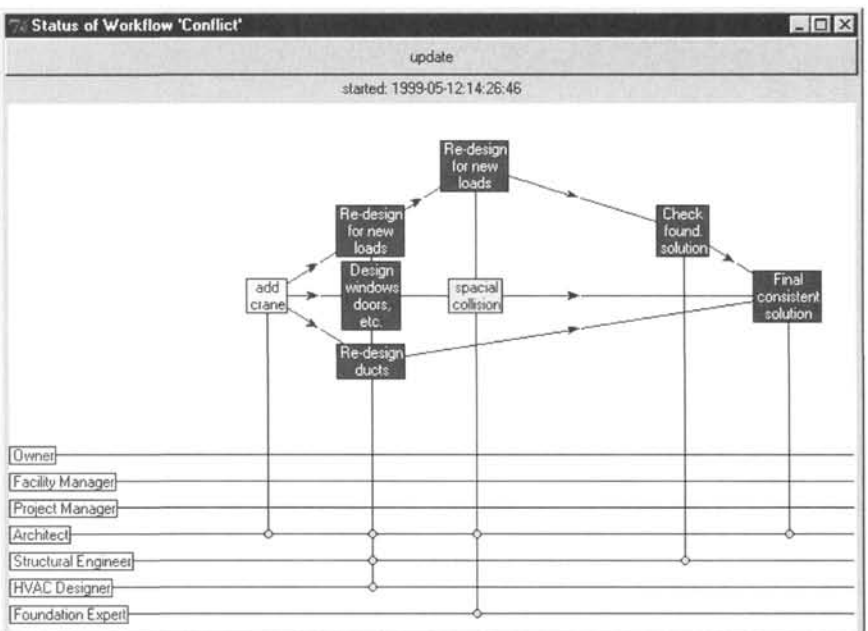
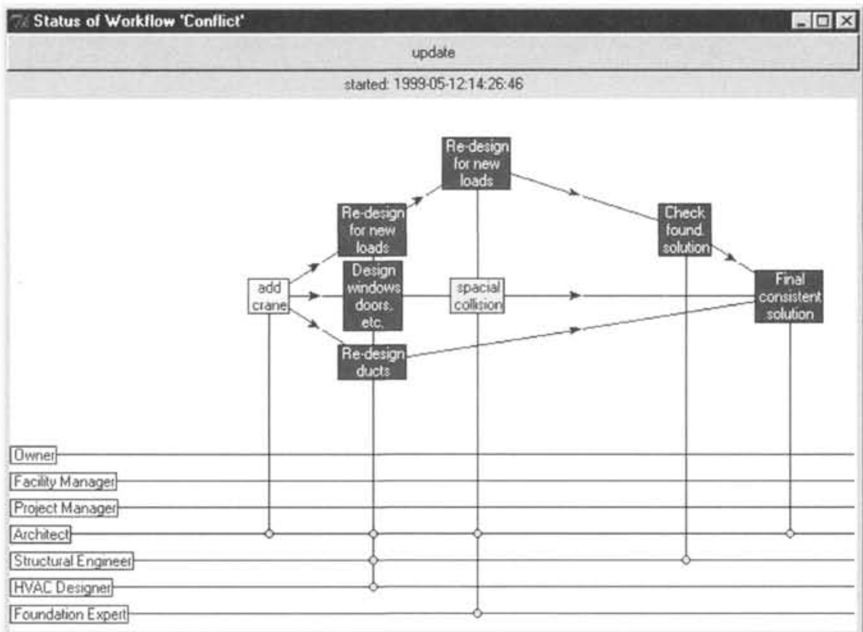


Figure 7.20
Revised Workflow with the Newly Added Conflict Resolution Workflow



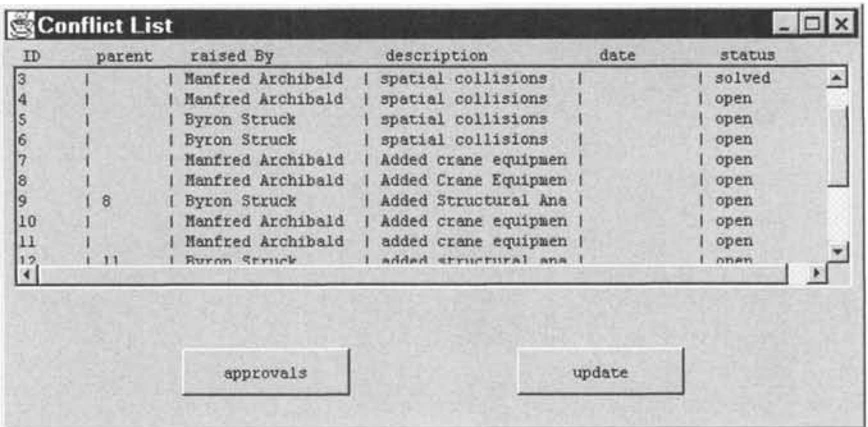
up the workflow for the needed redesign work (i.e., the virtual roundtable workflow (step A3), as shown in Figure 7.20).

After this coordination work, the architect can adjust his own solution with the help of his CAD system (step A4) and then upload the changed model back to the product data server (step A5) in a similar way as already described for the HVAC designer.

Finally, he approves the changes proposed by the HVAC designer as shown in Figure 7.21. The other designers can now use the updated architectural model as basis for modifying all other discipline-specific models. Their work will typically follow a similar path to the presented procedure, using the appropriate services of the Concurrent Engineering Environment.

A unique feature of the ToCEE Concurrent Engineering Environment is that it explicitly allows the existence of temporarily inconsistent data to restrict as little as possible individual and simultaneous work, which demands several versions and alternatives of one and the same design part and temporary conflicting data. Many of the developed services and tools

Figure 7.21
Conflict Approval

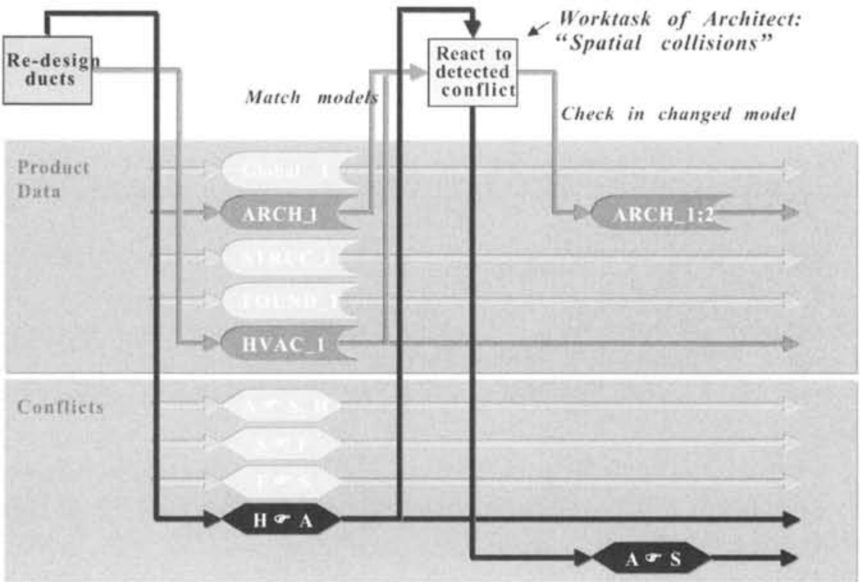


contribute to the solution of such conflicting situations. Their usage, briefly outlined in the presented scenario, is summarized in the following table:

Conflict management issues	**Tools**	**Developed by**
• Parallel work (time) conflicts, process coordination	• Process Management Server	TUD
	• ProcessWizard	TUD
	• Workflow clients	SOF, TUD
• Distributed data consistency • Distributed data access	• Product Data Server (PROMISE)	TUD
• Visualization of changes	• General purpose product data client	TUD
	• VR-enabled product data browser (ProMoTe)	VTT
• Conflict management, conflict propagation, data coordination	• Conflict Management Server	TUD
• Conflict notification and approval	• WWW-enabled conflict management clients	TUD
• Conflict detection	• Conflict detection tool	OPB
	• Change management tool embedded in AutoDesk's Arch. Desktop	SOF

Although all these tools provide a functional user interface and many useful stand-alone features, their full power is manifested only through their coherent use in the ToCEE environment. For example, in order to enable the functionality of the conflict clients and the individual work on the separate

Figure 7.22
Product and Conflict Data State before and after the Worktask of the Architect (Abbreviations: A = Architect, H = HVAC, S = Structural, F = Foundation engineer)

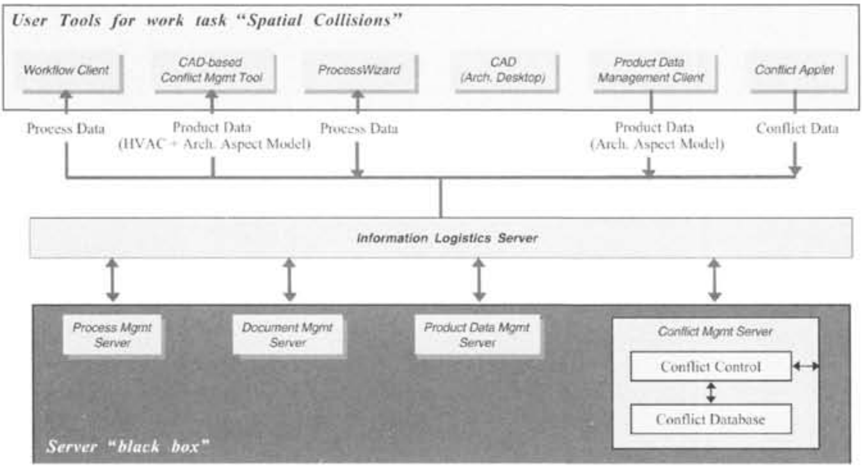


aspect models, a sophisticated coordination of the different aspect product models and their version (i.e., proposal for solving the conflict) at each stage of the design process must be maintained by the product data server. Figure 7.22 gives an impression of the problem, showing the product and conflict data state before and after the worktask of the architect:

1. Product model data shown in light gray exist on the server, but are not used during this worktask.
2. Aspect model HVAC_1 is only retrieved for comparison of changes with regard to the architect's model
3. Aspect model ARCH_1 is checked out, compared with HVAC_1, modified, and then checked in again as new model version at the end of the worktask
4. Conflicts shown in black are relevant to this worktask, other conflicts that might exist but are not handled here are shown in light gray.

However, even though conflict management requires the coherent use of a variety of tools, data, and models, to the end user and to client appli-

Figure 7.23
User View on the System for the Worktask "Spatial Collisions"



cations the whole Concurrent Engineering Environment appears as one consistent set of information logistics services as shown in Figure 7.23.

CONCLUSIONS

In AEC design we do have innovative as well as routine design. Of course, the mass of design work in AEC is routine design, but innovative design is just as important and should be supported, too. It should be possible at any time that it is felt to be appropriate. Due to cost effectiveness, quality supply, and innovation for design concerning aesthetics form and functionality (i.e., serving the client's objectives in a balanced and thus consecutively an optimized way) both kinds of collaborative working have to be enabled. That means it should make allowance for switching back and forth at any time, paying attention that asynchronous working is done as long and whenever possible due to cost effectiveness. Consequently, in a concurrent engineering environment, both ways of collaborative working, synchronous and asynchronous, should have their place. The spoken word (i.e., the communication in the human world, as named in part 2) should not only be recorded but at least the essence of the design decision-making process—not only the final decided decision—should be written to a protocol (i.e., archived also in the communication of the computer world) to make the information available in IT and take the benefits from IT. Then speech recognition is an important issue to fill the gap (i.e., replace the boring and tedious manual writing of protocols). Whenever information is captured on a computer representation form, text analysis methods can be applied and computers can assist humans to explore the information content.

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PART III
CASE STUDIES

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Introductory Note 3

João Bento

Innovation is a process enabling the creation of wealth in a context of change, be it social, cultural, or as more often happens today, technological change. Therefore, to foster innovation in the present context of remarkable changes associated with the knowledge economies, it becomes essential to promote the emergence of a new *knowledge attitude,* whereby the development and deployment of expertise occur much more flexibly, and thus frequently, than before. This should be facilitated by the use of techniques and tools made available by rapid changes in information and communication technologies.

Collaborative design provides a unique ground for the development and experimentation of those required skills, for the building of the competences deemed essential for innovation and, thus, for the testing of that change of attitude in what concerns the competence building and deployment of expertise. It is also an interesting field of experimentation, for it combines, in an almost unique way, the impacts imposed at the technological and the social levels.

It is not possible to address collaborative design—a teamwork activity by excellence (where team members might be geographically distributed)—without considering the case for *remote* collaboration. Thus, the need for addressing the issues involved in *remote learning* together with those associated to remote collaborative design.

This third part of our book is devoted to illustrating the case for remote collaborative design. It covers a number of education-related experiments relevant to our main topic. The case studies before us in the forthcoming pages range from perspectives on how a modern university should evolve to support and promote concepts such as *virtual teaming* (G. Schmitt), through the development of techniques that may be seen as enablers or facilitators for the promotion of change, in design environments (R. Naka, A. Simondetti, & K. Menzel et al.), to the presentation of comprehensive experiments of remote collaborative design projects, where the social and the technical dimension are both considered (J. Bento et al. & R. Fruchter).

Chapter 8, by Gerhard Schmitt, provides a fresh account of Zurich's *ETH World* initiative as a proposal of reinvention for the very space and environment where academic life should flow in a world of rapid development and predominance of information and communication technologies. He departs from the Principles of New Public Management—and its associated global budgetary view (one single budget for all expenses)—to develop a case for the need of moving from a *physical architecture* to a so-called *information architecture*. In other words, Schmitt advocates that sooner than later, virtual buildings should progressively replace physical ones.

However, such unmaterialization of the university daily life implies the need for mechanisms able to reinforce the sense of community of each student (i.e., because less physical presence is required, more other links of affiliation have to be provided for the participant in the virtual campus). The provision of free e-mail and Internet accounts for life is just part of that effort. Interestingly enough, these apparently minor facilities also provide the means for the establishment of much more durable links to the school in the postgraduation period, promising a lifetime relationship between student and university.

ETH World, the most relevant of three coordinated initiatives by the Swiss Federal Institute of Technology in Zurich (*ETH Zentrum* and *ETH Campus* being the others), is, interestingly enough, presented as a corollary to a number of collaborative design experiments lead by Schmitt, such as *Phase (X)* or *the Multiplying Time* projects; whereas the former dealt with *abstract design* problems, the latter addressed *real design* situations.

The description of two rather complete *real design* situations form, also, the core of chapter 9, where Bento et al. address the need to conceive and set up the means to enable distributed collaborative design to occur efficiently. The authors address the problem from a number of perspectives, spanning from the concepts and design models, through the methodologies to the actual tools required.

The two design problems—*The Lisbon Charrette* and *The Glass Chair*—were tackled in projects developed from 1999 to 2001 and involved Lisbon's IST, MIT (Cambridge, Massachusetts) and, in the first case, FAUP, the School of Architecture of Porto. The former addressed a rather complex exercise of architectural design and urban rehabilitation of an old area in central Lisbon, whereas the latter covered the design and fabrication of a paradoxical object, a glass chair.

One of the interesting aspects of this venture, the authors argue, is the fact of the first project being a *design-only* endeavor, whereas the second one extended the previous methodological experience toward a stage of *production of artifacts*. The *Charrette* dealt with design routines, organizational and teamwork problems, namely those associated with the social relations between the design team members (of different nationalities and of different courses, thus of diverse cultural and technical backgrounds), and the need to fulfill their cognitive, communication, and technical requirements. The *Glass Chair* envisaged evaluating how the previous learning and collaborative methodologies could be extended to accommodate the preproduction and production requirements.

Chapter 9 concludes by noting the high quality of the design products delivered, but the authors choose to emphasize that the achievement of their choice is the illustration that, given the adequate set of teamwork routines, design methodologies, and communication and collaboration tools, it is possible to reestablish, if not revive, all the components of a social relation of teamwork, even when physical and cultural distance interfere.

Renate Fruchter provides in chapter 10 a complete account of a *PBL pedagogical approach* to design learning in a cross-disciplinary, collaborative, and geographically distributed learning environment, launched and hosted at Stanford (PBL standing for *Problem-, Project-, Product-, Process-, People-Based Learning*). Fruchter presents the so-called architectural, engineering, and construction (AEC) global teamwork as Stanford's interpretation of the master's builder atelier equivalent of the knowledge society.

With a very strong emphasis in learning and education, the AEC global teamwork, first launched in 1993, is presented as a test bed for collaboration technologies—namely in terms of communication and sharing of data, knowledge, and tools. Fruchter contends that the results of further research around the AEC global teamwork test bed will allow for the demonstration that any novel use of IT produces changes on the communication patterns in the organizations in which they occur to the point of creating the need for new communication protocols, both at a technological and social level; the impact at the level of the actual business models should follow.

In chapter 11, Ryusuke Naka discusses the increasing importance of *tacit knowledge* or *informal information* in remote design collaboration, given the lower level of physical presence and even of synchronous communication. Tacit knowledge emerges, then, as a vehicle for the existence of mutual confidence among design team members.

The author endorses, then, the need for efficient tools to be available for designers to communicate and to share their knowledge and competences as compensation for their distance and lack of synchronous contact. Although skeptical at times about the perspectives for remote collaboration, the author provides a description on how some of such tools may be set up and deployed, while explaining their use for specific remote collaboration requirements.

Alvise Simondetti, the author of chapter 12, discusses the merits of rapid prototyping in Web-based remote collaborative design. He proposes to do so as a means of extending the boundaries of the virtual design environment out of the computer screen and communication devices, with specially arranged computer peripherals enabling the incorporation in the design process of physical prototypes, as often happens in architectural and product design.

A whole new set of issues may be discussed from the inclusion of prototyping, from the merely technological ones (e.g., the exchange of data sets that should be similarly reproduced as physical artifacts in any of the poles participating in a given virtual design studio) to the cognitive and perception related ones, such as the inexistence of scale in the virtual design world, as opposed to the requirement that scale be strictly defined in the transition from bits to atoms.

Simondetti contends that, depending on the subject and type of design, scaleless models are not necessarily worse than physically defined ones, therefore allowing for the questioning of the merits of the generalized use of prototyping in design. The author puts forward a set of evaluation criteria that should enable the choice between physical prototyping versus the use of *walk-in/walk-through* virtual models, or even their combined use in the search for richer and better computer-assisted remote design environments.

Chapter 13, by Menzel et al., closes by presenting a teaching-oriented perspective on how the AEC industry could benefit from a structured approach to the adoption of ICT and the notion of remote collaboration in the very act of educating their professionals. The authors describe a method for defining and structuring curricula for globally distributed, interdisciplinary teaching in architecture, engineering, and construction and support their proposal with the experience and results acquired across a period of five semesters involving schools such as CMU (Pittsburgh), BraUT (Braunschweig), BAUHAUS (Weimar), ETH (Zurich), and the Munich University of Technology.

The overall concept is that the students should be faced with a real-life and complete design problem and that they should fully solve it, from conception to detailing of the solution; in that sense, the assignment has to span various courses. Because various schools were involved, the participating courses in each school have to endorse, as part of their *curricula,* components of the overall project.

Menzel et al. provide a rich set of lecturing methods, communication, and teaching tools and their setup, while illustrating the achievements with results from various design assignments developed by the students involved.

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8

ETH World—New Perspectives for Collaborative Design

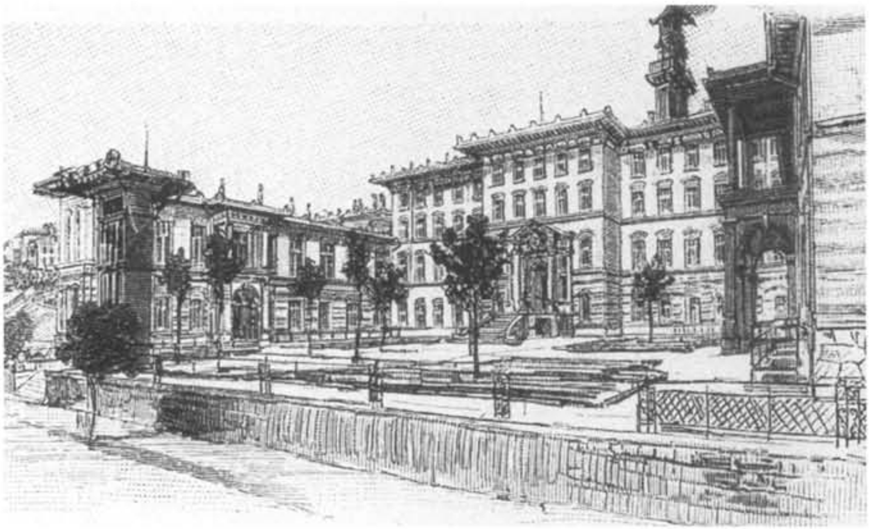
Gerhard Schmitt

INTRODUCTION

Universities and other educational institutions traditionally offer education and conduct research in physical buildings. University building types have developed from representative, castlelike structures to functional, intensively installed structures with a high level of sophistication (see Figure 8.1). The operation costs of the physical infrastructure represent part of the total operation expenses of a building. In the past, electricity, water, heating, and cooling costs dominated the operating budget. In the future, communication infrastructure expenses will be as high or higher than those for traditional infrastructure. At the same time, maintenance costs for clean rooms and other high-tech environments are increasing rapidly. In addition, research space will become increasingly specialized, thus reducing the flexibility of the overall space allocation. This, in turn, leads to an increasing demand for more physical space: a vicious circle. Although most faculty and students involved in advanced research and teaching do know about the newest information technology, various bottlenecks keep them from using it effectively. On the university planning level, the advantages of the new information and communication technologies could be employed more effectively.

Following the principles of New Public Management, several universities have moved toward global budgets for all expenses. Research universities, such as the ETH Zürich, have developed the need for a new approach toward space conception and space use (*Annual Report,* 1999).

Figure 8.1
Drawing of the ETH Zürich chemistry building by Bluntschli and Lasius from 1875 in the center of Zürich

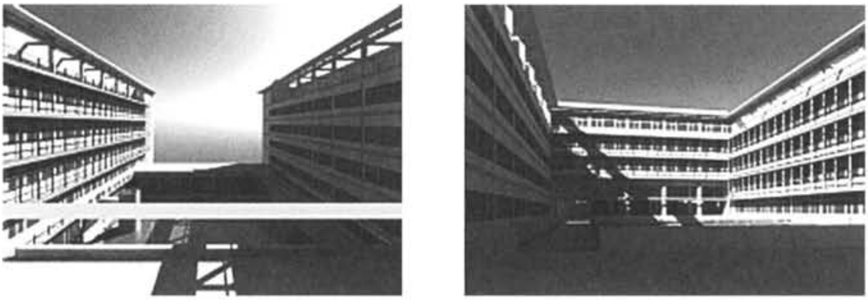


The cost of maintaining buildings and equipment, along with the increasing isolation of independent research groups, poses growing risks for financial and therefore research and teaching flexibility. In this context, those universities with a lean physical space budget will have a competitive advantage, as they can allocate a higher percentage of the overall budget to research and teaching (see Figure 8.2). This requires the parallel development of physical and information architecture (Schmitt, 1999).

GOALS FOR AN INFORMATION ARCHITECTURE

The development toward global budgets creates competition between the core business of every university—research and teaching—and other expenses. Two of the expenses—construction and facility management—are linked to physical architecture. Other quickly expanding costs are associated with communication, consisting of investments in networks, active components, and direct communication costs. To avoid this potentially dangerous situation, a vision for an information architecture is necessary. It has the following goals:

Figure 8.2
Computer simulation of the new ETH Zürich chemistry building by Campi and Pessina from 1999 on the ETH Zürich Hönggerberg. Model by Eric van der Mark et al.



- Overall increase of available research and teaching space through augmentation of physical with virtual architecture
- Local optimization of resources: Decrease operating costs through automated cooperation between buildings, for example through energy and load balancing
- Reduction of transportation of people and material: Decrease of overall operating expenses through advanced, IT-based cooperation between people in different buildings, cities, or countries
- Improvement of the quality of the built environment through augmentation of physical space with virtual space
- As a result, increase of the available resources for research and teaching

The realization of these goals requires a high degree of rethinking on all levels. It is also a departure from present practice on the base of which universities founded their success. The planning of new university campuses requires the presence of an information architecture with function, form, and structure. In an analogy to buildings that can be considered as information organisms, the entire university infrastructure of the future could be perceived as an information organism. The relation between physical architecture and information architecture becomes increasingly close (Schmitt, 1999).

ETH CAMPUS, ETH ZENTRUM, ETH WORLD

ETH Zürich, the Swiss Federal Institute of Technology, was established in the tradition of a polytechnic in the middle of the nineteenth century. Its facilities are located in more than 170 buildings in downtown Zürich (see Figure 8.3) and on the new campus Hönggerberg at a distance of 8 km (see Figure 8.4). The new budgetary process forced ETH Zürich to concentrate forces and resources. Individual departments are well equipped and well connected—sometimes better with overseas partners than with their industry partners only a few kilometers away. It is clear that cooperation between the two campuses and their context in terms of seamless scientific collaboration and teaching needs to improve.

ETH Zentrum is a name of a project with the goal to create a cultural university mile along the Universitätsstrasse in Zürich, where most of the original institutes and collections are located. Designs by Gottfried Semper, the architect of the main building, Bluntschli-Lasius, Hess, and others formed an ensemble of architectural masterpieces. The goal was to renovate those buildings for high-tech teaching and learning and at the same time to give the general public access to the collections located in those buildings. Thus, the university mile will demonstrate a unit of higher education and the benefits resulting from it to the general public.

ETH Campus is a name of a project describing the completion of a high-tech environment in a recreational area outside Zürich. After the completion of a new 81,000 m 2 chemistry and material science building, more

Figure 8.3
ETH Zentrum in the center of Zürich. Dark spots: collections; brighter spots: communication areas. Center right: building with oldest parts by Gottfried Semper.

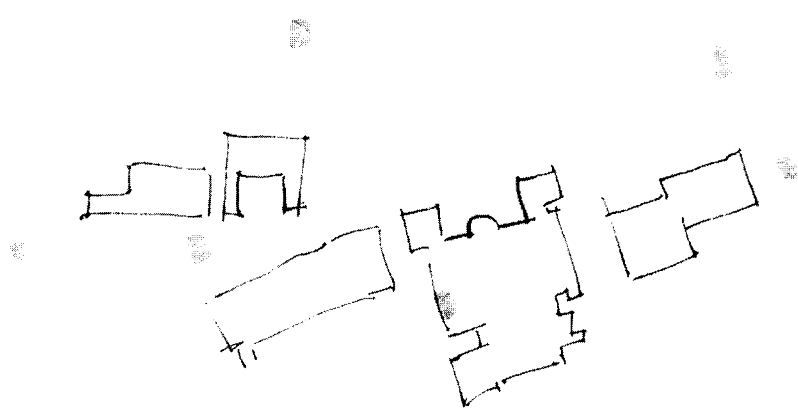
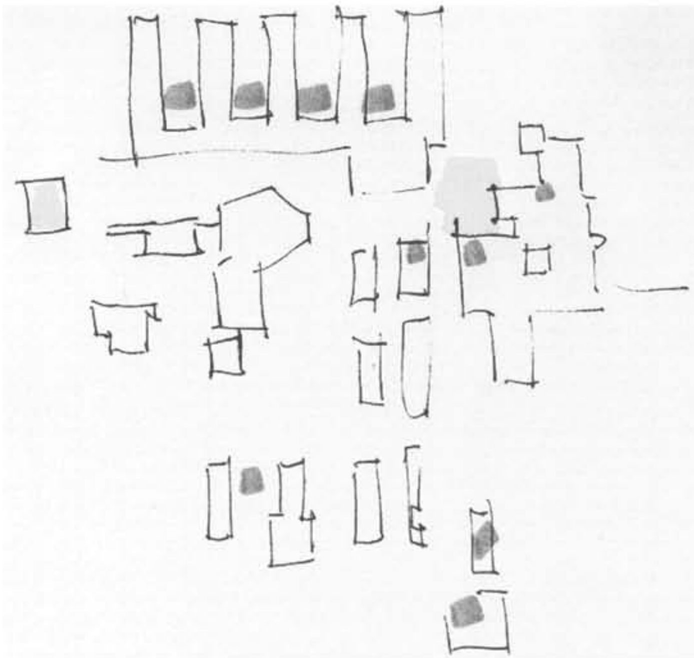


Figure 8.4
ETH campus in a recreational area east of Zürich. Dark spots: points of scientific interest. Bright spots: communication and sports facilities.



than half of ETH's 12,000 students will be studying on the new campus. It is a leading location for chemistry, material sciences, biotechnology, and high-energy physics. The need to connect this campus to ETH Zentrum is obvious; not only do students take courses in both locations, but also synergies between research in both places are possible. The disadvantages of spatial distance between campuses will be reduced through the construction of intelligent and cooperative buildings, research and teaching environments that allow for easy access of resources from one place to the other.

ETH World is the name of a project to create a third, virtual ETH campus (see Figure 8.5). It benefits from and builds on the existence of the two physical campuses. It provides distance teaching, distance learning, distance research, and the framework for the creation of a new university model. Together with the network for educational technology (NET, 1999) and the Campus Virtuel Suisse (VCS, 1999), it will enable external and ETH internal students and researchers to take part in the research and teaching activities at ETH Zürich (see Figure 8.6). It is, however, not

Figure 8.5
ETH World. Selected research and teaching exchanges today.

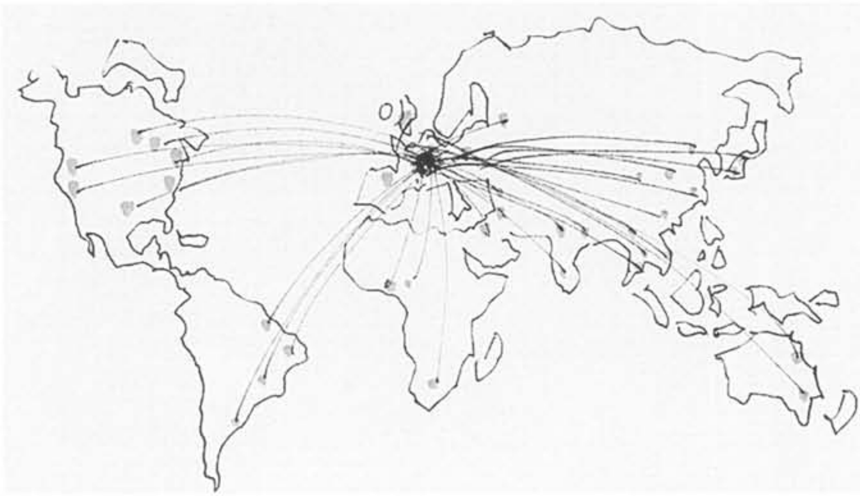
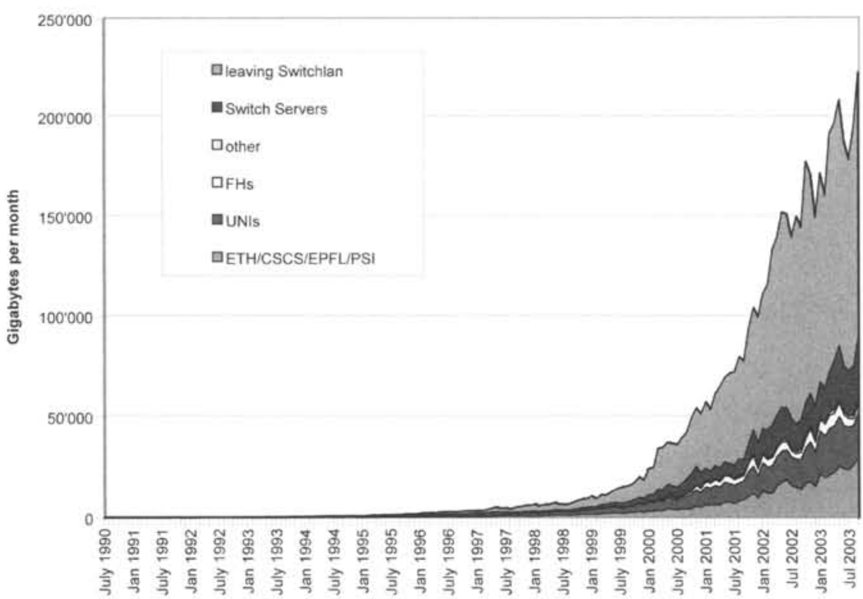


Figure 8.6
Development of Internet and Intranet data traffic in Switzerland since 1990.
***Source:* http://www.switch.ch/lan/stat/traffic.html**



intended to turn ETH Zürich into a provider of distance teaching and learning degrees. The ETH World project builds on an advanced information architecture and information infrastructure, named infostructure. It is planned that a certain percentage of the ETH construction budget will be reserved for this purpose, leading to the intelligent connection of buildings and to the augmentation of the physical architecture with virtual spaces. The infostructure will be planned and constructed, based on international competition. One of the purposes of ETH World is to create in students and external visitors a mental image of ETH Zürich that is close to the physical image. The imagery of the existing campus will be used as a first step for external visitors to connect or reconnect to ETH Zürich. They will be able to visit places or people they remember. In this context, a large infrastructure project, Gebäudeinformations-und Raumbewirtschaftungssystem (GIRBS, 1999) is under way. As a result, all spaces and their inhabitants can be visited in the future from the Internet.

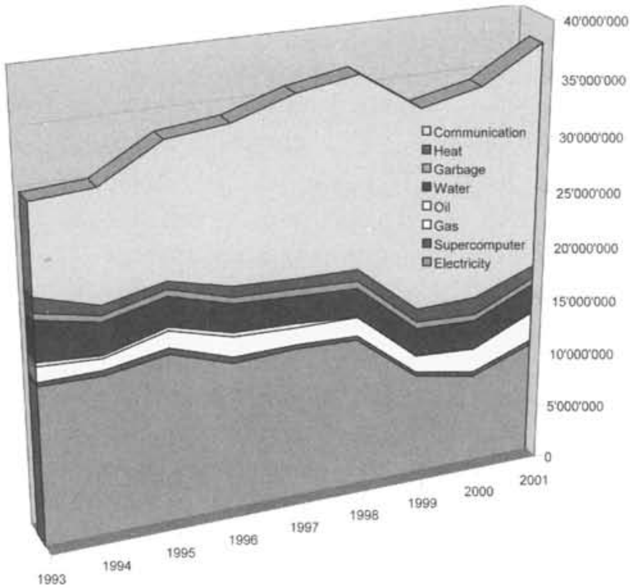
The three projects, ETH Zentrum, ETH Campus, and ETH World, demonstrate the need for and the advantages of intelligent and cooperative environments—first between the two campuses downtown and on the Hönggerberg, and secondly between the virtual ETH Campus and its worldwide participants.

COMMUNICATION INFRASTRUCTURE

A high-speed, 2 GBit communication infrastructure connects the buildings on ETH Campus and ETH Zentrum. This infostructure enables buildings and their inhabitants to cooperate. Communication costs have reached comparable levels as the sum of all other infrastructure costs (see Figure 8.7). This demonstrates the importance of the new information infrastructure. On one hand, it becomes a normal part of every building. On the other hand, it is one of the most rapidly changing elements of the built infrastructure. With the exception of some physical experiments and teaching seminars, advanced communication between buildings reduces the need for physical transportation between the two campuses. In addition, intelligent scheduling of lectures, seminars, and exercises further reduces the need of travel between the two campuses.

ETH Zürich, similar to other leading institutions of research higher learning worldwide, is faced with high maintenance costs for its physical building structures. 300,000 m 2 of usable area, more than 600,000 m 2 of total area cause significant building-related maintenance costs. The follow-up costs of large yearly investments in physical plants are clear: They

Figure 8.7
A comparison of traditional infrastructure costs (bottom areas) and communication cost (Top area) in Swiss Francs at ETH Zürich. ***Source:*** **Betriebsabteilung, ETH Zürich, 1999**

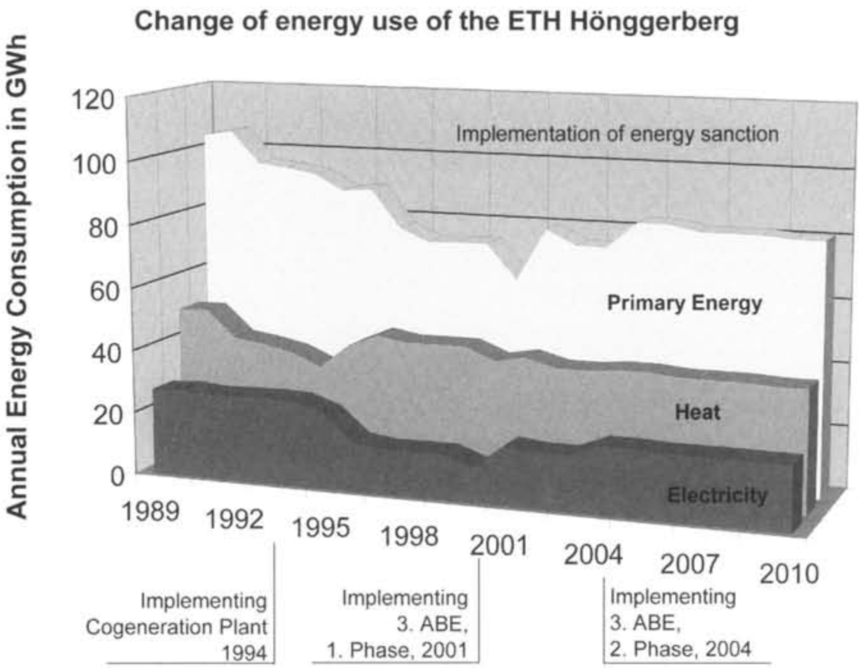


require a growing percentage of the overall budget. An intelligent cooperation between people and buildings to share and optimize their use of resources is therefore essential.

In the past, the cost for communication, consisting of network and active component investments and direct communication costs, were sometimes neglected or were hidden in other budgets. Communication is now a fast-growing cost factor. Ideally, falling electricity prices will compensate increasing costs for the communication and infostructure.

Buildings must not only cooperate in terms of communication, but also in physical terms: Energy use decreased drastically with the recent renovations in the context of the energy 2000 concept of the Swiss government. The changes brought reductions of up to 60 percent in newly renovated buildings. On ETH campus, even with the addition of the 81,000 m new chemistry and material sciences building, the overall energy use will not increase (see Figure 8.8). This is a practical example for cooperation of buildings through physical networks: Energy from the local plant is redistributed from energy-retrofitted buildings to new buildings.

Figure 8.8
Total energy use before and after the completion of the new chemistry building on ETH campus in 2001 (phase 1) and 2004 (phase 2). Energy conservation measures and intelligent load balancing keep total energy consumption in control in spite of a significant increase in area. ***Source:*** **http://www.verw.ethz.ch/planning/Bauplanung/3_ABE/index.html.**



ALUMNI@ETHZ.CH

The future inhabitants of ETH World are entering the university now: Each incoming student at ETH Zürich receives a free e-mail account and Internet storage space. Although this is common practice in several universities today, ETH Zürich will guarantee this service for the entire life of the student at no additional cost. This way, the university will be able to stay in touch with graduating students and to build a long-term relationship in which both partners can benefit. The e-mail address thus becomes the starting point of a digital room, apartment, research lab, or communication center. It is the entrance point to ETH World.

Several conditions must be fulfilled to guarantee the success of this approach. First, the relationship between alumni and the university comes into existence during the students' physical presence at the institution. Therefore, the quality of teaching, research, and the built environment are even more important than before: they need to create a positive memory. Second, the content of the university's site must contain a general part, a part tuned to the individual, and a configurable part. Third, the interface must be of highest quality and remind the student of the physical place while offering the most advanced and ergonomic information, communication, and collaboration platform.

SELECTED PRECEDENTS IN COLLABORATIVE DESIGN

The chair for architecture and computer-aided architectural design, CAAD, at the department of architecture has produced several prototypes of an environment of this type. Exercises in this direction have taken place since 1994. In the courses @home in 1995 (CAAD, 1995) and 1996 (CAAD, 1996), students explored the idea of the digital home and the establishment of connections to their neighbors. This approach was continued with the fake.space courses in 1997 (CAAD, 1997) and 1998 (CAAD, 1998).

Known under the name of Phase(X) and fake.space, researchers and students at the chair have developed and tested systems that contain important aspects for ETH World. Phase(X) and fake.space allow a large number of students to collaborate from distant locations on a common design project in synchronous and asynchronous mode. More than 1,000 students have participated in those experiments. The design methodology and the storage of design results have reached maturity over the last four years. The supporting Web sites have won prizes for their innovative character (Hochparterre, 1998), but also have proven to be useful for practical matters (Kolarevic et al., 1998).

There is evidence that students do revisit their previous designs and those of others even months and years after the course has ended. If the site and the student e-mail accounts are still valid, students can easily get in contact with each other and with the university. A growing percentage of ETH World will therefore be dedicated to the activities of its alumni, thus changing the character of the entire university. Another related research project at the chair for CAAD on an information and communication infrastructure for the building industry (ICCS, 1999) has been completed. It has lead to the development of a tool set for the virtual architectural, engineering, and construction (AEC) company. One result has been the cooperation and testing of the software between research and teaching groups at Zürich, Carnegie Mellon, and Braunschweig. The teams use the same database technology and interface, which could also be employed for the ETH World approach. Through interactive Web sites, the projects are viewed, downloaded, and uploaded. An Oracle database stores the results (Lottaz et al., 1998).

The projects have demonstrated the importance of data and database visualization and the advantages of asynchronous collaboration on a same project, as long as broadband communication is not available. Phase(X) showed that even with asynchronous design and communication phases, a high degree of interaction on the same project is possible between a large number of participants. It is our assumption that the same will be possible for ETH World.

MULTIPLYING TIME—A VIRTUAL DESIGN STUDIO (VDS)

The Multiplying Time experiments starting in 1997 are based on the same technology as Phase(X) and fake.space. They take advantage of the time difference between international research centers. In this way, students from Hong Kong, Zürich, and Seattle cooperated on a common design project over three time zones. Each group worked for 8 hours, deposited the results in the database, from where the next group continued (Multiplying Time, 1997).

Whereas Phase(X) leads to the design of abstract objects, the Multiplying Time project introduces a real design problem, along with some working conditions close to architectural practice (http://space.arch.ethz.ch/VDS_97/). The practical background is that globalization and specialization in the design and building industry require increased collaboration between partners in remote locations (Wojtowicz, 1995). Ideally, all of them could work on a common virtual building design, simultaneously together (synchronously) or separately (asynchronously), with the latest state of the design always available to all team members. Collaborating on a shared object would prevent information loss in file transfer. The Multiplying Time project approaches this goal. It allows at the same time the continuous work on a design or a set of designs through three different time zones around the world, thus multiplying one week into three working weeks.

The task was to design a residence for a painter and a writer on an island west of Seattle, Washington. Three partners from ETH Zürich (Urs

Hirschberg), the University of Hong Kong (Prof. Branko Kolarevic), and the University of Seattle (Prof. Brian Johnson) agreed on the common design project. The interactive program Sculptor, developed by David Kurmann at Architecture & CAAD, ETH Zürich (http://caad.arch.ethz.ch/~kurmann/sculptor/short.html), was installed in all three locations to enable synchronous and asynchronous design (see Figure 8.9). The common database at ETH Zürich was directly connected to the Internet, similar to that of Phase(X).

Students in Hong Kong started the experiment. At the end of their 8-hour working day, they placed their designs into the database. Students in Zürich began 8 hours later and could thus work with the results achieved by their Hong Kong partners. They also placed their designs in the database 8 hours later, so that the participants from Seattle were able to explore the designs from Zürich and Hong Kong. In addition, videoconferences took place about every 8 hours, during which students could share and explain their ideas. The setup thus created an intense global think-tank, operating 24 hours a day (see Figure 8.10).

Each working day of the exercise, a new phase was introduced along with a new design issue. Similar to Phase(X), students could select a design to develop further from any of the three locations. On the last day, a videoconference between all three locations took place for the evaluation of the final design proposals. Authors and critics discussed the individual designs and observed the design threads. Students from the three locations noticed that although they had not known each other before, they found a common language to communicate. The bases for this language were the modeling program and the individual designs. As a follow-up to

Figure 8.9
Sculptor models rendered with Radiance in the Phase(X) course at ETH Zürich. Mark Frey (left) and Christoph Loppacher (right), 1996.

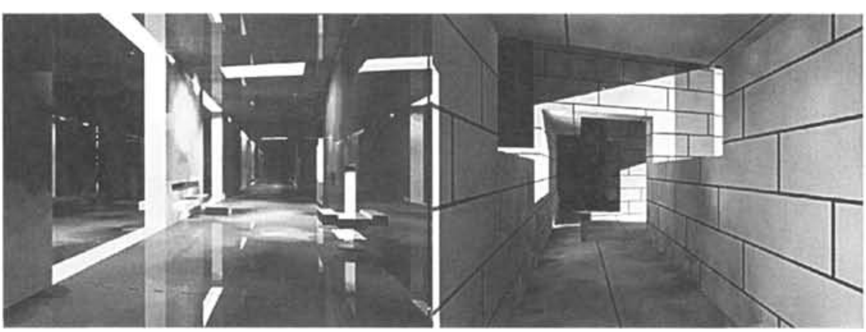
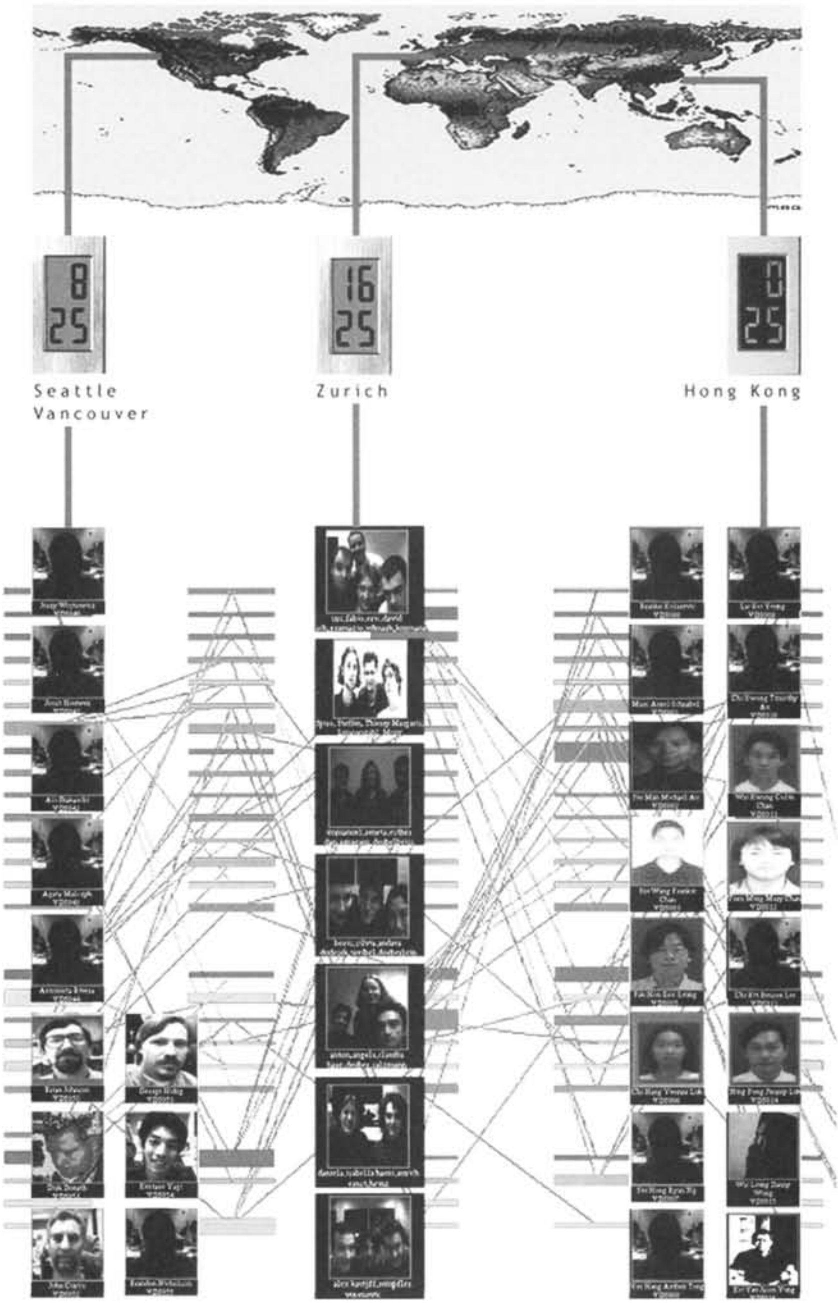


Figure 8.10
The Multiplying Time setup and participants. The individual designs of the first phases are shown underneath with the connections between the student projects. Malgorzata Bugajski, 1998.



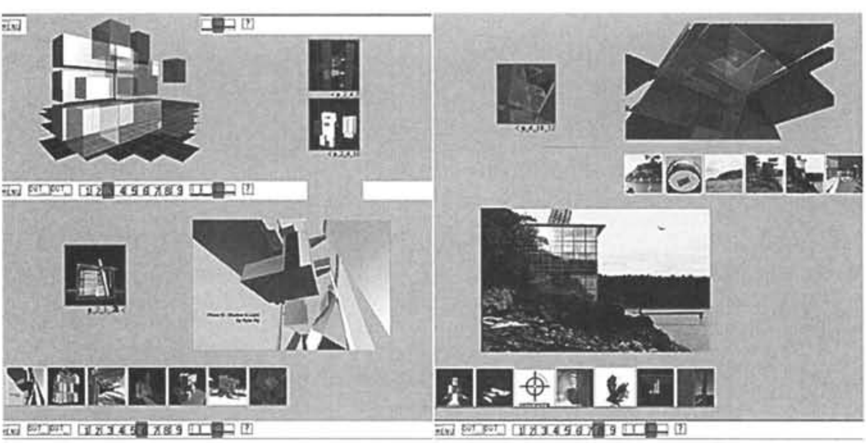
the Multiplying Time experiment, a group of students at the Technical University of Delft continued where the previous exercise had ended (see Figure 8.11). The Delft students had access to the results of all design phases through the database. In three additional phases, they developed more refined solutions. This extension demonstrated with surprising clarity that the principle would function, even if the modeling software, the hardware, and the operating systems changed.

The Multiplying Time and the Delft experiments demonstrate that it is possible to design from a common database, taking advantage of different time zones and special capabilities of particular sites. The resulting projects are of shared authorship, but the individual contributions are clearly identifiable, along with the evolvement and history of the design.

CONCLUSIONS

The three projects, ETH Campus, ETH Zentrum, and ETH World, demonstrate the need for a new type of building design for universities. No longer is it enough to plan the physical environment. The physical and the virtual environments have become an integral part of the new reality. As

Figure 8.11
Snapshots from the Delft experiment. The images show the development from conceptual models (top left) to more refined projects (bottom right) that evolved over 5 days in three time zones. Left: Dualities by S. Margaris, S. Lemmerzah, T. Musy, ETH Zürich; Light & Shadow, by Siu Hong Ryan and Chi Kit Benson, Hong Kong. Right: Situation, A. Amin, P. de Ruiter, Delft. Collected by Malgorzata Bugajski, 1998.



physical buildings become more intelligent in terms of instrumentation and communication, virtual buildings will be able to support better cooperation between people and buildings. The result is buildings as organisms with their own built-in intelligence, enabling communication and other forms of collaboration. Universities are best equipped and prepared to test the approach of intelligent buildings communicating and cooperating. It is therefore necessary that research at the academic level focus on this new need of building design. No major university will be able to neglect this trend in the near future.

ACKNOWLEDGMENTS

The author wants to thank his team at the chair for architecture and CAAD for its work in the Phase(X) and fake.space projects. He also wants to thank his new team at the vice presidency for planning and logistics of ETH Zürich.

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9

Remote Collaborative Design: Case Studies of Transatlantic Cooperation in Engineering and Architecture

João Bento, José P. Duarte, Teresa V. Heitor, and Manuel V. Heitor

INTRODUCTION

Remote collaboration is a relatively recent endeavor that has increased its pace of development through effective use of the Internet as the enabler of new forms of technical, professional, and social behaviors as well as a means for competence building and skill development.

That opportunity has found fertile ground in design environments, where the design team members might be located in remote sites, but also because the mobilization of different disciplines is often coupled with the relatively frequent requirement that the objects being designed are to be built or produced elsewhere. Thus, the ingredients seem to be ready for the interest in investigating and exploring opportunities, tools, and methodologies for remote collaborative design. Moreover, it seems interesting to evaluate what could be the main consequences for design activities resulting from the transition to a knowledge society in which most things and acts are acquiring a much less material nature.

This chapter describes how different research groups in three different schools from two different countries have tackled a couple of such collaborative experiments and how these related experiences have prompted the need for furthering the level of awareness around the subject from both a technical and an educational point of view.

Those experiences were *The Lisbon Charrette* (Duarte, Bento, & Mitchell, 2000) and *The Glass Chair* (Heitor & Duarte, 2002) and developed from 1999 to 2001 involving two departments of IST—the Department of Civil Engineering and Architecture and the Department of Mechanical Engineering—from the School of Architecture and Planning of MIT and the Faculty of Architecture of Oporto (FAUP). In addition, a number of collaborating institutions were also mobilized, such as the Municipality of Lisbon—the host city for the Charrette—and the firm Infusão, in whose factory the Glass Chair was fabricated.

THE PARTICIPANTS' POINTS OF VIEW

A preliminary question might be of interest to the reader of this chapter: Why would such a group of schools wish to get involved in a set of projects spanning from the urban and architectural rehabilitation of a former chocolate factory in Lisbon to the design and construction of a... glass chair?

Apart from the already stated interest in tackling remote collaborative design as a discipline in itself, both in terms of a research topic and of a (set of) teaching courses aiming at enhancing the capabilities of students when facing design problems and integrating design teams, the various schools have identified a sufficient level of complementarities that indeed emerged throughout the process; in addition, they had specific reasons of their own: MIT had been undertaking various such experiences under the *Design Studio of the Future Project* with other groups in the United States and in Asia, but was lacking this type of project with European universities. The FAUP, a highly regarded traditional school of architecture, famous by the work of some of their leading professors, such as Álvaro Siza, was willing to join a project that would challenge its ability to respond to the use of new technologies and to evaluate their possible role in different—more technologically driven—design environments. IST, the highest-ranked engineering school in Portugal, already had a strong involvement in design and computation as well as in innovation and management of technology and was, therefore, strongly motivated to further its interests in the direction of collaborative work as a ground for experimenting with the coordinated use of various existing or emerging competences.

The odds were clearly toward a successful experiment, and each group joined with interesting levels of expectation; the development of the projects would not frustrate them.

THE SEQUENCE OF PROJECTS

Accepted as it may now be that there was scope for cooperation, it seems appropriate to describe the rationale for the actual sequence of projects that instantiated the previously identified common interest.

The first project, *the Lisbon Charrette*, may be described as a *design-only* endeavor (i.e., a project in which the central issues to be tackled were associated with design problems, namely those associated with the social relations between the design team members and the need to fulfill their cognitive, communication, and technical requirements, while collaborating in a geographically distributed and culturally diverse environment). It was a venture whose main deliverable was the design solution itself.

As for the second project, it was clear that all the ingredients of the first one were also present, and therefore, some of the methodological progress achieved by *the charrette* could be used; however, there was a clear intention to further the first experiment by extending it toward a stage of *production of artifacts*. Having in mind that one of the distinctive features of design problem solving is the existence of a time lag between the design phase and the delivery of the artifact (Goel & Pirolli, 1989), it seemed more than appropriate to evaluate how the previously experimented collaboration methodologies could accommodate activities related to the pre-production and production phases, the reason why *the glass chair* project came as a natural sequence to the earlier experiment.

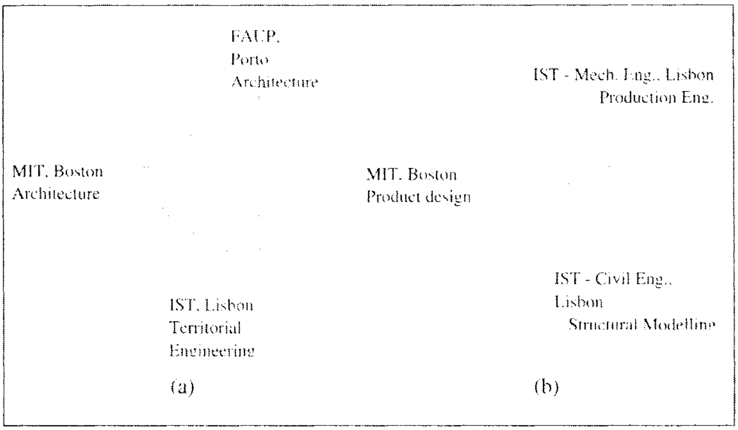
The sequence of projects may, thus, be seen as one in which the parts evolved from an immaterial set of collaboration issues—where the central object of the collaboration was achieving a *description of an artifact* (a design)—to a material one, which included the actual *fabrication of* conceived (thus *fully described*) *artifacts*.

THE STRUCTURE OF THE PROJECTS

Although under the described rationale there was a reason and coherence for the chosen collaborative design projects, each of them had both distinctive and common characteristics. The most interesting of the latter is, perhaps, the sharing of a common structure that might be described as follows:

1. The students' work was, in both cases, a teamwork assignment.
2. Teams were formed by students from more than one school, thus assuming a geographically distributed nature (Figure 9.1a).
3. Both projects had a multidisciplinary content, requiring the presence of multiple competences not found in any single team member (Figure 9.1b).
4. In both cases, the design teams were competing for a design solution (i.e., various teams were developing the same design object, thus producing different design solutions.

Figure 9.1
(a) Charrette and (b) Glass Chair Teams



5. In both projects, there was scope for the work to develop in different platforms, thus involving a local dimension and a remote one; consequently, it was necessary to provide exchanging and sharing mechanisms for data, information, and knowledge.
6. Finally, the deliverable was a design product for both projects: the description of the designed solution, in the case of the Lisbon Charrette and the designed artifact—the chair itself—in the case of the Glass Chair.

BRIEF DESCRIPTION OF THE LISBON CHARRETTE

The Lisbon Charrette project referred to an urban planning and architectural intervention in a site located in the periphery of the historic center of Lisbon. The chosen site was formed by a large and irregular plot (6,700 m^2) with two-street fronts, strategically located within the urban tissue occupied by a former chocolate factory built in the 1920s and closed for economic reasons in the 1990s. The design problem was, in summary, its conversion to a housing solution for *teleworkers*.

The *active* phase, in which team members did get involved in the actual design work and did cooperate effectively, took place as a full-semester course with a more intensive period of cooperation of about eight weeks of deep collaborative work (thus the name *Lisbon Charrette*). Students in

Lisbon (IST) were responsible for describing the target site for the design episode, namely in its morphological, functional, social, and legal components. No other member in each team was allowed to visit the site. The need for sophisticated means for exchange of information (across the Web and using VC) was, therefore, clear.

The work developed in four steps. First, there was the development of a design plan determined by the interaction of the existing physical form, land-use patterns and policies, and existing and forecast development pressures. The following step envisaged the selection and prioritization of interventions. The third step corresponded to the production of the design brief; it was supported by a detailed site analysis, gathering of advisory information, and development of control procedures ensuring that the full range of planning considerations and design criteria would be addressed. The design criteria were put forward not as a rigid program but as guidelines to be used by design teams in planning their projects.

The transmission of information to MIT and FAUP teams, which could have no sensorial experience of the place, was the concluding step of the

Figure 9.2
Design Brief and Forms of Communication

DESIGN BRIEF		EFFECTIVE COMMUNICATION	
REQUIREMENTS	**MEDIA**	**PROBLEMS**	**SOLUTIONS**
SITE ANALYSIS Historical background Physical form Social component Land uses Social uses Development pressures	written statements historical cartography survey maps 3D diagrams sketches photographs video	NO SENSORIAL EXPERIENCE OF THE PLACE MIT / FAUP	**MULTIMEDIA MATERIALS** video audio photos **VERBAL DESCRIPTIONS**
DESIGN GOALS PERFORMANCE CRITERIA	written statements exploratory / 3D diagrams sketches	DIFFERENT CULTURAL BACKGROUNDS MIT / FAUP / IST	**COMPLEMENTARY INFORMATION** **city characterization** spatial evolution townscape economic activities people social use of space iconography significance
CONTROL PROCEDURES ADVISORY INFORMATION	written statements diagrams legal texts	PORTUGUESE REALITY UNKNOWN MIT	

Figure 9.3
Used Tools along the Sequence of Activities

used tools		subject
	start	
email contacts		Preparatory stage
		Selection of the intervention site
Web page structure		
		City characterization
		Site analysis
Introduction of «pinup pages»		
		Ambiance of the intervention area
		Design goals / performance criteria
		Legal framework / control procedures / advisory information
First plenary videoconference		Introduction of participants / telework / Site description
		Availability of urban indexes and limitations
		Geometric correction of aerial photography
		Characterization of built environment: physical forms / land uses
		Social survey
Introduction of «chatting» tools		
		Existing urban normative
		Detailed characterization of the plot
Plenary VC		Midterm Review
		Materials about *Vilas Operárias*
		Complementary information / historical background
Multi-point or point-to-point small VCs		Selection of teams
		Architectural design
		3D modeling
Introduction of «webcam»		
		Design recommendations
		Coordination of teams
		Climate information for the site
Introduction of FTP site		
		Details of the case study
		Physical models and mock-ups
		Digital movies of the intervention area
Plenary VC	▼	Final Review
	end	

preparatory stage. It was the main challenge placed to the IST students because the efficiency of the design process and the consistency of the final product would depend on effective communication of the design brief to the other participants in a way that enabled them to understand the site to develop an adequate solution.

Figure 9.2 (Bento et al., 2002) synthetically describes the main tools that were used for solving communication needs and how they contributed to the identified goals.

The basic principles that were adopted relating communication needs were the following: (1) support to the various types of communication protocols, (2) simplicity of use, and (3) minimization of (equipment and communication) costs. Those guiding principles had, then, to cope with the main technical requirements: support for *synchronized, nonsynchronized, verbal,* and *visual* modes of communication, support for *small* and *large meetings,* and support for the *exchange* of *graphical* and *written documents.*

As for the tools, they were all Web-based except for the use of (non-Web) videoconference. Among the former, there were *Web cams, chat, pinup pages, ftp,* and *e-mail;* as for the latter, there were facilities for small (desktop-based) or large (room-based), point-to-point (two sites), or multipoint (three sites) videoconference sessions, all using PictureTel technology based on ISDN links. Figure 9.3 provides a short summary of the tools used along the design process.

As it may be seen, the kick-off for the Charrette phase of the project was a large videoconference with the participation of all the students, critics, and instructors. MIT introduced the concept of telework and launched the design goal: housing for teleworkers. IST then described the design brief and the site in detail using material posted on Web pages, such as sketches, charts, texts, thematic maps, movies (Figure 9.4), photos (Figure 9.5), and 3-D elevation models (Figure 9.6).

The students were then required to form the groups and to post on the Web a small paragraph on their ideas for the project. Following that, they had to look at each other's texts to find those with similar ideas and then to use the chat system to assess the possibilities for teaming up. They were

Figure 9.4
Sample of Movies of the Site Posted on Web Pages

Figure 9.5
Existing Buildings and Restrictions

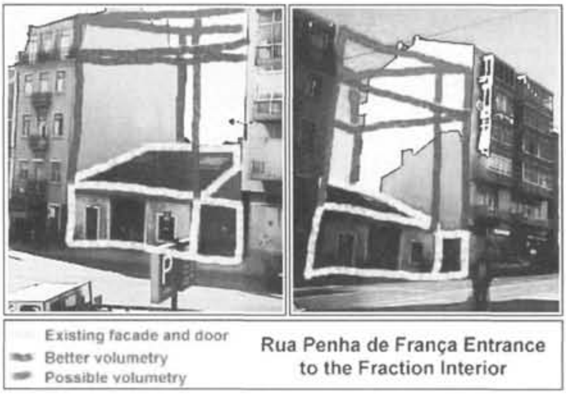
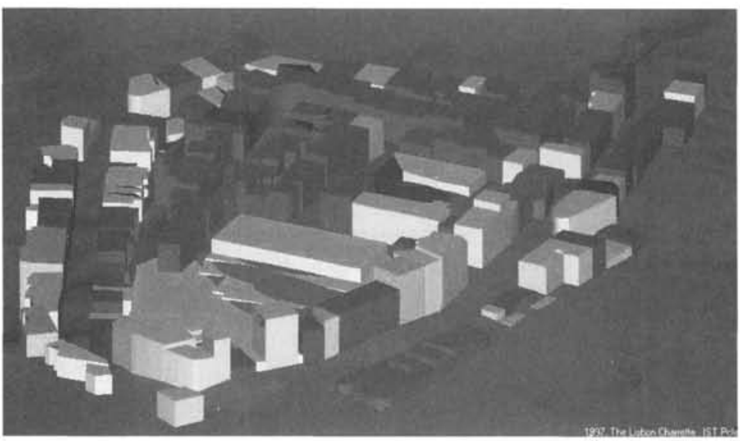


Figure 9.6
Current Uses



given two days before announcing the final composition of the groups on a pinup page, including all the possible ways for contacting each other (mail, phone, etc.). Four groups were formed, with two students from MIT, two from FAUP, and one from IST.

Two weeks after the first large videoconference, there was a midterm review videoconference, where the team presented its design strategy, the envisaged concept of telework, and a preview of the proposed solution. The groups used Web pages to structure and present their case, and some used cameras to show physical models. The final review happened another two weeks later. The strategies used by the different teams did not differ much, although the presentations were much more elaborate.

In between reviews, and throughout the development of the real teamwork, a number of *small videoconferences* were organized involving only the students (it was noticed that the presence of instructors inhibited discussion among team members). In these sessions, there were document cameras, lipstick cameras, and room cameras. The first were used to display sketches, whereas lipstick cameras illustrated physical models. A typical interaction during these sessions was one pole sketching and talking to describe ideas, while the others listened and reacted (as in Figure 9.7). Eye contact was particularly important in assessing mutual reactions, and it determined the actual layout of the rooms, which suffered an evolution as a result of accumulated experience.

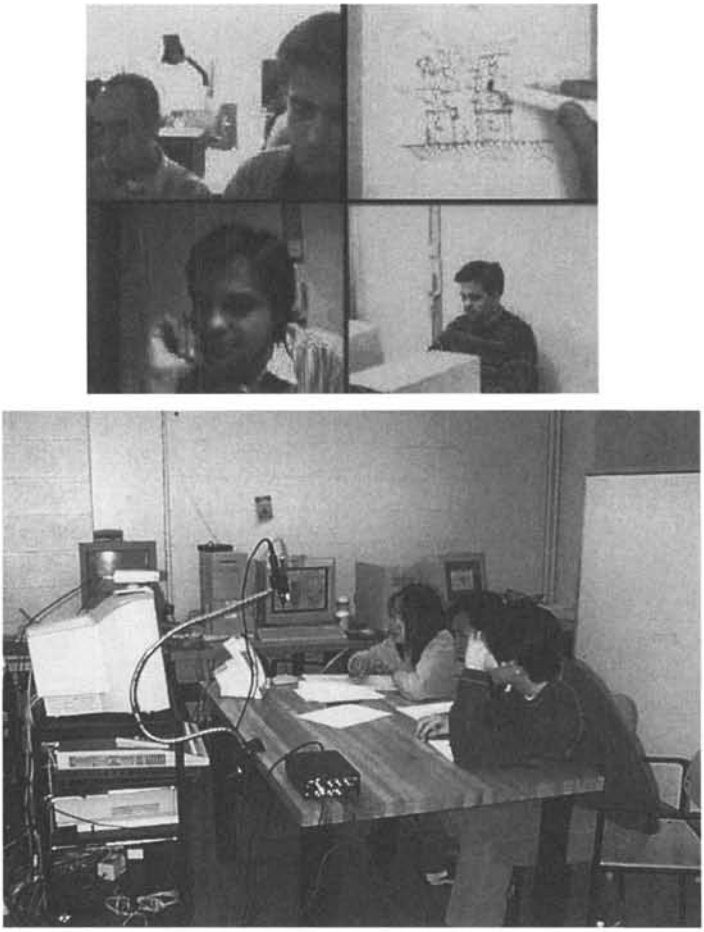
The number and schedule of small videoconferences was initially rigid (two per team and per week at specific times), mainly due to financial constraints. However, experience showed that these needs varied from team to team and that periods without videoconferences were required to develop the projects before further discussion. Thus, the videoconferences schedule was relaxed in the second half of the Charrette and booked on demand. At that stage, it was not uncommon for team members to schedule the next videoconference after a chat session. At the end, there were also cases of urgent call-in videoconferences (i.e., sessions resulting from team members from one pole calling another pole's standby unit).

The breakdown of work among members of the different poles varied from team to team. This was due to the adoption of different working strategies, but also because the design history on each of the teams evolved differently. One team, for instance, spent the first week working on a common proposal and then split the site into halves, being MIT in charge of one half and FAUP in charge of another, while IST ensured coordination. One other team allowed a radically different strategy as it insisted on working together on the same buildings.

BRIEF DESCRIPTION OF THE GLASS CHAIR

Because one of the objectives of this project was the design and actual production of the design object, a chair was chosen as it encloses most of the problems present in any design venture, and it facilitates actual physical production. The complexity, and indeed challenge, of the design situation was mostly related with the use of glass, which is a highly resistant

Figure 9.7
Snapshots of (*small*) Videoconferences



material to compression, but very weak under traction and, therefore, flexure (for details, see Heitor & Duarte, 2002).

Again, the *active* phase of the project developed throughout a full-semester course.

The structure of the teams was, in this case, slightly different; at MIT, there were two teams of architectural students, competing for a "more feasible solution" because it was envisaged from a very early phase of the project that only one solution would be actually built, given time and funding restrictions. Because of this, the most prominent criteria under consideration, besides aesthetics and ergonomics, were constructability of the solution.

At IST, there were two groups of students: one was from civil engineering dealing with structural aspects, namely taking care of structural analysis and modeling, and the others were from mechanical engineering, handling all the manufacturing aspects, including the fabrication process, the type of glass, the design of the molds, and the relations with the factory.

The type of communication tools was basically the same already described for the Charrette, although, due to the intensity of the preproduction phase, a greater use of *chat* sessions took place, for they provided a fast and cheap means for discussing all the technical details involved.

The work developed in various stages. First, the teams at MIT endorsed an exploratory work on any type of glass furniture, during which there were no serious restrictions on materials or production techniques. It was a time for daring proposals as varied as a glass tub (Figure 9.8)—rendered impossible to build with the available fabrication technology—or various types of glass benches (Figure 9.9) or chairs. There were benches for public places or for home use, chairs that were curved, cut, glued, single-pieced, and composed of various parts (Figure 9.10, Figure 9.11, and Figure 9.12).

Figure 9.8
Glass Tub Model and Prototype

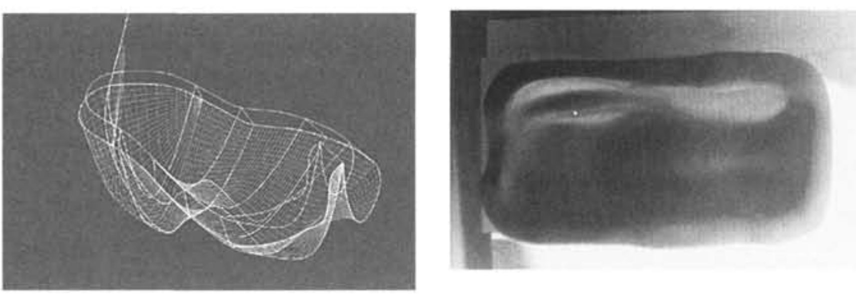


Figure 9.9
Curved Bench

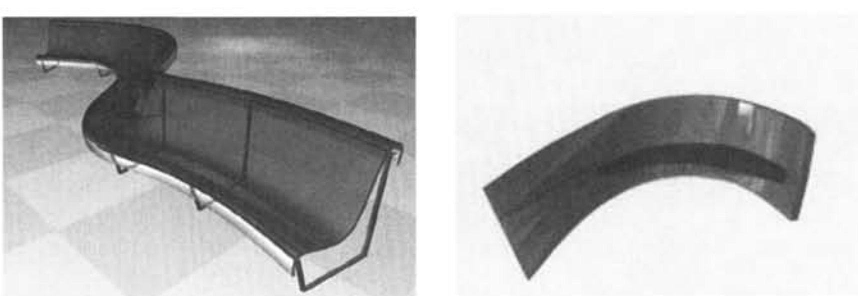


Figure 9.10
Wood and Glass Chair

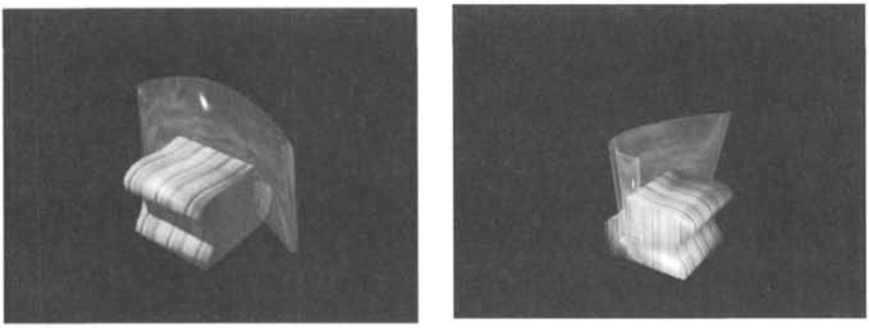
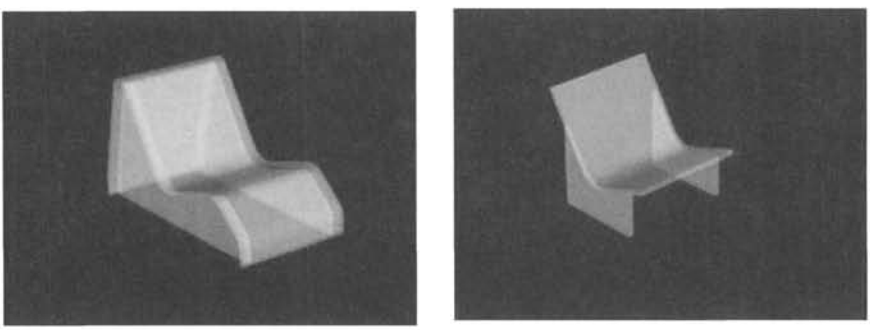
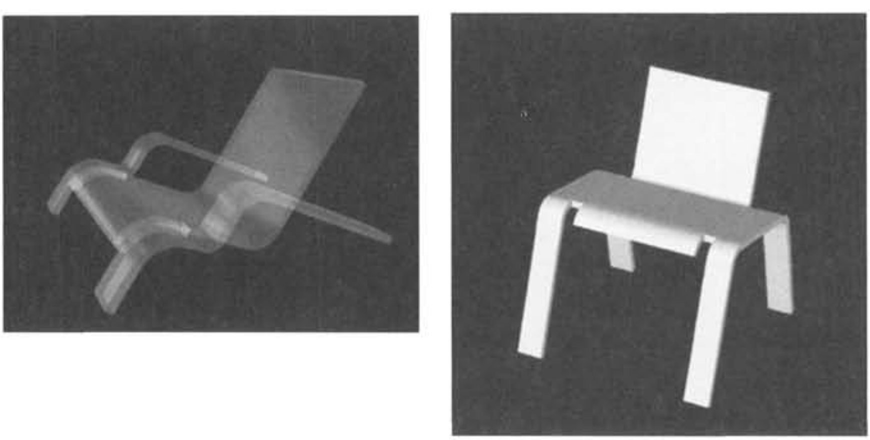


Figure 9.11
Sides Supported Chairs



a b

Figure 9.12
Bent-cut Chairs



a b

At some stage of this initial exploratory phase, the students of both teams were instructed to stick to available glass technology. The engineering students, in Lisbon, then gave general recommendations concerning the production process, and the teams at MIT endorsed a more pragmatic approach to the objects they were envisaging. This was a phase for more realistic proposals to start to emerge.

The team that would eventually come up with the selected proposal, thus proceeding to the production phase, was, by then, discussing various options for a chair departing from a flat sheet of glass; two options were considered—a side chair and a beach chair (those of Figure 9.12). A critical review of the mechanical engineering students excluded the side chair, far more difficult to build with the available process, for it would require a much higher level of cutting and finishing, if structurally feasible, which was not evaluated. In fact, the following phase consisted on the structural analysis of the beach chair.

The beach chair being analyzed was basically a single-pieced curved glass supported at both ends, but not at the sitting area (Figure 9.12a). It was concluded by the various structural models tested that the chair would develop too-high bending stresses. These were due to bending under the seating area and to the fact that both ends of the chair would displace apart, thus inducing high tension in the curved areas.

Various solutions were then tested between the architects and the engineers (Figure 9.13) to avoid the formation of such a high level of stress. A first decision was taken to include metallic tie-rods that would prevent the two ends to displace apart (Figure 9.14).

Figure 9.13
Early Version of the Beach Chair

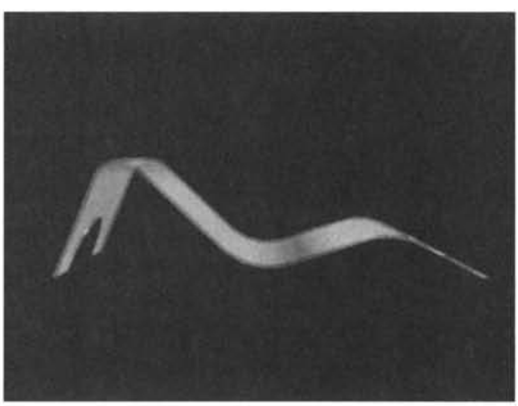


Figure 9.14
Rods Preventing Excessive Bending

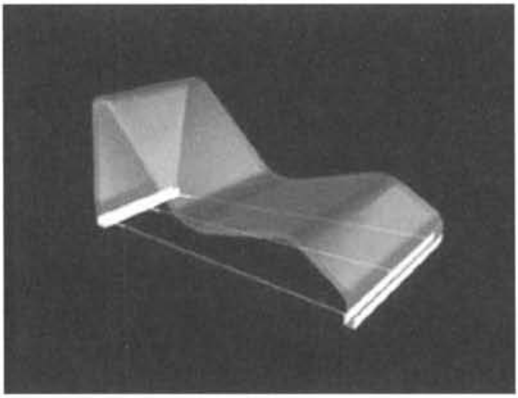
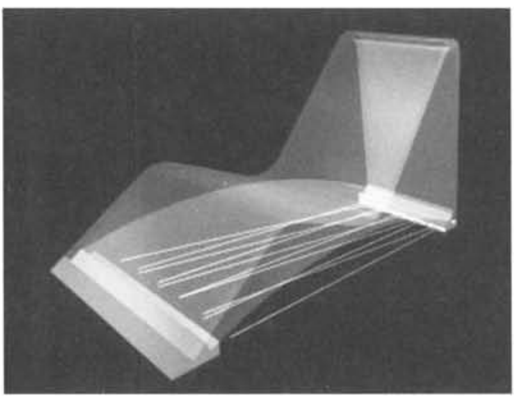


Figure 9.15
Final Design of the Glass Chair



Nevertheless, and because the rods would not solve the remaining problem of excessive tension below the seating area, the team came up with the idea of supporting the seating area also with glass. A first solution used a pair of cut sides, but proved difficult to build, for the need of the extra cuts and the difficulty of adjusting the sides to the main curved plate (Figure 9.11a). The final, and truly brilliant solution for that problem was finally achieved: a glass arch supporting the seat (Figure 9.15). The beauty of this solution is related to the fact that glass behaves better under compression, thus would be an excellent material for this additional support.

With the final design at hand, the project entered the production phase. At this stage, communication between MIT and IST team members was

Figure 9.16
Sequence of Production Steps

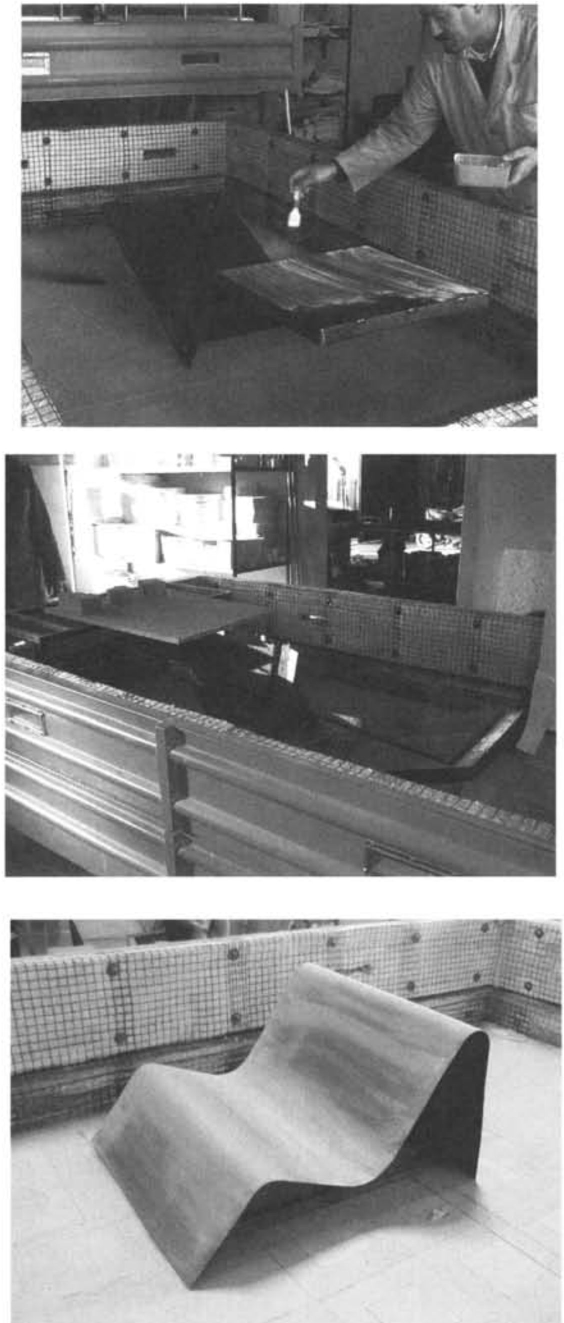
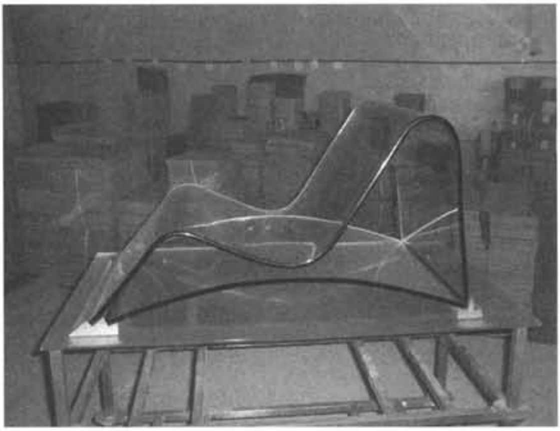


Figure 9.17
Final Built Chair



ensured mostly using Internet relay chat or equivalent, for there was no need for exchanging of large amounts of information or of discussing any remaining issues. Figure 9.16 and Figure 9.17 summarize the production phase and illustrate the final built chair.

CLOSURE

The knowledge society is introducing deep changes in the economy, culture, and social habits and, therefore, in the ways of teaching, learning, designing, and building. Design, and particularly collaborative design, is part of a number of social and professional activities that will dramatically change with the new era.

The Lisbon Charrette and the Glass Chair projects were aimed at experimenting with both technological teaching and learning issues related with remote collaboration. However, design experiments as they were, it is interesting to stress that it was not the excellent set of designs that produced the most interesting of their achievements, but rather the demonstration that it is possible to establish or even to revive all the components of a social relation of teamwork, even when physical and cultural distance interfere.

Despite the informality of the used tools (Duarte et al., 2000) it may be said that the whole of strong cultural and technical differences that were expected and effectively emerged were soundly tackled with the communication and collaboration environment made available to participants.

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10

Global Teamwork: Cross-Disciplinary, Collaborative, Geographically Distributed *e*-Learning Environment

Renate Fruchter

INTRODUCTION

Not since the introduction of the chalkboard in the nineteenth century has the curriculum and classroom been so challenged in regard to its basic design configuration and pedagogical setting. It is the synergy of sociotechnical pedagogical objectives, powerful computers, good software, and the Internet that today provides the first real challenge to the traditional classroom and learning setting. They challenge the philosophy of how one teaches, of the relationship between teacher and student, of the active role of academia and industry in the learning environment, of the way in which a classroom is structured, and the nature of curriculum.

This chapter describes the education model, information and collaboration technology of an e-learning environment, and assessment methodology developed and deployed at Stanford to address these challenges and create a global forum that will significantly increase the number of Architecture/Engineering/Construction (AEC) students who will

- Understand how the AEC disciplines interact and impact each other
- Gain hands-on experience with new information technologies (IT) and learn how such technologies can support collaborative teamwork
- Understand how IT will impact the learning experience and collaboration technology will effect team dynamics, performance, and behavior

Similar efforts are being pursued in other departments at Stanford (Toye et al., 1993) and at other universities (e.g., CMU [Fenves, 1995], MIT/Cornell/Hong Kong and others [Chen et al., 1994], Georgia Tech [Vanegas & Guzdial, 1995], Penn State [El-Bibani et al., 1995, Riley 1995], and University of Sydney [Simoff & Maher, 1997]). Most of these efforts are discipline centric (e.g., a group of geographically distributed architecture students collaborating on a design project).

The master builder's atelier in the information age is the vision behind the integrated research and curriculum program on AEC global teamwork at Stanford University. The AEC global teamwork program is a cross-disciplinary, collaborative, geographically distributed course that was established at Stanford's Civil and Environmental Engineering Department and launched in 1993. It is the result of a three-way partnership between academia, government, and industry. It engages students, faculty, and industry practitioners from the three disciplines in a distributed learning environment including universities from Europe, Japan, and the United States. The PBL Lab is the home of the AEC global teamwork program at Stanford. The AEC master builder's atelier (i.e., the PBL Lab and AEC global teamwork program) is based on a PBL pedagogical approach, where PBL stands for *Problem-, Project-, Product-, Process-, People-*Based Learning. It is based on two theses:

1. Global teamwork and learning are sociotechnical activities.
2. Any e-learning and collaborative design-build environment requires computer support for different modes of interaction in time and space and diverse needs of content capture, sharing, and reuse.

The AEC global teamwork program acts as a test bed for new education paradigms, mentoring, and cutting-edge information technologies. Its aim is to prepare a new generation of professionals who know how to team up with practitioners from other disciplines and take advantage of information technology to produce a better, faster, cheaper product. The following sections present the motivation, discuss the modes of interaction and content sharing, present an overview of the AEC global teamwork education test bed and e-learning information infrastructure, and propose new cross-disciplinary learning metrics and methods. In closing, the author presents observations, challenges, and quandaries related to global teamwork and e-learning.

MOTIVATION

The AEC global teamwork program comes in response to an industry perceived need to improve and broaden the competence of graduate and undergraduate students to understand the acquired theoretical knowledge in a multidisciplinary, collaborative, practical project-centered environment. The critical problems this project-based course addresses are summarized by the following observations about the current practices in the AEC industry and the status quo of AEC education:

- *Fragmentation:* Fragmentation among AEC professionals, which is emphasized by divergent education, is today's status quo. It is the author's belief that many of the reasons for the current poor coordination and communication among professionals in the fragmented AEC industry and among project phases are rooted in the way education is structured today, by discipline. Emerging technologies promise to provide the means to bridge the gap among professionals and organizations and to overcome the limitations of both geography and time. However, technology by itself, without improved teamwork, will fail. Because the corporation of the future will be built on information, it will be necessary to educate professionals about the tools that control and manipulate information and support collaborative and concurrent work. And because teamwork will be the primary work mode, it will be essential to focus on training in consensus building, group dynamics, and problem solving by using diverse technology advances.
- *Discipline-based education:* In many fields of engineering, higher education has been reactive rather than proactive for a long time. Core curricula were developed decades ago based on the then-perceived needs of the profession as seen from an academic perspective and based on educational principles of the past. Curricula have been updated in reaction to professional or research developments, but have not been reshaped to initiate much-needed educational changes or accommodate the rapidly changing needs of the profession. A typical example is the conventional structural engineering curriculum implemented at most U.S. universities. This curriculum focuses on independent and unlinked courses that communicate knowledge in fragments, which leaves students confused about the objectives of their education and unaware of many issues that are critical in professional practice. Structural engineering practice is controlled by economic, social, and legal constraints and by constraints imposed by other professionals involved in the design/construction process of civil engineering structures. It is time to evaluate and change this educational approach and pose the professional problems to students before they get exposed to solutions, rather than presenting solutions with partial or no exposure to the problems.
- *Assessment of cross-disciplinary learning:* Cross-disciplinary teamwork and learning in an e-learning environment pose new assessment

> challenges. It is important to determine how to design and conduct an assessment within the perspective of cognitive and situative learning theory. The assessment study comes in response to two distinct problems. First, there is a pedagogically perceived need to enhance traditional assessment methods to monitor and evaluate the evolution of the cross-disciplinary learning experience students have in multidisciplinary project-based studies, such as the AEC course. Traditional assessment dimensions included in course evaluation questionnaires focus on the teaching aspect rather than on the learner and learning perspective. This assessment approach is effective in the case of conventional classes where there is one discipline-centric focus, one instructor, a reader or textbook(s), homework assignments, and a final exam.

In addition, current studies of university courses in which technology is a key component tend to focus on the technology—specifically, on media selection and media effects. Neither of these issues addresses the individual learner (Walther, 1997). Technology is central to the design of the AEC learning environment—without it; the students would not be able to collaborate across geographic distances. This study focuses on the importance of the learner's experience that includes the interaction with and through various technologies.

MODES OF INTERACTIONS AND CONTENT SHARING

Unlike traditional distance-learning education systems, which rely heavily on printed materials supported by audiotapes, videotapes, telephone contact, and color slides, the Internet gives increased access to graphics, sound, and real-time multimodal interactive communications.

Telecommunication technologies have provided a vast array of teaching opportunities for educators charged with providing information. The distant learning IT infrastructure in the AEC course permits augmented communication in diverse interaction scenarios, for example, (1) instructor–students, (2) instructor–student, (3) peer-to-peer (i.e., student–student and instructor—instructor), (4) students–instructors–practitioners, or (5) team–owner.

Faculty, AEC student team members, and practitioners are engaged in diverse teaching and learning settings, such as lectures and face-to-face team meetings, as well as in independent work. Throughout this process all participants are able to express, capture, and share knowledge, experiences, design intents, critiques, and decisions by using (1) a shared workspace in collocated or distributed synchronous lectures and face-to-face meetings, and (2) feedback and change notifications in collocated or distributed asynchronous work. The e-learning environment is characterized as a function of *time, space,* and shared *content.*

- *Time.* Throughout the teaching, learning, and team project process participants transition between synchronous and asynchronous types of interaction:
  - Synchronous collaboration occurs in face-to-face meetings. At that time, faculty and practitioners offer lectures and present case studies, and team members define the overall design of the future building and determine the various discipline models. They communicate discipline concepts and assumptions that have cross-disciplinary impacts.
  - Asynchronous collaboration, in which (1) faculty and practitioners provide feedback to students, (2) students go over course material delivered over the Internet or via the Web, and (3) team members work independently at concurrent or different times on detailing discipline subsystems of their project.
- *Space.* Faculty, practitioners, and students get together for lectures, roundtable discussions, or project team meetings to review design proposals and decisions. Such face-to-face meetings can take place in a collocated setting, where all members travel to the meeting place, or in a distributed setting, where team members remain in their offices and use network applications (e.g., groupware, videoconferencing) to share and exchange information and discuss their design decisions.
- *Shared content.* Project team members work on their discipline design solutions. As the design progresses, team members, faculty, and industry mentors need to
  - Use a shared project workspace to publish shared 3-D graphic building models to identify shared interests, multicriteria semantics of graphic features and share symbolic, multicriteria critiques, explanations from all disciplines, and expert feedback as they work in a synchronous mode.
  - Use local discipline models and exchange design information and change notifications related to building features in which they expressed a shared interest, as they work in an asynchronous mode.

THE AEC GLOBAL TEAMWORK EDUCATION TEST BED

The AEC global teamwork program is based on a *PBL* pedagogical approach, where PBL stands for *Problem-, Project-, Product-, Process-, People*-Based Learning. *PBL* is about teaching and learning teamwork in the information age. PBL is a methodology of teaching and learning that focuses on *problem*-based, *project*-organized activities that produce a *product* for a client. PBL is based on reengineered *processes* that bring *people* from multiple disciplines together.

The AEC student teams represent the core atoms in this learning environment. The students come from the different programs, departments, and universities and bring to the program their discipline cultures (i.e., egos, goals, constraints, languages, representations, and tools). During the first four AEC generations (i.e., 1993/1994 through 1997/1998), Stanford partnered with UC Berkeley. This partnership engaged students from the Structures & Geomechanics and Construction Engineering Management from the Civil and Environmental Engineering Department at Stanford and architecture students from the School of Architecture at UC Berkeley. In 1997/1998, PBL Lab organized the fifth-generation AEC program in a nationwide pilot, engaging students from Stanford, UC Berkeley, Cal Poly San Luis Obispo, and Georgia Tech. In 1998/1999, PBL Lab organized the sixth-generation AEC program in an international pilot, engaging students from Stanford; UC Berkeley; Georgia Tech; Strathclyde University, Glasgow, UK; Ljubljana Technical University, Slovenia; and Aoyama Gakuin University, Tokyo, Japan. AEC teams are typically distributed over two or three time zones (e.g., architect at Georgia Tech, structural engineer at Stanford, construction manager in Glasgow, UK, and apprentice at Stanford). Since 1998 the PBL Lab has been offering the AEC global teamwork program in worldwide e-learning forum that is growing every year. New university partners that joined in the academic year 2000/2001 include Kansas University in the United States; Bauhaus University, Weimar, Germany; Fachhochschule Aargau and ETH in Zurich, Switzerland; and TU Delft in Netherlands, from Europe.

AEC global teamwork program structure. The AEC global teamwork course is a two-academic quarter program. It starts in January and ends in May every year. The learning and teamwork activities are both structured and unstructured. There are three types of structured weekly activities—*IT lecture, lab session,* and *AEC professional practice session.* The *IT lecture* series aims to introduce the concepts, system architecture, advantages, and limitations of information and collaboration technologies from a user's point of view. Emphasis is placed on the affordances of each of the collaboration technologies, its impact on the behavior of the individual and team dynamics, as well as on the build environment. The *lab sessions* introduce the students to these collaboration technologies through hands-on exercises. Each collaboration technology has a pedagogical objective and teamwork justification in the context of the AEC program. AEC students actively use the IT e-learning infrastructure to communicate, collaborate, and coordinate among the geographically distributed team members.

The *AEC professional practice session* can take one of the following forms, depending on the stage of the course:

- *Roundtable discussions* are organized at the beginning of the course. AEC industry practitioners and faculty are invited to discuss the role of each discipline, the value it adds to the project and product, building systems integration, and the teamwork process (i.e., cross-disciplinary interactions and impacts in the decision process).
- *Role modeling* through case studies. Signature project case studies are introduced to the students, such as Frank Gehry's Guggenheim Museum and the Music Experience and KL&A's Aspen Music Hall. All these case studies are dissected and analyzed from a cross-disciplinary perspective, emphasizing (1) the exploration of alternatives in the concept development phase, and (2) the project development and construction, as a function of the cross-disciplinary impacts among architecture, structural systems, mechanical systems, and constructibility.
- *Informal AEC project reviews.* These are sessions in which each AEC student team meets with a full AEC mentor team (including faculty and industry practitioners) to discuss their concepts and preliminary solutions and receive constructive and critical feedback, as well as guidance and real industry data.

The unstructured activities engage the students on a daily basis in their building project. It is during the project teamwork activity that the students exercise their discipline knowledge, learn how to work in a multidisciplinary team, and exercise the newly acquired skills to use IT to communicate, collaborate, and coordinate with their team members, faculty, and industry mentors.

The project is structured in two phases—concept development, which takes place during winter quarter, and project development phase, which takes place during spring quarter. At the end of each quarter the AEC student teams present their product and process during formal presentation events at which all students, owners, faculty, and industry mentors participate. The winter quarter presentations take place in cyberspace. This gives AEC student teams an opportunity to experience a project review and presentation in a geographically distributed setting. The spring quarter presentation is a final event at which all students, owners, faculty, and industry mentors rejoin at Stanford to evaluate the team projects and celebrate the end of the global teamwork journey.

It is the author's belief that teamwork is a sociotechnical activity. Both the social and IT awareness have to be built and strengthened from the start. Consequently, all the students, owners, faculty, and industry mentors meet at Stanford twice during the AEC global teamwork program: first during the kickoff week in January, and second during the final AEC project presentations in May. These two events are critical to build a strong sense of community of practice. During the kickoff week there are multiple activities aimed at setting the stage, raising questions and challenges related to cross-disciplinary, geographically distributed teamwork, team building exercises and games, introducing some of the basic communication and collaboration technologies.

Team formation in the AEC education program has been a function of team size, member roles, and participant location. One of the innovative features of this course is represented by the role each of the participants plays:

- Undergraduate and graduate students play the roles of apprentice and journeyman, respectively.
- Faculty members and researchers play the role of "master builders."
- Industry representatives play the role of mentors, owner, and sponsors.

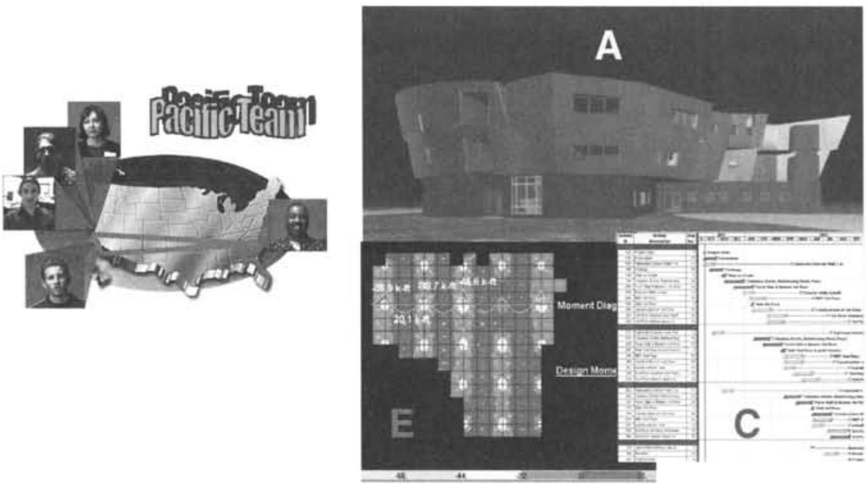
The size of the teams is determined by two factors, (1) the three disciplines, and (2) the roles (i.e., journeyman and apprentice). Consequently, each team has one architect, one structural engineer, one construction management student as journeymen from the MS programs, and one or two apprentice students from the BS program. The pedagogical reason behind the decision not to have more students from any of the AEC disciplines in a team is to ensure that all students maintain a constant, high engagement in the project and have a well defined responsibility to represent their profession within their team. AEC students are challenged to cross three chasms during their learning experience (i.e., discipline, space, and culture). The geographical location of the team members provides the students with an opportunity to be exposed to a virtual teamwork in a cross-cultural environment, as well as justify the use of information technologies to accomplish the goals of the project. Interaction between the disciplines is key to the functioning of the team and to the development of the cross-disciplinary learning experience for each individual.

The Building Project. The core activity in this learning environment is a building project with a program, a budget, a site, a time for delivery, and a demanding owner. The project is based on a real-world building project that has been scoped down to address the academic time frame of two academic quarters. AEC teams model, refine, and document the design product, the process, and its implementation. The students learn to (1) regroup as the different discipline issues become central problems and impact other disciplines, (2) use computer tools that support discipline tasks and collaborative work, and (3) use videoconferencing and desktop sharing technology to have face-to-face meetings and interact with the teaching team and industry mentors. The project progresses from conceptual design to a computer model of the building and a final report. As in the real world, the teams have tight deadlines, engage in design reviews, and negotiate modifications. A team's cross-disciplinary understanding evolves over the life of the project. The international structure of AEC teams adds the real-world collaboration complexity to the learning environment, which includes space, time, coordination, and cooperation issues. A key focus is the effective use of IT resources to support instruction and learning outcomes. Typical project examples can be viewed in the project gallery of PBL under http://pbl.stanford.edu. Figure 10.1 illustrates one of the many AEC global team projects.

Teamwork Process. Teamwork, specifically cross-disciplinary learning, is key to the design of the AEC PBL. Students are expected to engage with other team members to determine the role of discipline-specific knowledge in a multidisciplinary project-centered environment, as well as to exercise newly acquired theoretical knowledge. It is through cross-disciplinary interaction that the team becomes a community of practitioners—the mastery of knowledge and skill requires individuals to move toward full participation in the sociocultural practices of a larger community. The negotiation of language and culture is equally important to the learning process—through participating in a community of practitioners (AEC), the students are learning how to create discourse that requires the constructing meanings of concepts and uses of skills. As the project progresses, a number of events are expected to happen: (1) the concepts are transformed into models, (2) the models become more detailed, (3) discipline models are linked, providing the students with a building systems integration perspective, and (4) information is reorganized so that it can be shared among the participants.

Mentoring and Coaching. The role of the instructor is changing in a PBL learning environment, from the traditional teacher who delivers the course material in class to the *coach* and *mentor.* Industry practitioners play the role of *mentors.* They become active participants in the teaching

Figure 10.1
Example of AEC Team Final Project (i.e., 3-D Architecture Rendering, Structural Simulation, Construction Schedule—One of the Pacific Team that had the Architect at Georgia Tech, the Structural Engineer at Cal Poly, the Construction Manager at Stanford, and Two Undergraduate Apprentices at Stanford)



process and education of the next generation of practitioners. This change in role from teacher to coach, industry practitioner to mentor, provides a structure for modeling and coaching that scaffolds the learning process, both in the design and construction phases, as well as for modeling techniques such as articulating and reflecting on cognitive processes. The PBL AEC global teamwork program has established a strategy for *mentoring* and *reverse mentoring*.

Mentoring is both structured and flexible; students are required to engage periodically with mentors, but are also encouraged to connect regularly beyond the course requirements. Mentors are afforded dedicated class time to provide feedback on projects, and each student is required to meet with at least two mentors from their discipline to get a variety of perspectives. In addition, PBL lab hosts informal social hours, in which mentors and students exchange ideas and stories. Student-initiated meetings with mentors take place either in person at Stanford or in the mentor's work environment, or via Internet, asynchronous communication via e-mail or a Web-based consulting forum.

Students come to the AEC global teamwork program with extensive domain knowledge but lacking experience implementing that knowledge.

Thus, the mentoring relationship is designed to provide spaces in which the student is at times the center of the activity, scaffolded by support from mentors, and other times peripheral to the activity, learning through contributing, observing, and discussing from the sidelines of the design space. The latter strategy harnesses the power of "legitimate peripheral participation" (Lave & Wenger, 1991), a term describing the induction of an apprentice into a community of practice. In this case, the apprentice receives little direct instruction; instead, novices participate in peripheral tasks as they learn the language, skills, and actions of the activity.

PBL's AEC global teamwork program offers a bidirectional mentoring strategy (Fruchter & Lewis, 2000). Students are at the same time peripheral and central (Figure 10.2). This bidirectional strategy provides students with the self-directed learning experience afforded by a complex building project for which they are centrally responsible, as well as a forum to observe experts at work solving a similar problem. During most mentoring meetings, students participate in design tasks while mentors coach and question. Midquarter, however, mentors lead a two-hour "Fishbowl" design session, in which they tackle the challenges faced by a particular team while students watch, ask questions, and provide input from the sidelines. By participating at the periphery of a cross-disciplinary design task, students are given the opportunity to see the effect of the design process on the creation of the product itself. They are able to see how "A," "E," and "C" practicing professionals use cross-disciplinary knowledge to facilitate design.

Reverse mentoring aims to influence practices beyond university walls. Although mentors influence students' design practices by connecting them to larger communities of practice in industry, students clearly influence mentors' practices within these communities as well. By making explicit the commonly practiced but little understood skills of interdisciplinary design, PBL lab's AEC global teamwork program encourages mentors to rethink the importance of these interactions in their own design practices. Additionally, industry mentors have worked in the field for many years using traditional tools. As a result, most have had little experience employing high-tech communications technologies. Not only were they unfamiliar with how to operate these technologies, they were unfamiliar in harnessing the types of communications these technologies afford and changing the business process to leverage the communication technologies. Exposure to these technologies enabled mentors to bring a vision of distributed design to their organizations.

Like the "Fishbowl" session, mentors participated at the periphery (Figure 10.2), observing student interaction in a high-tech medium, partici-

Figure 10.2
Mentoring and Reverse Mentoring Strategies

Mentoring
Students at the Center of the Activity
Scaffolding

Mentoring
Students at the Periphery of the Activity
"Legitimate Peripheral Participation"

Reverse Mentoring
Students are IT Experts and Industry Mentors are Apprentices

pating in high-tech practices in increasingly sophisticated ways as they learned. Although mentors expressed enthusiasm for the potential of videoconferencing technology for facilitating communications in their industry, they were most moved by the potential of collaborative technologies to speed up the design process. Using large touch screen technology, mentors were able to rapidly generate sketches and recover previous iterations quickly; because of its size, the SMART Board is able to include large groups in the conceptual design.

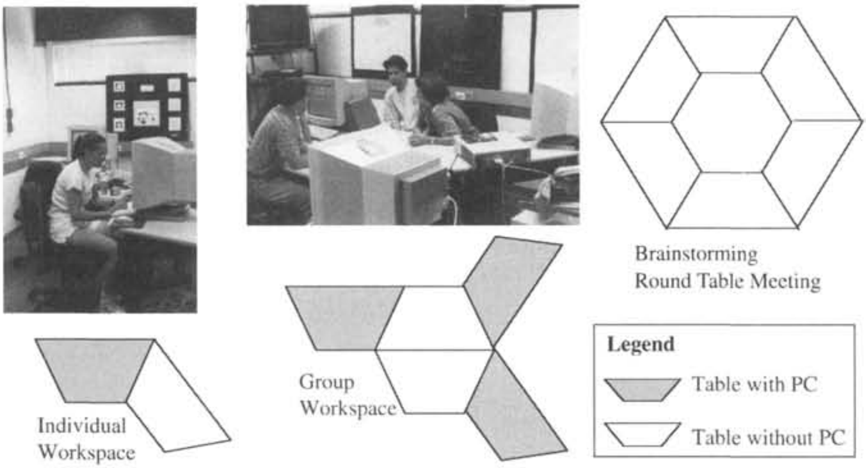
The Flexible PBL Learning Space and e-Learning Distributed Spaces. The design of the PBL lab is grounded in cognitive and situative learning theory. The cognitive perspective characterizes learning in terms of growth of conceptual understanding and general strategies of thinking and understanding (Dewey, 1928/1958). The design of the PBL Lab—to provide team interaction with the professor, industry mentors, and team owners—provides a structure for modeling and coaching that scaffolds the learning process, both in the design and construction phases, as well as for techniques such as articulating and reflecting on cognitive processes. The situative perspective shifts the focus of analysis from individual behavior and cognition to larger systems that include individual agents interacting with each other and with other subsystems in the environment (Greeno, 1998).

The PBL lab is built as a flexible learning space that can be reconfigured by faculty and students on an as-needed basis to accommodate the different learning and teaching activities described earlier, such as computer lab activities, individual work, teamwork, presentations, and interaction in a geographically distributed setting (Figure 10.3).

To support this goal, the PBL lab has modular furniture, ISDN, wireless, and Internet-2 links, and the floor and wall perimeter has a grid of network and power sockets that enables connection of computers in any location of the learning space. All the PCs in the PBL lab are equipped with videoconference tools. This enables students to interact with team members or mentors when needed. The group workspace configuration offers private workspaces (tables with PC) for the individual team members and a shared public workspace in the center (tables without PC). These allow students to smoothly transition from private to public workspaces and share their work on their workstations or laptops with team members in both collocated and remote settings.

As wireless technology, handheld devices, and large touch screen technologies become available and affordable they are integrated into the e-learning infrastructure environment. This in turn changes the behavior,

Figure 10.3
Examples of PBL Workspace Configurations Using Modular Furniture, a Flexible Grid of Power and LAN Network Connections, and Workstations



learning, and work habits of the students. Learning takes place in very different settings, including formal activities and spaces, for example, teamwork and interactive lectures take place in the flexible PBL lab, or informal activities and spaces (i.e., learners meeting in a park or at the coffee house) (Figure 10.4). Figure 10.4 illustrates an IT lab session in PBL lab where each student comes with his/her wireless laptop and interacts with both the instructor and the remote students.

Students use large touch screen technology (i.e., SMART Board) that enables them to rapidly generate sketches and recover previous iterations quickly. Because of its size, the SMART Board is able to include large groups in the conceptual design. Figure 10.4 illustrates the use of the SMART Board during the "Fishbowl" session in which three industry practitioners, Scott Dennis from MBT Architecture in San Francisco, Dr. Greg Luth from KL&A structural engineering firm in Menlo Park, and James Bartone from Dillingham Constructions, worked on one of the AEC student projects for two hours. Collocated and remote students watched them interact and explore alternative solutions.

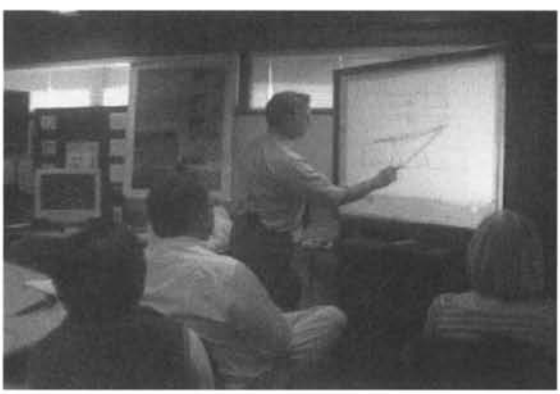
E-LEARNING INFORMATION INFRASTRUCTURE

The e-learning infrastructure developed and deployed by the PBL lab is aimed to take the *distance* out of distance learning and support collabora-

Figure 10.4
Mobile Learners in PBL Lab and e-Learning Distributed Spaces (e.g., at Stanford's Coffee House), Using Wireless Technology, Laptops, SMART Board

Mobile Learners during IT Lab Session in PBL Lab

Mobile Learners at the Coffee House Meeting with an Industry Mentor



"Fishbowl" Session

tive building design. Internet-mediated design communication, integration and organization frameworks, groupware technology, and multimedia are used in the AEC global teamwork course. A brief overview of key collaboration technologies developed by the author's research team as well as commercial applications that are deployed in the e-learning infrastructure of the PBL Lab are described in the following sections.

Knowledge and Information Capture in Informal Media

Concept generation and development occur most frequently in informal media where design capture tools are the weakest. This statement has strong implications for the capture and reuse of design knowledge because conceptual design generates the majority of initial ideas and directions that guide the course of the project. Sketching is a natural mode for designers, instructors, or students to communicate in highly informal activities such as brainstorming sessions, project reviews, lectures, or Q&A sessions. Often, the sketch itself is merely the vehicle that spawns discussion about a particular design issue. Thus, from a design capture perspective, capture of both the sketch itself and the discussion that provides the context behind the sketch are important. It is interesting to note that today's state-of-practice or best practices are not captured, and knowledge is lost when the whiteboard is erased or the paper napkin sketch is tossed away.

RECALL (Fruchter & Yen, 2000), a learning and collaboration technology that facilitates transparent and cost-effective capture, sharing, and reuse of knowledge in informal media, such as sketching, audio, and video, was used by the AEC students. RECALL is a drawing application written in Java that captures, indexes, and synchronizes the sketch activity with audio/video. A key advantage of RECALL technology is that it serves two purposes: (1) a technology for capturing knowledge and information in rich informal media such as sketches, audio, and video, and (2) it serves as a nonintrusive data collection and observation instrument.

The RECALL technology invention is aimed to improve the performance and cost of knowledge capture, sharing, and reuse. It provides the following benefits:

- Transparent graphical, audio/video indexing
- Zero overhead cost for production (i.e., editing/indexing)
- Zero overhead cost for publishing rich multimedia Web content

- Immediate interactive access and retrieval of knowledge and information (i.e., sketch audio/video on demand)

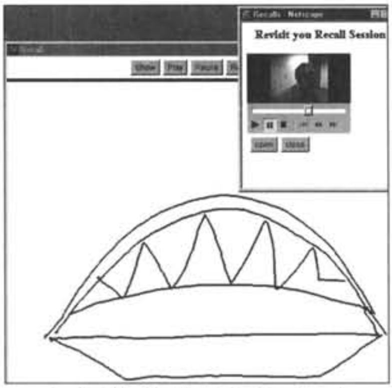
The AEC students received from the PBL lab laptops for the time frame of two quarters. These laptops were specifically chosen to have stylo-enabled screens that facilitate sketching. The laptops were augmented with RECALL to enable the students to capture, share, and revisit their design ideas, rationale, and feedback anytime, anywhere. RECALL was used in the following learning and teamwork scenarios during the AEC global teamwork program.

Interactive learning scenario: In this scenario the actors included the instructor and the students. The activity facilitated by RECALL focused on capturing lectures and explanations of concepts and best practices in both synchronous and asynchronous interactions. The synchronous interaction took place during formal sessions in the PBL lab. The students were able to revisit and interact with the captured explanation of the concepts in the form of RECALL content published on the course Web site. The dynamic and interactive replay of the RECALL session gave the students a sense of having the instructor at their side redrawing the sketch in front of them as they explained the concept (Figure 10.5). The asynchronous interaction facilitated Q&A and feedback. This captured the interaction as an ongoing conversation between the instructor and learner population. The RECALL content created by students enabled the instructor or mentor to gain a better understanding of the student's solution or question, as well as assess the level of knowledge retention and rationale of the learner.

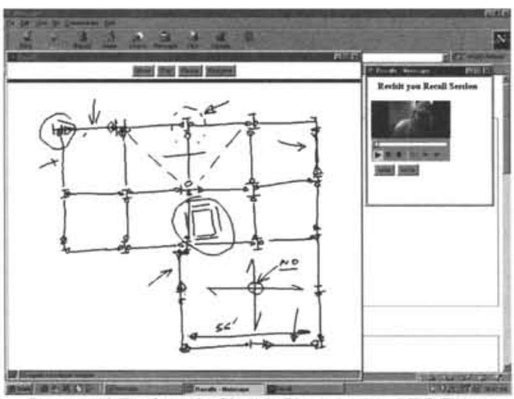
AEC Global Teamwork: In this scenario the actors included the AEC student team members, faculty, and industry mentors. The activity facilitated by RECALL focused on the building project (i.e., concept generation, project review, and feedback from faculty and industry mentors). Design alternatives were created and critiqued in both synchronous and asynchronous interactions. Conceptual design ideas were created with RECALL during

- Individual brainstorming sessions in which each team member captured their solution and the rationale behind it through sketch-talk RECALL activities (Figure 10.5). This represents a reflection in action of the designer that emulates the notion of the reflective practitioner described by Schon (1983).
- Brainstorming group sessions in which part or all team members would explore alternative solutions.

Figure 10.5
Screen Shot of a RECALL Playback Session



Industry Mentor Best Practice Capture



Structural Engineer's Sketch Shared with AEC Team

- Project review sessions in which the team members would critique different solutions. During these sessions students could, for instance, import into RECALL JPEG images of CAD drawings and annotate them with sketches and audio/video explanations as a rich media redlined session.

RECALL sessions were revisited and replayed by team members in support of the ongoing decision process. RECALL sessions were used to convey design ideas and their rationale to faculty and industry mentors and elicit feedback from them. Finally, RECALL sessions were used to communicate the design ideas to the owner in an intuitive fashion.

World Wide Web

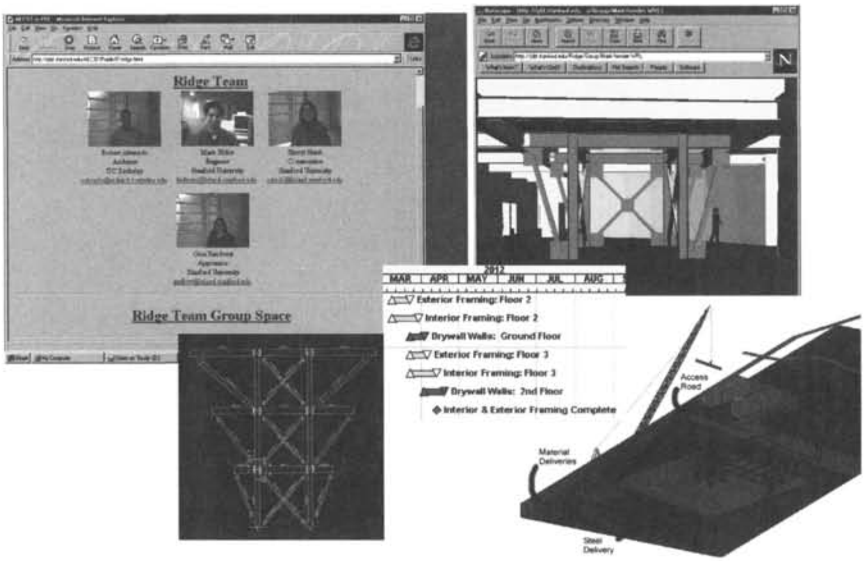
The Web is used for team building and as a medium to disseminate and share conceptual design solutions of the design teams.

Team building on the WWW. The "team building on the Web" exercise is based on generic skill definitions of the AEC students and hypothetical project calls for bids posted on the Web. Students have to identify the specific project they can work on among the different calls for bids and publish on the Web their skills, project preference, and request for collaborators from the other disciplines. This exercise exposes students to the Web and one of its future potential commerce and business applications.

Cyberarchive for building project case studies used for role modeling. The "Joan & Irving Harris Concert Hall" in Aspen, Colorado, was used as a case study presented by Dr. G. Luth, from KLA Inc. and the teaching team. The project team of the music hall consisted of architect Harry Teague, structural engineer G. Luth, acustitian E. Cohen, detailer D. Rutledge, and contractor Shaw Construction. The WWW and MediaWeaver (Wei, 1994), a graphical database, were used to create a Web-based information archive that describes the case study project and can be shared and accessed by both faculty and students "anytime, anywhere." MediaWeaver provided a computational infrastructure to capture, index, and search graphical information consisting of pictures and AutoCAD files that can be shared over the Internet. Students could learn more about the discipline issues of the case study by searching the project database on a particular discipline of interest (e.g., architecture, structure, construction) and at different levels of detail (e.g., music hall interior view, structural conceptual layout, retaining walls, excavation).

Shared WWW Project Workspace. A shared WWW workspace is created for each AEC project team to archive, share, access, and retrieve project information that ranged from sketches, VRML product models, Word documents, Excel spreadsheets, AutoCAD drawings, e-mail notes, and CAD-related change notifications (Figure 10.6). The shared WWW project workspace includes private workspaces for individual team members, shared workspace, and hypermail archive that contains a log of all the electronic interactions between team members, students, and faculty members and students and industry mentors. Each AEC student team managed its shared WWW project workspaces and provided access permissions to faculty and industry mentors on an as-needed basis. This emulates the industry environment with intranet and extranet permissions to specific project information.

Figure 10.6
Illustration of Shared WWW Project Workspace



Digital Sessions. The IT sessions, PBL lab sessions, and AEC professional practice sessions are digitized and stored as digital modules. This enables the students to review the material anytime, anyplace. They can go through the material at their own pace and revisit ideas, concepts, or debates related to critical issues. The digital modules are created using Microsoft Windows Media technology.

AEC Team Discussion Forums. The AEC Team Discussion Forum was developed at PBL lab at Stanford to support the asynchronous interactions among distributed team members. A private discussion forum is set up for each team to facilitate the capture, sharing, tracking, and reuse of ideas, issues, topics, and project solutions. Team members can establish a series of interactive forums at different levels of granularity (i.e., general project forum, design concept forum, component design forum, design alternative forum). The key impact in using the discussion forum is an emerging collaboration process in which collaboration is initiated before design begins. That means that team members identify and communicate their goals, constraints, and concepts before they start to define concrete solutions for their building project. Consequently, cross-disciplinary exposure, awareness, appreciation, and understanding are built during this process.

Another result of using this tool is the capture of the design rationale and process itself, which enables further reuse and analysis of project progress.

Internet-Mediated Synchronous and Asynchronous Collaboration through Information, Knowledge, and Product Model Capture, Sharing, and Reuse

ProMem (Fruchter, 1996; Fruchter et al., 1998; Reiner & Fruchter, 2000) is used as an integration environment to support the development of a shared building model that uses an AutoCAD graphic representation as the central interface among designers (human-to-human) and as the gateway to tools/services (human-to-machine) in support of interdisciplinary design. This computer-based graphical environment enables designers to share and explore designs; capture multicriteria semantics; and design rationale critiques, explanations, and change notifications. ProMem enables AEC team members to explore the different cross-disciplinary issues and allows them to

- *Augment* shared graphic product models with the (1) team members' intents, interests, and responsibilities, and (2) formal and informal design rationale, knowledge, and information
- *Gather networked information* by using the discipline models to customize their search for additional discipline information
- *Analyze and evaluate* the discipline models to derive building behavior and compare it to function
- *Explain* the results to other members of the team
- *Capture* versions at different levels of granularity, such as feature, discipline perspective, and project level
- *Create* private, public, and consensus versions in a hierarchical archive
- *Infer* shared interests and route change notifications with regard to a modified feature or perspective
- *Visualize* the design evolution of features, discipline perspectives, and the overall project
- *Reuse* previous alternatives

Gathering network information using the *WWWCoach* tool (Fruchter & Reiner, 1996), analyzing and evaluating designs using networked services, and explaining evaluation results using knowledge based tools like *Comfort* for passive energy conservation critique and *Egress* for floor plan egress evaluation (Fruchter, 1996), *QLRS* (Fruchter, Krawinkler, & Law, 1993) for qualitative structural analysis, CMM (Fischer & Aalami, 1996) for constructibility evaluation are beyond the scope of this discussion. These tasks and the tools supporting them have been presented in a previous paper (Fruchter, 1996).

The information and knowledge related to the shared product model is organized by ProMem as follows:

Graphics Objects contain Drawing Interchange File (DXF) representations of the graphic model entities.

Interpretation Objects encapsulate features for a particular perspective. An *Interpretation Object* has two primary attributes: a list of *Feature Classes* and a list of *Feature Objects.* Feature Classes provide an ontology to describe the semantic meaning of the graphics within a context. This ontology can be defined or augmented by the user at run time. The list of *Feature Objects* is edited by the user and contains the instances from a particular graphic model that are relevant to an interpretation.

Feature Objects capture the link between graphic entities and symbolic entities. We define a feature to be a constituent element of a design that has meaning to a designer within a particular context. The basic components of a *Feature Object* are a *Feature Class,* an identifier or *Feature Name,* and a list of *Graphics Objects.* Other information objects can be linked to *Feature Objects* such as *Note Objects, HyperLink Objects,* and *Notification Objects. Feature Objects* allow graphic entities to have multiple meanings within different interpretations.

Person Objects serve as a record of the project participants and their declared roles and interests. A *Person Object* consists of the designer's name, a user name, a user password, an e-mail address, a list of responsibilities, and a list of interests. *Person Objects* can be added, updated, and deleted by the users. The lists of interests and responsibilities are used by ProMem to infer which team members should be sent e-mail notifications about changes to a portion of the design.

Note Objects contain text written by the project members. *Note Objects* are used to capture the design rationale or other design-related information that a designer traditionally records in notebooks, memos, and so on. Notes are encapsulated in *Feature Objects* to describe design requirements or intents. ProMem's *Note Browser* allows the user to browse and search *Note Objects* to locate specific *Feature Objects* or *Interpretation Objects.*

HyperLink Objects provide a mechanism to link a *Feature Object* to sources of information. ProMem currently handles references to World Wide Web (WWW) pages and electronic images. A feature in the graphic model can be linked to component specification sheets, code pages, structural details, schedule, and cost information available on the WWW or a photo of a prototype. Additional functions enable the user to launch AutoCAD sessions with specific 3-D product models from within the shared WWW project workspace of a team.

ProMem facilitates the use of the shared 3-D CAD product model and the project WWW workspace as navigation vehicles that enable the team members, project manager, or owner to access and retrieve project information and knowledge (Figure 10.7).

Notification Objects record the communications among the designers and are routed in asynchronous mode. These notifications can be used to solicit feedback, to give approval, to broadcast change notifications, or to initiate negotiations. A *Notification Object* consists of

- *Feature Objects,* the focus of the notification
- Affected *Interpretation Objects,* which share an interest in the *Feature Objects*
- *Person Objects,* the mailing list
- A *Note Object,* which describes the rationale or situation.

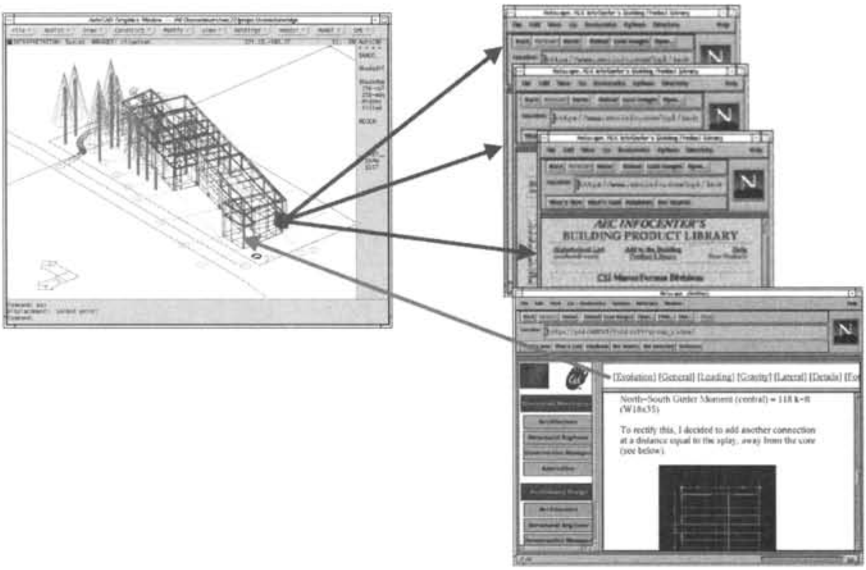
Notification Objects are stored as a part of *Feature Objects* in the shared product model.

ProMem enables AEC team members to explore the different cross-disciplinary issues among architectural and structural form modeling and constructibility.

Videoconferencing and Desktop Sharing

Multidisciplinary design teams are often geographically distributed, which implies a large time and budget allocated for traveling to meeting places. *Video conferencing* (i.e., Kodak systems NetMeeting, and ProShare) provides the medium that can take the *distance* out of distance learning. These videoconference technologies enable participants to share drawings and documents in AutoCAD, Word, Power Point, and other applications and collaboratively edit their products. This provides the necessary medium for the AEC teams to have virtual face-to-face meetings between AEC team members, AEC design teams, and "owners," industry mentors and faculty who were in different geographic locations, to discuss the design solution in real time. NetMeeting and ProShare videoconferencing were successfully used over Internet and ISDN lines in four different distance-learning scenarios:

Figure 10.7
Use of Shared 3-D CAD Product Model and WWW Project Workspace as Project Information Navigation Vehicles



Face-to-Face Meetings in Cyberspace. AEC team members who were geographically distributed over two or three university campuses had weekly project review meetings.

Distant-Learning Lectures. Students and faculty from all participating universities engaged in real-time interactive lectures in a geographically distributed setting.

Office Hours in Cyberspace. The videoconference with desktop sharing session enables the student team and faculty to focus on what-if scenarios, manipulate and edit the content of documents and AutoCAD models.

Final Project Presentations. The videoconference technology enabled practitioners and faculty members to participate in the project presentation session at the end of the AEC course.

ASSESSMENT OF AEC CROSS-DISCIPLINARY LEARNING

The PBL lab presents a new metric *cross-disciplinary learning (CDL)* as a journey from the state of *island of knowledge* (discipline-centric) to a state of *understanding* of the goals, language, and representations of the other disciplines (Fruchter & Emery, 2000). The CDL metric and assessment method proposes a four-tiered classification, designed to measure the students' evolution of cross-disciplinary learning that is based on the perspectives of cognitive and situative learning theories. The four tiers are

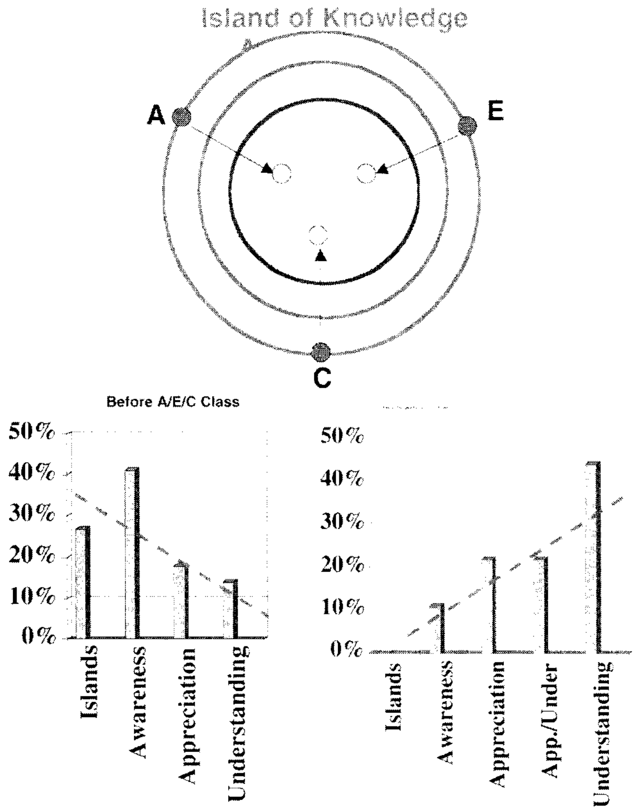
- *Islands of knowledge:* the student masters his/her discipline, but does not have experience in other disciplines.
- *Awareness:* the student is aware of the other discipline's goals and constraints.
- *Appreciation:* the student begins to build a conceptual framework of the other disciplines, is interested to understand and support the other disciplines' goals and concepts, and knows what questions to ask.
- *Understanding:* the student develops a conceptual understanding of the other disciplines, can negotiate, is proactive in discussions with participants from the other disciplines, provides input before the input is requested, and begins to use the language of other disciplines.

This classification is grounded in the situative perspective—that effective participation in practices of inquiry and discourse leads to conceptual understanding and skill acquisition.

The methods used for data collection in the CDL assessment of the AEC students were based on surveys and ethnographic observation of AEC team interactions. The surveys were developed and distributed online in an interactive format for self-administration by the students. Students responded to a questionnaire in which they were asked to reflect on the interaction between team members. The students were asked to situate themselves within the four classifications of cross-disciplinary learning (*Islands of Knowledge, Awareness, Appreciation, and Understanding*). This request was posed at three distinct moments during the two quarters—at the start of the program, at the end of the first quarter of the program, and at the end of the second quarter of the program. Students were also required to provide rationales for their assessment. Ethnographic observation included videotaping, transcribing, and analysis of synchronous team meetings to determine key moments in which individuals or teams demonstrated awareness, appreciation, or understanding of another discipline. In addition, observations were conducted of asynchronous team interaction, via e-mail and online communication programs such as discussion forums and shared Web workspace.

Figure 10.8 presents the evolution of cross-disciplinary learning per class, recorded before the class began and at the end of the first quarter. At

Figure 10.8
Assessment of Cross-Disciplinary Learning Evolution



the beginning of the first quarter, 27 percent of the students identified their interaction with other disciplines as *Islands of Knowledge*. These students recognized that they were masters of a particular discipline, but did not have experience in other disciplines. Forty-one percent of the students claimed *Awareness* of other disciplines' goals and constraints, and 18 percent of the students responded that they demonstrated *Appreciation,* an active interest to understand and support the other disciplines' goals and concepts. Fourteen percent of the students claimed a full *Understanding* of the other disciplines. Further data showed that these students had a 1 to 3 years' working experience. The data shows that 68 percent of the students had yet to achieve appreciation or understanding of the other disciplines—this confirms that indeed AEC students, at the entry graduate level, have little experience with the disciplines they will collaborate with in the industry.

At the end of the first quarter, the class as a whole showed progression toward understanding. In Figure 10.8, no students remained in *Islands of Knowledge*, 11 percent of students claimed *Awareness* of other disciplines, 22 percent claimed an *Appreciation*, and 22 percent of the students defined a new classification, *Appreciation/Understanding*, to represent movement beyond Appreciation, but not full *Understanding* (44%). At the end of the first quarter, 88 percent of students classified themselves as having achieved an *Appreciation* or *Understanding* of other disciplines.

An additional key metric is based on a longitudinal assessment that can track the programmatic changes that such a cross-disciplinary education program can lead to. More specifically, a survey posed the following questions: *After this experience, do you plan to take any courses in any of the other disciplines? Which topics?* Preliminary studies of the past five AEC generations indicate that a large percentage of the students take classes in the complementary programs after going through the AEC program. For instance, architects take construction classes, structural engineers take costing and scheduling classes, and construction management students take structural design classes. Results of this study indicate that at the beginning of the course, only 25 percent of students were interested in taking courses outside their discipline. At the end of the first quarter, 75 percent of the students planned to pursue courses in another discipline.

The results demonstrate the use and effectiveness of the assessment methodology, data collection, and analysis. The assessment metrics and method will be used in the future AEC classes for further validation and improvement.

OBSERVATIONS AND CONCLUDING REMARKS

Engaging AEC Global Teamwork e-Learning Environment

Information technology augmented learning can play an adjunct role to the traditional classroom instruction or be a primary delivery system for distributed learning courses. It can provide the following pedagogical benefits and better end products:

- Immediacy—especially compared to the print-based correspondence courses
- Sense of group identity—the shared project workspace becomes a meeting place for students, faculty, and industry
- Improved dialogue—students interact and articulate their issues more than in traditional classroom settings

- Improved capture, sharing, access, and retrieval of logged activities
- Active learning—students' participation improves

There is evidence that IT enhances the interaction among participants and course content. The impact of IT and IT-mediated mentoring on teaching and learning includes key transitions:

- From passive to engaged learners: the dominant model of learning has been for the student to passively absorb knowledge disseminated by the professors and textbooks. With IT, students can move away from passive reception of information to the active engagement in the construction of knowledge.
- From coverage to mastery: traditional courses give students problems that they can solve using theory and knowledge taught in traditional discipline courses (i.e., *know-what* and *know-how*). The use of IT in project-based learning can guide students to discover disciplinary and interdisciplinary objectives and thereby to develop *know-why* knowledge in an interdisciplinary context.
- From classroom problems to real-world projects: too often students walk out of the class ill equipped to apply their new knowledge to real-world problems and contexts. Conversely, too frequently the course examines concepts that are out of the context of real-world projects. IT can help break down the walls between classroom and the real world.
- From text to multiple representations: linguistic expressions can be augmented by multidisciplinary and multimedia representations.
- From products to process: we can move past a concern with the products of academic work to the processes that create knowledge. Students learn how to use IT tools that facilitate the process of scholarship.
- From isolation to interconnection: IT helps students move from a view of learning as an individual act done in isolation toward learning as a collaborative activity. In addition, ideas and concepts are examined in multidisciplinary contexts.

Observations of IT deployment and use indicate:

1. Deployment of any information or collaboration technology requires a transition period in which the users and team change their work habits and the way they interact, share, and communicate. For instance, students need between two to three weeks to adapt and adopt videoconferencing tools like NetMeeting.
2. That no communication media and resources (e.g., e-mail, phone, shared Web Workspaces, or NetMeeting videoconference) can replace the

effectiveness of face-to-face meetings. However, the next best to face-to-face interaction is videoconferencing with application sharing. The current drawbacks of videoconferencing on the Internet are bandwidth and quality of audio that is again a function of the available bandwidth.

3. Some of the social dynamics observed in face-to-face project review meetings are emulated in cyberspace interaction environments such as videoconferencing. For instance, after a collocated meeting some participants leave and some continue to discuss a critical issue that remained unresolved during the meeting. Observations in the AEC class show that students continued to discuss informally design decisions and issues in a NetMeeting videoconference, after the formal meeting concluded. Data collected in 1997/1998 illustrated a videoconference scenario in which a team with the architect at Georgia Tech, structural engineer at Cal Poly, and construction manager and two apprentices at Stanford, concluded their formal meeting. The three Stanford students left the meeting. NetMeeting session was still going on. The architect from Georgia Tech, however, continued to discuss with the structural engineer at Cal Poly a critical design conflict related to the location of some columns in the area of an auditorium. During this informal discussion that emerged spontaneously, both students brought up additional CAD models and analysis results through application sharing. The informal debate continued for another 20 minutes after the closure of the formal meeting, until a consensus was reached.
4. Trust in virtual teams is one of the most challenging efforts. AEC team members have to learn to build and maintain trust, as well as recover from situations of trust failure (Zolin, Fruchter, & Levitt, 2000). In PBL students learn that trust is the deciding factor in a social process that leads to a decision to accept a risk that another party will meet certain behavioral expectations.
5. Effective cross-disciplinary global teamwork performance requires early and continuous awareness of multicultural behaviors with respect to time, information flow, language, context, and preferred communication channels (Fruchter & Townsend, 2001).

Because of the widespread access provided by IT, the way we teach and pass information to learners around the world will change from the traditional teacher/classroom environment to interactive hybrid collocated and e-learning environments.

Challenges

Computer support for collaborative teamwork is still in the early stages of development. Robust integrated systems are needed that link commercial applications in a seamless fashion and support interoperability and information exchange and communication in heterogeneous network computer hardware and software.

Web environments and networking programs today allow information sharing among team members. However, linking applications on an as-needed basis still needs major developments in the industry sector and standards for interoperability. Key industry efforts that address these issues are under way, such as the Industry Foundation Classes (IFC) effort initiated by Autodesk, the Industry Alliance for Interoperability (IAI), and STEP.

The AEC course is an innovation; like most innovations, its implementation is hardly straightforward. Numerous barriers have to be resolved. In order to encourage such PBL endeavors the institution has to put in place the necessary support and reward system. Development, field testing, and revision of PBL courses is time, resource, and budget intensive. Faculty members have to be ready to invest the effort to develop and manage a PBL course, establish the IT infrastructure, and train support staff. Having departmental and institutional support is crucial. Finally, engaging practitioners in this type of teaching and learning endeavor will prove beneficial to both the education and industry environment. Practitioners play an active role in educating the new generation of professionals. They offer their expertise and real-world project case studies and are exposed to cutting-edge IT tools that can provide a competitive advantage to their companies.

Concluding Remarks

Assessing and responding to the rapidly changing information and collaboration technologies and their impact on the global business environment are continuous challenges that industry and education are faced with. As we establish new learning and working environments that exercise collaboration technologies, a number of quandaries arise and have to be addressed in future research. These include

- How should IT be treated in any deployment plan? The author conjectures that information technology deployment in both academia and industry should not be treated as a "fix" to a problem, a project, or an organization, but rather as a strategic plan that takes into consideration four key factors (i.e., technology, culture, economics, and politics).
- How does each IT change the behaviors of the individual, team, and organizations? The author conjectures that any information technology changes the communication patterns in the organization and requires

new communication protocols not only at the technology level but also at the social and business model level.

The AEC education program offers an excellent test bed to conduct empirical studies of the impact of specific IT on the interaction among people and the formalization of new communication patterns and protocols.

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11

Sharing Tacit Knowing or Informal Information in Remote Design Collaboration

Ryusuke Naka

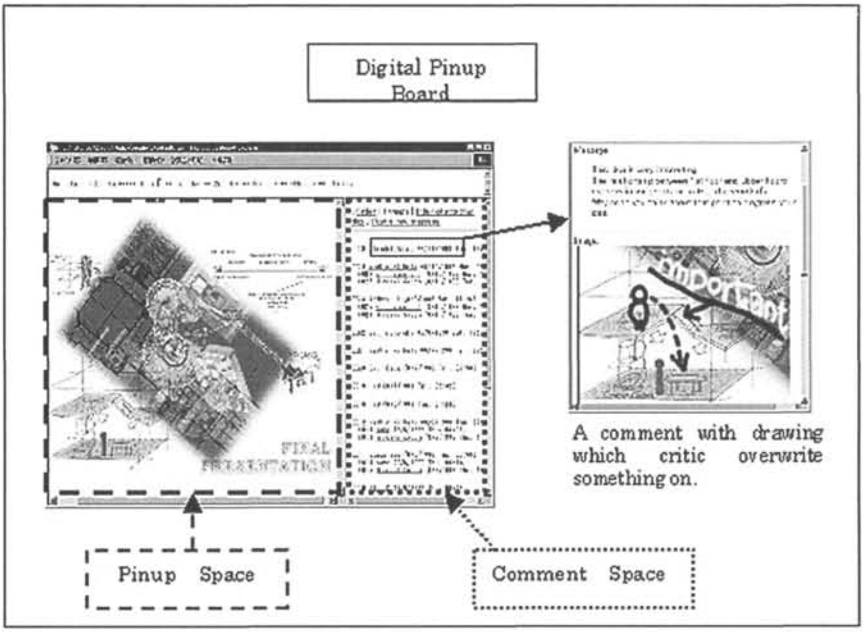
CONVENTIONAL COLLABORATION VERSUS REMOTE COLLABORATION

According to Michael Polanyi (1966), the ultimate devices used to gain knowledge of the "outer" world, whether intellectual or practical, are our bodies. In a conventional collaboration, human bodies as "the ultimate devices" are fully utilized because members work at the same location; meanwhile, in remote collaboration (RC), at present, our bodies are not utilized as such because members often work far from each other (Cheng et al., 1994; Mitchell, 1994; Wojtowicz, 1995; Yee et al., 1998). One of the functions of the body that is not utilized in RC is the sharing of informal information or "tacit knowing." RC is carried on by using text-based communication tools, such as e-mail or an instant messaging system, a Web-based information sharing system such as a digital pinup board (DPB), teleconferencing, and so on (Naka et al., 1999). RC greatly differs from a conventional collaboration in the respect that asynchronous communication being conducted among those who are not in the same location has increased. In addition, the naturally occurring opportunities for members to share the same time and location have decreased. In RC, information is mainly based on text exchange and what cannot be sent as a text file is put on DPB or a similar program. Conferences are conducted by using teleconferencing and application sharing systems. Thus, it has become possible to conduct conferences in a similar functional condition as that of a conventional one, except that interchange of an actual object cannot be made. Participants can have a real-time talk with each other and look over same documents or data synchronously. They can take notes and point to specific parts on documents. RC seems to function well enough. Still, it is very different from collaboration on work conducted at the same location. What, then, is different about it? Communication between participants who are separate from each other includes necessary information, but cannot include what is conveyed unconsciously among those who are working in one room. Though necessary information such as meeting schedules, results of surveys, opinions, project plans, and so on can be conveyed, informal information on the physical or mental condition of the addresser cannot be conveyed by this method. For example, the addresser might feel sick or might be angry. Of course, within one location, it is impossible to grasp the other participant's emotional condition perfectly. Still, they get much more information from each other working in collaboration. A significant difference between RC and conventional collaborations seems to be in the quality of the conveyable information.

CONVEYABLE INFORMATION

Communication (in collaboration) is conducted with the purpose of conveying something to other members. Here we call the information that is intended to be conveyed "primary information" (Figure 11.1). This information is conveyed through text or image data. Most of the information that we intend to convey is primary information. However, it does not include all that we hope to convey to others. In order to make ourselves understood, it is necessary to convey something vague that is sometimes called nuances; we will call it "secondary information." This is information relating to the general atmosphere, the condition of the speakers, and so on, which cannot be conveyed directly or intentionally. How can such information then be conveyed? Such information is exchanged among those who are physically in the same space. They get such information through other members' expressions or the atmosphere of the situation. In RC, this type of information cannot be conveyed. You can only feel that your counterpart is in a bad mood if you are both in the same location. However, in teleconferencing, in which you can see only the face of your counterpart, it is difficult to know their true emotional condition. Exchanging primary information through text rarely includes this type of information (secondary information); an important issue for RC is how to convey it. At present, it is of no use to expect everything to be conveyed. If you have something you cannot convey by RC, then you should meet and com-

Figure 11.1
Example of Primary Information Conveyed in RC, Consisted of Texts and Images



municate with the concerned people in person. The important consideration is to understand what can or cannot be conveyed by RC and, when necessary, to meet your counterpart to convey it. At the same time, it is necessary to make efforts to convey as much as possible by RC.

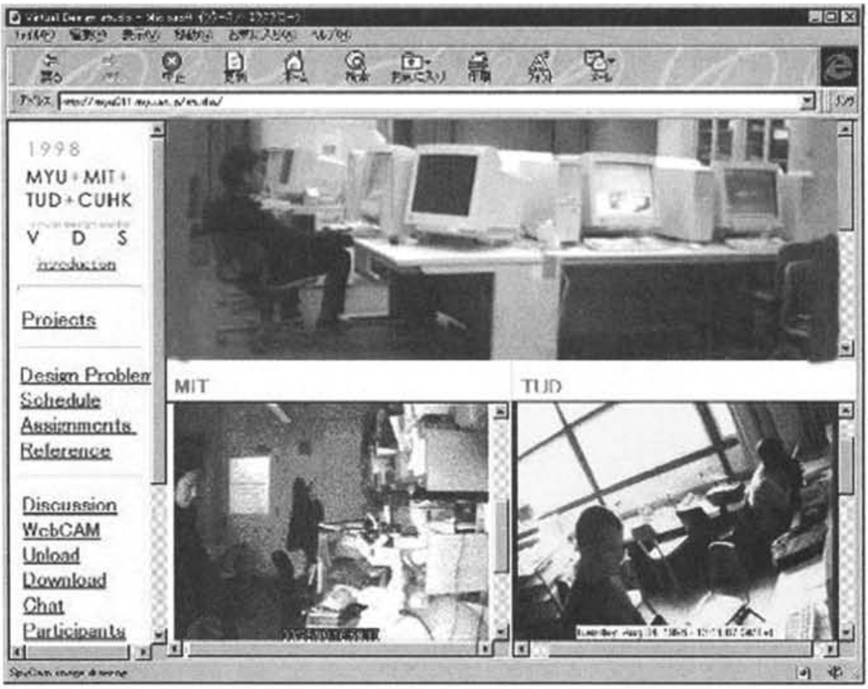
SHARING SECONDARY INFORMATION

First, we will clarify the contents of primary information and secondary information. Then we will discuss how to communicate secondary information that cannot be conveyed by RC.

Primary Information

- Information on business (plans, various reports, draft prepared and circulated by the person in charge to obtain the sanction to a plan, various inquiries)
- Information on office administration (schedules, clerical work)

Figure 11.2
Example of WEBCAM, It Shows Workspaces at Japan, Boston, and Germany



Secondary Information

- Informal information (attributes of individuals, groups, locations, and so on)
- Atmospheric information (complexions, mental conditions, and circumstances of other members, the atmosphere of the location, the passage of time, and so on)

Important factors for secondary information are "location" and "people."

Location

Location in RC consists of a virtual common space on the Internet and separate multiple real spaces (Cheng et al., 1994; Hirschberg et al., 1999; Kolarevic et al., 1998; Mitchell, 1994). Each participant in the RC possesses at least one real space as his/her own position. The real space might either be shared by more than one person or by one person only. However, no work is conducted with all the members at one location. RC is carried on by using networks and teleconferencing systems; members seldom visit each other's workplace. It means that members do not get any information on where or how others are working. Only the results are conveyed via this network. They can see, if anything, a little bit of the interior of the location where other members are working only when they attend a videoconference.

When all members are working at one location, they naturally have a sense of sharing a common location. They can see other members working, talk to each other at any time, and know who is there and what is happening. This type of information is obtained naturally and easily in a conventional collaboration, but it is quite difficult to communicate such information in an RC setting. This type of information is very significant to carrying out collaborative work, though it can be done without such information. We can work in collaboration without knowing the atmosphere of the other members' workplaces or how they are working. However, in the many RC experiments conducted so far, WEBCAM (full details will be mentioned later) was used as a method to show the situation and atmosphere of each member's workplace. This means that there is a demand to show the situations and atmospheres of other members' working places. It seems that they feel uncomfortable when they are deprived of being in common locations that they used to enjoy in conventional collaborations. The following is our attempt to share secondary information as it relates to location.

WEBCAM. A home page is a place on a World Wide Web network that connects separate locations (Figure 11.2). This report does not give full details concerning these places, home pages, but it can be said that they provide a lot of primary information. Those places on the network need to have certain functions to convey secondary information to separate locations.

WEBCAM is one of the methods to connect locations. A camera was set in each member's room, and image data was presented on the home page every several minutes. Members could see whether it was bright or not at the opposite location, whether it was day or night (in the case of international collaboration, it is often night at one location and day at another location), whether the member at the separate location was working or at a meeting, and so on. However, simply describing the situation at the location is not so significant. It is important to convey the procedure of the work, the atmosphere, and the passage of time. Although it can hardly be said that WEBCAM fulfills this role completely, it seems to enhance the sense of sharing a common location among members.

Figure 11.3
Face-to-Face Meeting on Videoconference

Double Teleconferencing: Teleconferencing Using Two Sets of Teleconferencing Systems. In teleconferencing, members can see each other's faces, which naturally enables them to make better communication with each other (Figure 11.3). Real-time image data (atmospheric information) can be sent synchronously along with primary information. However, image data, in ordinary usage, can only present a small amount of secondary information, such as the speaker's face and a small amount of background. Therefore, we prepared two sets of teleconferencing systems. One was for presenting the speaker's face and surroundings. The other was for presenting an image that encompasses the whole room (Figures 11.4 and 11.5). This enhanced realism and communication was successful. For example, members could grasp not only the surroundings of the speaker but also that of all other members in the same room at the other end of the line. That every participant could grasp the physical situation of all the participants is quite significant. However, showing the entire situation without the speaker's expression is not enough. This is why two sets of teleconferencing systems are needed to present both the whole situation

Figure 11.4
Video Conference Using Document Camera

Figure 11.5
Videoconference Seeing Speaker's Face and Whole Room

and the speaker's expression. The problem is that communication costs double.

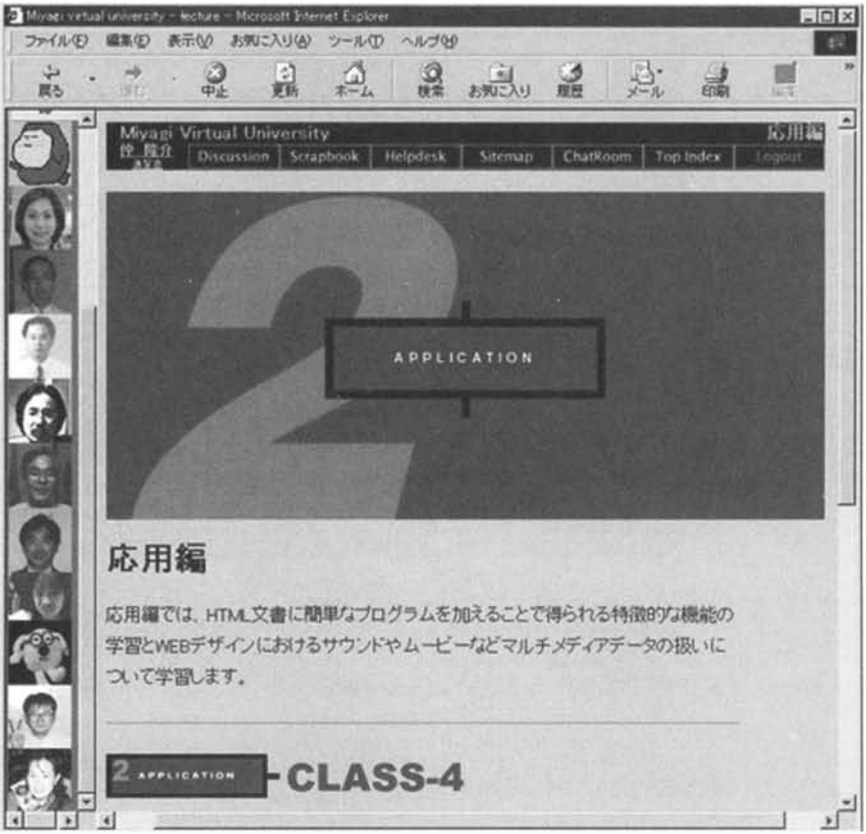
People

In RC, it is difficult to see those one is communicating with. When primary information only is exchanged, we sometimes feel inclined to want to know about the person who is sending it. In fact, knowing the personality and the situation of the person who is sending it sometimes affects the significance of primary information. It is necessary to convey as much information as possible on members in order to truly connect them with one another. We need to establish systems for connecting people, not only for just sending information. This report introduces a few such systems, though they are still in their infancy.

Virtual University (VU). Students study at the university on a computer network (VU), which is accessible at home. Most students sit in front of a computer, have access to textbooks, and work on exercises after they return home from work. When they submit exercises through the network after they finish them, teachers send them back with their comments to the students. What is going on in the real space is that students sit at computers. It seems to be solitary work. In an ordinary university classroom, students can see who is there, and they can talk to each other if they like, which is not available at VU. Then, we prepared pictures of the students. When a student logs onto VU, pictures of those who log in appear on the screen (Figure 11.6). If the student feels like talking to someone, he/she can send a message to that person's computer by pointing and clicking on the person's picture. Some students may discover that many fellow students are studying hard and others may find very few colleagues and decide to cease to attend VU. Getting information on fellow students is very significant. This helps students feel that VU is a substantial university, and a sense of fellowship is created among them. This was well received by participants. The positive effect of this idea was demonstrated in a collaborative work conducted as a graduation exercise, where members carried out the work in a friendly manner, as if they had been classmates in a conventional university.

Diary. We also made an attempt to convey secondary information in a joint design exercise conducted between an institute in America and one in Japan. As both locations were far apart and we knew little about each other, we put pictures on the home pages showing how members were working and progressing on the exercise. This allowed participants in either location

Figure 11.6
Pictures of Those Who Log in Appear on the Screen



to know one another's situation very well (Figure 11.7). Though it required a significant amount of time and labor to set up, it was well received by teachers. The teachers who could not participate directly in teleconferencing were especially impressed and enjoyed the diary. They were so enthusiastic that when the Web master was late in updating the diary, the teacher in charge sent an e-mail and urged the Web master to hurry.

The same attempt was made at VU, where participants at different locations posted his/her own personal information. One posted his children's pictures; another used a picture of his favorite machine (Figure 11.8). This contributed to the promotion of friendship between members (Figure 11.9).

Location for Chatting. If people work at one location, they have many chances to exchange information by chatting during lunchtime and so on.

Figure 11.7
Pictures Showing How Members Were Working

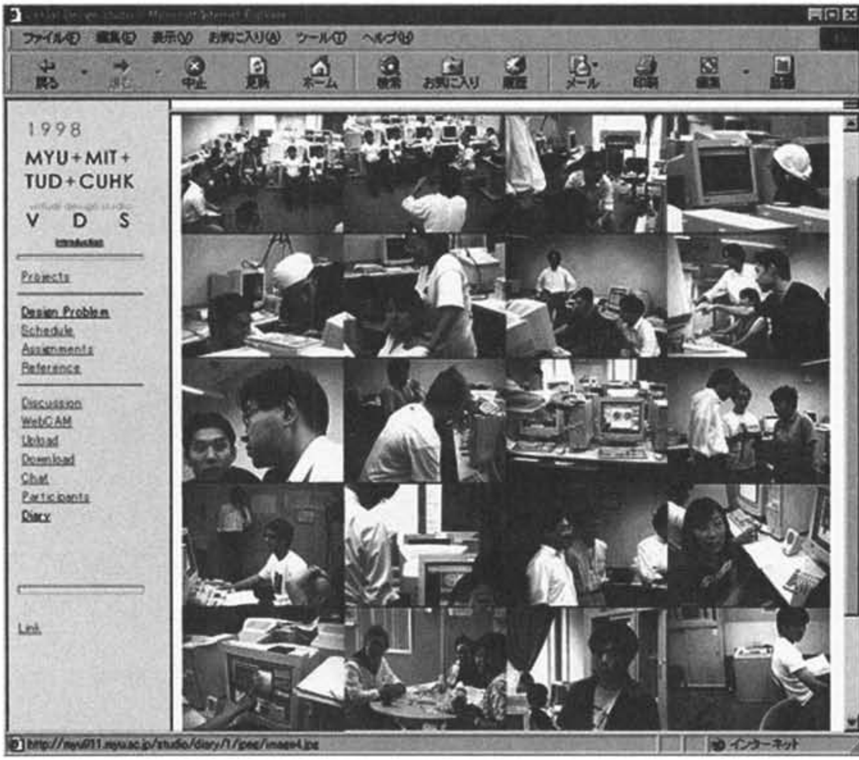


Figure 11.8
Children's Pictures and Picture of His Favorite Machine

Figure 11.9
A Teacher Introduced Himself by Presenting His Own Picture

In principle, RC does not provide such chances. So we established a location at which members were free to chat about issues apart from their work. This was a location for members to communicate either synchronously or asynchronously. Informal communication between members enhanced collaboration at work and members were encouraged to use such chances. However, the chat space for synchronous communication was not so popular (Morozumi et al., 1999). This may mean that adjusting time was difficult for members who are separate from each other.

CONCLUSION

"Symbolism, cosmology, and performance, play important roles in grasping the 'outer' world by common perception" (Nakamura, 1984).

It will be interesting to assume that the symbol, cosmos, and performance in RC are represented by home page, location, and people, respectively. Home pages have come to bear significance as a symbol that eventually clarifies the significance of location and people, as well. This way of thinking leads to the idea to make efforts to gain a better view of people as a performance. It can be also assumed that the reason why participants seek more information about location is that they feel that they have lost location as a "cosmos" when being separated physically.

As Michael Polanyi (1966) pointed out, it is fundamentally wrong to believe that grasping the details of a thing will lead you to understand the whole nature of the thing. In other words, accumulation of information on something does not necessarily lead to the development of the whole image of it. It may mean that even if we convey various kinds of secondary information to each other, we still cannot present a reality that we can perceive as being compete. If this is so, it might be dangerous to expect too much from RC. It is still too early to come to any conclusion. The theme of our future work will be to establish, through trial and error, a method for grasping various kinds of information more comprehensively.

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12

Remote Computer-Generated Physical Prototyping-Based Design

Alvise Simondetti

INTRODUCTION

This research explores some of the opportunities offered by the field of computer-aided design. It differs from much of the research in this field (Mitchell, 1998) in the sense that it extends beyond the boundaries of the computer—what is commonly referred as "getting out of the box"—by building and testing a computation and communication design environment made of computers, computer peripherals, and digital communication devices.[1]

In this research we created a computer-based environment and observed a range of volunteer designers in the early stages of their design process. The focus of our observation was how these designers interacted with the environment with the aim of exploring the environment's advantages and limitations and found that it raised novel questions about research in computer-based environments. This ongoing research focuses on the exploration of the field of design for manufacturing using mass-customization systems.

This chapter describes (1) the computation and communication-based environments, (2) the methodology used to conduct the experiments, (3) its advantages and limitations, and (4) further possible research questions. The chapter focuses especially on unexpected outcomes.

TWO COMPUTATION AND COMMUNICATION-BASED ENVIRONMENTS

The designers produced a three-dimensional computer model and then used Rapid Prototyping[2] systems to produce three-dimensional physical objects. The three-dimensional computer models were produced using both traditional software, including AutoCAD, Rhino3D, and Alias, as well as algorithmically generated design alternatives (Duarte & Simondetti, 1997), including rule-based parametric methods and genetic algorithms. The Rapid Prototyping systems used were Fused Deposition Manufacturing (FDM) and Stereo-lithography (SLA), both available at the Industrial Centre in the Hong Kong Polytechnic University.

To enhance communication, the research team installed a series of videoconferencing systems over the Local Area Network (LAN) using Classpoint Software for multipoint continuous (24 hours a day) connections between the designer's workstation (Figure 12.1), the RP workshop, and the observer's workstation (Figure 12.2). We wanted to simulate the studio environment in which the designer concurrently sketches and produces physical models while being observed by the principal investigator. The designer made use of this setup for experiments that were conducted in the school of design.

For experiments conducted outside the school of design, we used e-mail. The designer would send three-dimensional computer files as e-mail attachments, and then three-dimensional physical models were produced in University's Industrial Centre. Photographic images of the models were then sent back to the designer, also as e-mail attachments. The observation was limited to personal comments sent back and fourth over e-mail; only in one case was the physical model sent back to the designer in Australia.

It is worth mentioning that we always respected each designer's inclination to use one traditional software or algorithm rather than forcing the designer to use those specific systems that better interface[3] with current Rapid Prototyping (RP) systems. Our choice resulted in all designers producing surface models as opposed to solid models, generally considered more appropriate for RP technologies. The same attitude made some of the experiments unique from a strictly technical point of view.

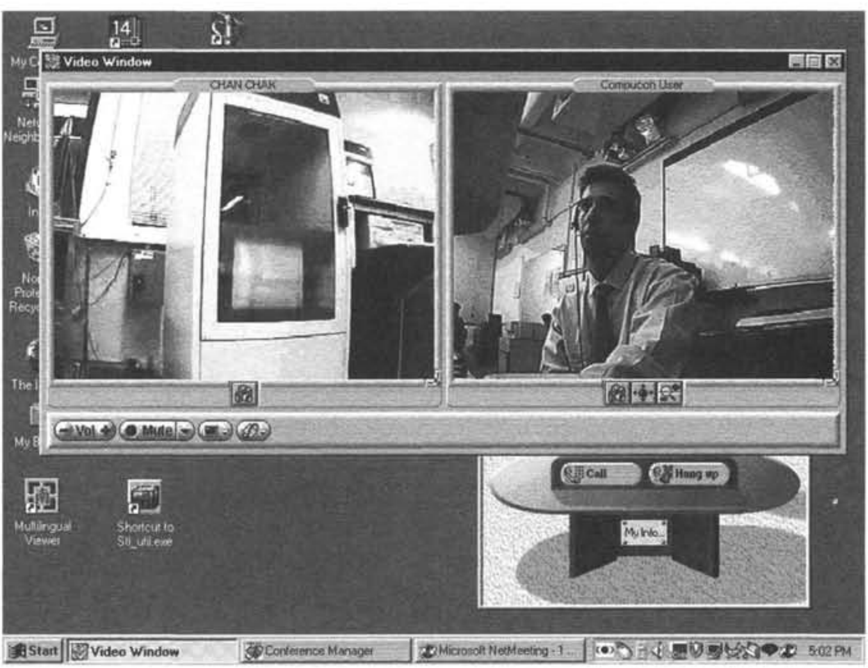
THE METHODOLOGY USED TO CONDUCT THE EXPERIMENTS

To explore the limits of this fast-evolving field of research and to secure immediate results, we conducted a series of case studies that seen together give a sense of the range of possible interaction with this technology and open questions for further discussion.

For example, to optimize the range of the experiments, the test group included designers geographically distributed in Hong Kong, India, and

Figure 12.1
Multipoint Videoconferencing Screen

Figure 12.2
Designer—RP Lab Videoconferencing Link



Australia. Designers ranged from highly educated practitioners to first-year degree students and even included a computer graphics programmer.

The aim of this broad methodology is to compare what designers do during the early stages of their design process, before and after the introduction of new technology. We then attempted to evaluate if and how their design process had improved by presenting the results to a panel of experts.

DESCRIPTION OF CASE STUDIES

The following case studies are listed according to the designer's level of experience and education, the stage of design development, and the level of access to the in-house environment.

Michael Cheng is a second-year student in the BA(Hons) course in the school of design. His knowledge of CAD software is above average within his class, although limited to the use of software for 3-D visualizations. Michael interacted with the in-house environment at a later stage in his conceptual design, when most of his decisions had already been made. Michael was able to fully and repetitively experiment with the in-house environment (Figures 12.3 and 12.4).

Manit Rastogi practices and teaches architecture in New Delhi and has previously carried out research in design and computation (Frazer, Rastogi, & Graham, 1995). Manit has an expert understanding of CAD, CAD programming, and architecture. He did not interact with the in-house environment. He e-mailed the design to the principal investigator, who generated a physical model and e-mailed an image of it back to him. Manit produced a Genetic Algorithm code in AutoLISP for AutoCAD to generate the design. He generated a three-dimensional cellular automata (CA) using closely packed spheres (Frazer, 1995). The designer used a mapping algorithm that generates surfaces through the points of the CA (Figure 12.5). The complexity of the surface is controlled by the complexity of the rules of the CA generated using genetic algorithms that in this case evolves for increasing complexity. The designer has frozen one instance of the evolutionary data space and produced a physical prototype (Figure 12.6).

The code generated a surface model of the design with intersecting surfaces. The AutoCAD software couldn't export the .stl file necessary to prototype the design. A utility software, downloaded from the Web,[4] was used to generate the .stl file.

Michelle Flowry, Grant Dunlop, and Gregory Duncan are first-year students in the master of architecture course in Deakin University, Australia.

Figure 12.3
Michael's Design (Sketch model)

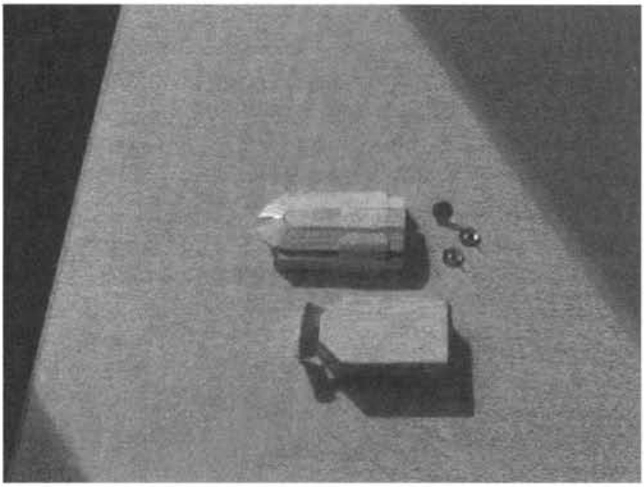


Figure 12.4
Michael's Design (FDM model)

Figure 12.5
Manit's Design (CAD)

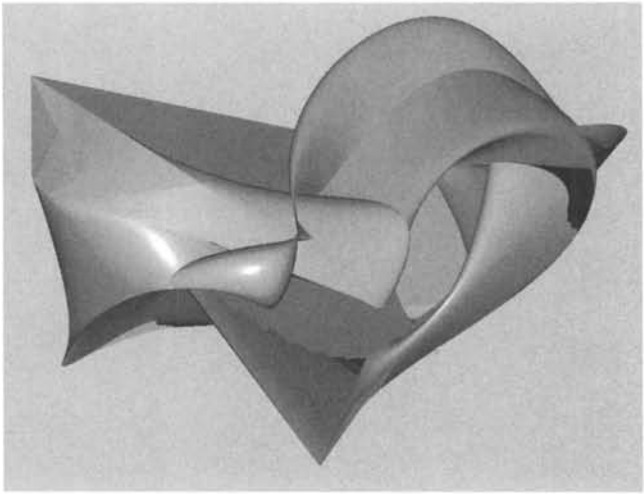
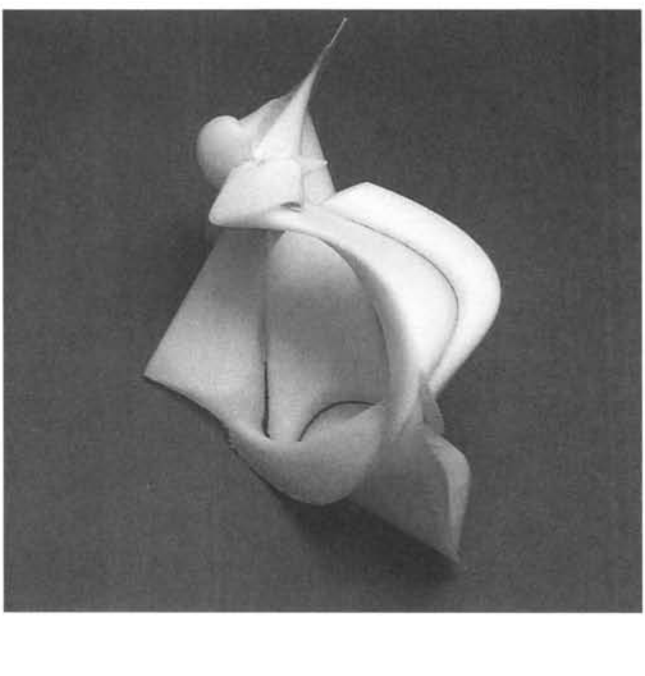


Figure 12.6
Manit's Design (FDM model)



Their designs (Figure 12.7, Figure 12.8, and Figure 12.9) were produced for a course offered by Prof. Mark Burry, which is aimed at teaching "programming for enhanced CAAD productivity and design capability."[5] The students sent their files by e-mail and received images of their physical prototypes.

Benny Leung is a senior industrial teacher currently teaching at school of design. His three-dimensional computer model was created by his assistant. Benny did not interact with the in-house environment because he did not personally use the computer. His design was already partially developed (Figure 12.10). When Benny received the physical prototype (Figure 12.11), this was his first reaction: "If we look at the drawing it is not that thin, when you made the prototype something must have happened…". He added: "I do appreciate the slightly translucent white colour." The designer's reaction suggests that he is getting new types of feedback from the 3-D prototype.

Chan Kwai Hung received graduate education in computer science. He is currently conducting research in the field tools for algorithmically generated designs in school of design. Hung was mostly concerned about his process of developing a generative design tool. Therefore, the design instance that was prototyped did not represent a memorable step in his process and did not produce the kind of feedback that is necessary for his work. Professor Frazer, the leader in Hung's research, commented that the physical static prototype represented a trivialization of his evolutionary design, intended to be experienced over time, or in the fourth dimension.

ADVANTAGES AND LIMITATIONS OF THE ENVIRONMENT

The following comments are in addition to the results of previous research conducted in a similar environment by the author (Simondetti, 1998). In that earlier study, major advantages to the designer offered by Rapid Prototyping Systems were identified in haptic feedback, feedback on designs in motion, and feedback on complex free-form designs.

Computer Generated Physical Prototyping[6] Based Design environments evidently appear limited in providing the feedback necessary to help the designer proceed when confronted with a design, as in Manit's and Hung's case, that is an instance of an evolving data space. In a limited number of generations, these designs begin to show complex interpenetrated surfaces. From a technical point of view, interpenetrated surfaces proved challenging for the slicing software that prepares the files for rapid prototyping.

Figure 12.7
Michelle's Design (CAD)

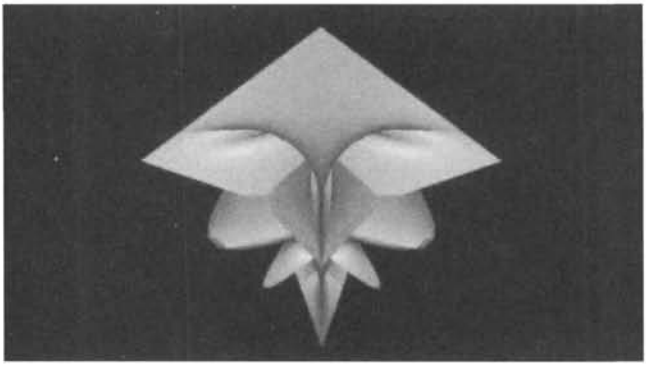


Figure 12.8
Greg's Design (CAD)

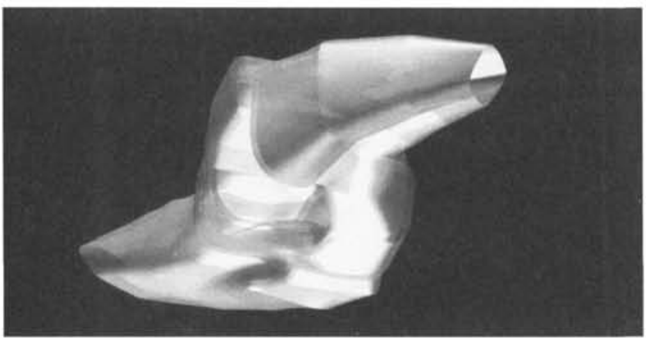


Figure 12.9
Grant's Design (CAD)

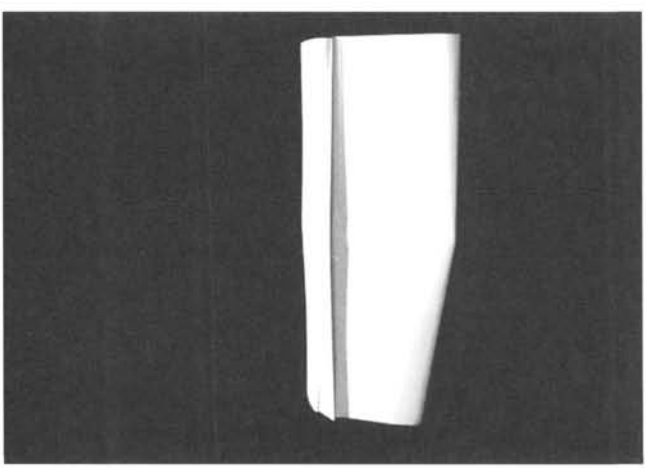
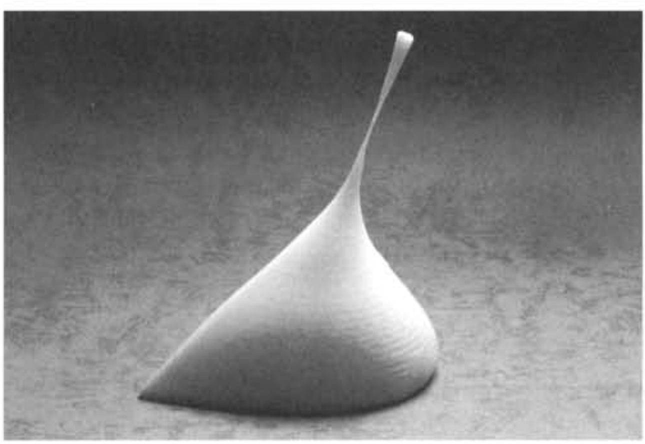


Figure 12.10
Benny's Design (CAD model)

Figure 12.11
Benny's Design (FDM model)



The computer-generated physical model made using FDM (fused deposition manufacturing) processes proved to be hard to read because of its opaque and static qualities as opposed to the dynamic translucent visualization offered by a rendering software. The SLA (solidified resin) prototype, with its translucent material, proved to be more readable than the opaque FDM one.

An interesting discussion also occurred around the issue of scale. In the virtual world designs evolving on the screen are scaleless. In the transition process from bits to atoms, the designer must specify a scale at which the design will be produced. By doing so, the visualization offered by the computer-generated physical models drastically limits its effectiveness to the designer. It was discovered that it is easy to imagine oneself walking inside the data space when it is dynamically evolving on the screen, but once it was prototyped with an overall size of 20x20x20 centimeters, that design did not appear to offer the same inspiration to the designer. The haptic feedback offered by the ability to hold the design, in these particular examples, appeared to be information of no use.

Global Virtual Design Environments, similar to the one recently set up at school of design, was suggested as a possible solution to the problem raised earlier. With its supercomputer for real-time multipiping rendering and real-time design generation and its semicircular walk-in screen and 3-D glasses, this environment promises to offer the designer the necessary four-dimensional interaction and feedback.

However, when the designer is developing the design of an object that is meant to be touched, as in Michael's design for a handheld pin collector, it was noted by Professor Frazer that "[...] none will dispute that having something in your hands and being able to turn it around, it makes it somehow very much easier to appreciate even than very dynamic images. There is something about its three-dimensionality and its tactile qualities that is more communicative to the brain."[7]

The success of Michael's experiment is also related to the fact that the prototype of Michael's design was produced at full scale as opposed to a scaled representation, generally used for interior and architectural designs that tends to turn a building into an object, sometimes a toy.

FURTHER RESEARCH

It is clear from these experiments with algorithmically generated design alternatives that potentially terrific opportunities lie in their combination with computer-generated physical model systems. My current research project in Design for Mass Customization Manufacturing Processes is exploring these opportunities offered when a designer develops a series of parametric algorithms to generate families of designs that share selected parameters and differ one another according to some others.

From some of the comments by the panel of experts on the results of the experiments, it appears clear that designs algorithmically generated, as in the case of Manit's and Hung's, were perceived as much more appealing when represented as dynamic images on the screen if compared with their physical prototype. It was noted that screen representation offers a distorted view of the real design, and that may have made some designs look more interesting than what they actually would be when prototyped.

However this only a hypothetical observation, and a systematic testing that compares all sorts of representations, including dynamic rendering, is necessary.

Computer-generated physical models, as this research reinforces, are imposing themselves as an alternative representation for designers. Together with the development of Walk-in Three-Dimensional Virtual Design Environments, or CAVE, it seems that there is an opportunity to extend the research toward building a matrix of comparison with a historical perspective. The matrix may list design representations, including, for example, preperspective, projected geometry, early computer-aided design systems, early solid modelling, generative systems, virtual design environments, computer-generated physical models, and compares them according to criteria of appreciation, including tactile qualities, intelligibility, robustness, and cost.

This possible development of the research will have a practical use, because it will offer guidelines to the inexperienced designer on which representation may be most appropriate to his/her necessity. It may also cast light on the too often hidden relation between the representation used during the design process and final result of the design.

I would like to thank Professor John H. Frazer and the designers for their stimulus and continuous support. This research was made possible thanks to a grant from the University Grant Council of the Hong Kong Polytechnic University.

NOTES

1. The computers used were PC Pentium II, 300Mhz, SGI Indy, and PC Pentium 166 Mhz. The computer peripherals were: FDM2000 by StrataSys and SLA 3500 by 3D Systems. The digital communication devices used were: PC Pentium II, 300Mhz NT Server for Class Point multipoint videoconference, PictureTel LIVE 200, and Intel Proshare. LAN used was 100 baseT Networking system (UTP 100Mb/s).

2. Rapid prototyping systems build three-dimensional objects according to the data provided by a three-dimensional computer model by depositing or solidifying various materials layer by layer.

3. For example ProEngineer by Parametric Technologies, Unigraphics, etc. In some cases designers used AutoCAD surface modeling and 3D Studio; in other cases the designers used Rhino3D instead of using a solid modeling module or software.

4. Most common 3-D software, including AutoCAD, allows the user to export 3-D solid geometry in STL format used by Rapid Prototyping systems. We used a freeware found on the Internet called STL_Util to export closed surfaces in STL format. As for open surfaces, we manually applied a minimum thickness to be able to export in STL format. STL_Util 2.1, written by Benoit Michel, Rue de Sendrogne 100, 4141 Sprimont, BELGIUM, 1994, e-mail: 2:293/2202.12 @FIDONET.ORG

5. Advanced Computer Application in Building and Architecture, src421, http://www.ab.deakin.edu.au/src421/

6. This notation of what may be commonly referred to as Rapid Prototyping was found by the author for the first time in William J. Mitchell, "Change, Time and Speed," *Thresholds*, no. 16, Dept. of Architecture, MIT, 1998.

7. Notes from the panel of experts discussion conducted at School of Design, HKPU, January 1999.

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13

Collaborative Learning and Design in Architecture, Engineering, and Construction

Karsten Menzel, Volker Hartkopf, and Mustafa Emre Ilal

INTRODUCTION

In the architecture/engineering/construction (A/E/C) industry there is a strong need for developing competitive advantages that can be gained and protected. The percentage of new construction tasks among all building projects is continuously at a decline. The same applies to the cost of traditional A/E/C tasks (e.g., rough construction work) within the total cost of a project. This is forcing architects and engineers to move toward new disciplines such as facility management. Information generated during the planning and design phases provides the perfect base for these new fields. The proper use of all data processing and telecommunication techniques across borders and among corporations is a prerequisite for the success of these endeavors.

The traditional A/E/C processes do not reach collectively competent results when evaluated from the end-users' and organizational perspectives. Buildings should achieve life-cycle cost-effective settings for user satisfaction, organizational flexibility, technological adaptability, and energy and environmental effectiveness. Currently, collective competence is difficult if not impossible to achieve because of

- The largely linear process through which buildings are financed, planned, designed, constructed, operated, and maintained, as well as modified and eventually replaced
- The litigious environment that forces the individual participants to limit their roles, contributions, and accountability

- The least-cost, first-cost approaches, favoring the lowest bidder rather than the most competent and competitive enterprise. (It is a well-known fact, particularly in U.S. construction, that the lowest bidder, when awarded the contract, must find mistakes in the previous architecture/engineering services to make money through change-orders.)

Regarding these shortcomings of current prevailing A/E/C practices, Lee Evey, the Manager of the Pentagon Renovation Project, a multibillion-dollar 10-year effort, has instituted a new contracting and professional cooperation environment.

This contracting and cooperative process rewards the appropriate behavior and is not least-cost and lowest-bidder oriented. Details of this revolutionary and innovative common sense process can be studied by visiting the Web site: http://renovation.pentagon.mil

New tools, as discussed in this chapter, can address the shortcomings discussed earlier. The tools also assist teaching and educational processes that aim to overcome critical divisions between disciplines that should be prepared already in their educational learning phase and how to work effectively to meet user and organizational objectives.

Besides the opening of new business fields, a reorganization of the existing core areas of civil engineering will also be necessary. In practice, new company structures and forms of organization are introduced that provide companies with the flexibility and dynamism needed in today's market. They design, control, and manage international projects of increasing volume and complexity. They try to quickly and efficiently put together design teams from employees of different companies and highly qualified freelance specialists. The team structure is changed and adjusted dynamically as required by the construction task. International project teams (within companies) and cross-company cooperation (virtual companies) are some of the corresponding organization forms.

In order for future architects and civil engineers to be able to cope with these demands, a modification of their education, in particular the use of communication and information technologies, is necessary. Yet, the teaching practice in many cases still takes place in specialized fields and is technically structured very deeply. Interdisciplinary projects, courses, or seminars are still the exception and not the rule.

Recently, many publications have been written about the necessity for interdisciplinary education and collaboration of A/E/C students (Fruchter, 1996; Menzel et al., 1997; Menzel, Hartkopf, & Lee, 1997). However, some reviewers argue that there is little or no evidence of improvement in the quality of teaching, resulting from the use of computer-based media or interdisciplinary teaching scenarios. Should we conclude that investing in the development of computer-based interdisciplinary teaching scenarios is worthless? This chapter presents results of a more than five-semester-long teaching collaboration between Carnegie Mellon University (CMU), Pittsburgh, and Braunschweig University of Technology (BraUT). Throughout portions, the BAUHAUS University, Weimar; the Swiss Federal Institute of Technology, Zurich; and the Munich University of Technology joined this distance-learning effort. Additionally, the chapter presents a methodology for organizing and documenting a multinational teaching project continuously and successfully.

FRAMEWORK

The main part of the project is a common assignment that focuses on the development of a complete design, the approval process, and the development of detailed construction documents (e.g., drawings) for a specific building. This assignment is coupled to courses that are already a part of the curriculum of the participating universities and institutions. The contents of the lectures remain unchanged. The goal is to improve the assignments and to connect the assignments within an interdisciplinary multinational context.

The course "Design of Integrated Systems" at CMU and the course "Civil Engineering Projects" at Braunschweig University aim to enable students to apply their knowledge within a multidisciplinary project-centered context. Furthermore, in both courses the students need to work in teams. A combination of an architecture and civil engineering education is obviously desirable. The course *"Design of Integrated Systems"* at CMU focuses on the next generation of building systems and commercial buildings and presents a holistic approach to building design aiming at achieving four main goals: individual comfort, organizational flexibility, technological adaptability, and environmental sustainability.

The course "CAD & Facility Management" at Braunschweig University focuses on the strategic use of A/E/C software and its integration into a uniform planning and design support system. In the course students are taught how to use A/E/C software and also to plan, prepare, and organize data management for building-related information for later use in facility management.

Figures 13.1 and 13.2 outline the utilization of various systems and the interaction between participants.

Figure 13.1
Hard- & Software Architecture—Winter Semester 1998/1999

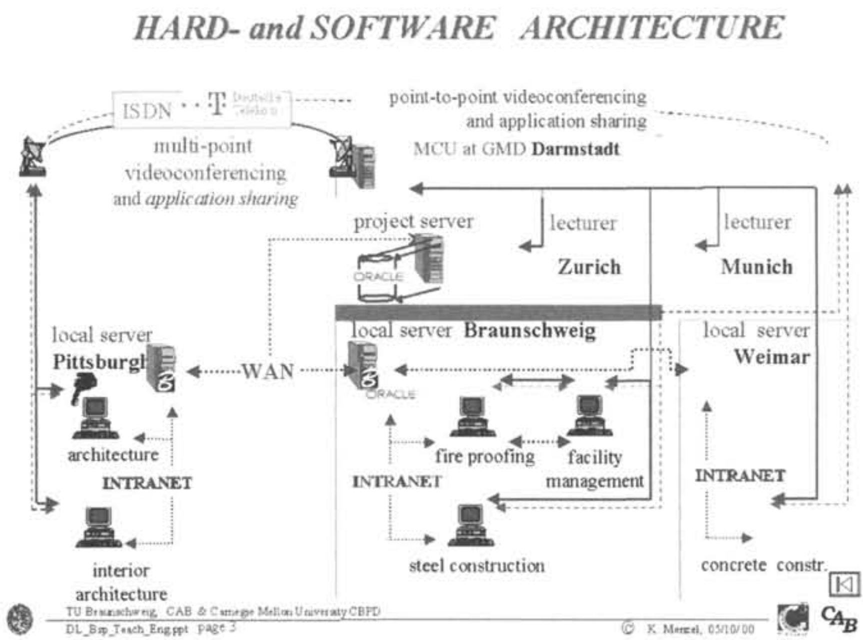
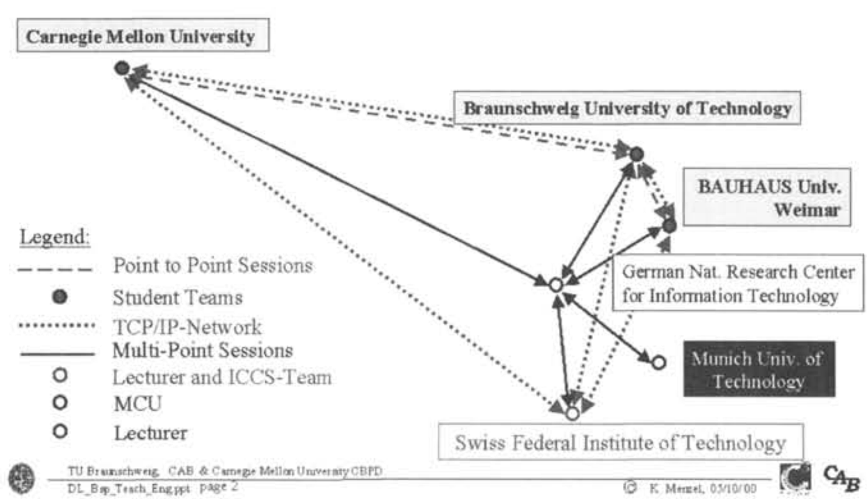


Figure 13.2
Participants and Modi of Interaction—Winter Semester 1998/1999



The students worked in project teams corresponding to various tasks and responsibilities on a real construction project. The team structure is depicted in Figure 13.3.

The collaboration between the various institutions can be divided into three phases:

1. ***Phase I:*** During the winter semester 1997/1998 four student teams from CMU and BraUT developed the design of an exhibition building for EXPO 2000, the World Exhibition held in Hannover, Germany, in 2000. The participating students had to use various computer-supported cooperative work (CSCW) techniques to frequently discuss their design ideas with their transatlantic partners. Presentations and project discussions were organized with lecturers from both universities.

   The pilot course was evaluated during the summer of 1998. The organizers noted a further need for improved team management, as well as for document management and for integrating additional lecturers who could impart highly specialized knowledge to the participants.
2. ***Phase II:*** After having become familiar with the various IT tools and the various new teaching scenarios, we were able to develop an improved course scenario. Team and document management were organized with the Interdisciplinary Communication and Collaboration System (ICCS-software) developed at ETH, Zurich. Ten guest lectures were organized and broadcast to the student teams by videoconferencing. The technology allowed the inclusion of an additional team during the ongoing effort to take advantage of the opportunity to integrate a group from BAUHAUS University, Weimar.

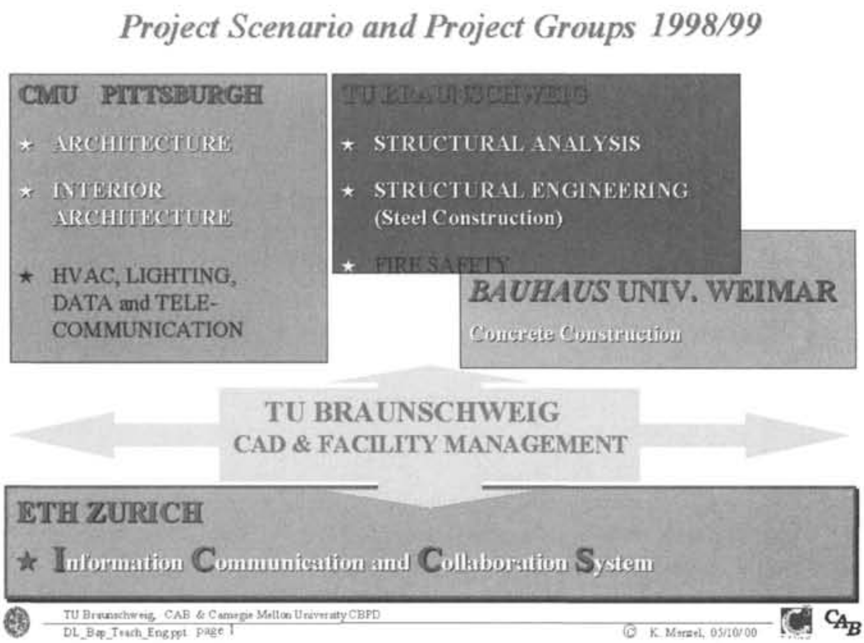
   During the summer of 1999, the content of the guest lectures was broken down into modules of knowledge. The size of each module is based on the average attention span of adults, which is 15 to 20 minutes (Wiezel, 1997).
3. ***Phase III*:** During the winter semester 1999/2000 student teams from Weimar and BraUT created a detailed documentation of the Scene Lab, a teleteaching facility described later in this chapter. Selected guest lectures were presented to the students.

Project Goals

The goals of the joint teaching and research project can be divided into the following subjects:

- To teach knowledge of applied computer science in architecture and civil engineering to the broadest possible audience with an application-

Figure 13.3
Team Structure—Winter Semester 1998/1999



oriented profile, a project-related approach, and within an interdisciplinary context.

- To teach teamwork and leadership characteristics on an appropriate methodic-didactic foundation that demands and supports team-oriented work in the various areas of civil engineering and architecture.
  - Braunschweig University uses a "tutor/mentor process." This was tested in various scenarios: The CAFM team consisted of 7th-semester students. Each team was supported by a tutor of the 9th or 11th semester. The structural analysis team consisted of two 5th-semester students and two 9th-semester students. Therefore, the tutors (students in their 9th/11th semester) could improve their leadership and management abilities. The team members (students from the 5th and the 7th semester) could experience teamwork at an early stage of their curriculum.
  - Each team had to organize its *intra*team collaboration. The teams had to meet at least once a week for a face-to-face team meeting. During these meetings the team members had to report on the current project status and define new goals.

  - Between major reviews the teams had to perform an *inter*team communication. The collaboration between the teams was controlled and managed by news groups, Web pages, and groupware (e.g., NetMeeting) and was supervised by the course instructor(s) and tutors.

- To teach methodologies and skills for presentation.
- To use new media in teaching. Teaching materials were made bilingually available via the Internet. Partial results were published using the Internet. Design discussions were supported by videoconferencing tools. These were either discussions between coordinator/tutor(s) and student(s), or between students.
- To develop a platform that enables and demands an interdisciplinary application of the knowledge obtained during the whole curriculum.

Management and Organization

We proposed to the students a collaborative framework. This framework aims at combining modeling, functional, and operational aspects of a holistic design cycle. The students were asked to

- Develop general models and to define or use common descriptive semantics. These activities led to a definition of an area of common interest as well as areas of local interest (or profession-specific partial models). The result of this activity is a meta model.
- Translate (or implement) such descriptions and semantics with existing, commercial tools used by the various teams involved in the project. The results of this project phase are application-specific representations of the meta model. An application-specific representation (temporary partial model) may consist of one area of local interest "checked out" on a local workstation referenced to [1 ... n] areas of global interest. "Area of global interest" means a collection of publicly accessible, checked in, revised partial models. "Referenced" means the information is available, but users have no right to delete or modify any information of this global model.
- Reorganize existing digital information. During this project phase the students learn to evaluate previous work.

Synchronous Work and Discussion

In order to ensure data consistency and to prevent the loss of data in the synchronous work mode during reviews and virtual team meetings, we used a CAD-tool in combination with a viewing tool. This way, one team played the role of the master team and the decision maker and the other teams played a passive role. This meant that these teams only had the right to view the design documents and to suggest changes of the design proposal. A prerequisite for this scenario was that all teams had to check in their partial models. No local models had been allowed during this review event. After these reviews the partial local models could be checked out again.

Communication

In order to support the different levels of communication, we created several B-Boards (Palfreyman & Rodden, 1996). One level allows contact to individual team members through their e-mail address and through access to his/her individual home page. Another level allows for internal group communication through access to individual news groups and design documents. The third level of communication is the project level, intergroup communication through various news groups and common design documents (see also Figure 13.4).

Throughout our project, we made use of both synchronous and asynchronous communication. The distribution and study of reference project documentation (see following), readings, and so on through the Web is a typical example of asynchronous work. Each student in Germany and the United States was able to access these documents with no limits on time and location. Another example of asynchronous work is the exchange of design information through e-mail among team members and teams, as well as feedback from the instructors to students.

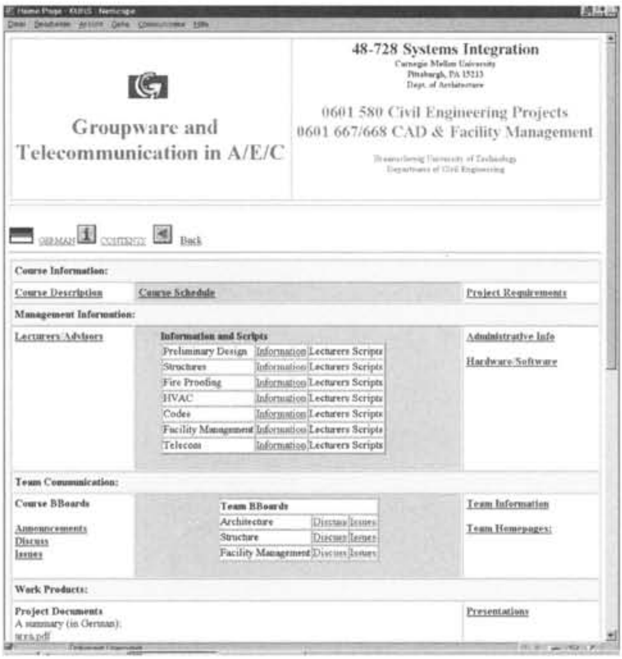
We used synchronous communication for normal lectures, seminars, and reviews. During selected seminars and reviews, the teams had to present their various partial models as part of the overall design of the building and to exchange interdisciplinary design criteria with each other. These IT-supported team meetings and design reviews were necessary because of geographical limitations. The design team was distributed over the two sides of the Atlantic.

REFERENCE EXAMPLES FOR THE DESIGN TASK

The Robert L. Preger Intelligent Workplace Building

The construction of a building with a complex requirements profile demands extensive scientific and practical knowledge and experience. The team from the School of Architecture at CMU contributed this practical

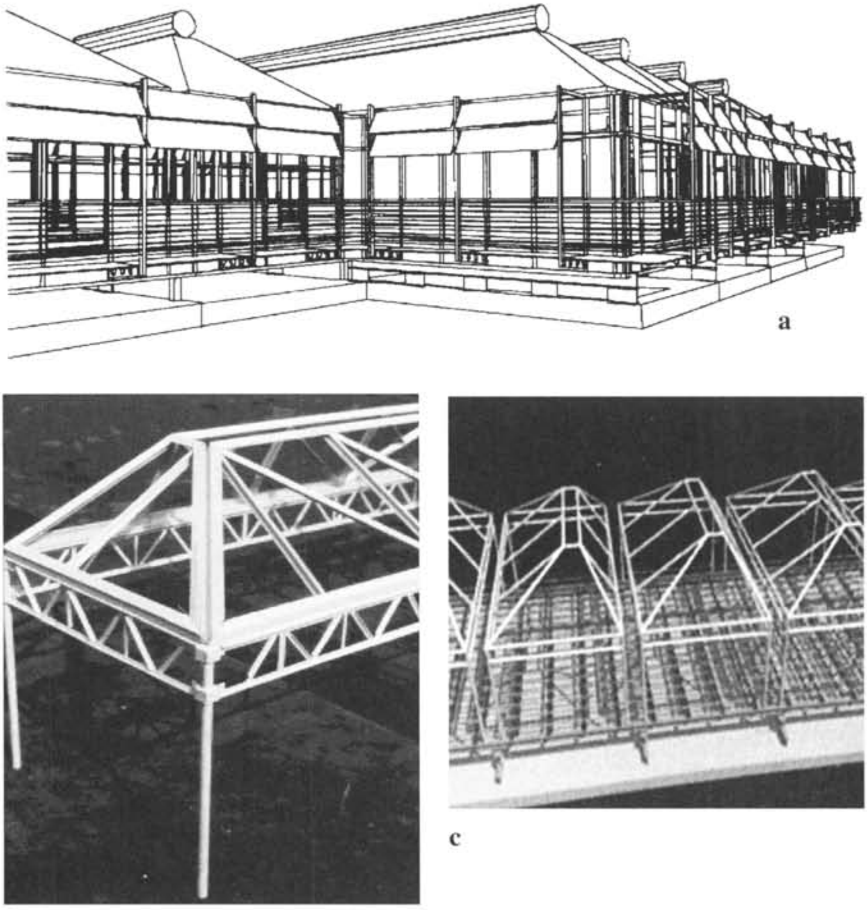
Figure 13.4
View of the Home Page for the Course



knowledge, which had been accumulated through design and construction processes of the Robert L. Preger Intelligent Workplace inaugurated in December 1997. The Intelligent Workplace (IW) (see Figure 13.5a) is a "living laboratory" demonstrating the capabilities of a next generation of commercial buildings to support organizational and technological change, to improve environmental sustainability, and to ensure high-quality indoor environments for individuals. This building is used to test construction parts and components, as well as different office layouts, data processing- and telecommunication technologies for their efficiency in operation. The novelty is that all components are integrated into the complete system—the "building"—during the tests and can therefore be evaluated comprehensively. This interdisciplinary work is carried out in cooperation with other university institutions (e.g., Human Computer Interaction Institute, Dept. of Civil and Environmental Engineering, Software Engineering Institute).

The modularity in design and construction of the IW-building simplifies the development of digital models for the administration of the relevant

Figure 13.5
The Robert L. Preger Intelligent Workplace. From traditional sketch via 1:1 model to a complete 3-D computer model.



a

c

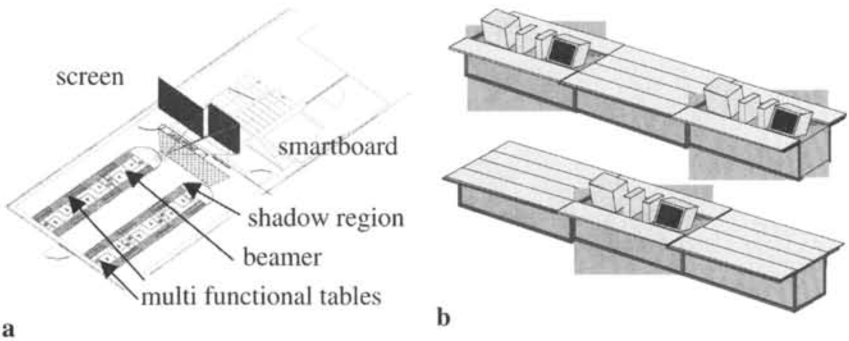
b

information to building management (see Figures 13.5b and 13.5c). Thus, information and knowledge about the various building parts and components, their interdependence, and their design sequence is easily accessible to the students through information systems.

Scene Lab

The Scene Lab is a multifunctional classroom for teleteaching and computer simulations at BraUT. It supports various CSCW-scenarios, such as

Figure 13.6
(a) Layout; (b) Furnishing



- The conferencing scenario
- The *engineering and design scenario* for locally distributed, computer-aided collaborative design
- The *high-performance computing scenario* for modeling and simulation of problems in the area of environmental science, building physics, and architectural visualization

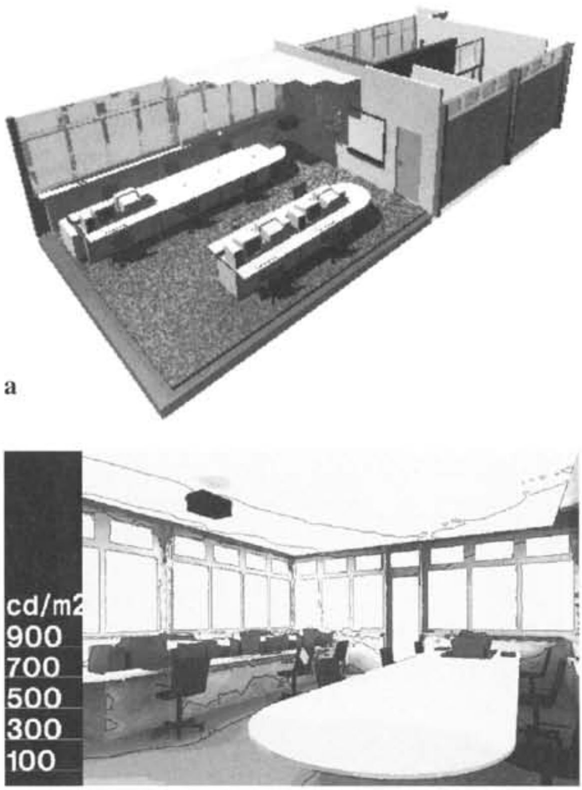
The layout of the room should allow for the arrangement of at least 12 PC workplaces for a maximum of 24 users. The tables are special constructions. Computers and monitors can be retracted into the tables so that the different application scenarios can be quickly brought about (see Figure 13.6b). A SmartBoard and a LCD-projector, a document camera, as well as a videoconferencing room system are available supporting the various CSCW scenarios (see Figure 13.6a).

During the planning phase, numerous subaspects of the desired room functionalities were modeled and simulated such as different lighting models and furnishing variations, as well as the integration of communication and presentation technologies. Examples are given in Figures 13.7a and 13.7b.

Through dealing with these real-world examples, architecture and civil engineering students have the unique opportunity of

1. Familiarizing themselves with the technical setup of systems by utilizing and experiencing them in their design work (location of workplaces, ergonomic design, effects on room climate, energy efficiency, etc.)
2. Absorbing information and communication technologies and learning how to use an integrated complex computer-aided design and control

Figure 13.7
(a) Visualization and Simulation (Furnishing); (b) Visualization and Simulation (Lighting)



a

b

system efficiently and in a goal-oriented way to solve certain subtasks of building design and management

In this way, it is possible for the students to experience a design scenario that is very close to current practice in architecture and civil engineering during their education. The students experience team spirit and flexibility. They are trained using the most modern communication technologies available on the market today. Also, they are taught to use highly specialized abilities and skills in a goal-oriented way to deal with a precisely described construction task in architecture and civil engineering in a global setting.

DESIGN TASKS

Traditionally, A/E/C processes present difficulties to students in acquiring cross-disciplinary knowledge due to real-world complexity. This is exacerbated by the fragmentation in teaching. The use of real-world examples in the classroom is one possible solution for overcoming the problem of inert knowledge. One speaks of inert knowledge if students are able to recall and use knowledge only if asked specifically about the topic. However, the students are not able to use or recall this knowledge actively in situations when that use is appropriate but not explicitly asked for. Various theories are proposed to deal with these issues of complexity in teaching, such as cognitive flexibility (Spiro et al., 1991). Cognitive flexibility means knowledge representation from different viewpoints appropriate to different situations or cases.

A preview center for the Hannover World Exhibition (EXPO 2000) was to be developed in *Phase I*. The concepts behind the Intelligent Workplace were to be tested in a multistory scenario. Also, the temporary nature of the exhibition provided an additional challenge. The visualization of the building is depicted in Figure 13.8.

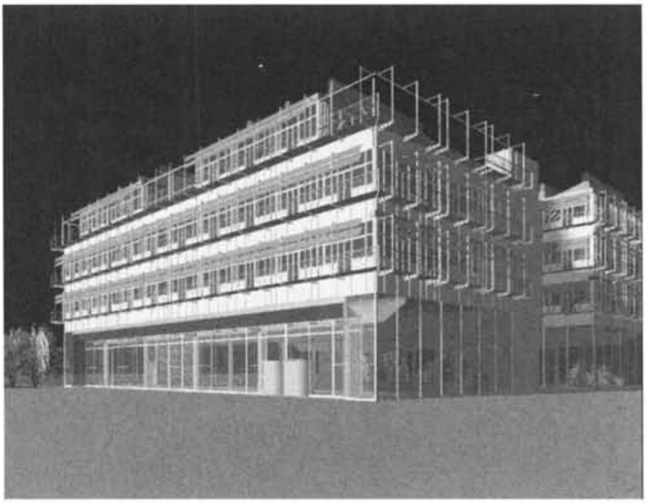
Before the courses started, the architectural programming and some preliminary designs had already been completed. Students were able to focus on the selection and integration of systems and technology.

The following requirements were to be taken into consideration:

- Short building time, simple manufacture and construction, and the possibility of disassembly and reassembly at another location after the exhibition
- Multifunctional use (exhibition areas, service areas like restaurants, shops, and offices)
- Achieving total flexibility with regard to layout and technology:
  - Allowing change between any combination of office types
  - Maximum adaptability in case of infrastructural change
- High installation density of building services, as well as information and communication technology
- Environmentally sustainable life cycle (construction, operation, management, reuse, or relocation in part or in total, recycling of materials, components, and systems).

During *Phase II*, the students were asked to work on a Marketing Academy for a global Automotive Company. This Marketing Academy was to

Figure 13.8
Visualization of the Preview Center

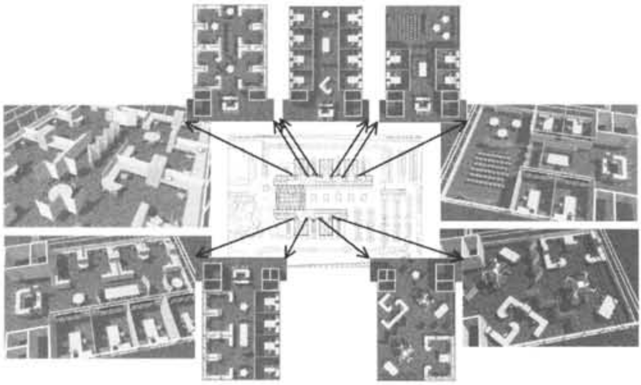


serve as a central facility for the training of trainers and the training of maintenance and repair personnel. In addition, the facility was to function as a workplace for the development of teaching tools and the support of presales and after-sales services. Furthermore, the facility had to support large gatherings for product introductions and exhibitions.

The architectural program (see Figure 13.9) included

- Workshops to directly explore the functioning, maintenance, and repair procedures of cars and trucks in a "hands-on" mode
- Teaching and seminar spaces adjacent to the workshops to enable the dissemination of theoretical knowledge directly related to the practical experience
- Office spaces conducive to individual solitude, teamwork, and global multimedia communication for voice, video, and data
- A television studio for the dissemination and audience feedback of information on new products to be introduced in the marketplace and/or major systemic repair and maintenance requirements
- A representative exhibition and meeting space for the introduction and exhibition of new products
- Supporting (ancillary) functional area such as parking, delivery, storage of material, and so on

Figure 13.9
Proposed Layouts for the Marketing Academy



The Marketing Academy presented several interesting integrated systems challenges that could only be addressed by the students through interdisciplinary teamwork:

- Located near Stuttgart, Germany, between a river and a noisy highway, the site presented challenges for acoustics and air quality. Too noisy for operable windows on the highway side, the noise levels do not allow for operable windows, and fresh air needs must be supplied by alternate means.
- The training program utilizes a "hands-on" approach where real vehicles are used on the lower levels. Trucks have to transport these vehicles into the building, requiring a structural system that allows for the maneuvering of these trucks as well as for infrastructures that will help isolate the fumes and noise in the mechanical areas from the offices upstairs.
- Advanced telecommunications equipment needs to be integrated throughout the building because the Marketing Academy was to also be the global center for the training of remote vehicle dealers and mechanics worldwide.

Again, a preliminary design was ready when the course started. The students were asked to apply the principles established at the Intelligent Workplace to the selection and integration of various building systems.

The focus was on the following: (a) enclosure, (b) structure, (c) interior systems.

Information Management

In both teaching and real-world A/E/C projects, an enormous amount of time gets allocated for information acquisition. Although a substantial array of multimedia products have appeared on the market over the last few years (Mark, Haake, & Streitz, 1996), only a few of them meet the requirements for multiviewpoint knowledge representation. The development of a knowledge management system is one major effort at BraUT. It is used to collect all information on the example project, related lecture notes, and the various design tasks. The analysis, design, and prototypical implementation of such a system is one important assignment of our course scenario. It is the authors' belief that future civil engineers and architects should be able to organize knowledge and information in their organizations. The intent is to observe issues of knowledge transfer through the growth of this knowledge management system.

In the course of the project, extensive documents were created that can be seen as knowledge containers of valuable information. This project information should be made available to everyone working on the project in the future. The numerous documents and their different forms (texts, models, drawings) require a well-organized structure. Because most documents are available in digital form, it seems sensible to establish a computer-assisted administration of the collected knowledge, a knowledge base. One advantage of the described procedure is that further corresponding documents can be attached to an already existing document. This is done with the help of "tuples," which combine documents of different types into logical units (see Figures 13.10a and 13.10b).

Additionally, the user can assign a value to the tuples to express a valance. In this way, a filter function is available that can be used according to the qualification and information demand of the user.

Access to and work with the knowledge base is possible from every computer with an HTML browser and a network connection. This makes the use of HTML a basis for the input and output operations unavoidable. Furthermore, the data quantity, which will increase in the future, sets relatively high requirements. Requests and information presentations are processed dynamically and made available by using Web and database servers through the Internet.

Figure 13.10a
Classification

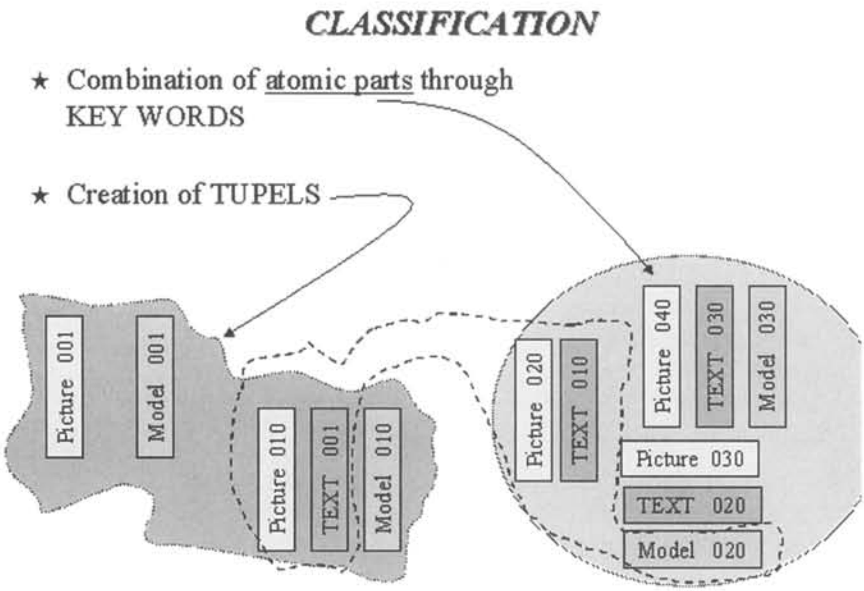
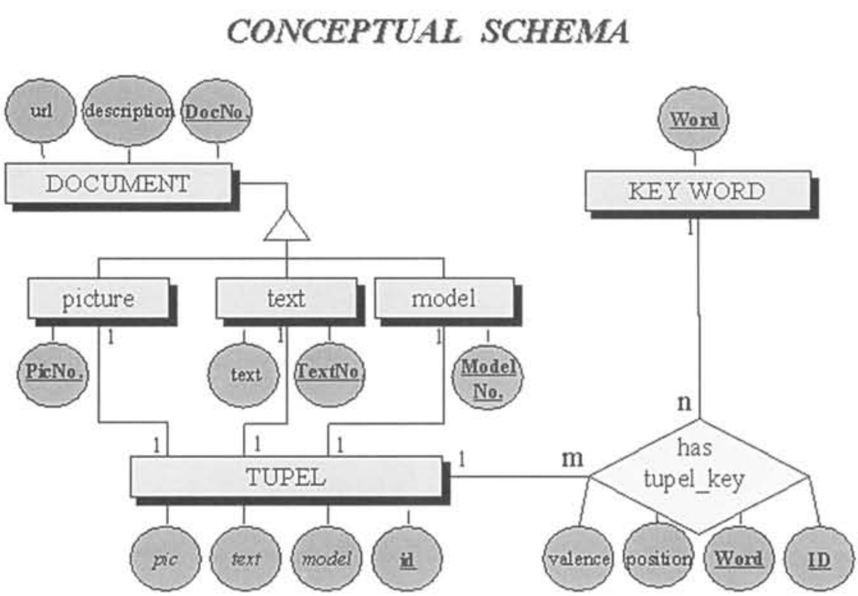


Figure 13.10b
Database Scheme



LECTURE ORGANIZATION: METHODS

The basic principles of this international collaborative teaching effort are hierarchy, patterns, and modularity. The author developed the curriculum and the lecture notes in an inductive way—from the example to the general case. The principles are applied to three fields:

1. A/E/C—the architecture and engineering aspect
2. Computer science—the management aspect (data, information, knowledge)
3. Teaching—the educational aspect

The employed principles can be characterized as follows.

The idea of *Pattern Languages* originated with Christopher Alexander, an architect (Alexander, 1979; 1995). Alexander's approach defines and models always one single common invariant process underlying other variations of this process. Thus, such a collection of invariant processes provides a common framework of knowledge and expertise. In 1987, several people from the software engineering community rediscovered Alexander's work and applied it to their work. However, it took another seven years until design patterns entered the mainstream of the software engineering community (Bruegge & Dutoit, 2000; Larman, 1998).

Buschmann (1996) defined three categories of patterns for the field of software engineering: (software) architecture patterns, design patterns, and idioms. For describing our lectures we use two (Software) Architecture Patterns: the Layer Pattern and the Blackboard Pattern.

The Layer Pattern allows for structuring of an application. The Layer Pattern is based on the principle of hierarchy. The Blackboard Pattern helps to describe problems for which there is no known deterministic solution strategy. In the Blackboard Pattern, several specialized subsystems make their knowledge available to develop a solution. The Blackboard Pattern is, among other things, based on the principle of modularity.

The second basic principle used for our work is *Hierarchy.* Hierarchy can be defined as a special case of structures. By using Hierarchy a complex problem can be decomposed into smaller problem areas. In the present case, the hierarchy principle will help the involved lecturers and course coordinators to establish a clear arrangement and, if necessary, to fill individual parts of the curriculum with further information and teaching contents.

The principle *modularity* is frequently employed in both software and construction engineering. It represents a combination of resources and an exact description of the interface to the outside. This interface description contains a precise explanation of which functionality is provided and which resources from outside are needed to fulfill the function.

LECTURE ORGANIZATION: EXAMPLES

Briefly, the approach to defining a course structure can be described as follows: The description of patterns becomes possible on different levels of abstraction through a hierarchic arrangement. From these patterns, modules can be generated through an exact description of the boundary conditions. These modules contain exact procedure descriptions, respectively well-structured information.

This hierarchy makes it possible to set up practical examples, the documentation of reference projects, and teaching materials in a structured way. Additionally, it is possible to improve the combination of the individual subareas of the information space into a uniform teaching documentation. Furthermore, this complex teaching documentation is easier and more flexible to maintain.

Within the individual hierarchies, patterns are defined that can be used for the generation of teaching material, for the project documentation, and for the description of the reference projects. A general pattern description is given in Figure 13.11. With the help of these patterns, the lecturers are now able to process their lecture contents.

This is done by adding further attributes to the pattern description. In this way, a pattern description is transferred into the definition of a module. The context between the modules can be illustrated graphically with the help of the method IDEF-0 (for a brief example, see Menzel & Kirschke, 2000).

In the end, the teaching contents, the documentation, and the project descriptions can be made accessible to the students through the World Wide Web. Because of the modularity, a quick and uncomplicated update of the Web contents is possible, even with annually changing guest lecturers.

From the authors' point of view, this system delivers the necessary flexibility needed for international teaching activities. All participating lecturers (see Figures 13.11 and 13.12)

1. Are able to get a quick, well-organized overview of the current course status
2. Can quickly and easily integrate their lecture(s) into existing course scenarios
3. Can compare the contents of similar courses and evaluate/accept course results/grades in a much easier fashion

Figure 13.11
General Pattern Description

ID-Part

NAME	**:**	**[a concise name]**
ID	**:**	**[Number]**
TYPE	:	e.g. lecture or lab

CONTEXT-PROBLEM-SOLUTION Part

Context	:	short text
Problem	:	short text
Solution suggestion	:	short text
Link	:	from: lecture, course to: lecture, course

STATUS-description

Precondition (Initial state)	:	which courses / lectures / knowledge
Education goal (Final state)	:	

Figure 13.12
Extension of Pattern Description for Module Definition

Material	:	personal material
Literature	:	external authors
Test questions	:	for (self) testing

CONCLUSIONS

A questionnaire to students and tutors initiated by our partners from the Department of Pedagogy and Instruction at Braunschweig University has shown the course project to be well accepted and evaluated as being excellent by students and colleagues. This is especially true for the project-related, interdisciplinary scenario and the heavy use of information and communication technologies. The international context contributed additional motivation to all participants.

One of the key goals of this course was to gather experience in how to use the various groupware and telecommunication tools meaningfully and successfully. In general we can conclude the following: Both groupware and telecommunication are necessary, helpful, and powerful in supporting such scenarios. However, we strongly believe that completely virtual scenarios would fail. The instructors have worked together since 1993 in several research and exchange programs. Also, some of the participating German students had the chance to work as exchange students at CMU in Pittsburgh for several weeks before or during the project.

This personal contact was one of the key characteristics for the successful use of our videoconferencing tool. The use of this tool began to increase dramatically when the German exchange students became an integrated part of the student teams in Pittsburgh. They worked as catalysts or icebreakers. During the project, the authors and participants often had been confronted with the question of whether or not video contact was necessary. It is the authors' experience, with complete agreement by students and colleagues, that video contact is very helpful in establishing a personal contact and in instilling a sense of personal accountability to others and the overall project. This cannot be achieved by only having audio and data connections available. This is true for discussions, reviews, and even ISDN-transmitted lectures.

The participating students also agreed that the balance between *theory* on newly developing future methods and technologies and *practical experience* using robust, commercially available, but state-of-the-art software tools, resulted in an excellent atmosphere.

It should also be mentioned that the approach of starting with a common, project-centered, course-related project was very helpful in getting the project started quickly, without the burden of extended administrative efforts.

SUMMARY

Distance learning can either be a completely new method of teaching or a supplementary tool to the traditional classroom instruction. In our distance-learning project, we proved that IT-supported teaching methods contribute to an improvement of interaction and an enhancement of the course content. We considered a change from individually acting course participants to collaboratively working students in interdisciplinary contexts. The students made active and passive use of multimedia problem representations. These two transitions led to an improvement in quality of problem-solving strategies. The interdisciplinary, project-centered framework encouraged the students to shift their learning strategy from learning plain facts and "cookbook" algorithms to discovering cross-disciplinary interdependence. This was possible because the students had many more opportunities to work actively and not to "consume" knowledge in a passive manner.

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PART IV
EXPANDING HORIZONS

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14

Space, Time, and New Media—Virtual Design Studio Revisited

Jerzy Wojtowicz

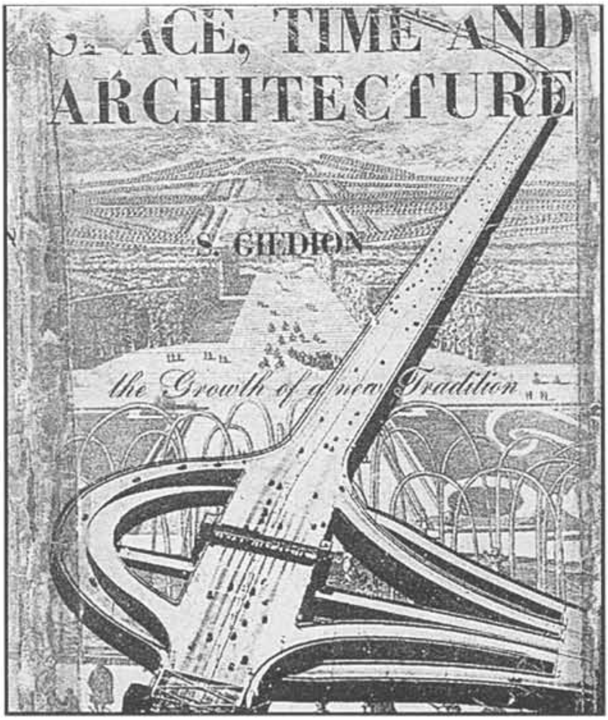
> We had to wait until the middle of this century for the crossing of long separated path: that which arrives at the physical world by the detour of communication, and that which, as we have recently come to know, arrives at the world of communication by the detour of the physical.[1]
>
> Claude Levi-Strauss, 1962

INTRODUCTION

An early edition of the modernist treatise "Space, Time and Architecture"[2] depicts a traffic interchange on its cover (Figure 14.1). This seminal book, based on Giedion's lectures delivered to Harvard students over half a century ago, is subtitled "The Growth of a New Tradition." The implicit connotations of the image on the cover are different today—because of the emerging impact of the so-called Information Highway, it has gained new meaning. Yet, the significance of the new tradition remains. Walter Gropius presented the modernist case well in his essay titled *Tradition and Continuity in Architecture:* "The word "tradition" comes from the Latin word *tradere,* i.e., transmit, carry on."[3]

The impact of the information technology (IT) revolution on design practice and education is now massive because broadband networks are more widespread. Networked communication is transforming our lives by giving us new methods of direct access to distanced individuals and issues.

Figure 14.1
Fragment of jacket cover



Many theoretical positions and narratives that aspire to contemporary architectural discourse are triggered by the emerging condition of continuing change. The claim that "With use of new digital technologies in the design of architecture, animation and movement appear to have freed architecture and the image from issues of representation"[4] is not confronted here. This postmodern, digital questioning of visual representation deserves a separate critique—in the meantime, like other formal experiments, it is sufficiently challenged through the act of its production. The reflections on modern tools for design and communication presented here are derived from the author's introduction of the new media to architecture students and from his design practice.

What are the characteristics of this contemporary condition, what are the limits and opportunities of New Media in Design? Several aspects of this problem are addressed: first, the creative aspects of digital media in the design process; second, the role of projections and motion in generat-

Figure 14.2
Screen captures from 1993 Virtual Design Studio involving the Massachusetts Institute of Technology, University of British Columbia, and Washington University

ing and representing the design. But my foremost concern will be the nature of distributed design collaboration across borders of time and space. This last issue is reviewed from the perspective of the last decade.

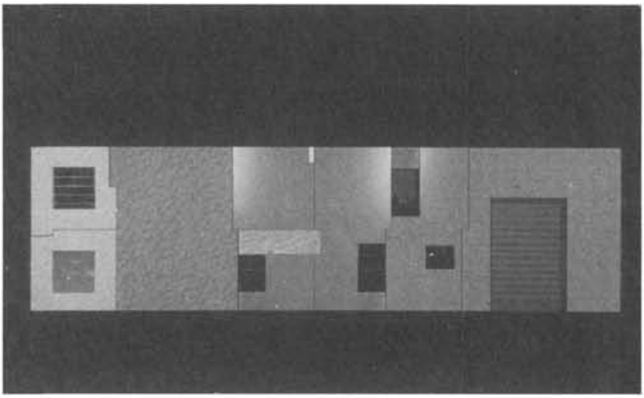
The modern tradition regains significant today when engaged in the context of the contemporary design studio—a studio in which students of architecture collaborate at a distance, sometimes continents and time zones apart (Figure 14.2). The evolution of this virtual design studio[5] (VDS) attests that operating across the boundaries of space and time and using asynchronous and synchronous techniques in design collaboration is now feasible. The polemical search for the new tradition introduced by Giedion is still relevant today as we face the continuing redefinition of space and time. Among the fresh issues in design is the growing application of complex surfaces resulting from the proliferation of NURBS modelers. Furthermore, motion models, animation, and kinematics are engaged not only in design representation, but also in its generation and in questioning the established nature of the design discipline. Quick prototyping with numerically controlled tools offer the promise of production, upstaging the traditional role of orthogonal aspect and abstraction in design. Yet, distributed design collaboration in the form of VDS has a rather unique position among those current trends due to its social dimension.

VDS RETROSPECTIVE

The early VDS experiments took place well prior to the popularization of the Internet and before NCSA Mosaic, the first massively used Web browser. Ten years ago, Bill Mitchell's studio at the Harvard Graduate School of Design collaborated with University of British Columbia (UBC) students on a design studio problem. They exchanged project files via ftp to a common, mirrored account and conducted real-time reviews over speakerphone and chat. The subject was the design of a small, prefabricated, tilt-up building. First, students contributed a variety of panel designs to a common library and then assembled two diverse, collective versions of the projects (Figure 14.3). The initial paper based on this exercise, titled "Design as Digital Correspondence," was presented at the 1992 ACADIA Conference. Apart from its now historical significance, several key points that led to the formulation of the distributed design studio or VDS method remain interesting:

1. The development, control, and assembly of design knowledge is a highly structured process when computational tools are engaged. It is structured in the case where the designer engages the machine in the creative process as a sort of "collaborator," and it is structured where two or more designers collaborate from separate locations. To deserve to be labeled creative, this type of partnership has to allow for unpredictable, nondeterministic procedures during the initial stages of design.
2. Correspondence can be understood as a creative process of collaboration. It works like this: the sole designer generates an idea making use of some initial constraints. The outcome calls for a revision or elaboration. The new proposition introduces new constraints, which did not exist at the initial stage, prompting a new or different idea, initiating review again. This process is magnified during the act of collaboration where the role of the critic and the role of the creator are substituted and interchanged between the key players. Ultimately it leads to the formulation of a feedback loop between the idea and the critical judgment.

Figure 14.3
The tilt-up project made out of panels contributed by VDS participants



3. The technology for networking in design is at hand. For architects of the next generation, digital design in the networked environment begins with reintroducing the collaborative act to design.[6]

This problem of creative and distributed collaboration is not new, as indicated in the conclusion to "Design as Digital Correspondence": Will those new techniques and tools be seminal in making a significant architecture? According to Diodor Sicilian, over 2,000 years ago two Greek sculptors were working on a statue of Apollo. The sculpture was made in two parts, with one of the artists working on the island of Samos and other in Effez. Despite this separation, when parts of the monument were brought together, they fitted perfectly. "This result was due to the certain rigorous method of work common to both collaborators." Modern computational tools impose new collaborative methods and when applied in the creative process confirm the importance of correspondence as a constructive method of design.[7]

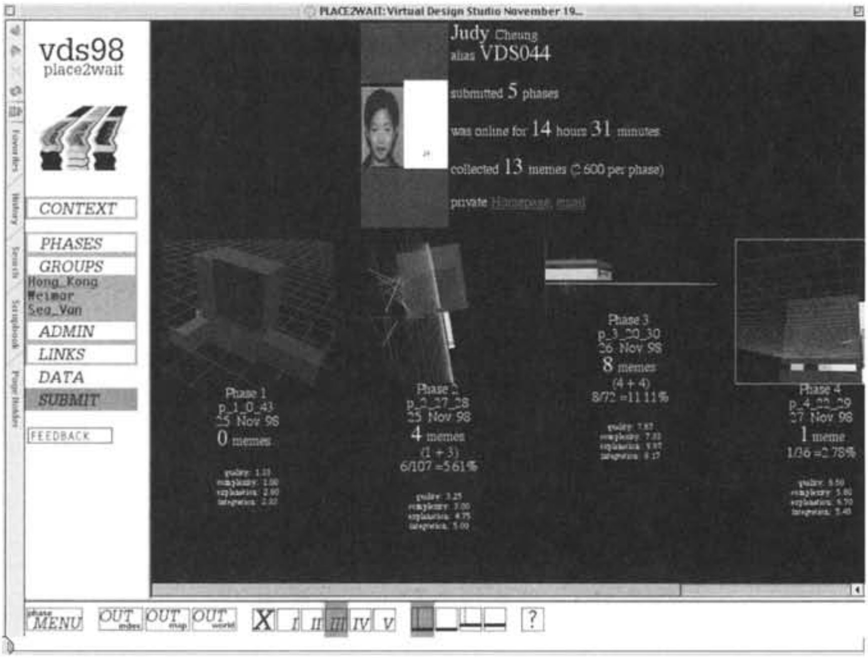
The following year, VDS '93 involved designers at Massachusetts Institute of Technology (MIT), UBC, Hong Kong University (HKU), Cornell, and Washington University (WU). The common project was the redevelopment of a walled Chinese village on which the construct of the Virtual Village was to be based. Among the key points derived from this exercise were the recognition of the seminal importance of asynchronous collaboration in design and the observation that "VDS membership varies in time and is NOT space dependent."[8] The idea of the "Digital Pinup Board" was

Figure 14.4
The 1997 VDS between Chile and Canada

also postulated and developed during this project. Dissemination of Web browsers, growing accessibility of the Internet, and increasing bandwidth led to a series of collaborative projects and at the same time to the gradual dissolution of VDS into a common method of working used today by many. Yet, as recently as one year ago, VDS between students in Chile and Canada was largely delivered asynchronously over the Internet with synchronous videoconference sessions limited only to the time of reviews. This was in part due to the cost of ISDN lines, but in part was a clear choice in dealing with temporal differences between the two sites and as a preference for the casual mode of working so typical to design studios. The success of this project attests to the lasting practicality of this mode of working (Figure 14.4).

Numerous other VDSs from recent years are worth revisiting, and brief descriptions of many of them still can be located on the Web.[9] The VDS '98 project titled Place2Meet (Figure 14.5) was conceived at ETH Zürich and involved also Bauhaus Weimar, HKU, UW, and UBC.[10] The project utilized a relational database and the Internet to explore the potential of

Figure 14.5
Screen capture from VDS '98 titled Place2Meet



asynchronous collaboration in design while tracking the transformation of the authorship of design at each stage. The Virtual Design Studio between MIT and PARC XEROX probed the limits of synchronous collaboration relying on practically unlimited bandwidth connectivity resulting in videoconferencing at will between all participants. The VDS between Nancy Chang's studio at the University of Oregon and UBC students incorporated an early experiment in quick prototyping at a distance. A project called Screen2Screen involved the collaborative design of screen panels followed by the production of prototypes with a numerically controlled laser cutter and the final publication of the revised digital models and a machined physical one on the Web (Figure 14.6). At UBC, the VDS worked also with the First Nation Community as the client participating in the project development (Figure 14.7). The VDS_Y2K webboard was shared by architecture students from Krakow, Warsaw, and Berlin working on a proposal for the Wanchai Waterfront Reclamation organized by HKU. The project currently under development will involve Canadian and Japanese students using workspace environment developed by the Morozumi

Figure 14.6
VDS'96 students located in Vancouver and Eugene designed elements and made prototypes with a numerically controlled laser cutter

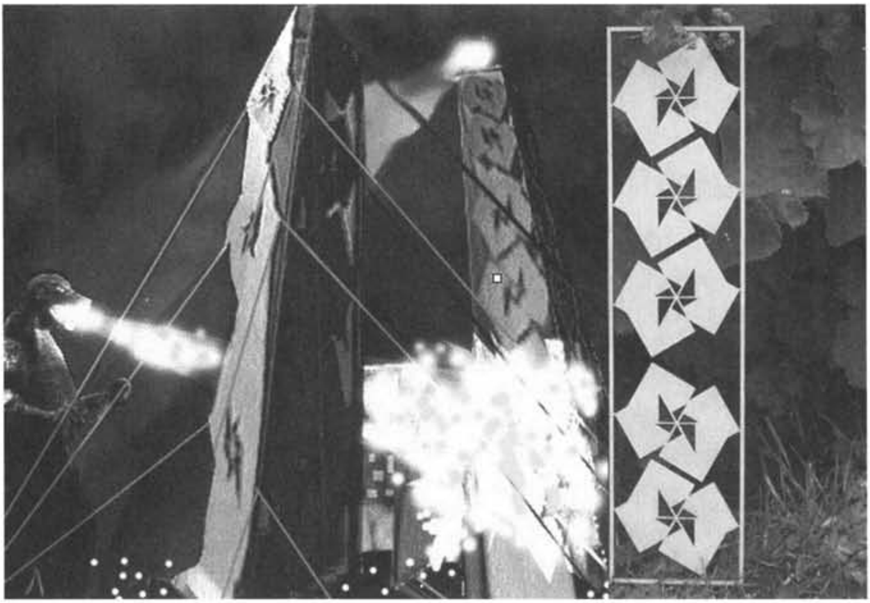
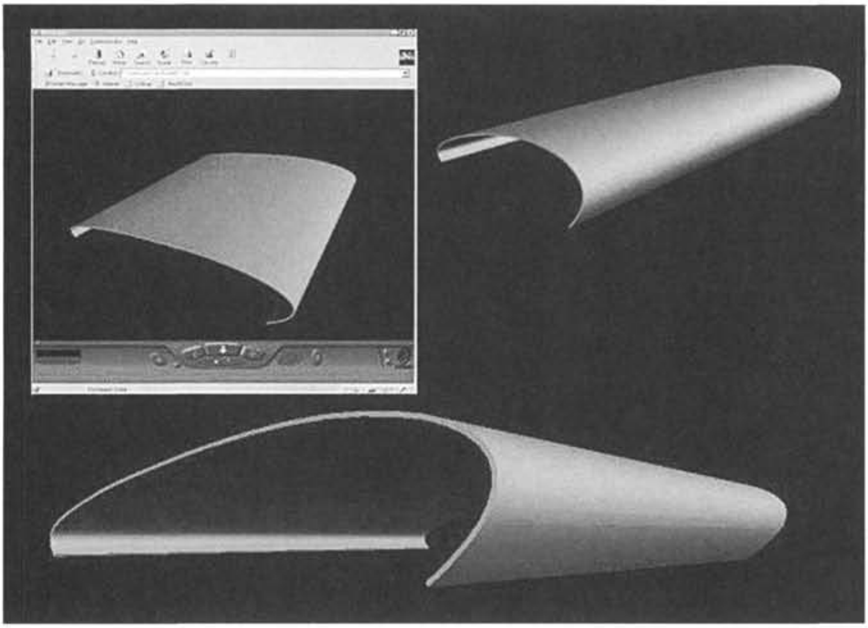


Figure 14.7
VDS'97 included UBC and First Nation Community as the remote client participating in the development of Long House project

Figure 14.8
Study model of Krakow Olympic Arena competition



Lab at Kumamoto University and the design of the Millennium City Project to be viewed during the Internet Expo in Japan.

Design projects involving collaboration over the Internet are increasingly frequent in the professional context, outside academia. VDS-format collaboration has been applied by the author in several architectural design competitions. The design proposals illustrated in Figures 14.8 to 14.15 were formulated with the new media by the collaborators separated by five time zones and submitted for review by a conventional jury. The VRML study model of the roof surface for Krakow Olympic Arena[11] crossed the Atlantic many times during its development (Figure 14.8), though the designers did not meet while working on the project, except for desktop video sessions (Figure 14.9).

The two images (Figures 14.10 and 14.11) are from projects generated under the same, distributed condition and submitted for two housing competitions. In architecture, motion is difficult to convey with the traditional media. The window shutters in the elevation for the Krakow Social Housing Competition attest to this difficulty; to portray the shutters' dynamic potential, interactive examination of the motion model used in their development is essential (Figure 14.10).

Figure 14.9
Designers meeting with desktop video session during the development of the study model of Krakow Olympic Arena competition

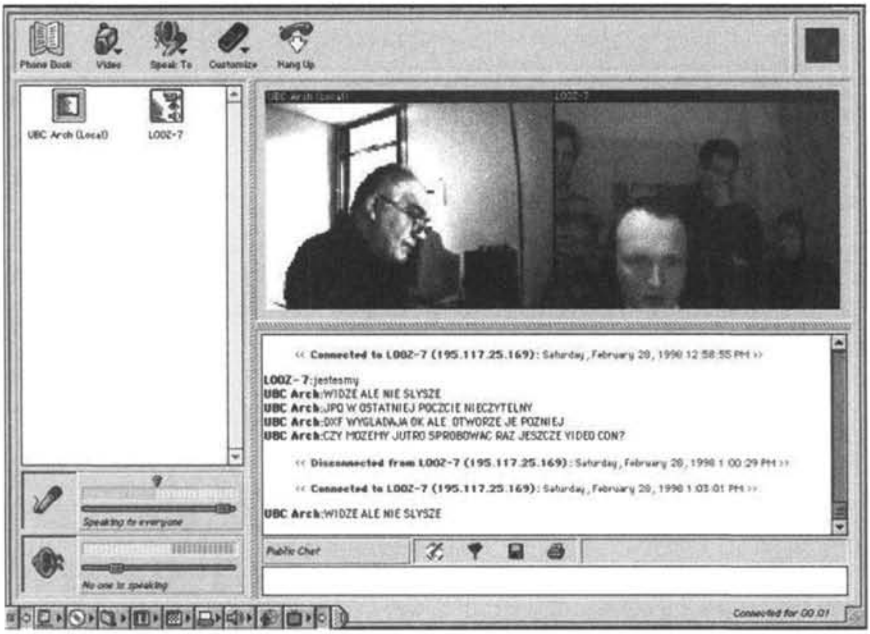


Figure 14.10
Project submitted for the Krakow Social Housing Competition, awarded with distinction even though its authors worked in distributed mode

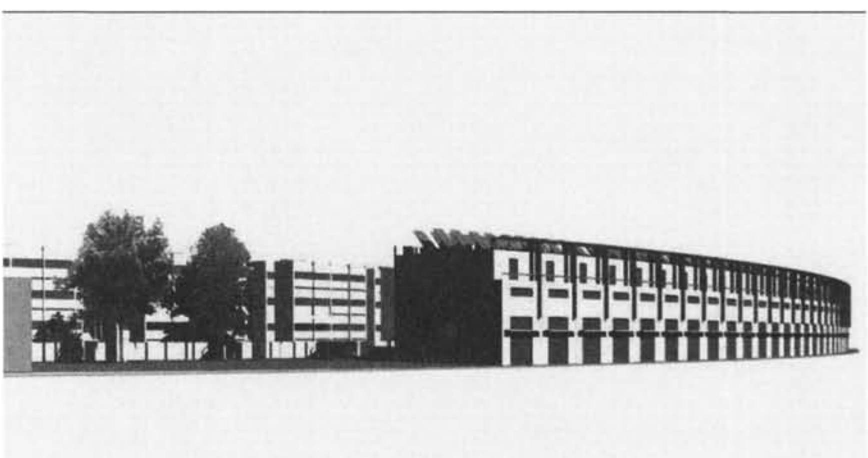
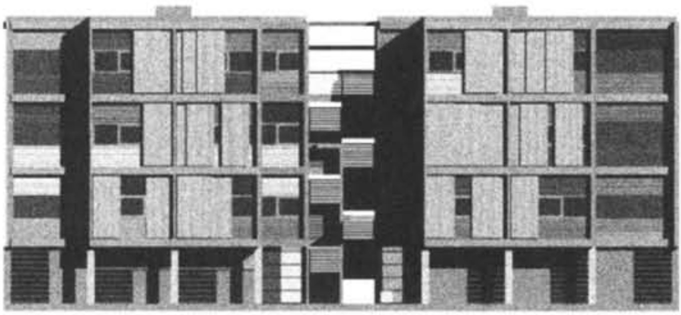


Figure 14.11
(a) Project submitted for the Wroclaw University Library, awarded with distinction even though its authors worked in distributed mode; (b) Project submitted to the Wroclaw University Library Competition developed in VDS mode.

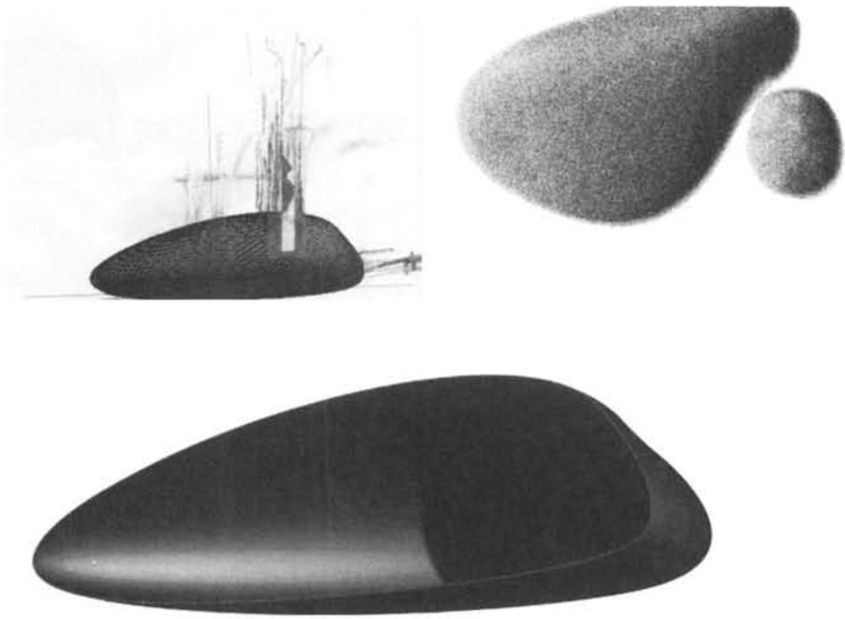
a



b

A formulation of the digital and virtual facade was attempted in the competition entry for the Wroclaw University Library (Figure 14.11). Apart from the move toward the new materiality, complex surfaces derived from nature became a template for the conceptual design for the recent New Oslo Opera Competition (Figure 14.12). The two final design competition projects bring together an agenda for complex shapes, new materiality, and implicit narratives, all formulated in the distributed, VDS mode. The following images are from a competition proposal for the Pol-

Figure 14.12
The complex surfaces digitized from nature became a template for the New Oslo Opera Competition formulated in the VDS mode



ish Pavilion, Expo 2000, Hannover (Figure 14.13) and the Sopot Arena competition, 2000 (Figure 14.14).

BASIC DESIGN AND NEW MEDIA

VDS projects assume past exposure to the new media and working familiarity with IT. In the case of the fresh student of architecture, a different, rudimentary approach is required: one calling for the combination of the modern, basic design agenda with the introduction of the new media. The fundamental digital design pedagogy for VDS is young and not fully established. This is a considerable problem because the practice and learning of architecture today is increasingly aided by and dependent on digital media. The contemporary student of design must engage new and dynamic conditions, in parallel to the traditional methods, at the formative stage of his or her education. In the recent past, the computer was considered as just another device, requiring the development of mechanical techniques or skills. Although those skills still have to be mastered, more recently in design education and practice, IT has become accepted as

Figure 14.13
The competition proposal for the Polish Pavilion at Expo 2000, Hannover

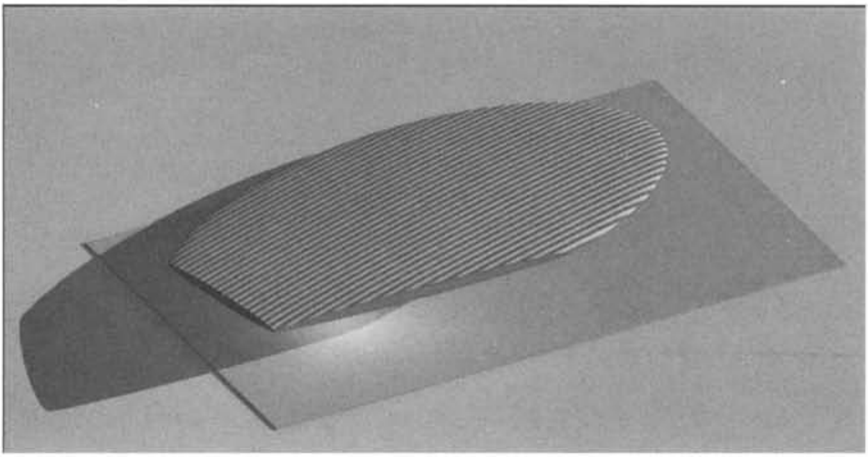
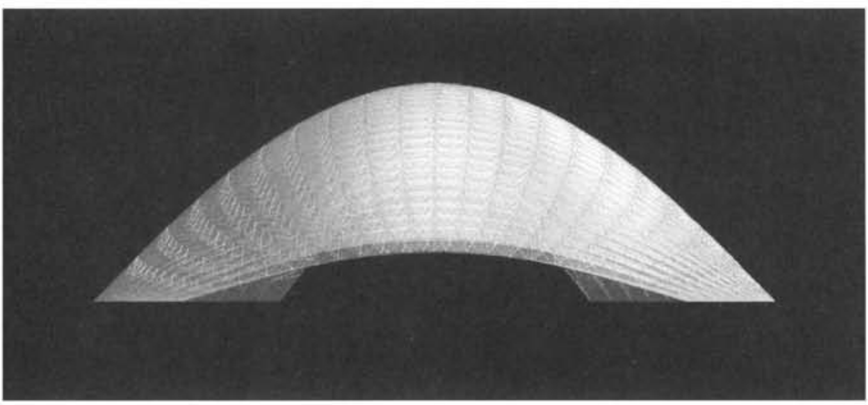


Figure 14.14
The proposal for the Sopot Arena Competition 2000



media—not just as a drafting or modelling tool. This process is perhaps due to the rapid dissemination of computing literacy and to the progressive accessibility and ease of use of IT. At UBC, the Foundation Studio course is intended to make students engage the new media in parallel with the established conventions in design.

This introductory design course assigns particular importance to short, machine-based design exercises. These problems, set as brief design etudes, are offered throughout the semester in parallel to a main project. Digital etudes are tightly framed, addressing limited aspects of design with the new media, while formulating the pedagogy and fundamentals of digital design. Their nature and content loosely relates to the ongoing major project. The following plates illustrate the recent Digital Collage Etude (Figure 14.15).

This etude was to probe students' compositional talents with the aid of electronic collage while working on the design of a pavilion for the old flying boat. The collage technique formulated by Dada and Cubists, based on combining "found" fragments, was to be extended with the digital media. The objective of this short exercise was to engage notions of the layer and its diverse attributes (e.g., transparency). At the same time, the concept of layers, imbedded in all major computer graphic software, was explained to students as analogous to tracing paper in the case of vector-based computer programs, or to the silk screen effect in the case of image processing software. The layer concept was first presented as potentially very interesting, because the contemporary designer encounters layers with increasing frequency and applies it as explicit command during the digital design process. Yet, s/he rarely has a chance of probing its creative potential, using it primarily as a form of drawing data management. Exploring the creative aspects of the layer structure imbedded in the new media, students were asked to develop and publish a digital collage as a form of concise design research. The digital collage was to be presented not only as a complete and static image, but also as delaminated surfaces used to construct the dynamic idea for multilayer, interactive electronic collage affording new readings of the subject.

In the Foundation Studio, initial deployment of the new media in the design studio can be easy if the limits and opportunities associated with it in design process are recognized in advance. The newcomer to computer-aided design might expect major time savings as a result of the move to a digital design studio. Yet, even after developing a basic fluency with a given program, this efficiency is not likely to be immediately possible. Initially, a significant amount of quality time must be devoted to mastering computing in the design context. It is important to anticipate the "time sink" at the early stages of the digital engagement and to allow for it. The traditional one-night design charette, prior to pinup review, is usually counterproductive, as work on the machine requires planning, time management, and a steady work pace. It is advisable, therefore, to start outputting the design material well ahead of the deadline and to document the design process by keeping a record of it. Screens recognized as seminal

Figure 14.15
Digital collages from UBC Foundation Design Studio, 2001

can be easily captured for future reference. The design process can be documented with frequent captures and prints of the screen state, well prior to final presentation. This documentation in the form of a digital sketchbook can broaden students' design universe.

Designers often work with reductive models, in an abstraction of reality. Constructing the digital design model in 3-D, or even using a simple 2-D CAD trace, tends to be time consuming. Creating models that represent a given design involves a major time investment, and exploiting that investment has to be encouraged. For example, the floor plan can be easily edited and used to generate a structural grid drawing, reflected ceiling plan or conceptual parti diagram. The geometric model of the project can be used in creating a diagrammatic axonometric view, immersive pictorial space, or a base for the development of elevation or building section.

Digital, paperless design is first viewed on a screen whose resolution is far less than that of the paper hard copy. Plotting and printing from the machine is often an involved process, because what the new student of design sees on the screen is not necessarily the same as what s/he will get on paper. Outputting the final design from the machine to paper is a recursive process, and ample time must be allowed for the editorial process. A design review in the form of screen-based crit often is limited to one image at a time and needs to be augmented by sketchbook, physical model, or prints of other aspects of the project. Studiowide review can merge the paper plots or prints with a sequential projection of digital images approximating slide presentation. Relying solely on the digital pinup may be detrimental to the critical review process. It would require the simultaneous use of several projectors, or screens in the case of a studiowide pinup, to afford the opportunity for the roving eye of the audience and critic.

Planning and integration of paper- and screen-based presentations is recommended at UBC, as is the use of mixed, digital, and conventional media in design.

At UBC, the student designs short projects that explore the new media and are often narrative driven. For example, the premade digital model of the Mies Farnsworth House was to be examined, rendered, and placed in a new context (Figure 14.16). As a digital etude, this exploration was to give a new meaning to the familiar, but served also as a rudimentary introduction to the 3-D environment. The adjacent plate with the Typology of Beijing Courtyard Housing is from a 1997 master's thesis (Figure 14.17)—it illustrates the potential of integrating the moving picture from digital video with the static images of typology, introducing new conventions to design.

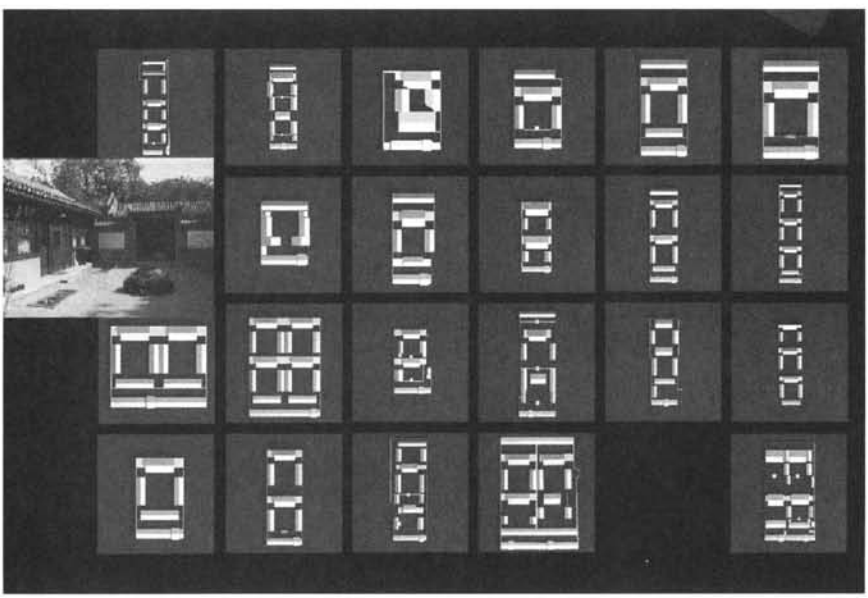
INNOVATION AND PRACTICE

Parallel to the growing significance of the new media, new trends in the practice of design can already be recognized. Following the rapid dissemination of computing, the global expansion of the Internet is now evident, and the issue of connectivity is rapidly becoming an integral part of design. This connectivity can be seen both as an instrument for communication and for the remediation of past conventions in practice and education of design. IT facilitates design collaboration. It expands the possibilities of creative design work if computers are regarded not as tools, but as the means to further engage with other designers in the creative aspects of design development. New forms of practice, such as distance design collaborations over the Internet and participatory design in virtual environments, are being integrated into the creative process of the contemporary architect. Design can assume the form of correspondence across borders of space and time because architecture can be practiced anywhere and at any time. We are witnessing a redefinition of time and space and seeing architects operating outside the limits of locality. Design teams are structured more like a film production group; multidisciplinary teams are coming together for short-term and intense tasks. Often teams fall apart or assume a different guise after the project's completion. Yet, this type of new practice, although very dynamic, begs serious questions. What are its social implications? Will it bring the designer and public closer together, or will it make us more detached from the situation, whereby we start inhabiting it only temporally and often remotely?

For centuries, the abstract, Euclidean constructs of orthogonal projections were used not only to describe and to represent architecture. They

Figure 14.16
Narrative power of digital media illustrated with the short student project

Figure 14.17
Integration of the moving picture with the static, orthogonal view is introducing new conventions to design



were also used for conceptual notation during the formative design process. Conventions of orthogonal projection quoted from classical plates and illustrated here are understood only to those familiar with the particular convention (Figure 14.18), whereas the interactive QTVR model of the classical Japanese carpentry joint affords its immediate understanding for all (Figure 14.19). The new media facilitate the collapse of established and professional boundaries and increase the accessibility of the discipline.

In recent years, we have witnessed the growing importance of the complex 3-D digital model in the representation of design and in its generation. New media with strong narrative possibilities are being deployed in the architectural design. The interactive motion models can amplify this potential. Initially, moving pictures entered the design discipline as a tool of presentation, offering convincing walk-through, simulation, and real-time immersion into pictorial space. Apart from motion, the film culture brought us the notion of montage almost at its inception.[12] In French, *monter* means "to assemble." It stands for editing, cutting, and piecing together bits of exposed film to compose and convey the intent of the work. Montage, creatively conceived by Eisenstein in his *Battleship Potiomkin,* was unique to motion pictures for a long time (Figure 14.20).

Today the notion of montage is admitted into architecture, whereas the massive proliferation of digital video becomes as important as was the introduction of desktop publishing and image processing a decade ago. The connection to the motion picture discipline, now an over 100-year-old culture, is important and worth exploring, although in terms of design conventions the situation is still radical and unstable. Finally, there is the fascinating ability of new media to extend 3-D models into immersive space as well as the ability to work with the illusionary materiality and new projected digital image. Those aspects have already been utilized in theater, TV, and movie culture for some time, but with the collapse of professional boundaries and the proliferation of new, digital media, all of these techniques are now widely available to all designers.

More recently, motion models are being deployed during design generation. Using morphing or twinning with key framing and with a variety of parametric constraints, the designer can now algorithmically generate a vast array of formal transformations and select from the results of this automated or serial production a condition of particular interest. Those digital motion models, characterized by complex surfaces and kinematics, are often uncritically embraced by students of design, who see it as a tempting automata for the generation and testing of design. Combined with the growing popularity of NURBS modelers, this gives the fresh

Figure 14.18
Orthogonal projections from classical plate is understood only to those familiar with this particular convention

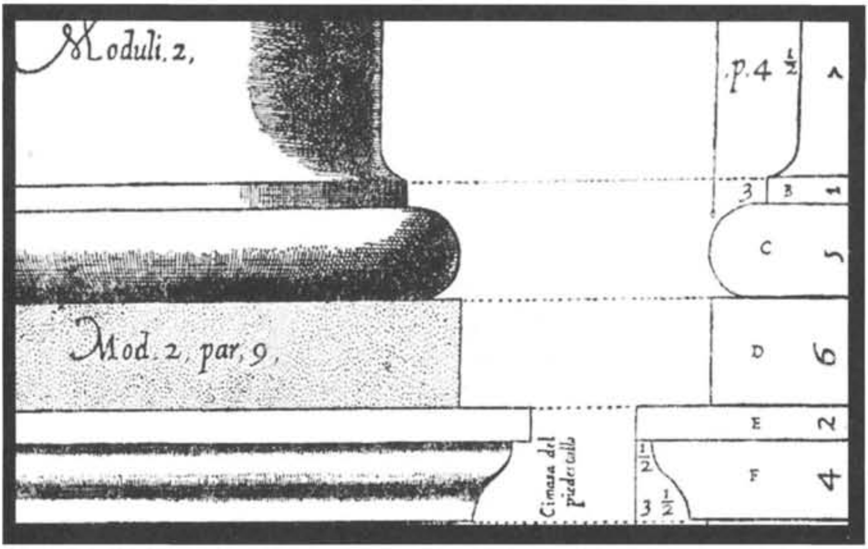


Figure 14.19
The interactive QTVR model of the classical Japanese carpentry joint affords its immediate understanding

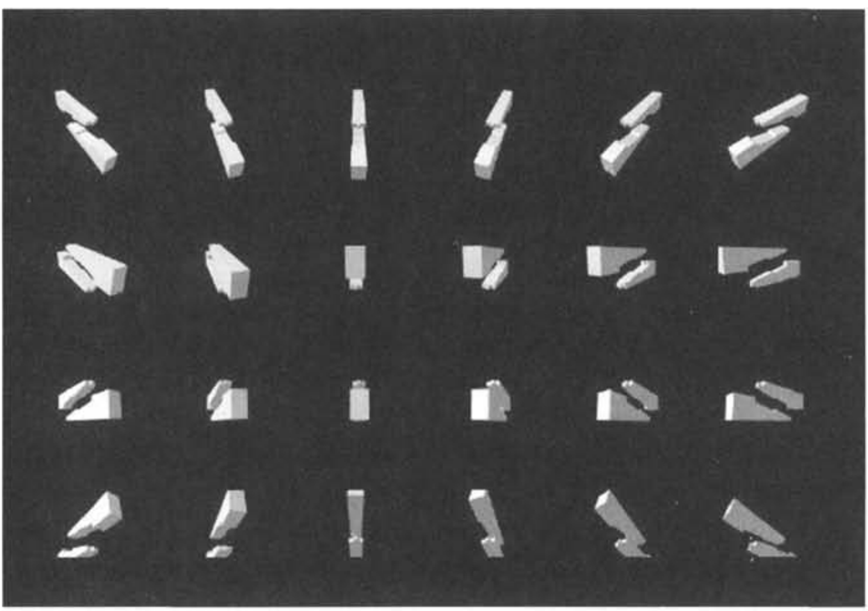
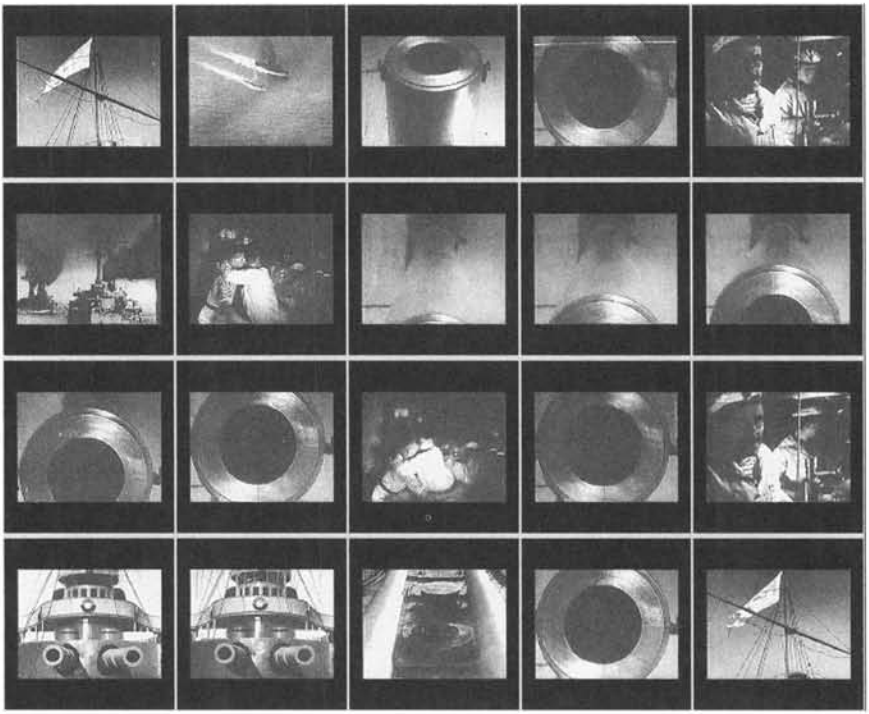


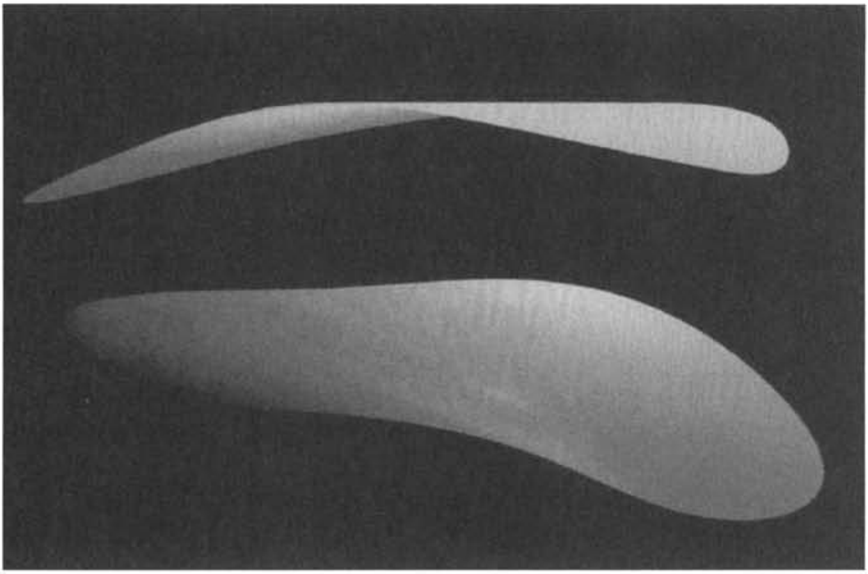
Figure 14.20
Example of montage from Eisenstein motion picture *Battleship Potiomkin*, 1925



designer the exceptional opportunity to access the magically complex universe of forms (Figure 14.21). However, the enthusiastic embrace of this formalism cannot produce significant results until it becomes more rigorously critiqued and tested by the process of its prototyping, construction, and materiality, as well as by the environmental, economical, and social context.

Few of the modern masters relied on complex geometries prior to the computer age. The constructions of Luigi Nervi, shells of Felix Candela, and Philips Pavilion or Ronchamps Chapel by Le Corbusier are among the notable but rare examples of modern architecture in this category. Le Corbusier at the end of his life considered the ruled surface as a particularly interesting convention in describing the complexities of some of his objet types and *objets de reaction poetique.* Yet, the majority of modern architecture can be still described by orthogonal extrusion with the occasional

Figure 14.21
Design exploration of complex surface with NURBS modeler, 1992



rotational sweep. A promising aspect of the digital model lays in its inherent ability to be used as data for the production of design and to serve as data in CAD-CAM, or the quick prototyping process. This can potentially create a new relationship between designer, project, and object of design, perhaps turning architect into the digital artisan–craftsman.[13]

The discipline of architecture derives its strength from the explicit engagement of Euclidean geometry. In education today, the new media can have a destabilizing effect due to the redefinition of those time-honored conventions. The crisis became evident as Rafael Moneo observed: "Electronic communication, global information and virtual imagery seem to have dissolved all interest in forms and their representation. Continuous choice is ours. Form, related to performance, hinders the future and therefore has fallen from grace.... Will architecture become more and more landscape of situations, rather than assembly of structured languages?"[14]

CONCLUSIONS

The idea of a basic design education was formed at Bauhaus out of the conviction that designs for mass production and modern architecture needed a new fundamental strategy. "*Exact knowledge of material and machine are equally necessary to give the product organic function.*"[15] Today, 75 years later, the modern, basic design pedagogy needs to be revisited as we begin to deal with the new machinery.

The emergence of computers has been extremely rapid. Has it upset established conventions and redefined the boundaries of the architecture as an established discipline? Certainly, evidence of crossing of boundaries to alien professions exists. Yet, despite the growing engagement and interest in the digital realm, the guiding and effective power of abstraction, established in design conventions, must be acknowledged. The power of abstract conventions in conceptualization remains in place. The two-dimensional, orthogonal projections of plan, elevation, and section, have developed into abstract design notation, which has been well understood by the initiated since the times of Euclid. The critique and rejection of this abstract notation with the aid of kinematics and complex surface modelers, abused by fresh students of design as some form of digital Play-Doh, is naive. Even the serious protagonist of new topological space speaks in defense of Euclidean geometry, much needed in the act of production: "*The value of Euclidean space would be of less consequence to us, were we not involved in numerically controlled manufacturing. For a tool path is fundamentally a parallel to the surface to be manufactured. In other words, a machining program generator starts by calculating the set of points at an equal distance from the surface, distance given by the radius of the spherical tool of the router. A machining program is basically the parallel to a free surface, whichever it is. And the concept of parallel, so fundamental in Euclidean geometry, starts creating interesting problems long before we contemplate free surfaces.*"[16]

On the other hand, IT should be now accepted as media, crossing the boundaries of familiar conventions to those of nonarchitectural disciplines. The nature of these media permits the designer to think in three dimensions more naturally and to a greater degree than she or he previously could. However, the ease with which simulated complex surfaces are generated by new media could be disturbing to the additive rigor of traditional design conventions. Today, with ease of visualization and design, digital simulation in the early design stages can enable the collaborator, client, and ultimately the public to develop a full understanding of the design narrative from its conception.

Our experience has allowed us to expand the definition of new media types used in architectural design, acknowledging the necessity of communication media for discussion and negotiation that occur in the design cycle. In the not-too-distant future, immersive environments will amplify this VDS paradigm even further. The use of collaborative architectural authoring can be reformulated by the Virtually Augmented Reality environment, further enhancing the ability of collaborating designers, as well citizens, to construct design solutions across the borders of time and space. Asynchronous collaboration can be seen as an asset in the design process because the design universe can be stabilized and structured by the limited feedback in the temporally distributed studio. Moreover, diverse individual schedules can be easily accommodated with little consequence to the project overall. The seesaw between abstraction and simulation as well as between virtual and real are central conditions of contemporary design. The design process can easily be recorded and the possibility of backtracking through design might be a significant source of its understanding.

The narrative power of the new media might transform the nature of design practice by bringing the client–citizen closer to the design process and by communicating visual information more effectively and more often. Information Technology has to assume the guise of design facilitator, who can impact the nature of contemporary practice through the development of a new relationship with the public. In this context, it will be interesting to further amplify the VDS experiences once the participatory feedback of all design actors is facilitated by growing connectivity and distributed design practice. The modernist tradition is thus not substituted but only extended by the IT revolution. With the distributed, collaborative modes of working and learning, the space-time condition introduced by Einstein and the Cubists remains central to architecture, whose conventions today are challenged by the new media.

NOTES

1. C. Levi-Strauss, *The Savage Mind* (Chicago: University of Chicago Press, 1967), p. 296.
2. S. Giedion, *Space, Time and Architecture* (Cambridge, Mass.: Cambridge University Press, 1946).
3. W. Gropius, *Apollo in Democracy* (New York: McGraw-Hill, 1964), p. 74.
4. A. Imperiale, *New Flatness* (Boston: Birkhauser, 2000), p. 83.
5. J. Wojtowicz, *Virtual Design Studio* (Hong Kong: Hong Kong University Press, 1995).
6. J. Wojtowicz, J. Davidson, and W. J. Mitchell, "Design as Digital Correspondence," in *Computer Supported Design in Architecture*, ed. K. Keenest and D. Noble (Charleston, SC: The Association for Computer Aided Design in Architecture, 1992), pp. 98–102.

7. Ibid.

8. Together with a few following projects, it became the basis for the VDS book (see earlier).

9. See www3.arch.ubc.ca/jerzy/vds_r/

10. D. Donath et al., "Virtual Design Studio 1998—a Place2Wait," in *Architectural Computing from Turing to 2000*, ed. A. Brown et al. (Liverpool, UK: University of Liverpool, 1999), pp. 451–458.

11. J. Wojtowicz and K. Butelski, "Lessons from Distributed Design Practice," in *Architectural Computing from Turing to 2000*, ed. A. Brown et al. (Liverpool, UK: University of Liverpool, 1999), pp. 482–487.

12. S. Eisenstein, *Battleship Potiomkin*, 1925.

13. M. McCullough, *Abstracting Craft: The Practiced Digital Hand* (Cambridge, Mass.: MIT Press, 1998).

14. R. Moneo, "Recent Architectural Paradigms and a Personal Alternative," *Harvard Design Magazine*, 5(Summer 1998), pp. 71–75.

15. L. Moholy-Nagy, "New Approach to Fundamentals of Design," in *The Bauhaus*, ed. H. Wingler (Cambridge, Mass.: MIT Press, 1985), p. 196.

16. B. Cache, *Earth Moves* (Cambridge, Mass.: MIT Press, 1995).

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