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Stamatina Th. Rassia
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Future City Architecture for Optimal Living

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Future City Architecture for Optimal Living

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Preface

Future City Architecture for Optimal Living presents a unique interdisciplinary combination of architecture, engineering, physics, and related fields in strategic planning, thinking, and designing future cities as livable urbanized environments.

Cities in the words of Geoffrey West are "the crucible of civilization." In our belief, cities and their development can provide an impact on future ways of living as they can transform our lifestyles through a wide network of attributes. By combining together a variety of disciplines, this book presents new ideas and research practices on a variety of topics related to architecture and interdisciplinary mathematical thinking, network design, smart city development, as well as related theories for the future.

The chapters composing this book are written by eminent researchers and practitioners who offer expert opinions and hands-on international approaches to shaping future cities. Together, experts from the United Kingdom, Portugal, France, Italy, Switzerland, Netherlands, Greece, USA, Canada, Singapore, and Hong Kong present their work, experience, and new ideas. New questions are presented, such as whether cities can really be livable and how one can build sustainable systems and resilient cities to climate changes. This book offers a forum of novel ideas that are presented in a unified manner.

We would like to express our special thanks to all the authors of the chapters contributed in this book. Last but not least, we wish to acknowledge the superb assistance that the staff of Springer has provided during the preparation of this publication.

Singapore — Stamatina Th. Rassia
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If Robots Conquer Airspace: The Architecture of *The Vertical City*

Jan Willmann, Fabio Gramazio, and Matthias Kohler

Abstract Today, more people than ever live in the metropolises of our world. The tension between the explosively growing metropolises and their satellite cities, and between these interconnected regions and the diminishing rural communities, present immense social and economic challenges that require entirely new ways of thinking about and materialising architecture if the twenty-first century's urban adventure is to succeed. And this is expressed in the most radical way in *Flight Assembled Architecture*.

Keywords Computational design • Digital fabrication • Airborne construction • Urban diversity • Mass-customised modularity • Architectural utopia

In *Flight Assembled Architecture* a group of quadrocopters cooperatively assemble over 1,500 elements to form a complex building structure [1]. Their flight behaviour is generated by an algorithmic translation of digital design data: the quadrocopters land on a platform where they pick up foam elements and then set them down precisely on top of one another (Fig. 1). An overall undulating figure emerges, whose individual layers are offset from each other, creating a geometrically differentiated outer envelope. *Flight Assembled Architecture* not only represents the world's first installation built by flying robots but simultaneously embodies a vision.

Presented at the *Regional Fund for Contemporary Art* (FRAC Centre) in Orléans, the installation is a 1:100 model of a 600 metre tall urban structure, which, with its 180 floors, possesses a total useable floor area of 1.3 million square metres—a kind of "vertical" utopia [2]. Comprised of vertical core structures and horizontal module chains, the structure is notable on two counts: its porous arrangement not only creates living space for over 30,000 inhabitants with a great variety of programmatic and urban potential but also enables a large degree of freedom for the spatial arrangement of the modules and their space-enclosing, self-stabilising formation. Here it is not the absolute height that is decisive, but rather the spatial order resulting from the structural composition (Fig. 2).

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Fig. 1 The complex structure of the 1:100 installation has been assembled by autonomously flying "quadrocopters" which land on a platform to pick up building elements and then set them down precisely on top of one another (Image by François Lauginie)

Fig. 2 *Flight Assembled Architecture* represents the first architectural installation assembled by flying robots and was demonstrated in 2011 at the FRAC Centre, Orléans, France (Image by François Lauginie)

Overall, *Flight Assembled Architecture*, with its rationalised acquisition and treatment of data, unifies all stages of the architectural process—from the original digital design needed to the final built structure [3]. At the same time, the threshold between robotics and architecture increasingly begins to disappear, and the architectural installation becomes an expression of an architectural future utopia—a *Vertical Village*.

At a scale one hundred times smaller than the vision, this certainly appears to be an abstraction, but its physical significance is both real and tangible. It is this perception and the interaction of many different disciplines and potentials, which allow the project to hover between utopia and a built architectural installation, in order to design new kinds of dynamic structures for a future urbanity and to transform technological, architectural and urban design analogies into built reality [4].

1 How to Tilt the Grid?

The Vertical Village makes use of a grid-like organisation. This however does not run horizontally, as in an ideal city or a usual city grid, but is turned vertically and closed to form a circular entity. A geometric assemblage is generated that not only is the basis for the particular constructional features of the whole structure but also enables a varied urban programme: the individually positioned modules communicate with each other; the spaces in between grow and shrink and change their position and size (Fig. 3), and yet nevertheless form a unified whole.

Indeed, according to Peter Sloterdijk, for a city to be able to function and to survive in the future, a consideration of the structural form of the contemporary city is essential. He argues that urban spaces must be connected vertically as well as horizontally, in order to ultimately form multi-directional spatial relationships and with them, urban "Wohnschäume" [5]. With its network of interrelated modules, in-between spaces, and connections, *The Vertical Village* enables a decentralisation that avoids not only the point-like restriction of older settlement planning and the orthogonal and therefore laborious pathways of the modern city but also the confusing chaos that characterises almost all unregulated urban expansion today [6].

Consequently, circulation in *The Vertical Village* can remain constrained to solely pedestrian access. Inhabitants have quick and direct access to all important functions such as schools, shops, public services and leisure activities. As such, *The Vertical Village* offers a healthy and communicative urbanity of short distances and a mixture of work and living; everything remains decentralised and freely accessible. Furthermore, the high-density architecture of *The Vertical Village* offers not only a high amenity value and capacity for adaptation but an enormous economic and ecological potential as well. Simultaneously, the complete "transcendence of the grid" enables a spatial occupation and linking of new uses, functions and programmes, from which ultimately emerges a wholly new urban ontology (Fig. 4). This integrates the entire constructional morphology through to its detailed architectural articulation. In this sense, *The Vertical Village* negotiates the transition from an ideal order of a city to a

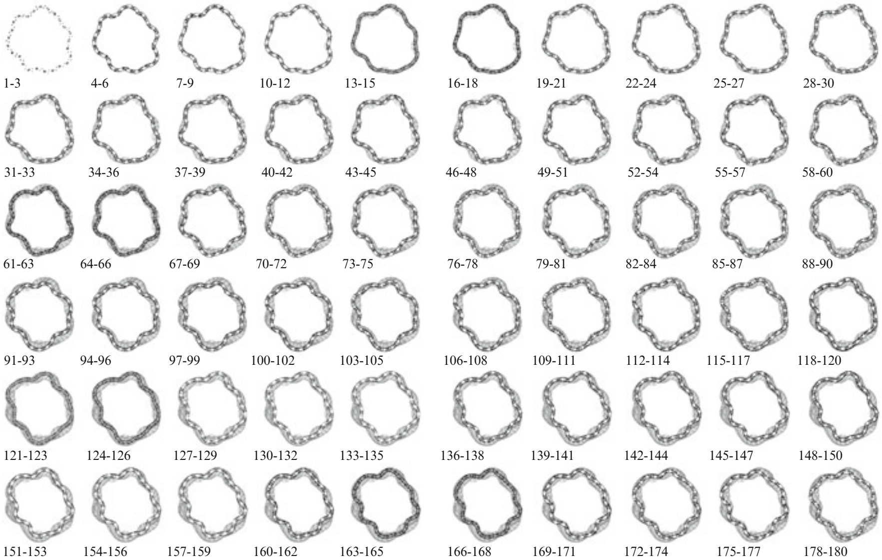

Fig. 3 *The Vertical Village* generates a geometric assemblage that not only is the basis for the particular constructional features of the whole structure but also enables a varied urban programme on 60 individual building layers (Image by Gramazio Kohler Architects, Zurich)

spatial differentiation—no less than a complete revision of the city's organisational nature: the monotonous, often unbearable density of earlier eras thus becomes the engine of a newly discovered urbanity.

2 Understanding a Vertical Urban Landscape

The sustainable development of the twenty-first century city has long been a topic of discussion. On the one hand, in the coming decades it will be developing countries, with their rapidly growing cities, that will absorb much of the overall urban growth. On the other hand, and no less important, more than half of the world's population will live in cities of less than 250,000 inhabitants [7]. There is no doubt that the European city faces exciting and important challenges. These tasks can no longer be tackled with old design and planning processes, or with simplified strategies of densification or of social housing [8]. It is these phenomena that form a fundamental basis for *The Vertical Village* since its adaptable size enables a shift in the form of development from a traditional city grid and rigid block structure towards a "village-like" densification of urban landscapes.

Thus the priority of this concept is in the design and practical usability of such urban landscapes, and their characteristics. Here, there are fewer collective or prestigious aims in mind, instead: liveliness and balanced social composition [9]. An "image of the city" arises, principally emerging from the individual activities of

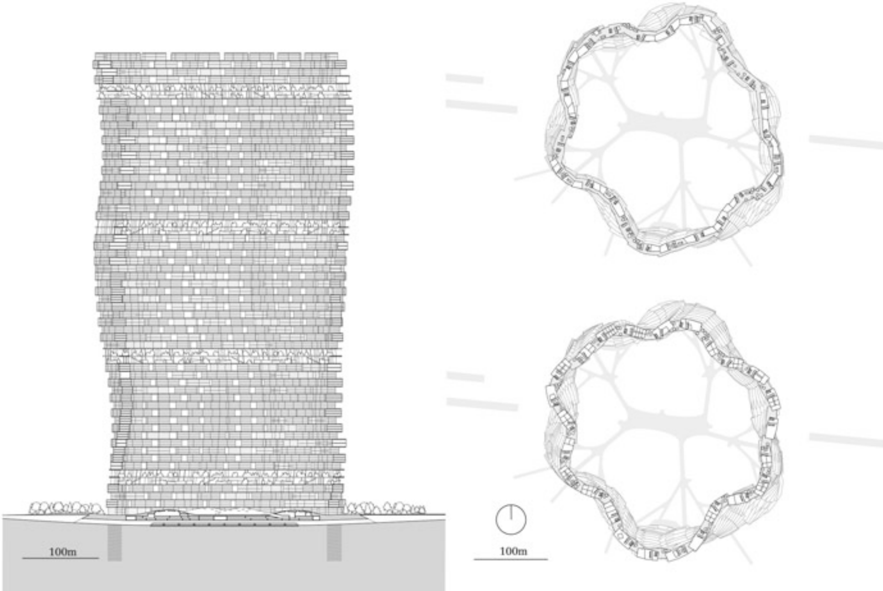

Fig. 4 The high-density architecture of *The Vertical Village* offers a healthy and communicative urbanity of short distances and a mixture of work and living—everything remains decentralised and freely accessible (Image by Gramazio Kohler Architects, Zurich)

its inhabitants [10]. This is possible in *The Vertical Village* because of its "porous" outer envelope, which remains recognisable as a whole despite its adaptability, and its scenic depth, which is achieved through the seamless integration of its outer surface, its construction and its contents. While traditional systems for towers, multifunctional building-types and networked towers require a defined order, in *The Vertical Village* a cohesive urbanity arises, which is formed by an intricate layering of private, semi-private and public space (Fig. 5). Within this high level of density, the various bifurcations and intricate structure allow an increased amount of diversity and "publicness" [11].

The question of the variety and accessibility of urban spaces and their contents becomes one of the central themes of *The Vertical Village*; this inasmuch as the four giant continuous public double-rings with a combined length of one kilometre, which are located not—as usual—on the lowest level, but rather spread out through the entire height of the structure, creating heterogeneous city structures [12]. The public space thus extends over the entire height. Together with the enclosed space, which with a diameter of over 300 metres is quite comparable with a river valley, this creates the possibility of an urban generosity and permeability, which treats public life, with everything it offers, less as something unified, horizontal and insular, and far more as an essential feature. For because of the sheer size and structure of *The Vertical Village*, the inhabitants and their activities are only vaguely discernable,

Fig. 5 Computer rendering of the self-stabilising, porous arrangement of *The Vertical Village*, creating living space for over 30,000 inhabitants (Image by Gramazio Kohler Architects, Zurich)

whilst still maintaining a presence that enables the life and intimacy within *The Vertical Village*.

3 What Is the Architecture of the Supersized Modularity?

Seen against the background of the radically changing production conditions in the digital age [13], it becomes clear that the acceptance of industrialisation's serial repetition and the romantic notion of the uniqueness of handcraft are both no longer tenable in the context of this project. What is more conceivable than to transpose this new architectural framework to the scale of the city? For many places a new language of variation is already being created, whose formation allows processes instead of final forms to be designed. In these processes, different elements are assembled to form a continuous, differentiated, yet coherent whole. As *The Vertical Village* demonstrates, such processes need not be limited by their application to individual objects or prototypical building elements, but could allow a new approach to architectural criteria, relationships and degrees of freedom within an urban scale.

Prerequisite for this is a generic modularity of the individual elements (Fig. 6). In *The Vertical Village* there are up to 25 modules on each horizontal layer. They rest upon on another only near their ends: odd and even floors are offset from one another, creating an intermediate space underneath the middle of each module.

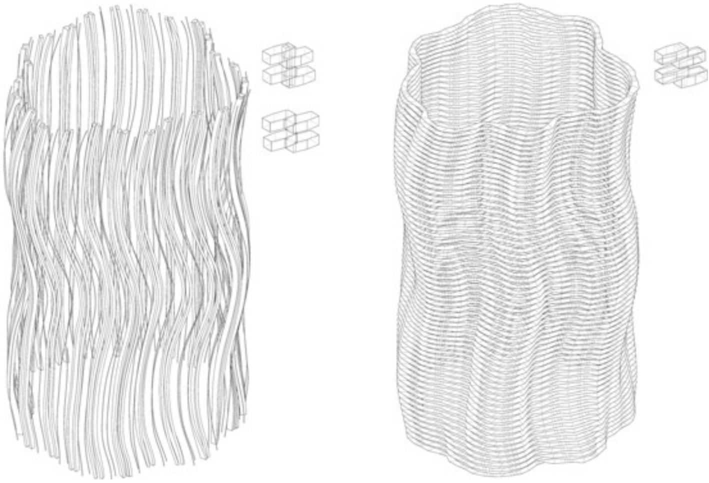

Fig. 6 *The Vertical Village* makes use of a grid-like organisation. This however does not run horizontally, as in an ideal city or a usual city grid, but is turned vertically and closed to form a circular entity (Image by Gramazio Kohler Architects, Zurich)

Additionally, all even and odd floors are displaced in relation to each other, so that the structure gains a geometrically differentiated figure as a whole. The modules are then differentiated only internally, where they contain between one and three floors. The outer dimensions of the modules are, in contrast, unified. They are 30 metres long, 12–15 metres wide and 10 metres high. Whereas a module is traditionally defined in its function essentially as a building component or a spatial unit, something else is apparent here: the module acquires a particular variability, freed internally from any specific functionality, and is thus versatile in its actual form whilst externally remaining unified and generically deployable. The consequence for the geometry of the overall structure is a "seriality", which externally and internally is never monotonous or repetitive, but rather differentiated and adaptable. To make this possible to construct, a special assembly process was chosen for the load-bearing structure of the module. This comprises an inner core of concrete, steel and reinforced concrete columns, and a steel framework for the floors and ceilings. A shell of complex curved glass panels—membranous, flexible and adjustable—forms the outer layer of the module. Simultaneously the modules establish their own relationships to the outside space, through which the terraces and semi-private areas can be individually adjusted and embedded within the undulating structure. From an apparently unified modulation, a principle is produced that is robust, comprehensive and versatile all at once [14]. This also shows how important insights from the construction of elements and floors can be transferred to the capacity for configuration at an urban scale [15].

4 The Village as Object

Planned nature, the intermediate state of the suburbs and the resulting loss of the clarity of the city—all this today appears normal; at the same time the classic distinction between city and landscape disappears, and everything becomes blurred. What emerges instead is a suburban idea in which established and preferred cultural products, gestures and artefacts lie "somewhere in between" and simultaneously create the desire to make hybrid forms and interventions. This was the main reason to set *The Vertical Village* in the French Département of Meuse—a region that, like many other European regions, is already characterised by an exodus of the local population and should be considerably improved through politically determined structural measures. An existing TGV station that was built within the "diagonale du vide" [16], has a largely unused yet direct connection to Paris and other important destinations throughout Europe. The goal of *The Vertical Village* is therefore to activate hitherto unused potentials of the structurally weak region, and to bestow the place a new significance. It is no coincidence that *The Vertical Village* appears radical in this context, for in this the principle of independent place-making is at work: in the surreal surroundings of the region, *The Vertical Village* alone creates the potential for a new identity for the region itself.

It is surely fitting to embed the structure in the surrounding cultural landscape: the half derelict, half open landscape is both artificial and natural, and in its vastness forms a suitable setting for *The Vertical Village*. Seen in the context of its landscape—the most common view of the structure—*The Vertical Village* assumes the appearance of a large-scale sculpture that blurs and dissolves into smaller entities as one approaches. The somewhat surreal and transparent corporeality of *The Vertical Village* is therefore a kind of architectural apostrophe—an orientation within the scenic nothingness, mirrored simultaneously in higher realms of dissolved order. It is that visual unsharpness, that *Digital Materiality*, which is now being unfolded and translated at a completely different scale [17].

The bodily presence of the design is thus characterised by a distinct "aesthetic robustness". Despite the large number of intricately organised modules, the building volume remains integrated as an object in the landscape: it is easily recognised and reveals its inherent order depending on the point from which it is viewed. Seen from the outside, the first impression of a completely vertically stacked city is suddenly graspable and reveals itself in its true scale (Fig. 7). But a great variety of impressions and perceptions are also formed from inside *The Vertical Village*. At no time does the "porous" city structure appear deterministic or monotonous. Instead, it enables the inhabitant to be "in the city", with all its varied relationships—for wherever one is located in *The Vertical Village*, new insights and visual connections to the surroundings are continually being formed. This can be recognised not just in the texture or the outer surface of the structure, but equally in its entire sculptural depth and transparency. In this way it becomes possible to allow digital and material order to enter into a phenomenological correlation, in which they enrich one another and reflect many different layers of perception.

Fig. 7 *The Vertical Village* contains four giant continuous public double-rings with a combined length of one kilometre, which are located not—as usual—on the lowest level, but rather spread out through the entire height of the structure, creating heterogeneous city structures (Image by Gramazio Kohler Architects, Zurich)

5 Utopia Reloaded?

From a contemporary standpoint, the project represents a form of utopia. Flying robots of the size and ability required to realise the project do not yet exist. Yet this captivating approach merits further material study, such as with the experiments made in *Flight Assembled Architecture*, in the hope of one day translating these ideas into built reality [18]. With this deliberately confrontational and radical city design and sculptural installation, we seek not only to develop an architectural utopia but also to generate entirely new modes of perception and comprehension. History has shown us that we often repress the new, and as such prevent the realisation of innovative, but risky ideas. Hence the urban utopia—from antiquated visions of ideal states and cities, biblical approaches and Vitruvius' theory, and the idealised mediaeval representations of ideal cities to revolutionary architecture up until the early socialist, modernist or post-modern subversions—has a secure place in the history of the built and planned environment [19]. This surely holds true for *Flight Assembled Architecture*, for here the utopia becomes tangible, can be experienced, and expresses the transformations of an era. For when the great urban designs and models have fallen out of use, and when, through complex social and global conflicts, ideal or monolithic solutions have become obsolete, then, as the history of the city already demonstrates, *The Vertical Village* and landscape will become viable once more; then, there will be room for ideal structures and communities. And indeed, the search for a better world has never ceased, but has instead found a new home in radical materialist approaches and visionary collaborations. *Flight Assembled Architecture* also lies within this tradition: for utopia has become futurology [20].

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References

1. The project *Flight Assembled Architecture* is based on a collaboration of Gramazio & Kohler and Raffaello D'Andrea in cooperation with ETH Zurich. It represents the first architectural installation assembled by flying robots and was demonstrated in 2011 at the FRAC Centre, Orléans, France
2. Gramazio, F., Kohler, M., D'Andrea, R.: (eds) Flight Assembled Architecture. Editions HYX, Orléans: Editions HYX, pp. 15–17 (2013)
3. Kohler, M.: Aerial architecture. LOG **25**, 23–30 (2012)
4. Willmann, J., Gramazio, F., Kohler, M., Langenberg, S.: Digital by material: envisioning an extended performative materiality in the digital age of architecture. In: Brell-Cokcan, S., Braumann, J. (eds.) Robotic Fabrication in Architecture, Art and Design, pp. 12–27. Springer, Vienna (2012)
5. Sloterdijk, P.: Sphären III. Schäume. Suhrkamp, Frankfurt/M (2004)
6. See Kiyonori Kikutake's idea of a *Tower-shaped Community* (1960) that featured a joint core system, holding up to 1,250 living units for over 5,000 inhabitants. Koolhaas R, Obrist H-U (eds) (2011) Project Japan—Metabolism Talks . . . , Taschen, Cologne, p. 360
7. See UN Human Settlements Programme (UN-HABITAT), Report 2008
8. Beck, U., Giddens, A., Lash, S.: (eds) Reflexive Modernisierung—Eine Debatte. Suhrkamp, Frankfurt/M (1996)
9. Lootsma, B.: Der öffentliche Raum in Bewegung. Daidalos Nr. 67 (1998)
10. Lynch, K.: The Image of the City. MIT Press, Cambridge/MA (1960)
11. This is reminiscent of Christopher Alexander's notable essay *A City is not a Tree* (1965). Where Alexander describes the growth of a city, not in the sense of tree-like natural structures, but rather through semi-lattices—overlapping sets and spatial arrangements—and identifies these as the key generative principles. Early on, Alexander points to the formation of different territories and describes them as diagrammatically generated aggregations. Even if today it might be proven that the experimentation using such theory can hardly suffice to understand the city in all its complexity, Alexander deserves credit for having at least explored a comprehensive system and methodological consideration of urban dynamics. For *The Vertical Village*, it is particularly significant that Alexander's description of fine-grained, almost rhizome-like self-organising strands and structures representing an abstract structural relational order, which is however associated with specific structured and tailored spatial and architectural situations (Alexander later famously refers to these as "patterns"). With this he argues once again that the city is an "open" structure, whose individual elements are related to one another in the most different ways, much like that in *The Vertical Village*.
12. Saunders, D.: Arrival City: How the Largest Migration in History is Reshaping Our World. Knopf, Toronto (2011)

13. Carpo, M.: The Digital Turn in Architecture 1992–2010. John Wiley & Sons, London (2012)
14. See Kisho Kurokawa's tourist development project for *Umm Al Khanazeer Island in Baghdad* (1975). Here, it is remarkable that Kurokawa not only designed a metabolist building structure but also developed a concise strategy of how this could be built up and assembled from its parts. Koolhaas R, Obrist H-U (eds) (2011) Project Japan—Metabolism Talks . . . , Taschen, Cologne, pp. 622–623
15. An additional feature is the robot-based fabrication of the modules in an adjacent yard. The variously curved, multifunctional glass facades are assembled here in small series, and the overall structure and individual interior configurations are made. For the construction of *The Vertical Village* the modules are to a certain extent manufactured according to market dynamics, following supply and demand as required. This has a corresponding effect on the development of the overall structure, for this is similarly dependent on the possibilities and requirements of the particular social, economic and constructional circumstances. It is for this very reason necessary to give the modules "robust" dimensions, to allow for various adjustments not just in their use but also in their production
16. The "diagonale du vide" (diagonal of emptiness) is an area of France that stretches from the North East of the country through to the South Western regions. In the history of France there have been many efforts to upgrade this low-density zone with infrastructural measures. A bizarre illustration of the inability of political measures to address the problem of low density present in many regions across Europe, even the introduction of a TGV line could not revive this area's economy
17. Gramazio, F., Kohler, M.: Digital Materiality in Architecture, pp. 7–11. Lars Müller Publishers, Baden (2008)
18. Mirjan, A., Willmann, J., Gramazio, F., Kohler, M.: Designing behaviour: materialising architecture with flying machines. GAM **10**, 236–247 (2014)
19. Tönnesmann, A.: Monopoly. Das Spiel, die Stadt und das Glück. Verlag Klaus Wagenbach, Berlin, pp. 85–126 (2011)
20. Gramazio, F., Kohler, M., Willmann, J.: The Robotic Touch—How Robots Change Architecture, pp. 383–384. Park Books, Zurich (2014)

Smart Cities in a Smart World

Beniamino Murgante and Giuseppe Borruso

Abstract Very often the concept of smart city is strongly related to the flourishing of mobile applications, stressing the technological aspects and a top-down approach of high-tech centralized control systems capable of resolving all the urban issues, completely forgetting the essence of a city with its connected problems. The real challenge in future years will be a huge increase in the urban population and the changes this will produce in energy and resource consumption. It is fundamental to manage this phenomenon with clever approaches in order to guarantee a better management of resources and their sustainable access to present and future generations. This chapter develops some considerations on these aspects, trying to insert the technological issues within a framework closer to planning and with attention to the social impact.

Keywords Smart city • Smart communities • Urban planning • Open data • Citizens as sensors • Governance

1 Introduction

Nowadays an approach that narrowly combines the concept of smart city with the sudden spread of electronic devices and with the setting of a technological hard infrastructure is very common. A common and widespread interpretation

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The chapter derives from the joint reflections of the three authors. Beniamino Murgante wrote Sections 1, 2, 5, 6.1, 8, and 9, while Giuseppe Borruso wrote Sections 3, 4, 6.2, and 7.

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of the concept of smart city has been long related on one side to a centralized control system made of the network infrastructure and sensors, managed by local authorities, while on the other side its implementation is via an exasperated use of applications for smartphones or tablet PCs.

Hence, often the focus is mainly on mobile applications, forgetting that there is also a city. These approaches, despite having a certain degree of usefulness, can produce a waste of resources when completely disconnected from the context, especially from the essence of a city. When complex computer systems are proposed, it is crucial to ask, "Are they really useful to the city?"

This common belief evokes gloomy and distressing urban scenarios as we learned to watch on science fiction movies, as in Ridley Scott's *Blade Runner*. The idea of a city with many vendors should lead to a vision of cities similar to a Pioneer advertisement[1] of the late 1980s, which was very popular in Italy, where each person "wore" one or more cathode tube televisions that acted as a barrier to the outside world, projecting robotic behaviour. This approach to smart cities would lead to a "flood" of electronic devices in our cities, connected to improbable goals to be achieved.

If a city has a structural mobility problem, it is quite impossible to solve it only with a smartphone. The term "smart" is very popular today and has also been adopted in common language and in all kinds of advertisements. In order for us to describe the adoption of this term in everyday language, it could be useful to adopt a parallelism with the Smurfs cartoons.

Everything is "smart" today, and in the Smurf world, we have Smurf-Forest, Smurf-berry, Smurf-strawberries, and so on. It is very common in participation processes, smart participation, to find an interview with the mayor of a city or with the director of a journal called a "smart interview" or to find the term "smart questionnaire" for paper forms distributed to a sample of citizens.

Very often the concept of smart city is strongly related to the wide dissemination of mobile applications, completely forgetting the essence of a city, with its connected problems. In order to bring the smartness concept into the correct approach, it is important to highlight the challenges that cities will face in upcoming years.

2 The Real Challenges of Cities

A study developed by *The Economist* [1] highlights that despite the fact that the United States and the European Union have comparable total populations, in the US 164 million people live in 50 major metropolitan areas, while in Europe there are only 102 million inhabitants of metropolitan areas. These differences are in terms of productivity and incomes. The gross domestic product (GDP) of European metropolitan areas is 72 % of the GDP of the 50 largest American cities.

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[1] Pioneer advertisement for Pioneer Blue: velvet.mpg http://youtu.be/5rMI_aVYtR0

An article in *The Washington Post* [3] emphasizes that in 31 American states, one or two metropolitan areas account for the vast majority of the state's economic production, and in 15 other states, a large metropolitan area alone produces most of the GDP. Seventeen major metropolitan areas generate 50 % of the U.S. GDP. An article in *The Wall Street Journal* [2] explains how U.S. major metropolitan areas produce a higher GDP than the economies of entire nations. Urbanization is also different in terms of city size classes in the two areas. In Europe, 67 % of urban inhabitants live in medium-size urban centres, smaller than 500,000 inhabitants, while just 9.6 % are located in cities having more than five million inhabitants. In the US, one of five urban inhabitants lives in major cities having more than five million people.

From these figures it is very easy to understand that, despite common opinions against the quality of life in big cities, in most cases living in large cities becomes a necessity. Glaeser [4] defines the city as the greatest invention of mankind. Using the advantages of the agglomeration principle, a city emphasizes the strengths of a society. Despite the evolution of modern and contemporary cities having led to disadvantages resulting from congestion, urban poverty, and security, living today in an urban context, even one that is not of high quality, involves more benefits than living in remote areas. Consequently, cities play a central role for humanity, offering the opportunity to learn from each other, face to face. Despite economic contexts and production patterns having been radically changed, a city always represents the most vital element of the economy of a nation. Generally, in every developed country, cities are the economic heart and the most densely populated places, very attractive for people who want to exchange knowledge.

While in the past advantages were closely related to the reduction in transportation and distribution costs, today cities have huge benefits in economic terms due to the exchange of ideas; therefore, there is a transition from the idea of a city founded on the concept of location to that of a city based on interaction [5]. In the next few years, a 2.3 billion increase in the world population will occur, with an average increase in the population of urban areas of 30 % [6].

These scenarios can be inserted in a larger picture, in which cities already hold the majority of the world's urban population. Western and industrialized countries already have an urban population near 80 %, while developing countries to date come in at 47 %. Asia and Africa are expected to surpass an urban population of 50 % 2020 and 2035, respectively. The global urban population is forecasted to increase by 72 % by 2050, changing from 3.6 billion people in 2011 to 6.3 billion in 2050 [9].

By 2020, China's urban population will reach 60 %, and more than 100 million people will migrate to metropolitan areas or contribute to the creation of new urban centres.

This phenomenon is not only limited to countries where rapid economic development is occurring, such as in China [7] and India [8], but it is also taking place in Europe, as highlighted by the "World Urbanization Prospects" United Nations report [9], which projects that in 2050, almost 90 % of the population will live in urban areas.

Today we are facing the rise and development of several metropolitan areas that merge into a huge urban structure, or megalopolis [18], which in many cases represents the demographic and economic backbone of a national system. Megalopolises are becoming widespread and characterize industrialized areas, such as the United States, Europe, and Japan, as well as emerging economies such as India and China. Also, some authors have forecast the development of urban systems to form a unique continuous conurbation, separated only by oceans, higher mountain chains, and deserts. Without arriving at extreme cases, such as the planet cities hypothesized in science fiction literature and movies, like the Republic/imperial capital Coruscant in *Star Wars* [57], inspired by Asimov's homologous *Trantor* [58]—both planets are completely covered by artificial metal structures and fully urbanized to host several billion people—cities are large consumers of energy and natural resources that very often are not available in cities themselves but need to be transferred from outside. That is a major challenge: Obviously, an "urban" lifestyle implies a lower level of sustainability, more energy consumption, more pollution, more waste production, and so on. In China, 45 airports will be constructed within the next 5 years, cities will produce 80 % of the total carbon emissions, urban areas will consume 75 % of the energy, and 50 % of the water supply losses will take place in cities.

Some alarming predictions highlighted at the 1992 Rio de Janeiro conference are taking place. The planet's resources are used by 20 % of the population mainly living in the Western and most industrialized countries, but given the economic growth of countries such as China, India, Russia, and Brazil, an elevated number of inhabitants could completely blow up the environmental balance of the planet. Therefore, clever approaches to save money and preserve the environment are needed. We cannot reproduce an urban development based on the same model that has governed the process of urbanization that has occurred from the Industrial Revolution until today. It is necessary to move from an approach based on pure physical growth of the city to one founded on the ability to use energy, water, and other resources correctly and efficiently and to provide a good quality of life. In practice, cities should become smarter in programming and planning the management and use of existing resources.

3 A (Smart) City of Networks and Interactions (from Location to Interaction)

Our world is urbanized, and forecasts predict it will be even more urbanized in the future. Cities represent the most visible footprint of humans on the planet; nonetheless, an agreed-upon and unique definition of what is urban and what is not does not exist, and several criteria are used to identify urbanization. Other human-made artificial landscapes have characteristics in common with cities, but these are generally not sufficient to discriminate between cities and other manmade environments.

Geographers use different principles for identifying cities, such as the demographic principle, where the population and its density in a given area are used. However, there is no general agreement on the quantity of people and the population density needed to differentiate a village from a city in different parts of the world.

A second principle used is based on the quantity, shape, and concentration of buildings, but again, such a principle is not enough for discriminating between a city and a different kind of agglomeration, such as an industrial area.

A functional principle deals with the concentration of activities in cities, recalling the different nature of activities that occur in cities, such as nonagricultural ones and those serving an extra-urban demand.

As a summary point, cities can be identified as places where activities and functions are located and concentrated, so that not just the demographic and infrastructural points of view are considered, but, in addition, the functions that take place in that environment, typically consisting of a concentration of buildings, an infrastructure, and people, are also counted [17, 20]. That is a consequence of the fact that although, as we stated, the world in which we live is urbanized, cities are still quite rare in terms of their occupation of physical space on the Earth’s surface and therefore play a role in providing functions over a wider spatial range than their physical boundaries occupy.

The functions played by a city are dedicated both to fulfilling the day-to-day needs of those people who live in the city (e.g., schools, retail stores), or *city serving*, and to realizing those activities that are the essence of the city and make it special, including universities and research centres, specialized medical doctors, and so on, that work for both the strictly defined inhabitants of the city but in particular call people from outside the city to benefit from such activities, defined as *city forming*. A wider surrounding area of the city is therefore served, which implies gravitation towards the city, and an interaction occurs, thought of as a flow, or a movement of people from outside the city towards the city itself.

Thus, a city is not just based on steady, fixed elements like buildings, infrastructure, and localized economic activities, but on movements, too. Typically, commuting identifies metropolitan areas defining the range of a city in terms of its (physical) attractiveness over a certain geographical distance.

A key element in doing that is the distance decay function, which states that the amount of interaction among people and places tends to decrease—with different slopes and speeds—as distance from the place increases.

Interaction and distance decay are applicable at different scales and in different contexts: In the previously mentioned commuting case, the number of people heading to a city for work activities from the surrounding areas tends to decrease as the distance from neighbouring areas decreases. Similarly, in analyses made on telecommunication traffic, interaction decreases with distance. In such a sense, usually cities are seen as nodes in a network system, characterized by linear elements linking nodes and flows on such links [28].

In such a framework, smart cities are strongly related with concepts and metaphors of networks, in terms of both the cities' characteristic of acting as nodes within an interconnected system of relations in space and the urban scale, where (linear) infrastructures connect places and allow flows of people, goods, and data to be interchanged and interact. The network metaphor is not new; Nijkamp [33–36] stated that we are moving towards economies and network societies, or also a "network state," characterized by sharing authority, where all the nodes are interdependent and regions do not disappear but are integrated [29]. Also, Castells [30–32] discusses "spaces of flows" and of a network society, referring to technological and industrial changes intervened in contemporary society. Transport and communication networks contribute to the setting of spatial interaction phenomena and play a relevant role in the location process. Networks are characterized within a scheme of functional relations shaping a territory. Every location process implies the idea of movement in space and across space. Technological innovations in transport and communication influence the relations among networks and space, so as new phenomena of axial and nodal polarization [29].

The importance of scale is paramount, as the interactions intervening among different spatial objects or elements depend on the extension and on the spatial scale considered. A city is a point in a global system of cities, while it is an area if we consider its extension at the local level. In the first case, the city could represent a node within a network system, in which arcs and linkages towards other nodes converge and contribute towards organizing the layout of a territory; in the second one, the city represents a region in space, and therefore an area object, whose boundaries are not well defined and within which are situated network structures of nodes and arcs [60].

On an urban scale, geographers focus their attention on cities in terms of their physical and functional features and on their interaction, while on an extra-urban scale, the focus is on how different cities are organized and linked in comparison with other cities with which they maintain a relationship in terms of commuting, political presence, economic environment, and so forth.

The city itself, as an area object, results from some aspects defined by the network relations occurring inside the same city. The spatial organization of a city can therefore be defined by the urban road network or by "subnetworks" that insist on that, as the subsets of the urban road network where pedestrians or bikers can move, or the network of the public transport system. The network can be seen as an example of trans-scalarity [17], particularly in the urban case. Urban networks in fact can be considered both as single nodal elements with some particular functions and a certain spatial distribution and as networks of cities at different spatial scales. The concept of network as a metaphor is therefore extended from that of "material, physical connections" to that of a "set of relations" that, although based on physical networks, allow urban areas to be represented as networks of nodes. Michael Batty [5, 43] stresses such a concept, suggesting that "to understand cities we must view them not simply as places in space but as systems of networks and flows [5, p. xvii]." The same network metaphor can, however, be moved in the internal part of a city, identifying places where people gather and interact more, such as squares, shopping malls, and public offices. The same urban area, on a different scale, can be considered as a nodal element of the network [56].

Geographers consider cities and their regions as systems of nodes, connecting lines and flows, organized in a network and/or in a hierarchical system. However, the attention is generally focused on places and on the interaction between people and places. Recently, cities have increasingly been seen as complex systems, needing an even more integrated approach. In particular, then, the huge availability of data, often coming from users of portable devices and ICT social networks, provides suggestions and data sources to delve more in depth on the issue, moving the attention from interactions between people to what's happening in places.

According to Bettencourt [19], a city is a complex system characterized by a twofold soul: It "works like a star, attracting people and accelerating social interaction and social outputs in a way that is analogous to how stars compress matter and burn brighter and faster the bigger they are." He adds, "Cities are massive social networks, made not so much of people but more precisely of their contacts and interactions. These social interactions happen, in turn, inside other networks—social, spatial, and infrastructural—which together allow people, things, and information to meet across urban space."

4 Smart City, Smart Cities

4.1 Smartness or Dumbness

One of the challenges lies in the definition of "smart city," or trying to understand the level of smartness that a city can have. Although a certain agreement on the elements and indicators defining a smart city is set, such optimism cannot be directed towards their meaning and transformation into active practices.

Six axes represent the backbone of a smart city, with smartness translated into economy, society, mobility, people, governance, and environment. In all of them attention is given to the opportunity promised by modern ICT to boost such axes, optimizing and making cities more efficient. The philosophy behind the smart city is strongly related to the sustainable city, in which environmental, social, and economic dimensions are considered as part of the development to be pursued, to allow present and future generations to reach equity in living conditions. The difference lays mainly in the role played by technology, and ICT in particular, in allowing a more efficient management and organization of the different parts of life in cities.

However, how is that translated into the real world? Sustainability in urban contexts involves public participation. Possibly the Local Agenda 21 has been one of the first cases in which a bottom-up approach was suggested into political action at the local level, in such a sense anticipating—and putting the basis for—current public participation in planning, also helped and sped up by social networks and media. In smart cities, public participation is central and, of course, is boosted by new technologies, social networks, and the media, and it must therefore rely on a consistent network and infrastructure, allowing data and information flowing and sharing. However, the bottom-up approach is possible in the smart city also by means of citizens' and urban users' building and realizing their own services and activities, therefore meeting needs they do know and experience, often better than the final decision and policy makers.

Nevertheless, and as a paradox, the smart city concept is often translated into a "techy" top-down approach and consequent solution, with a single (set of) decision maker(s) preparing supposed valuable solutions for citizens. This is the case with new investments toward smart cities in which high-tech tools are proposed and realized as centralized systems to control several aspects related to energy efficiency, transportation, housing, and more. In such a big infrastructure, projects are implemented that couple hardware network infrastructure and control systems as well as more traditional, although generally technologically advanced, real estate investments.

Rio de Janeiro and Song-Do are among these examples. In the former case, a control system was sold to Rio de Janeiro to monitor traffic in real time, while in the second one, a brand new smart city, or smart suburb, was built from a blueprint in a greenfield area, separate from Seoul and close to the new South Korean international airport, having in mind energy efficiency and saving, quality of life, and a planned environment for business, living, and working. These examples are the offspring of a planned centralized system, often not so flexible at incorporating innovation: As an example, Song-Do was based on RFID technology and not ready to adapt to new communication tools like smartphones and tablets—whose role in locating sensors and devices helping us in automating activities was completely unconsidered or underestimated.

On the other hand, the bottom-up approach is based on how citizens or city-users live and interact with the city and develop their own applications and solutions for the different uses of a city. Similarly to what happened in the past, with new utilities and infrastructure both serving cities' expansion and also shaping it, technology is influencing how we live and set our relations with other people and places. As a trivial example, on the one hand, new devices and tools induce us to cluster close to free Wi-Fi hotspots; on the other hand, people's routine congregation in popular places may induce the authorities or private enterprises to set and reinforce wireless sensors.

Therefore, a similarity with other physical infrastructures (roads, electricity cables, freshwater pipes) arises, but how we now use what flows on such an infrastructure is quite different—and often unexpected—compared with what we used to. So it risks or tends to be for the physical infrastructure of the smart city, or the hardware composing the digital layer superimposed over the city. And that suggests that the bottom-up approach in a very "open" way should be based on the setting of an infrastructure (and a set of rules) and should allow people to "flow," to interact and develop their own activities.

4.2 Smartness in the World

A problem related to "smartness" refers to the differences that different countries and cultures put on "city" and therefore also on "smartness." European cities are different from each other, and the European model of city is different from the North American, Asian, and African ones, for instance. So when we consider a smart city, we must also consider cultural and national differences on how cities are interpreted and intended.

How does that fit with the concept of smart city? If we recall some of the data cited at the beginning of the present chapter, we observed that the mature economies of industrialized countries already have a high percentage of urban population, and the increase in these figures can be translated into an increasing density of existing cities or into urban sprawl with a growth of small and medium-size centres, or in a combination of both factors due to international migrations or, still, in rural–urban dynamics or blurring of the two processes. Europe and the United States possess older urban structures and heritage. In such places, the growth and development of cities happen on a physical infrastructure stratified in several decades (as in the North American case) and centuries (as in the European cases). In such cases, each change will have to face such a heritage, translated in the physical, cultural, and social infrastructure stratified with time.

The case of growing economies and developing countries is quite different. Often the urban growth occurred (and is occurring) at a very fast pace, with different kinds of impacts and consequences. In some cases, urban growth from a demographic point of view is not accompanied by an adequate supply of infrastructure and services. Therefore, a consequence can be that a part of the population is not served by basic services and infrastructure, and informal settlements characterize the urban landscape.

In other cases, cities grow very fast, without a precise model of the city in mind, or by simply creating urban fabric from the blueprint to fulfil a need for housing, industry, retail, and office spaces. Governments in Asia, and particularly Southeast Asia, are working on creating housing and expanding cities and the issue is related to the urban model to be adopted for brand new cities or neighbourhoods. In such cases, brand "new towns" or suburbs are built from scratch, in a similar way as settlements in the Western suburbanization era, but with dimensions comparable to medium-size cities or metropolitan areas in the industrialized world.

A smart city in an urbanizing, developing world means first providing services and infrastructure—starting with water and energy supply and management—and then thinking about optimization through high tech. In the rapidly industrializing world, it means building brand new settlements, from a blueprint and often in greenfield areas. Here a smart city appears as a new town, a planned city in which functions and activities are organized. Often this is also translated into new suburbs or mid-size cities to be realized, in such a sense following a suburbanized scheme already seen in other contexts, with the difference that smartness is put primarily onto energy efficiency and technological devices.

On the other hand, a smart city based on an existing urban fabric, stratified in years of history—as in Europe or even in some US cities—requires optimization and reuse. So, on a more traditional urban fabric, smartness is more related to the challenge of rethinking a city in a smarter way, therefore optimizing it particularly in terms of interactions between citizens or city-users and the "hard," infrastructural component of the city, not just building brand new settlements or suburbs that, in an unsustainable way, would consume soil and space.

5 The Pillars of a Smart City

The risks today lie in focusing on just the technological side of "smartness," maybe without a tight connection neither among techy initiatives, nor—and even worse—with spatial and urban planning activities. We do not deny that ICT is central in setting a technological infrastructure as the backbone of the growing flow of data and information. The role of infrastructure in both serving and boosting urban growth and expansion was already mentioned as having a heritage, since their shape and fabric remain over time and influence different periods and generations. Thus, focused planning is needed, not to be limited to the short term, but to persist.

In such terms, a true smart city acts as an "enabling platform for the activities that citizens are able to develop, linking those inherited from the past to those that can be realized in the future, so it is not focused just on applications but on the possibility that citizens realize them" [10]. Doing so is possible by thinking about it in terms of three main pillars [14]:

1. connections—as networks and technological infrastructures;
2. data—open and public or public interest data to allow the development of innovative solutions and the interaction between users/citizens and the city [22];
3. sensors—including citizens [11–13] able to actively participate in a bottom-up way in city activities (Fig. 1).

Such pillars need to be accompanied by an urban governance able to harmonize them and particularly to represent a set of minimum "driving rules," regulating a smart city in a neutral way, without entering too much into details concerning contents and applications developed by citizens, urban users, private companies, and so forth.

In this sense, a correct approach to smart cities should in some way try to resolve problems typical of urban areas and not just those of niches of users. As an example, our urban areas are often profiled on a category of users: generally male, in his productive age, driving a car, therefore cutting out other important parts of the urban population, such as young and elderly people, as well as the female component [15]. Hence, a purely "techy" smart approach risks reaching just those people actively using ICT (mainly mobile) technologies. Therefore, the technological layer needs to be linked to the spatial context where it is applied, as cities are different from each other. One of the key elements in planning is verifying the compatibility and complementarity of a plan with other ones just ended or to be licensed in a short time; another is considering the possible overlap with similar initiatives [16].

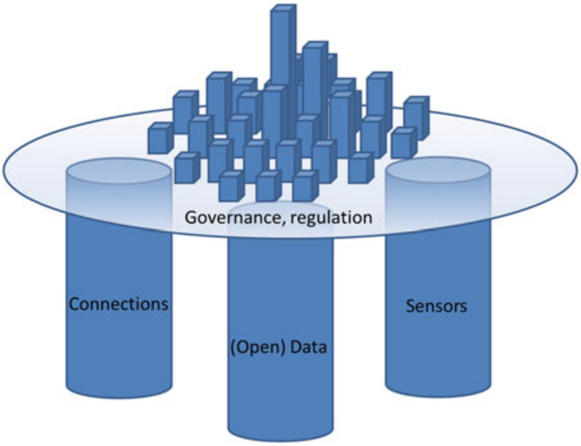

Fig. 1 The three pillars of a smart city and governance (graphical elaboration from [10], in [14, 21])

It is important to use the big impact of technologies on new forms of policy and planning. The six axes of smartness not only need to be connected to technology, but also need to be connected to the added value that innovation can lead to programs and plans already issued.

6 City, Open Data, Big Data

6.1 *The City and the Open Data*

As mentioned earlier, connections, sensors, and open data are the *smart city's* pillars that adopt an approach based on the transition from the concept of *government* to the concept of *governance*. The essence is a background vision of the city able to transform the "impulse" resulting from the pillar activities to be performed into the individual application domains, the six *smart city* axes: *economy*, *governance*, *living*, *people*, *environment,* and *mobility*.

A lot of people talk every day about open data—just as they do about smart cities—without getting into the details on the real meaning and the great opportunities that could arise from their correct use.

In most cases, the concept of open data is based on uploading a file in portable document format (PDF) on a website, allowing the download to everybody. When a public agency shares a PDF file, a monitoring authority should take action and if necessary sanction it, because a public employee spends his or her time to put constraints to data, and in another government agency, another public employee will waste much more time using that data just because of these constraints. The PDF type was created to allow document or drawing printouts, often in printing services, without using the software that produced these data, by simply employing a PDF file reader.

Tim Berners-Lee proposed an open data classification scheme, associating stars with the level of quality. The lowest level is based on providing an open license, making the data available on a website without defining the specific type of format (usually, the files are of PDF type). The only purpose of this type of data is to inform; it is only possible to read or print them. The second-level aim is to provide data preserving the original structure, allowing also their manipulation. It is a small improvement even if data remain in a proprietary format. Three-star open data allow manipulation and management of data and adopt a nonproprietary format, ensuring better interoperability. The upper level maintains interoperability properties of data and improves availability on the network through the use of semantic web standards (W3C, RDF, OWL, SKOS, SPARQL, etc. [23]). Five-star open data are linked open data.

The limit of this classification is that spatial aspects are not considered at all.

In the introduction to their book *Geocomputation and Urban Planning* [26], Murgante and co-authors cite the famous paper by Franklin [25], who in 1992 quoted that 80 % of all organizational information contains some references to geography. After the publication of the Murgante et al. book, numerous discussions started on social networks and blogs about how was it possible that in 1992, 80 % of information contained a spatial component [24]. The Murgante et al. book was published in 2009 and now, after only a few years, the situation has completely changed: Each mobile phone has a GPS, and Google OpenStreetMap has transformed geographical information from specialist interest into a mass phenomenon and probably 100 % of data have a spatial relation. Consequently, ignoring spatial aspects as an intrinsic component of data is a big mistake.

The spatial component has always been underestimated, sometimes intentionally, sometimes ignorantly. In the first experiences of implementing master plans in a spatial information system, data were deliberately shifted from the original coordinates in many cases and the values of the translation were jealously guarded like the access codes to a bank account. The main aim was to avoid overlapping of planning tools with other layers, allowing the level of subjectivity of some decisions to be discovered. In Italy, for instance, there is a great tradition in creating barriers to the immediate overlapping of information layers: Cartographical maps and cadastral maps have always been produced at different scales to allow some subjectivity for technical bureaus of municipalities.

A comprehensive approach to open data should consider Open Geospatial Consortium (OGC) standards and the INSPIRE directive.

Nowadays, data represent a significant unused economic potential, because if they were available to everybody, the collective imagination could create new companies and produce additional business to existing companies. The great majority of these possible business initiatives should be based on applications for smartphones and tablets, which in 100 % of cases require a spatial component.

Considering the classic application for parking, there is a great difference if the application allows only ticket purchase or if it indicates also where the nearest free parking is located. Consequently, open data for this type of application should be distributed at least as OGC Web Feature Service (WFS) standard.

It is crucial to radically change public authorities' approach: Very often the term "service" is synonymous with "contract."

A municipality does not have to pursue a contract for a parking application, but it has to make open data available in OGC Web Feature Service standard, allowing local startups or to produce an application or to reuse an application produced for other municipalities. The municipality receives a free service and the enterprise benefits with advertisements; if someone does not like the advertisement, he or she can delete it by paying 1€. Local authorities save money and contribute to creating or consolidating enterprises in the field of innovation. To achieve this goal, it is essential that authorities produce and distribute high-quality data.

6.2 The Big Data Challenge

However, the question today is not only on the openness of data but on the dimension data can reach. The term is known as "big data," and it is destined to play a crucial role in the smart city debate. As said, size matters; under the big data label, a wealth of data in different formats and storage systems can be aggregated. In general terms, "big data" encompasses any set of data so complex and large that it becomes difficult to process and analyse using traditional database management systems or processing techniques [44]. All the traditional aspects related to managing data are involved and require new instruments and techniques: acquisition, editing, storage, search, transfer, analysis, visualization, and representation. More than standard procedures and tools, big data requires "massively parallel software running on tens, hundreds, or even thousands of servers" [45].

However, the size of this "bigness" can vary, and so defining big data is not simple, often relying on an organization's ability to handle a certain amount of data [46].

Big data can come from different sources: government, market, private sector, big science, science and research. The widespread use of sensors, particularly mobile, and the capacity to collect wide sets of data in time and space are providing different players with consistent and abundant sources of information.

Furthermore, part of the *big* data could become *open* data, such as those collected by government and public organizations. Also, private organizations could provide open data too, but industrial strategic considerations often heavily limit this option.

The debate is quite vivid, in terms of both the problems connected to the paradigm and the applications. On one side, the critiques focus on the fact that little is known concerning (1) the empirical micro-processes that cause big data characteristics to emerge [47] and (2) the real effectiveness of big data in helping to make good decisions [37], while alerts are posed on the fact that, in any case, data

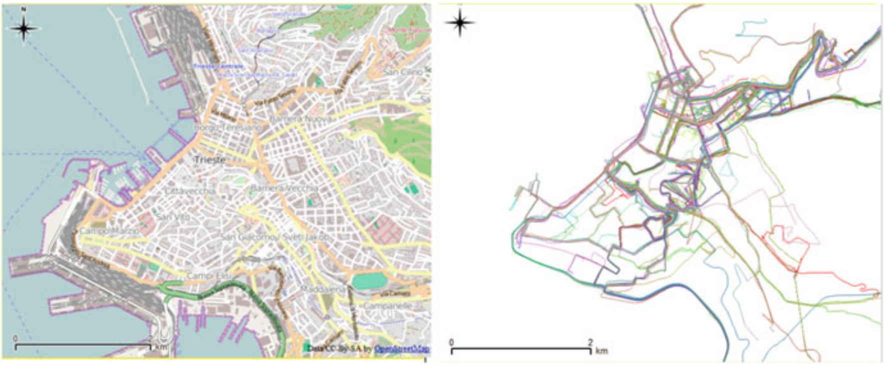

Fig. 2 Personal data as big data: 7 months of car-driven individual paths (*right*) in the city of Trieste (*left*). [*Source*: OpenStreetMap (map); authors' elaboration of individual data]

need to be contextualized into social, economic, and political contexts [48]. On the other side, part of the scientific community expresses concerns about the use of big data in scientific research [50, 52], given the lack of a sound theory behind their use [38, 39], the difficulty in choosing representative samples of data, the management issues, and the difficulty in integrating data from heterogeneous sources [40–42]. However, the challenges posed by these issues are also seen as the promising new frontiers in science [47, 49, 51].

Nonetheless, data collected in space and time, by users and organizations, can provide interesting hints about a city's behaviour and can better orient planning strategies. Well aware of this attribute, Ratti and Townsend propose just connecting people to an urban network and letting them play. Their behaviour, actions, and comments will be more useful than predefined top-down planning policies [53, 54], recalling Adam Smith's assertion that an individual "pursuing his own interest ... frequently promotes that of the society more effectually than when he really intends to promote it" [55].

As an example, Fig. 2 presents individual movement travel data taken over 7 months, used as a starting point for research on how people "live and drive" in a city. Personal routes can be useful both for an individual in understanding his or her traffic habits and, if aggregated, for urban planners in better understanding their city.

7 Smart Citizens or Devices?

What about portable and mobile devices when talking about smart cities? How smart are we in using smartphones, tablets, and the whole family of portable devices? How we work, navigate, and spend our free time is now mainly based on mobile devices, to date smartphones and tablets, whose diffusion has widely overcome that of more traditional desktop and laptop PCs.

How we use such devices is, however, still very limited to some kinds of uses and applications we, as users, are quite far to exploit their potential. Figures help us here [27], pointing out that at the end of 2013, 91 % of people on Earth had a mobile phone and the number of mobile phones exceeded the number of people [61]. Smartphones cover 56 % of the population. Games consume 32 % of people's time spent on smartphones, followed by social and media networking (24 %), web browsing (18 %), and productivity and utility (10 %). Professional uses have ranked at the top from the beginning, and so email (28.85 % of all emails are still opened on a mobile device), live meetings, and calendars were features differentiating smartphones from more traditional mobile phones. That made the initial fortune of a company like R.I.M., Research In Motion, which created the smartphone concept and the popular BlackBerry platform but is now suffering from—and losing to—the competition of giant ICT players such as Apple and Android. Such a competition is also a symptom of a blurring of personal and professional uses, creating a generation of users whose activities no longer have a marked spatial and temporal separation. So a question arises: Is the use we make of smart devices really smart? When we talk about smart cities and communities, is the use of such devices really helping us in reaching such targets?

We are probably far from reaching a really smart and complete use of such devices, similar to what happened with standard PCs and the software running on them: Spreadsheets or database management systems, for example, are generally designed for a wealth of uses that most users would likely not rely on in their lifetime. This is probably what will happen with smartphones and their apps.

We are facing a very wide and extensive coverage of mobile devices that, however, appear as Formula 1 or NASCAR racing cars driven in a peak-time urban traffic jam, queuing at crossroads.

As Fig. 3 shows, smartphones and portable devices in general can be viewed in different ways and from different perspectives, as tools to connect accounts to social media or to check emails and contacts, but capable of hosting several tools and applications actually enhancing our capacity to act as real mobile sensors [5].

Fig. 3 What is in your smartphone? (Authors' elaboration; also in [28])

We can choose how to use them and view their potentials. On one side, there is their use, as presented in Fig. 3 on the left, as that of social network-media devices, allowing phone calls, email, chatting, weather forecasts, video and picture cameras, among other functions. On the other side, we can exploit their capacity of being real, fully integrated microcomputers, hosting a network broadcasting system, based on both the cellular phone network and Wi-Fi points, a set of software more or less sophisticated, including also GIS and geographical and technical applications, GPS, and other position receivers. Such a combination allows such devices to act as true sensors for collecting a wealth and variety of data as well as to, more or less consciously, participate in the city's choices and decisions. Our smartness as citizens should therefore be that of using the potential of such devices to exploit our interaction with the city to monitor it and highlight both positive and negative aspects and help its better management. Private companies and public bodies already use data that we in a more or less aware way share, such as positional and movement data, which allow the estimations of traffic jams, public transport time, and so on. Also, our preferences for checking in and doing particular activities in certain places is already monitored and allow private companies to target marketing campaigns and products and could—and hopefully will—allow planners and scholars to better understand how cities shape themselves from a social—not only in the ICT way!—point of view. Accepting Ratti and Townsend's suggestion, let's "jack people into the network and get out of the way" [53].

8 Designing a Smart City Is Only an ICT Project, or It Is Also a Planning Activity?

A lot of terms have been adopted in the last few decades to describe different approaches to the city. Hanzl (see Fig. 4) defines a sort of ranking of these terms according to popularity at this moment. Obviously, the term "smart" is most popular in this period and has been adopted in every context concerning the city. The term "smart" has become a sort of telephone prefix to put before each term or concept already defined in the literature. In this way, "participation" becomes "smart participation," "mobility" becomes "smart mobility," and even "sustainability triangle" becomes "smart triangle." The result was the loss of sight of the city, with the decision makers concentrating on mobile applications as a child might with videogames (Fig. 4).

The six axes of the smart city, when considered in an integration perspective, often described as a cultural revolution, are no more than the first lesson of urban planning. Moreover, it is quite obvious that mobility has close relationships with economy, people, governance, environment, and quality of life.

For instance, Masdar City, considered one of the symbols of the smart cities designed by Foster and Partners, is certainly a city designed according to all precautions in term of energy saving and reduction of emissions. The question is: Is a sort of futuristic city realized in the desert sustainable? We are not calling into

Fig. 4 Ten commandments for the city (Hanzl, 2014) (https://www.facebook.com/photo.php?fbid=10204196347015718&set=pb.1438171327.-2207520000.1403434139.&type=3&theater)

question the quality and details of the project, but the basic idea. Also, Ski Dubai has a lot of energy-saving measures, but it is surely not smart to build a ski resort in one of the hottest places in the world.

In the past, more attention was paid to many aspects strongly related to smartness without considering mobile applications.

Figure 5 shows how the oldest part of Sassi in Matera (highlighted in the image) is oriented in order to maximize heating in the winter and cooling in the summer [59].

Also, the cave dwellings were arranged in order to maximize the reuse of rainwater. Rainwater is collected by a system of conduits placed on the roofs; they discharge the water in tanks located inside the dwellings (Figs. 6 and 7).

Additionally, social relationships have been considered in Sassi. The neighbourhoods (*vicinati*) are the neighbourly relations formed between members of a small agglomeration of dwellings. More precisely, the neighbourhoods are groups of houses placed around the same space with a form of amphitheater with an important role in the organization of domestic and social life. Within the neighbourhoods, life was very intense; there were human solidarity and mutual aid. The neighbourhoods can be considered an urban sphere of relations and mutual assistance, a real cultural exchange, where the private coincides with the public space.

In analyzing technologies applied to the city, it is fundamental to distinguish whether or not the innovations have relationships with the urban environment. The main question is: Are these technologies useful for the city or are they simply solutions looking for a problem? The issue is that it is not easy for everybody to

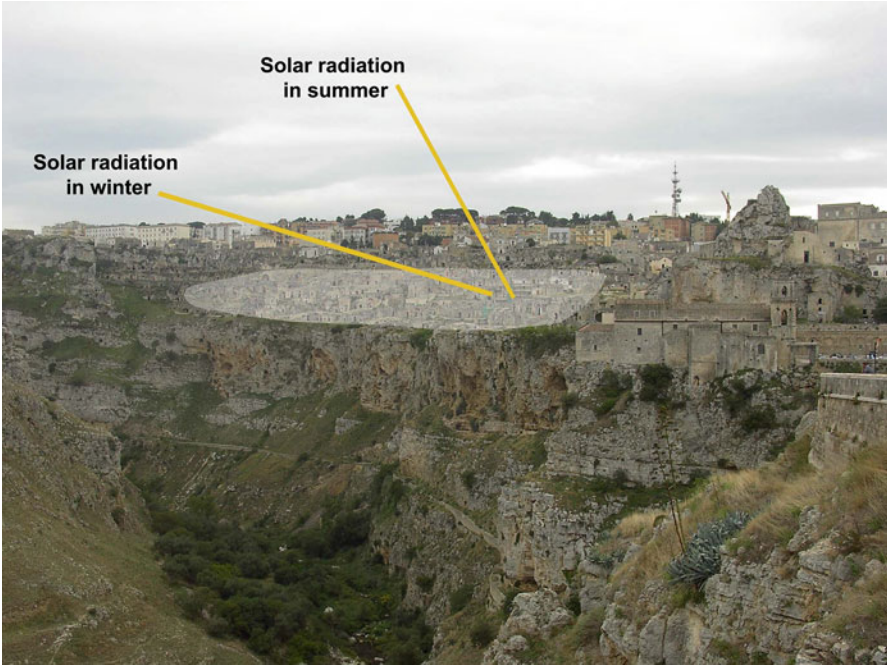

Fig. 5 Orientation of Sassi in Matera

Fig. 6 Reuse of rainwater from Sassi in Matera

Fig. 7 The neighbourhoods (vicinati) of Sassi in Matera

discern clearly these two aspects because of a communication campaign organized by device producers and because of a certain convenience that several applications produce. According to Brandolini, “The amount of energy necessary to refute bullshit is an order of magnitude bigger than to produce it” [63].[2] The main efforts in upcoming years have to be concentrated on distinguishing between what is bullshit and what is useful for cities.

9 Conclusions

The sustainability of cities and quality of life in cities are among the main challenges that current and future communities have to tackle. A “smart” approach to achieving these challenges involves the widespread use of the best technologies available, and particularly the ICT ones, which have experienced unprecedented growth in recent years.

There is a widespread belief that the realization of a smart city is based on an extreme use of applications for smartphones and tablets. Also, there is a belief that smartness in urban terms means building self-contained, gated settlements, realized with eco-friendly materials and a rainfall of ICT devices and advertised as sustainable. Such developments actually result in suburbs, thus continuing to reinforce the unsustainable urban sprawl and land consumption characterizing the last decades particularly in the second half of the Twentieth Century.

[2] https://twitter.com/briandavidearp/status/481304548305555456/photo/1

Very often the attention has been focused exclusively on device applications, with developers forgetting that there is a city to take care of. Whenever automation through mobile applications is proposed, it is important to consider its effects on the city. When someone proposes a complex technological system, it is important to ask, "Is it really useful for the city?"

In numerous cases, programs that originally declared their objectives to be mainly related to urban aspects have been purely transformed into programs based on ICT improvement. It is evident that in these experiences, the program has lost sight of its main original goal during implementation. In the first lesson of strategic planning courses, it is usually explained that when building a correct program, it is important, as a first step, to identify who are the beneficiaries. In most "technology-driven" programs, often this principle is not taken into account or is forgotten during the implementation.

Cities around the world are very different and in need of different solutions. Technology can play an important role now as it did in the past: Innovations in transport (e.g., tramways), energy (electric lighting), and telecommunications were often at first experiments in cities to contribute to the quality of life of urban people. Similarly, modern information and communication technologies (ICT) can help and be important factors for a city's success.

Technologies can represent a fundamental support in improving the efficiency and effectiveness of a city's planning and management, but it is important to have a clear understanding that technologies are the means and not the target. Given the complexity of the cause–effects relationships of ICT technologies and people, maybe today's challenge is to understand how to put them correctly into planning procedures, just as in the past the challenge was considering a new public transport line or power supply.

References

1. Hilber, C., Cheshire, P.: Concrete gains. America's big cities are larger than Europe's. That has important economic consequences. The Economist. http://www.economist.com/node/21564536 (2012). Accessed Dec 2013
2. Dougherty, C.: "U.S. cities with bigger economies than entire countries. Wall Street J. http://blogs.wsj.com/economics/2012/07/20/u-s-cities-with-bigger-economies-than-entire-countries/ (2012). Accessed Dec 2013
3. Cillizza, C.: The case for big cities, in 1 map. Washington Post. http://www.washingtonpost.com/blogs/the-fix/wp/2014/02/19/you-might-not-like-big-cities-but-you-need-them/ (2014). Accessed Dec 2013
4. Glaeser, E.: Triumph of the City: How Our Greatest Invention Makes Us Richer, Smarter, Greener, Healthier, and Happier. Penguin Books, London (2011)
5. Batty, B.: The New Science of Cities. The MIT Press, Cambridge, MA (2013)

6. Manyika, J., Remes, J., Dobbs, R., Orellana, J., Schaer, F.: Urban America: US cities in the global economy. McKinsey Global Institute, McKinsey & Company, Washington, DC (2012)
7. Woetzel, J., Mendonca, L., Devan, J., Negri, S., Hu, Y., Jordan, L., Li, X., Maasry, A., Tsen, G., Yu, F.: Preparing for China's Urban Billion. McKinsey Global Institute, McKinsey & Company, Washington, DC (2009)
8. Sankhe, S., Vittal, I., Dobbs, R., Mohan, A., Gulati, A., Ablett, J., Gupta, S., Kim, A., Paul, S., Sanghvi, A., Sethy, G.: India's Urban Awakening: Building Inclusive Cities, Sustaining Economic Growth. McKinsey Global Institute, McKinsey & Company, Washington, DC (2010)
9. United Nations, Department of Economic and Social Affairs, Population Division: World Urbanization Prospects, the 2014 revision. http://esa.un.org/unpd/wup/ (2014). Accessed Jan 2015
10. De Biase, L.: L'intelligenza delle Smart Cities. http://blog.debiase.com/2012/04/intelligenza-delle-smart-city/ (2012)
11. Goodchild, M.F.: Citizens as voluntary sensors: spatial data infrastructure in the world of Web 2.0. Int. J. Spat. Data Infrastruct. Res. **2**, 24–32. http://blog.debiase.com/2012/04/lintelligenza-delle-smart-city/ (2007)
12. Goodchild, M.F.: Citizens as sensors: the world of volunteered geography. GeoJournal **69**(4), 211–221 (2007). doi:10.1007/s10708-007-9111-y
13. Goodchild, M.F.: NeoGeography and the nature of geographic expertise. J. Location Based Serv. **3**, 82–96 (2009)
14. Murgante, B., Borruso, G.: Cities and smartness: a critical analysis of opportunities and risks. Lect. Notes Comput. Sci. **7973**, 630–642 (2013). Springer, Berlin. ISSN: 0302-9743, doi:10.1007/978-3-642-39646-5_46
15. Archibugi, F.: Introduzione alla Pianificazione Strategica in Ambito Pubblico. Alinea Editrice, Firenze (2002)
16. Tonucci, F.: La Città dei Bambini. Un Nuovo Modo di Pensare la Città. Editori Laterza, Roma (2004)
17. Dematteis, G., Lanza, C.: Le Città del Mondo. Una Geografia Urbana. UTET, Torino (2011)
18. Gottmann, J.: La Città Invincibile. Franco Angeli, Milano (1998)
19. Bettencourt, L.M.A.: The origins of scaling in cities. Science **340**, 1438–1441 (2013)
20. Haggett, P.: Geography: A Global Synthesis. Prentice Hall, Harlow (2001)
21. Murgante, B., Borruso, G.: Smart cities: un'analisi critica delle opportunità e dei rischi. GEOmedia **17**(3), 2013 (2013)
22. Berners-Lee, T.: 5★ open data http://5stardata.info/#addendum4
23. About W3C Standards.: http://www.w3.org/standards/about.html
24. Ball, M.: Reference for 80 % of data contains geography quote. Spatial sustain: promoting spatial design for a sustainable tomorrow. http://www.sensysmag.com/spatialsustain/reference-for-80-of-data-contains-geography-quote.html (2009)
25. Franklin, C.: An introduction to geographic information systems: linking maps to databases. Database **15**, 13–21 (1992)
26. Murgante, B., Borruso, G., Lapucci, A.: Geocomputation and Urban Planning Studies in Computational Intelligence, vol. 176. Springer-Verlag, Berlin (2009). doi:10.1007/978-3-540-89930-3. ISBN 978-3-540-89929-7
27. A.F. Studios and Super Monitoring, State of the Mobile 2013. http://www.digitalbuzzblog.com/infographic-2013-mobile-growth-statistics/ (2014). Accessed 15 Apr 2014
28. Murgante, B., Borruso, G.: Smart City or Smurfs City. Lect. Notes Comput. Sci. **8580**, 738–749 (2014). Springer International Publishing, Switzerland. ISSN: 0302-9743
29. Capineri, C.: Gli adeguamenti delle reti di trasporto Europee di fronte alla globalizzazione e alla sostenibilità. In: Bonavero, P., Dansero, E., Vanolo, A. (eds.) Geografie dell'Unione Europea – Temi, Problemi e Politiche Nella Costruzione Dello Spazio Comunitario, pp. 166–198. UTET, Torino (2006)
30. Castells, M.: The Rise of the Network Society. The Information Age: Economy, Society and Culture, vol. 1. Blackwell, Oxford (1996)

31. Castells, M.: The Rise of the Network Society. The Information Age: Economy, Society and Culture, 2nd edn, vol. 1. Blackwell, Oxford (2001)
32. Castells, M.: End of Millennium. Blackwell, Oxford (1998)
33. Nijkamp, P., Vleugel, J.: Transport infrastructure and European Union developments. In: Nijkamp, P. (ed.) New Borders and Old Barriers in Spatial Development, pp. 3–31. Aldershot, Avebury (1994)
34. Nijkamp, P.: Borders and barriers: bottlenecks or potentials? A prologue. In: Nijkamp, P. (ed.) New Borders and Old Barriers in Spatial Development, pp. 1–11. Aldershot, Avebury (1994)
35. Nijkamp, P., Perrels, A., Schippers, L.: La strategia delle nuove infrastrutture di trasporto in Europa. In: Tinacci Mossello, M., Capineri, C. (eds.) Geografia Delle Comunicazioni – Reti e Strutture Territoriali, pp. 151–168. Giappichelli Editore, Torino (1996)
36. Nijkamp, P., Rietveld, P., Spronk, J., van Veenendaal, W.E., Voogd, H.: Multidimensional Spatial Data and Decision Analysis. Wiley, Chichester (1979)
37. Shah, S., Horne, A., Capellá, J.: Good data won't guarantee good decisions. Harvard Business Review. http://hbr.org/2012/04/good-data-wont-guarantee-good-decisions/ar/1 (2012)
38. Bollier, D.: The Promise and Peril of Big Data. The Aspen Institute, Washington, DC (2010). http://www.ilmresource.com/collateral/analyst-reports/10334-ar-promise-peril-of-big-data.pdf. Accessed Jun 2014
39. Anderson, C.: The end of theory: the data deluge makes the scientific method obsolete. Wired Magazine (Science: Discoveries). http://www.wired.com/science/discoveries/magazine/16-07/pb_theory (2008)
40. Assuncao, M.D., Calheiros, R.N., Bianchi, S., Netto, M.A.S., Buyya, R.: Big Data Computing and Clouds: Challenges, Solutions, and Future Directions. Technical Report CLOUDS-TR-2013-1. Cloud Computing and Distributed Systems Laboratory. The University of Melbourne, Parkville, Victoria (2013)
41. Big Data for Good. www.odbms.org (2012). Accessed 12 Nov 2013
42. Hilbert, M., López, P.: The World's Technological Capacity to Store, Communicate, and Compute Information. Science **332**(6025), 60–65 (2011). doi:10.1126/science.1200970. PMID21310967
43. Batty, M.: Can it happen again? Planning support, Lee's requiem and the rise of the smart cities movement. Environ. Plan B Plan Design **41**, 388–391 (2014). doi:10.1068/b4103c2
44. Mayer-Schönberger, V., Cukier, K.: Big Data, a Revolution That Will Transform How We Live, Work, and Think. Eamon Dolan/Houghton Mifflin, Harcourt (2013)
45. Jacobs, A.: The Pathologies of Big Data. ACMQueue, ACM, New York (2009)
46. Magoulas, R., Lorica, B.: Introduction to Big Data. Release 2.0. O'Reilly Media, Sebastopol, CA (2009)
47. Snijders, C., Matzat, U., Reips, U.-D.: "Big data": big gaps of knowledge in the field of Internet. Int. J. Internet Sci. **7**, 1–5 (2012). http://www.ijis.net/ijis7_1/ijis7_1_editorial.html
48. Graham, M.: Big Data and the End of Theory? The Guardian, London (2012)
49. Delort, P.: Big data in biosciences; Big Data Paris. http://www.bigdataparis.com/documents/Pierre-Delort-INSERM.pdf#page=5 (2012)
50. Boyd, D.: Privacy and publicity in the context of big data. WWW2010 Conference (2010). Accessed 18 Apr 2011
51. Jones, M.B., Schildhauer, M.P., Reichman, O.J., Bowers, S.: The new bioinformatics: integrating ecological data from the gene to the biosphere (PDF). Annu. Rev. Ecol. Evol. Syst. **37**(1), 519–544 (2006). doi:10.1146/annurev.ecolsys.37.091305.110031
52. Boyd, D., Crawford, K.: Critical questions for big data. Info. Commun. Soc. **15**(5), 662 (2012). doi:10.1080/1369118X.2012.678878
53. Ratti, C., Townsend, A.: The Social Nexus. The Best Way to Harness a City's Potential for Creativity and Innovation Is to Jack People into the Network and Get Out of the Way. Scientific American, New York (2011)
54. Crickard, P.: How to build a smart city. http://urbantimes.co/2012/02/how-to-build-a-smart-city/ (2012). Accessed May 2014

55. Smith, A.: An inquiry into the nature and causes of the wealth of nations. Methuen & Co., Ltd., London (1776; 1904)
56. Bonavero, P., Dansero, E., Vanolo, A.: Geografie dell'Unione Europea – Temi, Problemi e Politiche Nella Costruzione dello Spazio Comunitario, pp. 166–198. UTET, Torino (2006)
57. Zahn, T.: Heir to the Empire. Bantam Spectra, New York (1991)
58. Asimov, I.: Foundation. Gnome Press, New York (1951)
59. Laureano, P.: Giardini di Pietra, i Sassi di Matera e la Civiltà Mediterranea. Bollati Boringhieri, Torino (1993)
60. Borruso, G.: Geografie di Rete. Patron Editore, Bologna (2011)
61. GSMA Intelligence. https://gsmaintelligence.com/ Worldmeters. Accessed 29 Jan 2015. http://www.worldometers.info/it/ Accessed 29 Jan 2015
62. Hanzl, M.: Ten Commandments for the city. In: Facebook, May 22 (2014). https://www.facebook.com/photo.php?fbid=10204196347015718&set=pb.1438171327.-2207520000.1403434139.&type=3&theater
63. Brandolini, A.: Bullshit Asymmetry Principle, Personal Communication at XP2014, 26–30 May, Rome http://www.slideshare.net/ziobrando/bulshit-asymmetry-principle-lightning-talk (2014). Accessed 29 Jan 2014

Understanding the Context

Robin Nicholson

Abstract As the global population continue to grow, new cities are being built, our expectations are rising, energy demands are increasing and the reservoirs of freshwater needed for our food are being exhausted. Meanwhile some modest European urban regeneration projects by architects/masterplanners like Cullinan Studio may offer some lessons for global sustainability.

Keywords Context • Scale • Sustainable urban communities • Urban regeneration • Climate change • Shared vision • Design audit

Increasingly we live in cities and our cities create our identity, but do we have a vision for our cities in the future, say 2050, and how widely is that vision shared? Clearly there is some general recognition that climate change will alter how we live, as will the continuing development of digital media and other as yet unforeseen innovations. In this chapter I will reflect on the nature of our cities, on the value of design audit and the opportunities that could arise from the changing climate if we accept the challenge. I will describe two Cullinan Studio urban regeneration projects and our masterplan for Shahat Garden City in Libya which might offer some alternative approaches for new sustainable communities, wherever.

The concept of 'Optimal Living' raises the question of Optimal Living for whom? Maybe part of the answer lies in a wider engagement of the community and the greater distribution of the benefits of city living. Cities were formed to gather the collective energies of the community and to facilitate trade both internally and between cities, but they developed to claim and defend territory, regions, nations and from time to time empires. The European city still displays its powers but needs good, accountable governance as the nature of trade shifts from food and goods to services and knowledge in a changing climate. At what scale is the future urban community more or less sustainable?

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1 The Opportunities Arising from Climate Change

The 2006 Stern Report[1] for the Treasury was the first UK report, suggesting that dealing with climate change was affordable providing we got on with it now, to have been taken seriously, globally. The report triggered a series of UK Government undertakings embodied in the Climate Change Act of 2008 with cross-party political support. This Act made it the duty of the Secretary of State to ensure that our net carbon account for all six Kyoto greenhouse gases for the year 2050 is at least 80 % lower than the 1990 baseline.

This target survived the economic squeeze in response to the ensuing global recession from 2007. Since then there have been a number of reports developing our sustainable thinking such as the impressively comprehensive 2013 third edition of Zero Carbon Britain.[2] But the most arresting is the Carbon Tracker report 'Unburnable carbon 2013: Wasted capital and stranded assets'[3] published by the Grantham Institute on Climate Change and the Environment at the London School of Economics (LSE). This argues that between 60 and 80 % of coal, oil and gas reserves of publicly listed companies are 'unburnable' if the world is to have a chance of not exceeding global warming of 2 °C.

The Edge think tank[4] has called for a tangible vision of what the future of London and other UK cities might look like and the extent to which the threat of a changing climate can be harnessed for the collective 'common wealth'. This implies a sharing of goods and energy within a finite global economy and diminishing resources to make new cities and goods, with less energy to be shared among a still growing population. 'Business as Usual' would see the UK population grow by one million by 2035 and the energy consumed increase by 41 % in the same time.[5]

With two thirds of the world's largest cities being coastal and housing 634 million citizens, the rising seawater level and the increasingly unlikely target of limiting temperature rise to 2 °C above 1990 levels would suggest that collective action is not just desirable but essential. Our approach to global warming needs first be behavioural rather than technical and is relatively straightforward if we

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[1] 'The Economics of Climate Change' by Nick Stern is a 700-page report published by the UK Government in 2006. Stern was commissioned by the Treasury and had previously worked at the World Bank and the Treasury.

[2] 'Zero Carbon Britain: Rethinking the future' published by the Centre for Alternative Technology in Wales is downloadable from http://zerocarbonbritain.org/index.php/current-report/report.

[3] 'Unburnable Carbon 2013: Wasted capital and stranded assets' is a research from Carbon Tracker and the Grantham Research Institute on Climate Change and the Environment and is available on http://www.carbontracker.org/site/wastedcapital.

[4] The Edge was set up in 1996 under the auspices of the Arup Foundation as a multidisciplinary group to help reform the professional institutions and encourage them to collaborate more by debating topical issues; see www.edgedebate.com for reports of the debates, Edge Words and members.

[5] Dr Cristof Ruhl, BP Chief Economist in a lecture at UCL Energy Institute on 1 April 2014

use less energy and share the available energy equitably. This has been promoted by the classical viola player Aubrey Meyer and the Global Commons Institute as 'Contraction and Convergence'[6] for over 20 years and is widely accepted by those countries, often the poorest, who are most threatened by rising sea levels; it has not been accepted by the major powers.

Despite the modesty of the present Pope appearing to support the Christian belief that 'it is easier for a camel to go through the eye of a needle than for a rich man to enter the kingdom of God' and similar exhortations in other faiths, history suggests that power is seldom shared, let alone willingly. The Gini index[7] measures the gap between the richest and poorest on a national basis, but the myth of money buying happiness was most clearly exposed by Richard Wilkinson and Kate Pickett in their 2009 'The Spirit Level: why equal societies almost always do better'.[8] So what chance is there that self-interest in a changing climate will encourage near-universal collective action for the common good?

'Optimal Living' allows us to dream of such a place, but it is difficult for most of us to be able to find the time to stand back from the tsunami of advertising that encourages us to spend money we don't have on goods we don't need. The rapid, if slightly delayed, take-up of the Circular Economy[9] provides a constructive model for making long-lasting goods and buildings with less built-in obsolescence. Since buildings are responsible for at least 40 % of the carbon emissions, as architects, engineers, landscape architects and urban designers, we have a crucial role to play in providing the opportunities for Optimal Living in a lower carbon world, and through championing the concept of place, we can encourage more collective behaviour.

Eighty percent of the buildings we will be using in 2050 in Europe already exist so we need to learn how to make much better use of them while using far less energy. Although new cities and now garden cities are attempted from time to time, the major activity in the mature European city is regenerative and the major political drivers are housing, employment, energy and waste within the existing infrastructure. In Shahat we were able to rethink this all in the special topography and climate of the Libyan Green Mountain region, but our schemes for Bristol Harbourside and Stonebridge in west London are typical urban regeneration schemes; in all three cases, there were high degrees of community engagement.

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[6] Aubrey Meyer causes Contraction and Convergence to be debated at UN in 1996; see www.gci.org.uk for details of the work of the Global Commons Institute.

[7] Gini Index—see http://en.wikipedia.org/wiki/Gini_coefficient.

[8] *The Spirit Level: Why More Equal Societies Almost Always Do Better*. Richard G Wilkinson and Kate Pickett 2009 publ. Allen Lane

[9] McDonough and Braungart's *Cradle to Cradle: Remaking the Way We Make Things* (2002) did not really take off till the Ellen McArthur Foundation was launched in Sept. 2010, dedicated to the Circular Economy—see www.ellenmacarthurfoundation.org.

2 The City

In Europe most of us are governed by representative democracies and our cities reflect this in the form of public shared space dating back to the earliest settlements. Although both economies were slave-based, the more organic Greek agora and the more formal Roman forum were at the centre of two different urban typologies that brought the citizenry together. Subsequently, providing we citizens behaved ourselves, we were encouraged to trade, debate and consort in public, although real power and wealth were held by just a few families.

The structure of our cities is largely fixed by the roads and the sewers and other services beneath the roads and is now fixed even more strongly by fibre optic highways. Most attempts at restructuring cities, such as the City of London following the Great Fire of London (1666) and the Second World War bombing (1945), failed as the existing property owners' desire to reconstruct as quickly as possible swept both Wren's baroque masterplan and Abercrombie's 1944 London Plan aside. The only major urban changes have been caused by seriously powerful property developers or by traffic engineers. The successes of the former include the Champs Elysées in Paris and Regent Street in London, while the pillage of the latter, wrought in so many cities, has only just begun to be unpicked.

Cities designed for the car such as Los Angeles and the thousands of new Chinese cities[10] tend to have a scale that is difficult to transform for use by pedestrians and cyclists, in a post-car age. By contrast even a 1 km road grid, such as that in Milton Keynes, is theoretically the right scale to be reclaimed. However, because that grid with its relentless roundabouts is defined by an extensive 40-year-old landscape, it is largely untouchable as trees are the new sacred. The earlier new town of Harlow is similarly constrained by landscaped roads. It is worth remembering that originally the Milton Keynes grid was chosen for an 80/20 modal split in favour of public transport with a local centre at the midpoint of each kilometre square, allowing adjacent squares to meet at the local shop and school; by 1969 the modal split had been reversed and the grid communities were condemned to isolation through high-quality landscape.

I am encouraged that, presently, young Londoners are not bothering to learn to drive[11] and I should admit that the car is not a central part of my 'Optimal Living' story. Just as we need to make much better use of the buildings we've got, we need to make much better use of the pre-motorway roads we have got rather than building new ones. Removing highways from lake edges, demolition of urban

[10]7 March 2012 WND reported about 64 million vacant homes in China and their construction of 20 'ghost' cities each year.

[11]25 Sept 2011 Guardian newspaper reported that 'In Britain, the percentage of 17- to 20-year-olds with driving licences fell from 48 % in the early 1990s to 35 % last year. The number of miles travelled by all forms of domestic transport, per capita per year, has flat-lined for years. Meanwhile, road traffic figures for cars and taxis, having risen more or less every year since 1949, have continued to fall since 2007'.

elevated motorways, as in Seoul, and removal of urban ring roads, as Birmingham is trying to do, will continue slowly. Meanwhile, interest, particularly in London, is growing in the densification of our suburbs and the parallel reduction of their carbon footprint.[12]

As an architectural and masterplanning practice based in north London, we have developed a range of low-energy projects involving consultation with the users and the wider community as a norm and responding to the context, be it urban, suburban or rural.

3 Cullinan Studio[13]

Our studio was set up by Ted Cullinan in 1995 as a design-led cooperative; so collaboration is an integral part of our practice. In the 1970s and 1980s, we shared an office with Max Fordham and his (cooperative) building services engineering practice.[14] Together we produced a series of radical low-energy projects which continued with Fulcrum Consulting (FC) when they split out from the Max Fordham Partnership (MFP):

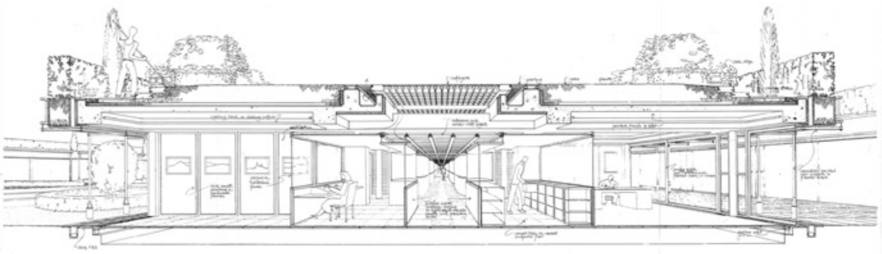
- 1990 RMC Headquarters, Thorpe near Staines (MFP)—naturally ventilated deep plan offices with early exposed thermal mass and groundwater cooling and covered with a large roof garden
- 1991 Carshalton Theatre (MFP)—transformation of a redundant church hall into a theatre with ground-source cooling
- 1997 Archaeolink Visitor Centre, Oyne near Aberdeen (FC)—inter-seasonal heat storage in the earth under the building
- 1999 Gaia Centre (FC)—demonstrating techniques for carbon neutrality
- 2001 Greenwich Millennium School (FC)—TermoDeck structural heating/cooling
- 2009 John Hope Gateway, RBGE Edinburgh (MFP)—displaying a portfolio of technologies
- 2012 Foundry (MFP)—our own retrofit BREEAM Excellent offices with a PV-powered air-source heat pump

[12]Ben Derbyshire, HTA Managing Director, described his study into the densification of a city block by Bexley Station for Greater London Authority at an NLA Conference ‘Delivering new housing models for London’ on 12 Feb 2014. He quoted LSE Prof Tony Travers as saying ‘There are 8.5 million Londoners today. There will be between 10 m and 10.5 m Londoners in 2040. All of London at (London Borough of) Ealing Densities could house a population of 10 m. All of London at (London Borough of) Islington densities could house a population of 20 m’.

[13]Edward Cullinan Architects changed its name to Cullinan Studio in November 2012. The website is www.cullinanstudio.com.

[14]Max Fordham and Partners’ website is www.maxfordham.com.

RMC and Carshalton were written up by Fordham partner Randall Thomas in his pioneering book ‘Environmental Design: an introduction for architects and engineers’ in 2006.[15]



Cross section through RMC Headquarter offices with natural ventilation and groundwater night-cooling of the exposed concrete slab supporting the garden on the roof

Many of our previous projects had been based on passive solar design, but from mid-1980s, we developed projects with a range of techniques from inter-seasonal heat storage to ground-source cooling. However, while the lower-energy approaches were integral to the designs, they never dominated the architecture, which always responded to the site, provided appropriate accommodation, and induced overall delight. As a result of this awareness, the environmental engineer has become an integral part of the concept design process.

Consultation became a key part of our working method in two urban projects in the early 1980s, the reconstruction of St Mary’s Church in Barnes and the Lambeth Community Care Centre. The two processes were very different with the reconstruction of the church being the focus of a public dispute between two factions of that community and the care centre being a continuous interrogation of the brief and the fitness of our designs by the project team of health professionals, with periodic presentations to the largely supportive community.

At Barnes we were appointed to design a new church to grow out of the ruins of the old that had been developed over the previous 900 years. Fortunately the tower and much of the original mediaeval church escaped the 1978 arson attack and allowed us to propose a sequence of designs that turned the main axis through 90°. For some 3 years we consulted with the community which had split into two factions, those who favoured the redesign and those who wanted to reconstruct the old church, despite the additional cost and the liturgical unsuitability. During the design development we progressively incorporated as much of the remaining fabric as possible while retaining the original plan for the church ‘in the round’ as required

[15]Randall Thomas ed. (2000). *Environmental Design: An Introduction for Architects and Engineers*. Spon Press

for a modern liturgy and flexible community use. When the church opened, all signs of this split had disappeared although two of those championing reconstruction chose to leave the area.

In Lambeth, the newly formed Community Health Council seized the opportunity to consult the community on the future use of the old and much loved Lambeth Hospital, which had been rendered largely redundant by the much larger but more distant St Thomas' Hospital. The result was a new kind of health facility, where 20 beds above a day unit for 35 allowed local doctors to look after their patients as though they were at home while having a full-care regime. The project team was formed from a group of young radical general practitioners, therapists and the secretary of the Community Health Council who wanted to challenge every aspect of the design and cooperation of this 'model' centre. The consequence was that we had to consult with them on every aspect of the design.

Cullinan Studio projects respond to the context in which they are situated in terms of their history, the existing buildings and/or landscape and the local climate and most focus on the public spaces between the buildings. We are continuously amazed that this should be seen as radical but, in so far as most architects and all 'starchitects' are obsessed with the increasingly irrational 'object-building', the three following projects can be seen as urban exemplars. In their realisation, our architecture celebrates the way the buildings are made.

4 Bristol Harbourside

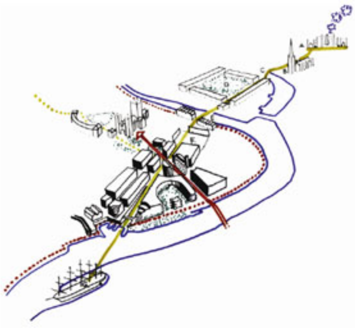
Cullinans were chosen by representatives of the wider Bristol community to masterplan the redevelopment of 16.5 acres of redundant and heavily polluted industrial land, on the edge of the Floating Harbour in the centre of Bristol; known as Canon's Marsh, this had been the grazing ground for the cattle belonging to the Cathedral on the hill behind. By 2000, part of the site had been occupied by a large office building for a national bank and a new public square made for the Millennium, on top of a magnificent underground public car park. One half of the remaining triangular site had been cleared of its eight-storey tobacco warehouses in 1988, while the other had the magnificent stone ruins of the early gas governor compound including the Purifier House. Like so many derelict British industrial sites along rivers and canals, much of our site was inaccessible as was the water's edge.

For 3 years before our appointment, another team had been working on proposals that had succeeded in upsetting the Bristol Civic Society, the Dean of the Cathedral and many other locals. Many in opposition overlooked the site and would rather it was left deserted than developed. In one of the most extensive consultation processes we have enjoyed, the consultant Opinion Leader Research identified 23 Bristol-wide stakeholders and formed them into the Canon's Marsh Consultative Group; this ensured that the Civic Society had no greater voice than say the Black and Asian Youth Group or the Business Roundtable, both of whom were eager to see the site redeveloped.

We were not allowed to design anything until a representative cross section of Bristol had established in workshops the criteria by which our scheme would be assessed. This and our developing proposals were very publicly displayed on a project website as they developed throughout the 15-month masterplanning process. By the end we had achieved unanimously an outline planning permission for the same quantum of space as the previous efforts that had incited such opposition.

The following drawing shows our response to the criteria established by the community including connections to existing monuments and total public access. There were five major urban moves:

- Realignment of the existing access road that cut diagonally across the site, retaining it as a single-lane dual carriageway, allowing more of the development sites to be rectangular.
- The completion of the pedestrian Brunel Mile (shown in yellow) connecting Brunel's 1840 Temple Meads Station and his 1843 SS Great Britain that had been lifted and returned from the Falklands in 1970. The front two masts of the ship are visible as you enter the site from Millennium Square, but from the centre of the scheme, all are visible as the path opens up and slopes down 3 m (10 ft) to the water's edge.
- The formation of a harbour inlet to allow small-scale boating activities to enliven the scene; the saved and cleaned historic stone arches were used to face the shops and stores, below the restored Purifier House (blue indent).
- The harbour edge was opened up as a delightful public footpath with spaces opening off it and periodic cafes (dotted red).
- The careful alignment of the Cathedral Walk so that the overpowering 15-storey Colston Tower is hidden behind one of the buildings and no longer damages the views of the Cathedral from the Harbour edge.




Masterplan diagram and the new Bristol Harbourside promenade (photo with kind permission of Crest Nicholson)

Having established this framework in response to the context and the consultation, the buildings fill in the gaps and define the public spaces. The planning permission allowed a mixed use scheme of 1.1m square feet, 40 % commercial offices, 40 % residential and 20 % retail and leisure. The detail design makes references to the great crescents of Bristol with extensive use of render, although this is now insulated render, and substantial balconies, which have played their part in the commercial success of the scheme. There is an extensive public art programme (in excess of £1m), the latest section of which celebrates the passage of rainwater from the sky to the harbour down the Millennium Promenade. The rainwater from the central part of the scheme is cleaned in reed beds floating on the edge of the harbour.

5 Hillside Hub, Stonebridge in West London

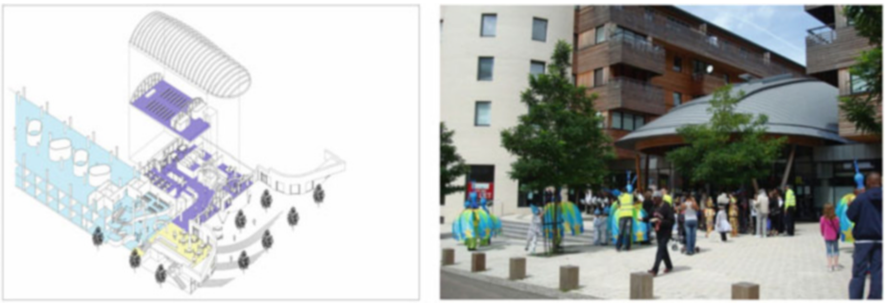
In 2004 we were appointed to add the social centre at the heart of the reconstruction of one of the most notorious public housing schemes in London. The Stonebridge Estate was constructed in the 1970s for the London Borough of Brent and housed 1,775 homes in forbidding 14-storey deck-access slabs, faced in large precast concrete panels and linked by flying high-level bridges. Almost instantly the scheme became the home of ethnic gang warfare, drug dealing, violence and crime. By 1988 it had been declared as one of only six Housing Action Trusts in the UK and funds were made available for its reconstruction, well before its anticipated lifespan.

Site plan for the Hillside Hub/Remains of the flying bridges connecting one of the 1970s precast concrete slab blocks

When we started the consultation process, much of the former estate had been replaced with terraced housing and flats up to four storeys high along streets. We were invited to design a health centre and a community centre on adjacent sites. After some good work with the local community, we were able to persuade everybody that it would work best if we made a single building with the health centre linked to the community centre and a neighbourhood store with 60 flats above. The building defines a public space on the street, too small to be called a square but a really useful public gathering and lingering space; at times such as Carnival, the community prepares itself in the Hub and then sets off in their wonderful multicoloured costumes.

There were three levels of consultation: our multi-headed client including the HAT Board, Hyde Housing Association and the Health Authority; the community had largely been rehoused on-site and were eager to get what they wanted in terms of services, and the health centre project team had to be consulted on the brief and disposition of the various elements of the health centre. In the background the project had to deal with the closing down of the (very supportive) HAT Board and changes in the health service. The result is a total success in terms of the three dimensions of sustainability:

- Socially it evolved from community consultation and is 'owned' by that community.
- Economically, the rent from the health centre and the neighbourhood store pay for the running and upkeep of the community centre.
- Environmentally it achieved the highest certificate for the health centre and meets the latest standards for thermal insulation while managing acoustic privacy for the flats above; the flats are elegantly clad in larch timber boarding.



Axonometric plan of main entry level with health centre (*pale blue*) opening up to the community café (*yellow*) and the community centre (*dark blue*) with the community hall above; getting ready for the 2011 Carnival in front of the building

The success of the Hillside Hub has led to our designing two further dense housing schemes at Stonebridge, the first of which is centred on a publicly accessible garden through which runs a small rediscovered river that will be un-culverted—making the most of what's there.

6 Shahat Garden City

In 2009 we were working on four Graeco-Roman sites in the Green Mountain World Heritage Site east of Benghazi in Eastern Libya. These cities had been established to manage the productive breadbasket for the Greek and then Roman Empires; then in the sixth century, a massive earthquake destroyed them and the area was quietly forgotten, leaving 50 miles of the only largely untouched coastline in the whole Mediterranean. When these projects were put on hold, we were invited to design first one half and then both halves of a surprising experiment, a carbon-neutral garden city for 60,000 people in an area of high housing need.

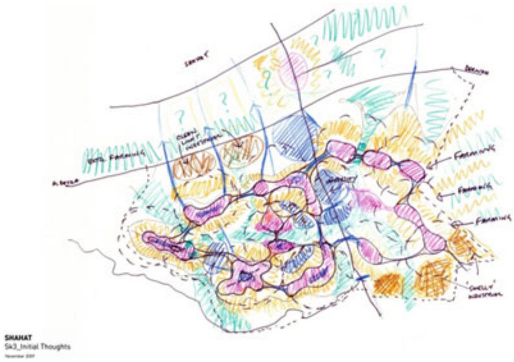
Libya had been under the dictatorship of Gaddafi since 1969, and so the normal democratic processes did not exist but rapprochement with the West was well underway; there was no data or up-to-date maps of the area and there was no one to ask what the rules were. So the challenge was to understand the topography, the local climate and the cultural traditions. What we did know instinctively though was that the existing town of Shahat built in the 1930s, close to the ruined Greek city of Cyrene, was an urban and environmental disaster. Laid out along wide roads with buildings set back behind equally wide strips of unused and unusable land, the car ruled and the houses were designed as though for the desert without insulation, which being 3,000 ft above sea level are very cold in the winter.

Extensive consultation with our Libyan partners and the local farmers established this as having highly productive land in wadis running up to and between relatively barren high ground. We learned about the two contrasting seasonal winds, so well understood by the Greeks 2,000 years before but since forgotten—the beneficial cooling north-easterly and the hot sand-bearing Ghibli wind from the desert to the south.

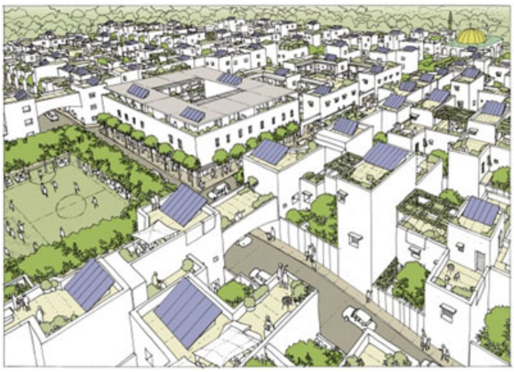
We observed the way people used Shahat, the 1930s Italian colonial architecture and the environmentally more effective traditional cities of Tripoli and Benghazi. We noted the lack of usable public spaces, the lack of interest in archaeological remains, the widespread litter and the individual homes in the centre of square sites, providing no definition or self-shading of the streets. Then we studied their domestic arrangements and explored ways of working with them and with the traditional architectural devices such as the mashrabiya screens providing privacy and cooling.

Seldom does one have such an opportunity to think about the whole story from the streets of extendable family homes to the waste management and electricity generation for a nearly 5×2 mile site (3,700 acres). The masterplan was based on our observations and the concept of the walkable neighbourhood. The city straddles the north-south road that connects Shahat Garden City to existing communities, with the main shopping and offices concentrated along it.

Shortly before the revolution in 2011, our masterplan was signed off, and since it broke what few planning regulations there were, it was adopted as the new model for the east of the country. The masterplan included models for the design of all the houses and the distribution of the now rectangular plots. Given the continuing



housing shortage and continuing enthusiasm for the scheme, we are waiting for the instruction to proceed with designs for the infrastructure buildings for health, education and the mosques.



7 Start by Using Less Energy, Water, Etc.

Carbon neutrality is achievable in new towns like Shahat, but it takes much longer and is more challenging for existing communities with their existing infrastructure. There are encouraging pilot projects in a number of European towns and cities most of which have developed over a long period like Vauban in Freiburg, Hammarby in Stockholm and Malmo West harbour[16]; these tend to develop from a strong vision with collaborative action, a sharing culture and demand reduction.

While the car may be largely expendable, we are dependent on energy for equipment and for space heating, yet we waste energy on cooling which, at present UK temperatures, would be largely unnecessary with better designed buildings. Few cities were as far-sighted as Copenhagen which started in 1920s building 1,500 km of distributed heat networks which now meets 98 % of the heating demand with much of the energy supplied by in-town waste-to-heat plants. Such a shared vision is essential if we are to reduce our carbon footprints towards one planet living.[17]

In the UK, as in many countries, the wealthiest of us pay less for their electricity than the poorest as the more energy you use the cheaper it is to buy, as though power

[16]Peter Hall's latest book *Good Cities, Better Lives: How Europe Discovered the Lost Art of Urbanism* 2013 Routledge has an excellent summary of the main European exemplars.

[17]'One Planet Living' is a global initiative based on ten principles of sustainability developed by BioRegional and WWF; see www.oneplanetliving.net.

was a supermarket two for one offer. So it is no surprise that we waste most of the energy we all use both at an everyday level and exceptionally; for example, 50 % of the energy used in the English School is used when no one is there. Similarly for water, where, compared with the average UK family consumption of 33 gallons of water each day,[18] the Observer newspaper (10 January 2010) reported that the Tiger Woods golf course in Dubai uses four million gallons of desalinated water every day.

8 The Crucial Role of the Primary School

Major urban schemes and national/regional policies are essential, but to begin to transform our community, it is essential to engage at a more local level. There has been considerable success in many parts of UK at engaging primary school pupils in understanding climate change, which they embrace wholeheartedly while helping the schools save energy and, crucially, money. New school design can provide a great opportunity for learning and for greatly reduced dependency on energy.

At the end of 2009, the Zero Carbon Schools Task Force[19] submitted its report to the Labour Party Secretary of State for Education Ed Balls; he had asked us to advise the Government on what they would have to do for all new schools to be zero carbon by 2016; a good question although how to upgrade the existing stock might have been more useful. The answer was not of the order the Department officials had anticipated, but all 30 recommendations were accepted and implemented, only for the incoming Coalition Secretary of State Michael Gove to cancel the whole programme.[20] The answer was not technological but rather adopted Amory Lovins' approach as interpreted by Bill Bordass as 'Halve the demand, double the efficiency and halve the carbon in the supply and you are down to one eighth of the emissions'. We produced evidence as to how a school could halve its energy demand (at little or no cost) and to double its efficiency (at relatively low cost for new schools); however, halving the carbon in the supply is a regional, if not national, issue.

One of the most inspiring schools we found was the Victorian Ashley Church of England Primary School where the Head had decided to tackle the school's energy use and costs. He made some minor investments in equipment and installed some light tubes in unlit areas; he installed smart metering to measure and monitor the

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[18]The average amount of water consumed by a UK family rises from 33 gallons to 748 gallons per day if you include the water used to produce the food and products we consume.

[19]The Zero Carbon Schools Task Force was set up in 2008 with members from practice, the research community and other Government Departments. Ellen McArthur was one key member 'as part of her journey of learning'. The report is downloadable on dera.ioe.ac.uk/672/1/00111-2010DOM-EN.pdf.

[20]After 13 years of New Labour, the Conservatives formed a minority Government Coalition with the Liberal Democrats and used the Global Economic crash of 2008 to cancel many programmes in an attempt to diminish 'the State' and drastically cut the welfare state.

electricity use and so they can use the data in their regular curriculum. Then he put the children in charge of running the electricity with a small incentive scheme. In the first year the children reduced the school's electricity use by 51 %, rising to over 80 % by year three, but equally importantly the children took the message home and their parents started competing to reduce their own emissions. The environmental ethos of the school continues to thrive.[21] Might this not give us some hope of a more rational, less wasteful way of living?

For nearly 4 years Cullinan Studio has been working with Rosendale Primary School to make their early twentieth century and later buildings work significantly better in a modest but model way, working with the school to transform its spaces for current teaching methods. The first project tackled the classrooms which would reach 43 °C (109 °F) in the summer due to the windows being painted shut, blackout blinds dropped and the lights permanently on for use of the heat-generating whiteboard technology; unbelievably a conservatory had been built on the south side further adding to the overheating. Stripping out the clutter, making the windows work and rearranging the conservatory roof glazing and ventilation have, with some calm interior design, transformed these classrooms into delightful well-ventilated places.

'Optimal Living' has to include active engagement within the community and shared learning, where the local primary school becomes the key facility being so much more local than the secondary school or college, both of which host wider community services and learning. Given the number of primary schools that have responded to the challenge of reducing their carbon footprint and using climate change in the curriculum, it is perhaps not too fanciful to imagine these schools expanding their roles as the community hub for the local management of energy, water and waste.

9 Existing Housing Is a Problem Now and the Opportunities of Community Energy

In England there have been a series of imaginative research programmes into how to improve the efficiency of our homes. In England and Wales we have 22,539 million homes roughly 50 % of which were built before 1950, the majority with no insulation.[22] To achieve the legal obligations set by the Climate Change Act of

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[21] See Ashley School website http://www.ashleyschool.org.uk.

[22] The 2006 *Review of the Sustainability of Existing Buildings* revealed that 6.1 million homes lacked an adequate thickness of loft insulation, that 8.5 million homes had uninsulated cavity walls and that there is a potential to insulate 7.5 million homes that have solid external walls. These three measures alone have the potential to save 8.5 million tonnes of carbon emissions each year. Despite this, 95 % of home owners think that the heating of their own home is currently effective—House of Commons Environmental Audit.

2008, we have to reduce those emissions by at least 80 % by 2050; this was enhanced by the Coalition Government (2010) to require a reduction of 34 % by 2020. To do this we would need to convert about 1,200 homes per day, every day to 2050. The (TSB) Technology Strategy Board's Retrofit for the Future[23] research showed how to do it (and how difficult it is).

So then the Government set off to establish an ambitious Green Deal programme which would allow us to upgrade our homes for free by making the energy companies do the work for free and reclaim their costs from the 'savings' on our individual energy bills. This really neat notion failed to attract sufficient homeowners because of the high interest rate charged; indeed, one might wonder why major energy companies would want to do work that would reduce their sales of energy and hence profits. Not only does this show how difficult these reductions are to achieve, but the TSB programme Design for Future Climate[24] showed how rising temperatures are going to make the task more difficult and demonstrates how buildings can be designed for comfort in 2030, 2050 and 2080 by adapting them as the temperature rises.

Might collective action be more productive? There are a range of organisations growing out of the Transition Town movement[25]; one such is OVESCO in Lewes which crowd-funded installations of photovoltaics on the town brewery's south-facing roof and on local schools for the benefit of the schools and community groups while producing a 4 % return on capital invested.[26] Currently Cullinan Studio is working with the support of Lambeth Council on a community energy project, Rosendale Energy, using the primary school and other local south-facing roofs to provide energy for the school and other community projects.

10 Commission for Architecture and the Built Environment (CABE)

When New Labour was elected in 1997 after 17 years of Conservative rule, during which investment in public sector buildings and maintenance had been almost completely run down, there was a strong desire to provide better services for the community and that meant new buildings. There was a strong belief that they needed to get better value from the money invested and that led to two major

[23]Retrofit for the future aimed at reducing carbon emissions by 80 % in 100 homes; case studies can be found in www.lowenergybuildings.org.uk/.

[24]Design for Future Climate funded 48 schemes by up to £100k to design and demonstrate the schemes' ability to survive in anticipated temperatures in 2030, 2050 and 2080; see connect.innovateuk.org/web/design-for-future-climate.

[25]See www.transitionnetwork.org for the Transition Town story.

[26]See www.ovesco.co.uk/ for the Ovesco story.

reports: ‘Rethinking Construction’ (1998) by John Egan[27] and ‘Towards an Urban Renaissance’(1999) from the Urban Task Force, chaired by Richard Rogers.[28]

The Urban Task Force supported the groundswell of support for the importance of design and this led to the establishment of CABE in 1999.[29] Starting small and inheriting from the Royal Fine Art Commission the task of running a national design review service, it rapidly established itself as a force for good design under the chairmanship of the developer Stuart Lipton; Lipton was an inspired choice as he had employed the best architects and engineers at no additional fee and had built a portfolio of major high-quality offices, often at lower than the going rate.

Apart from improving the design review process, the first real innovation at CABE was the awkwardly named Enabling Programme whereby high-calibre architects and engineers supported public sector clients to help them be more effective public sector clients and get best value from design and procurement. Since many public sector procurers were reluctant to admit that they might need help and tended to believe, wrongly, that lowest cost was the only *auditably* valid criteria, it was difficult to get involved early enough to be the most effective. Nevertheless, with the focus on the most disadvantaged communities, real benefit was delivered.

CABE grew as the Government appreciated its effectiveness and asked it to take on more responsibilities; by the time I joined as a Commissioner in 2002, there were about 30 staff which grew to more than 120 with Research and Communications teams as well as departments like HR that become necessary at a certain size. In 2003 CABE Space was established in response to a Government report on parks to champion the role of public realm, the importance of maintaining our historic parks and other green spaces and the need, as ever, for good design.

Both the Enabling Programme and CABE Space were focussed on support for communities and local authority officers, usually in support of Government programmes. One such programme that was well intentioned was the Housing Market Renewal (HMR) initiative, whereby there would be support for housing and communities in the Midlands and north to balance the market-driven housing in the more prosperous London and south-east. The HMR initiative was strongly supported by CABE by facilitating bimonthly meetings of the nine HMR pathfinders taking it in turns to host the meetings, so that they could share experiences and build up their in-house capabilities. There was some excellent work done especially in

[27] ‘Rethinking Construction’ 1998 was the report of the Construction Task Force to Deputy Prime Minister John Prescott and chaired by (Sir) John Egan and is downloadable on www.constructingexcellence.org.uk.

[28] ‘Towards an Urban Renaissance’ 1999 was the report of the Urban Task Force to Deputy Prime Minister John Prescott and chaired by (Lord) Richard Rogers.

[29] CABE was a Non-Departmental Public Body (NDPB); when the Coalition Minister for Architecture unilaterally and without warning withdrew its funding from the Department of Media Culture and Sport, it was shrunk and absorbed by the Design Council as a Charity. The CABE archives and publications are all housed in the National Archives http://webarchive.nationalarchives.gov.uk/20110118095356/http:/www.cabe.org.uk.

East Lancashire, north of Manchester, but it was never reported because the national press would just not go to East Lancashire for a good news story!

Before Stuart Lipton stood down as Chairman of CABE in 2004, he had cleared the way for CABE to embrace sustainability as an integral part of good design right across CABE's programmes and had begun a carbon audit of CABE's activities. A wide-ranging review by Beyond Green explored how CABE could become a low-energy public sector model and use its influence to greatest effect. Given London's lead on developing climate change strategies, it was decided to work with the eight Core Cities who, with support from the Deputy Prime Minister, had formed into a lobbying group; these were Bristol, Birmingham, Liverpool, Manchester, Nottingham, Leeds, Sheffield and Newcastle.[30]

CABE established that what the Cities wanted was a website to help them explain the issues to their leaders and chief executives with sufficient exemplars for them to be able to imagine a vision for their sustainable city. The Cities were each invited to send eight officers responsible for delivering climate policies in their cities for an intense 48 h workshop in Bristol with the intention of finding out how best CABE could help them. Everyone was excited, but to their surprise the CABE team quickly discovered that the officers, say the eight from Newcastle, did not know one another; the person in charge of climate change in education did not all know their colleague in say transport or housing, etc. CABE's engagement was well received by the Core Cities but was strongly opposed by the Government Departments, so sponsorship had to be sought for the Bristol gathering.

Having fleshed out the scope, the website development was tendered and the young planning consultancy Urban Practitioners were appointed. The excellent Sustainable Cities website developed with two sets of cross-cutting themes; on the one axis were the subject areas of energy, waste, water, transport, green infrastructure, public space and leadership which were cross-cut by scale—regional, subregional, cities, neighbourhoods and buildings. The site was then populated with best practice examples from around the world. The spatial scales allowed cities to think, for example, about how to manage surface water and flooding on a sub-regional basis, whereas the political boundaries would only allow them to think about surface water within the boundaries of the city, which is not where most of the rain falls. In 2010 Sustainable Cities morphed into Sustainable Places to widen access to the whole country.

11 Design Audit

A recent trip to Brazil allowed me to review the potential of design audit to improve the quality of projects subject only to development codes as in Brazil. The opportunity arose when the Ministry of Cites invited a team from London to

[30] See www.corecities.com for Core Cities.

join a review of the first phase of the ambitious 'My Home My Life' Presidential programme to provide six million homes in 6 years in urban extensions across the country[31]; the second phase is nearing completion. What changes might be made that would not slow down the programme yet improve the outcomes and incorporate a feedback loop?

I presented a range of techniques we have developed in England to review design quality:

- The formal CABE Design Review Panel where the applicant had 20 min to explain their 'significant' scheme and the Panel debates it in front of the applicant team with input from the local planning authority and, where appropriate, the relevant conservation body. Our Bristol Harbourside masterplan was endorsed by CABE Design Review on 2000. The funding for CABE was removed in 2010 by the Coalition Government, so a smaller and fully commercial operation is now integrated into the Design Council; they have introduced useful design workshops which can help develop or distil early ideas before the formal examination of design review.
- CABE developed with the Home Builders Federation (HBF) and the independent consultancy Design for Homes 'Building for Life' for measuring the layout and urban design quality of housing. Trained assessors scored the quality under 20 headings and awarded grades, which were in some instances used as a threshold for securing public funding. Both Bristol Harbourside and Stonebridge Hillside Hub were awarded Building for Life Gold Standard. However, the cost and complexity of this system were reviewed after a few years and the simpler self-administered Building for Life 12 criteria were distilled and launched in 2012.[32] The advantage of this as a tool is that the assessment criteria were agreed with all the stakeholders including the housebuilders and could easily be adapted for other countries and cultures.
- The Cambridgeshire Quality Panel was set up in 2010 to champion quality in the significant developments around the periphery of Cambridge and in the surrounding market towns that initially were expected to lead to 75,000 jobs and 73,500 homes. The Cambridgeshire Quality Charter for Growth[33] was developed by Urbed in consultation with the university, the local businesses and the local authorities. It was decided that the four Cs by which all schemes would be assessed were Community, Connectivity, Climate change and Character. This has proved to be a flexible and effective formula and seemed to offer considerable potential for schemes such as the My Home My Life Programme in Brazil.

[31] See http://pt.wikipedia.org/wiki/Minha_Casa,_Minha_Vida.

[32] See www.designcouncil.org.uk/knowledge-resources/guide/building-life-12. I don't think one can overestimate the cultural dimensions within which design review and performance measurement must work.

[33] See www.cambridgeshireinsight.org.uk/planning/cambridgeshire-quality-panel for the Cambridgeshire Quality Charter and the work of the Quality Panel.

- And then there is the quality of detail design and what gets built where the National House Building Council (NHBC) has over the last 70 years been improving, from a low base, the quality of house building by inspecting the detail design drawings and then inspecting the product as it is built and finished. NHBC provides home owners with a 10 year warranty to protect them from potential defects rather than ensuring great internal designs and delight. Although the housebuilders themselves fix most of the problems that emerge in the first 2 years, the NHBC still pays out £70m every year to rectify defects; clearly building defect-free housing is a problem in UK if not globally.

Cities are more complex than these tools might imply, but they do allow a wider awareness of the processes of design. For Cullinan Studio we have our own set of four Cs—context, consultation, climate and construction—to which I might add a fifth, collaboration.

12 Conclusion

The reality of climate change means that we have great opportunities to make our cities more liveable and more convivial, that is, “Optimal”. There is little doubt that the future is urban and that in Western Europe and in many other cities, we will see continuing densification and the adaptive reuse of our buildings; we will enjoy the benefits of high-quality urban regeneration for our many and varied cultures as they become less wasteful and reduce their dependence on the internal combustion engine. Engagement with the community will become the norm for all projects.

The challenge of a minimum 80 % reduction in greenhouse gases means that as architects and engineers we have the opportunity to use our skills to design collaboratively. Designing new lower-energy buildings for demanding clients is relatively easy although at the moment it is more challenging to deliver them; self-sufficient carbon-neutral buildings are more difficult. Designing new carbon-neutral communities like Shahat Garden City is more manageable, but few have been built thus far. We need a large number of model carbon-neutral developments across the globe, whose performance we can measure.

The necessary transformation of our existing cities is a very exciting challenge, but we have hardly begun and the political will is weak as the promoters of endless growth and the climate deniers still command largely unchallenged attention. As designers we will play our part in raising awareness of the opportunities that climate change offers, not least in designing environmentally much better homes, schools and communities. The choice is ours but our cities will be much more enjoyable places to live in when we do it differently.

Architectural Mithridatism?

Clement Blanchet

Inspired by the legend of Mithridates VI (born about 132 BC, died in 63 BC), the King of Pontus, mithridatism is the practice of protecting oneself against a poison by gradually self-administering various toxic products. This immunity is acquired via the repetitive and progressively increasing intake of these harmful substances. We could simply describe architecture and urbanism as two fields trying to become immune via some rather seriously dangerous phenomena, which I would like to describe here. The Hazard, the Image, the Seduction, the Fragmentation, the obligation to be Sophisticated, the Unknown, and the Overdose are some examples I will develop like a potential miscellanea of current architecture's toxic substances. Some projects will try to address those issues.

1 Hazard

I understand the work of the architect to be a careful search aimed at finding ways and strategies for action. We must give ourselves the means to see and know. To provide the architecture as well as to produce it, to think it, and to design it can exhaust all the tools available. It produces architecture perhaps, but it is urgent also to make it independent of production as well as to try to understand, at the most basic level, what is happening in the world and how certain events affect architecture. Of course, sometimes the original program is not about inventing knowledge, but rather about handling it, making it readable. Find a simple equation that can be unique. Complexity can arise, but it seems to me that it should only respond to and address the contextual demand.

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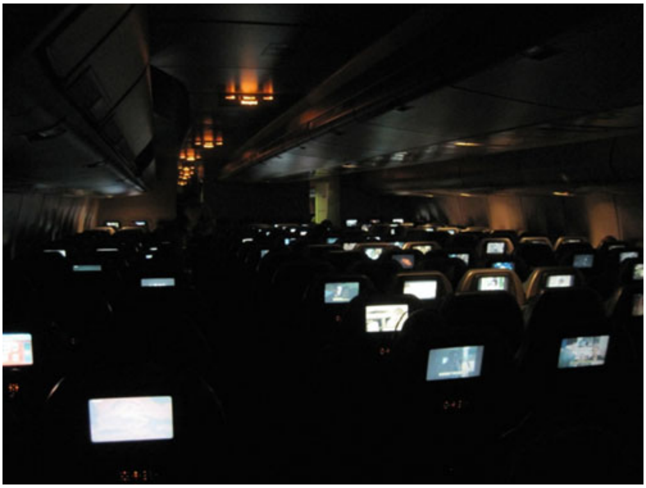
Design appears to be related to hazard. Hazard has a double-edged interest as it can be considered a bargain, but a destiny it can translate into a fatality, a risk, a trap. The creative process is to succeed in capturing this chance. This is an attractive friction. It is a kind of uncontrolled bleeding. Hazard can make and generate the ordinary and the sublime.

2 Image

The present culture is surrounded by images, graphics, and advertising. We must take a very careful look at their effects on architecture and our modes of representation. Our view of objects is transformed. The image kills the picture. We must keep an open attitude to these changes. Therefore, we favor substance over image. The desire to force a strictly visual order to cities by controlling only what is built is no longer plausible. Cities should address all issues or areas beyond the boundaries of architecture and urban planning, such as sociology, technology, and media. We no longer make cities as we did 50 years ago. Policies change; the economy fluctuates. Strategic thinking must prevail over the city administrators rather than allowing unbridled and unlimited planning.



3 Seduction

The world is double-sided. It wants to sell, but it also wants to preserve.

A double France: It wants to sell but also wants to preserve

Architecture should naturally attract. However, it is this reality that drives some to refuse—too often harshly—consistency, the ordinary. We are looking into the flexible, optional, seduction. You should know it's very tempting to stop this iconic costumed architect. We could just veer dramatically into immediate self-service. Architecture cannot only become a striptease with good intentions. This architecture hypertrophy values hyper choice. The architect to some extent must keep a devolved authority over time.

4 Fragmentation Versus Unification

What have we really learned in architecture and urban planning in the past 30 years? Or, more urgently, what have we not learned, or even forgotten? With regard to planning, after the worst excesses of the 1980s, we have developed an almost insubstantial consensus based on fragmentation. Each site is now routinely subdivided into smaller plots, which are then themselves subdivided into small groups of individual operations.

Our terror of megalomania and monoliths led us to embrace fragmentation and fractalisation as an antidote to our past follies. We want this approach (fragmentation) because we have all experienced the "failures" of some general plans. But now we have the opportunity to compare, and in this acceleration towards sometimes uncontrolled, infinite fragmentation, we can find new alternatives.

After this global assertion of composite and fragmented that apparently resurrected the traditional methods on which the city was founded, the results so heady, are artificial and lifeless. Aiming at the same time for variety and familiarity, we have become so incapable of the brutal power of anarchism that we're convinced of the potential coherence of the truly planned. Dare say it out loud: The vast majority of the urban stuff we're building in our mercantile-humanist language is possible without regrettable concessions. It's neither predictable nor surprising.

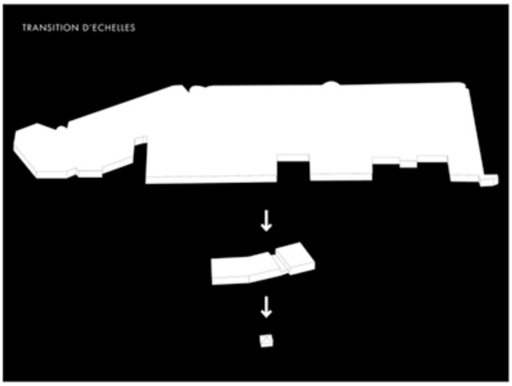
More and more architects feel compelled to demonstrate (to shoehorn) their peaceful coexistence and non-egocentric view. What we have lost as a result are our ability to be unitary, our courage to demand big ambitions, and our happiness with being visionary.

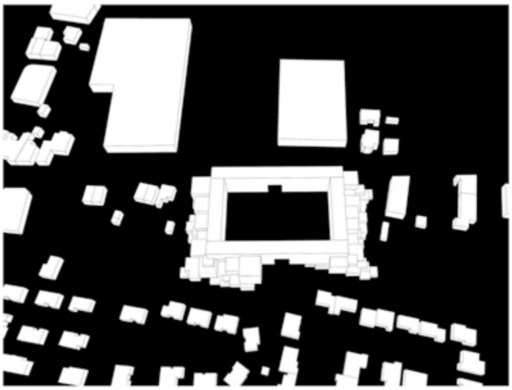
4.1 Merignac Housing Project: Bordeaux 2014

4.1.1 Clement Blanchet Architecture

The housing project in Merignac (Bordeaux) offers an approach that can be applied to a contemporary urban context that is fragmented and disorganized at first sight, where the traditional goal of development (i.e., the desire to create a visual order-wide town, controlling what is built) is not plausible.

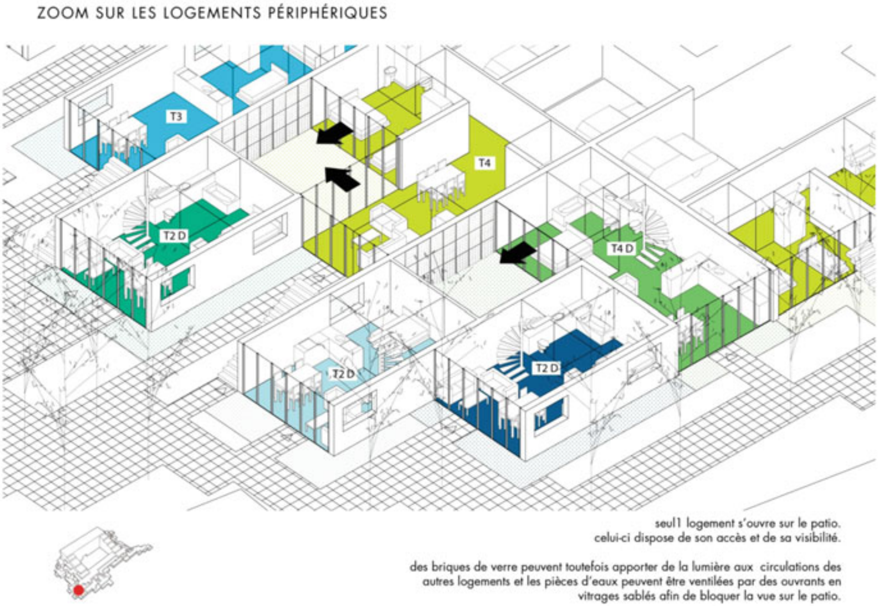
Housing is the raw material of the city and an infinite source of inspiration that architecture seems to forget sometimes. The housing project in Merignac is a kind of literal translation of its own context. The project remains a path for future developments more than an end. It is this action game, reflecting the scale in the very large and the very small: the link between unity and fragmentation.





Reclaiming space induced by the urban sprawl of recent decades is based on a desire to start from the existing to make it evolve, sublimate. Therefore, I am convinced that to intensify the city is to preserve it. The thoughts on how to do this have focused on the need for an exchange and contribution between different scales of action (district-level planning and housing, from public to private), invariably involving soft measures but also radical ones. The metropolitan condition finds cohabitation ladders. And actions taken across the country need to be profitable for the smallest unit of living, housing—and vice versa.

The link between the inside and the outside should not be the monopoly of the home typology (as it is a considerable source of spreading) but must be harnessed in collective housing. The purpose is to integrate the indoor–outdoor equivalence that provides individual housing. Bordeaux helping the climate has become a profit optional and accessible not only to the wealthy, but to all. Different tools or elements of architectures are possible, including simple loggia, balconies, and shared terraces. A room—in this case, the outer space—becomes a piece in itself.



Beyond spatial and qualitative considerations, it is a real social and functional space but also a space that values above all a natural cooling system, a complementary tool to enhance the natural ventilation in homes. Reconsidering collective housing, in terms of the attractions of traditional residential suburban housing, requires a reinterpretation of the pavilion. Hence, the idea to compensate for the fact of living in a dense urban environment with similar architectural features may offer terms of, or at least feel like, living in individual residences. For this, access to the outdoors is a fundamental programmatic basis to be imposed on any transaction.

Scalability allows one to answer the problem of the cost of housing in Bordeaux while providing a solution to a changing societal context. The architecture of this assumption is planned by different tools: single- and double-height seating mezzanine seating later; initially open space that can be a closure and isolation thereafter; or foundations laid for an extension in height as the need arises. In conjunction with good design and the structural work, the consideration of empty (double-height or reserve constructability) in the process of housing design offers these volume adaptabilities.

The principle would be to use systems of standard or generic frames that reduce construction costs. Finally, we should not think of the sale of homes on standardized plans, but rather to sell a volume that can grow and change, to allow a hybrid. The key to operation is the type of structure, or frame, available: the post/beam or pole/slab that provides this management flexibility.

The urban complexity of the contemporary metropolis is to take a whole effort to avoid sectorized problems, leading inevitably to fractures and inconsistencies. Thus, treatment of the interfaces between urban planning and infrastructure, integrated directly into the work of the architect, is what will give meaning to existing architectures and deploy new urban and architectural forms resolutely turned towards a lifestyle in line with the principles of a lasting and sustainable development.

5 Sophisticated Versus Primitive

5.1 Caen Library: First Prize 2010

5.1.1 OMA with Clement Blanchet Architecture

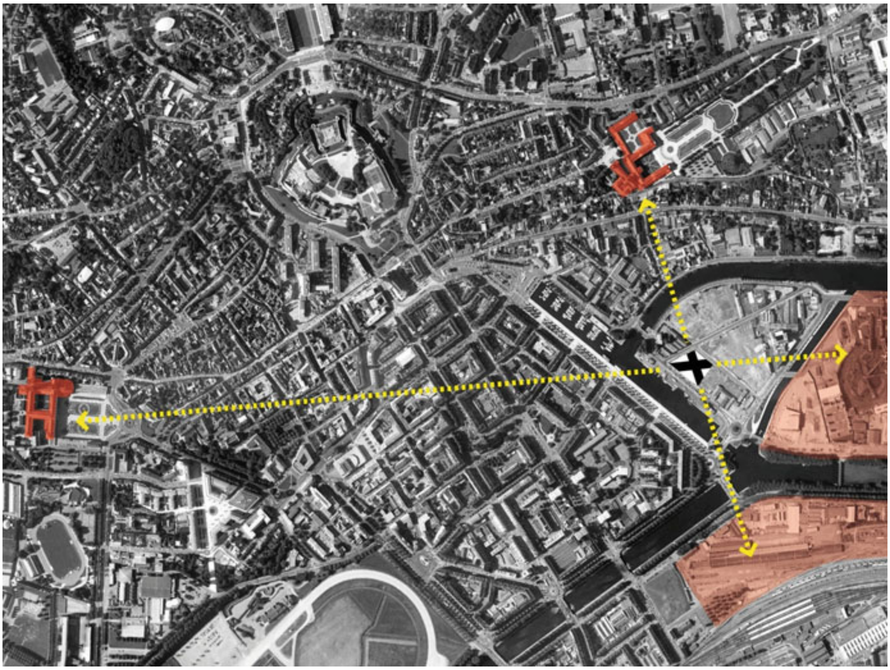
The proposed multimedia BMVR Library moved to the interface of the new development in the city of Caen. Its location, close to the historic center and the tip of the peninsula, must be a strong symbolic seat of learning and knowledge sharing with the dual aim of addressing the past and looking towards the future. The library seeks to address equity in the past, present, and future.

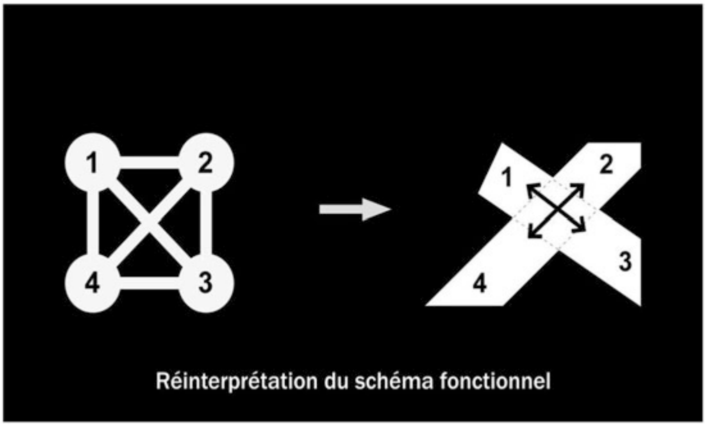
From the principle of the four divisions of the program (Art, Literature, Science and Technology, and Social Studies) and a position in the city echoing the structural entities of Caen's large territory, the building is being built at the intersection of two axes. The plan for the library is then based on the extent of this double conceptual and urban intersection. The organization of the plan naturally includes, due to its central plan, having the ground floor be a public space that forms an "inner space" connecting the park with the Bassin Saint Pierre. In direct contact with the ground floor is the Great Reading Room, with its high ceilings that define this unit of space as readable, transparent, and democratic. Dilated and composed throughout this stretch, "knowledge mapping" constituting the main part of the library is transcribed in a panoramic space and multiple, diverse, and oriented, open and built.

At the cross-axis, a global understanding of themes and all possible transversalities the ends, rather than particular and local expressions, pathways, walkways and fields unfold in a specific organization. At the top level are all the workspaces for librarians as well as the youth space, which is the ultimate discovery.

Merely generating a library schema helped to address the global context and anchored it in a very simple, very effective primitive see figure: the two intersecting lines generate their own context, their own location. The same thing happened with the programmatic transcription project. The specification asked to imagine a library of four polarities. Thus, in response to the suggested scheme of showing a multitude of bridges, I proposed a void that focuses and consolidates knowledge in a single platform, which will facilitate an easy library experience.

The library is for me a simple translation of the original diagrams. It became a metropolitan place that explores and defines the role of books in an increasingly virtual world. It is a unique forum, a common place for the territory.

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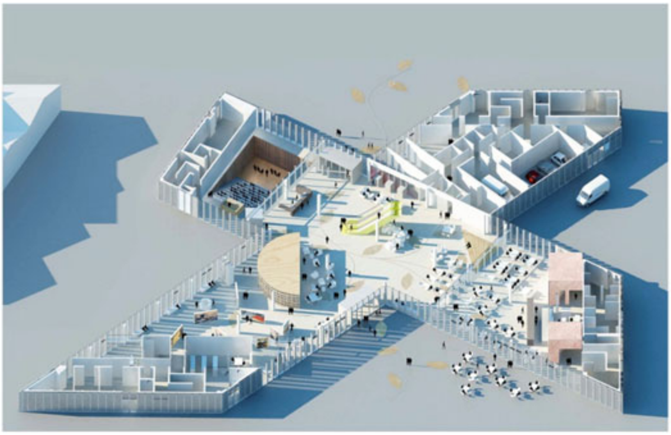


6 The Unknown Towards Creative Disorder

6.1 Central School: First Prize 2012

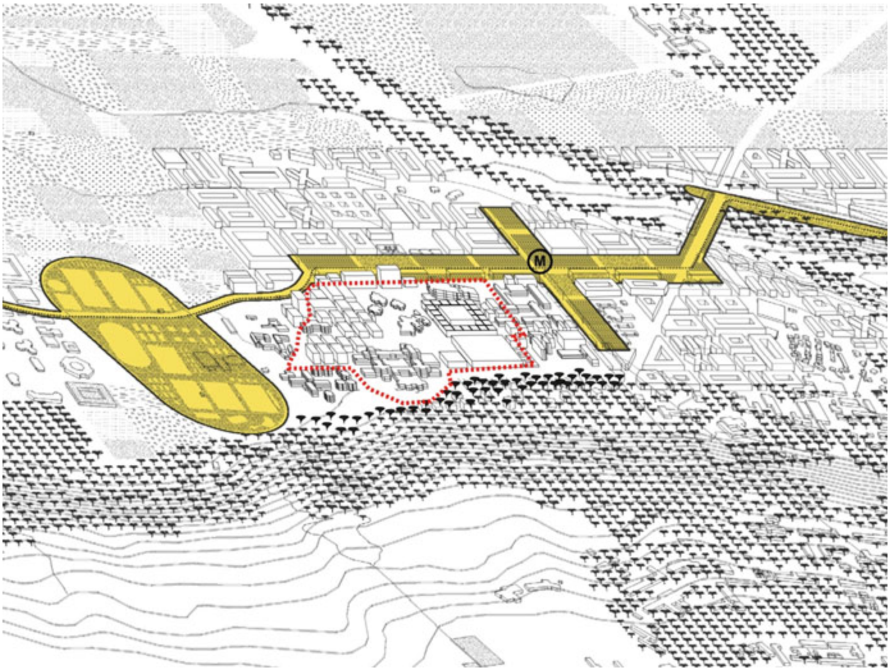
6.1.1 OMA Rem Koolhaas–Clément Blanchet

The new technologies are revolutionizing all sectors of the economy, all areas of society, and require a permanent industrial, entrepreneurial, and managerial (r)evolution. More than ever, research and innovation are the drivers of competitiveness in a world where competition is general. Engineers, researchers, and entrepreneurs experienced in these new technologies will become key players in the new economy and industrial knowledge quest.

The mode of the transmission of knowledge has evolved; teaching is tending more and more to become learning by doing. This requires a study of the transformations involved for traditional types of schools: The laboratory replaces the amphitheater; testing is preferred to theoretical courses; the collective takes precedence over the solitary cramming project.

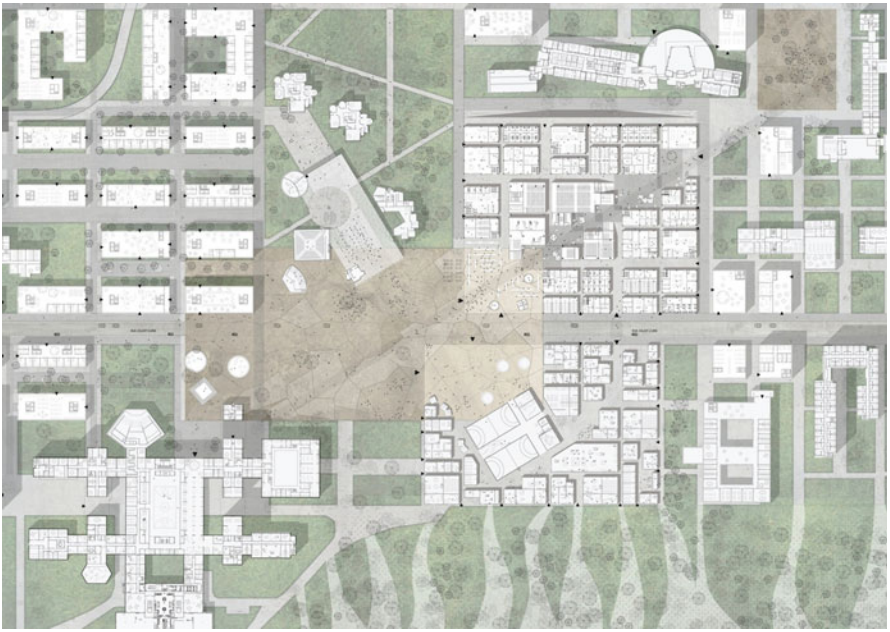
The proposal for the new Ecole Centrale Paris meets this educational revolution. Its location on the Campus Paris-Saclay also answers another transformation: the need for synergy between leading scientists and universities, between colleges and universities.

It could potentiate a dynamic meeting and exchange within the neighbourhood. By establishing close links, we hope to create connections between schools, thus dissolving the ideological barriers between them.

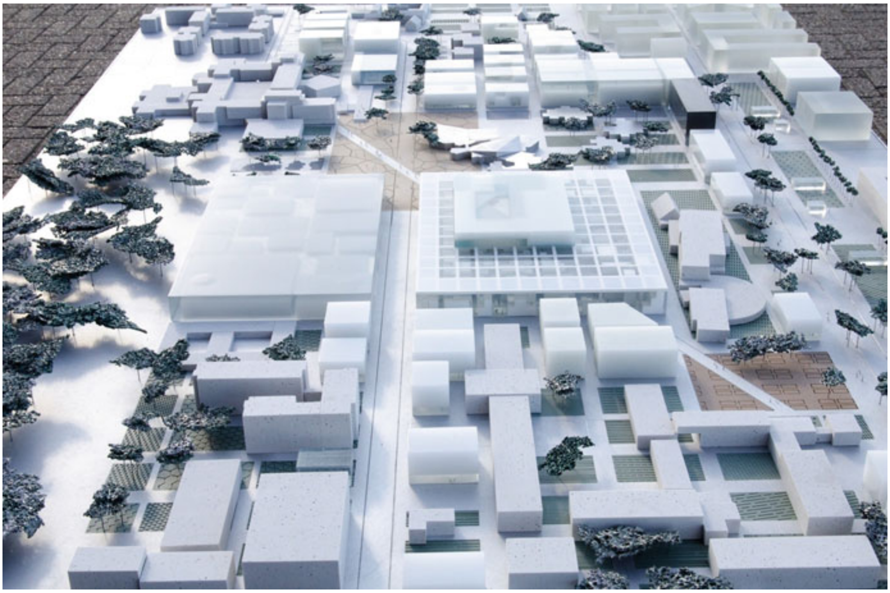


In an era of privatization that keeps growing, cities are facing a major challenge as investment in the public domain increasingly depends on the private sector. As a result of this reframing of the collective agreement, the role of architecture is often seen as reducing the visual impact of its form and surface rather than its potential contribution to a new educational, social, and urban dimension. For me, the competition launched by the Ecole Centrale Paris for the design of a new engineering school has become the best place to explore ways to achieve this demanding task.

It can be assumed that a typical laboratory plan is very challenging due to a number of functional requirements. Laboratories are generally planned in a large box that is divided by generating an endless corridor, thus forming a linear bar building. Such a construction generally creates a “blackout” on urban conditions when the building is transformed into a gigantic wall because of its extremely isolated and internalized programs.



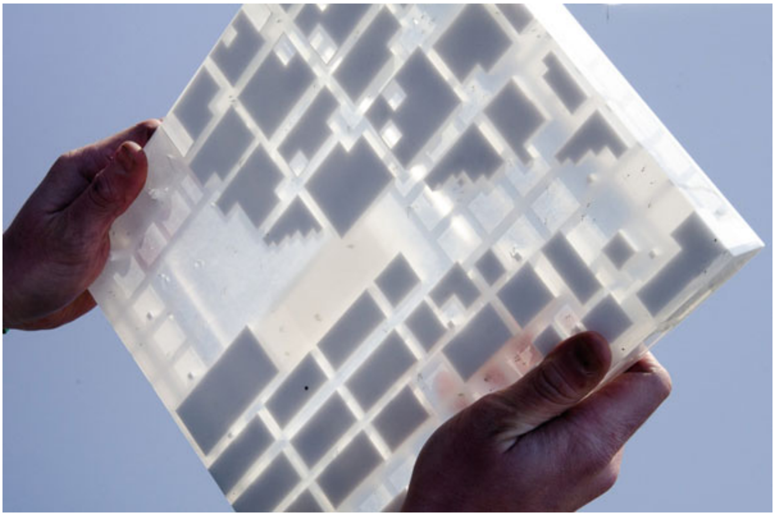
What if, instead, we imagined laboratories together as patches, such as an orthonormal city (as a grid)? It would be a city that could then effortlessly absorb different configurations of programs and activities mutation constant and independent vis-à-vis its various components. This would offer stability for unstable programs that could apply to be reconfigured or intensified, and this could also occur periodically as needed. It is this creative disorder that can be at the origin of a new educational model.



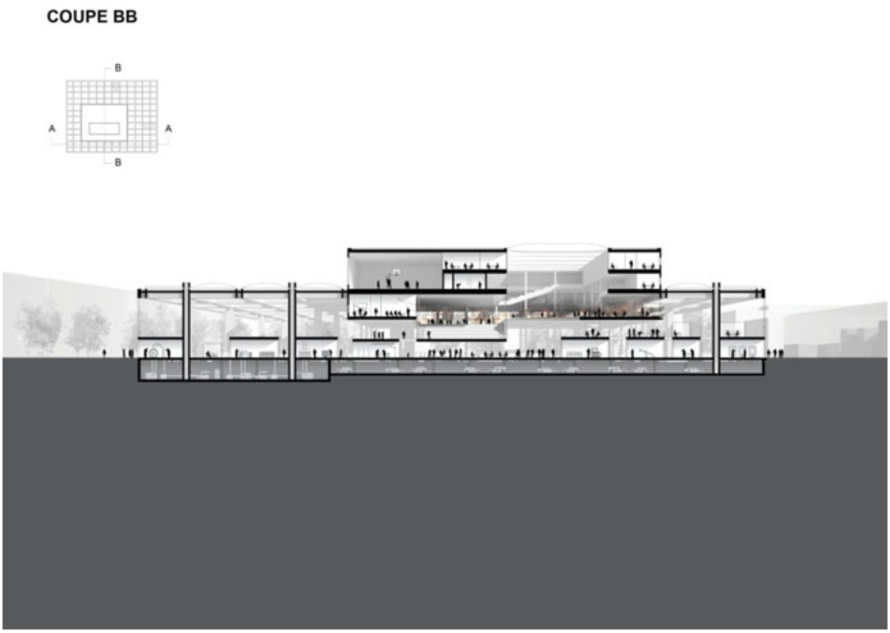
This re-contextualization implies the freedom to formulate new types of learning styles that promote the community, plurality, and diversity of the population in a dense field of knowledge, while ensuring the pure operation of an engineering school as an educational incubator. So, I have formulated the concept of LabCity. The architecture of the LabCity generates open urban indistinguishable from school—its creative disorder—framed under the structural skeleton. Coverage supplants a seamless experience on campus and tries to define a potential aesthetics of science.

Coverage ETFE allows optimal light transmission in LabCity, providing researchers with a comfortable microclimate in which it is possible to conduct and collaborate on their experiences.

A main street just across LabCity as a diagonal activated by a series of integrated utilities and provides a shortcut to the daily flow of students between schools existing engineers, “Supelec” and a future subway station.



Above laboratories, a platform multistory houses the sports areas, the administrative center, and classrooms for first-year students. From its position, it offers a permanent look at more specialized knowledge laboratories located below. This block is designed as a "cloud," a radical machine for training students, and provides



additional horizontal field condition. The LabCity school becomes an educational, architectural, and urban experience.

L'ESPACE DU FORUM

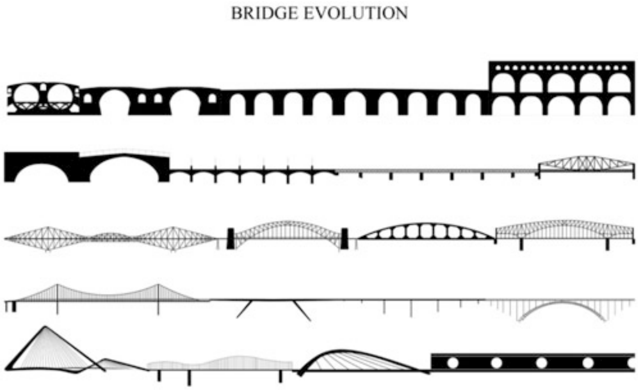
7 Overdose

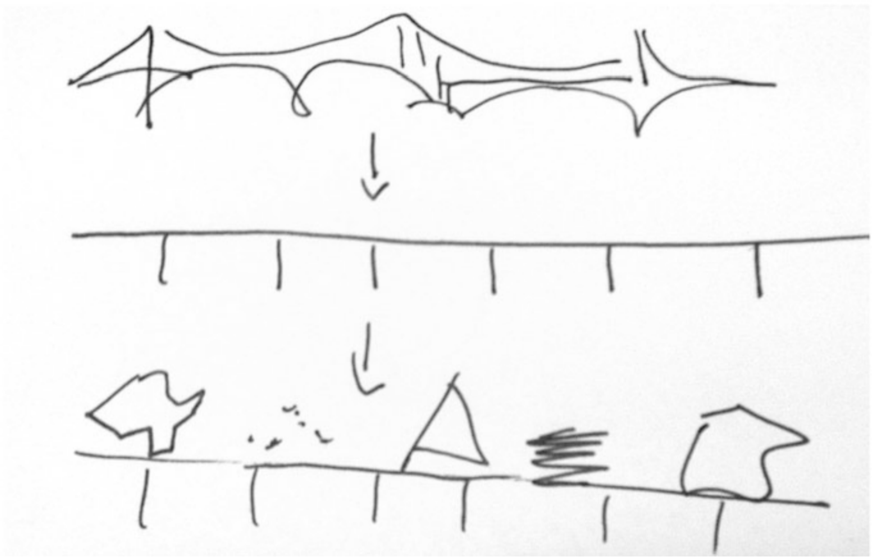
In a world bamboozled and distressed by the vein of "beauty" of seem, we are exposed to a mirage of signs, colors, and whimsical explorations in architecture. The architect survives in a model activated by signals from the immediacy of the consumption of beauty, sometimes even making his own mind unreadable, guaranteeing a degree of continuity. It is necessary to rethink the model and move a critical distance away from the sometimes unreadable bombardment of superlatives.

7.1 Bridge JJ Bosc Bordeaux: 2012 First Prize

7.1.1 OMA Rem Koolhaas–Clément Blanchet

With this "infrastructure bridge" I wanted to give the simplest expression, the most direct meaning, less lyrical, resulting in an almost primitive structural solution—a kind of sublimation of the ordinary.



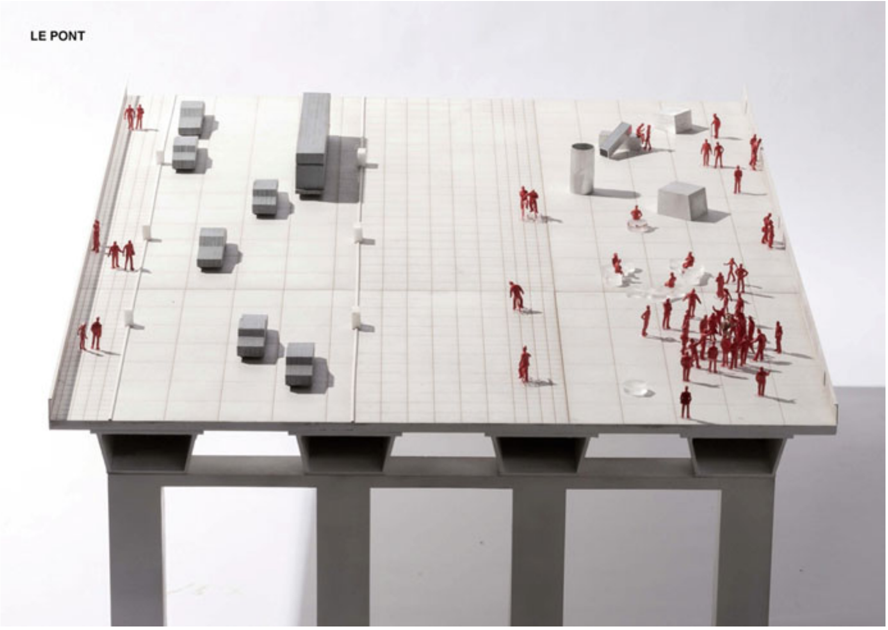


Sketch by Clement Blanchet for OMA

How is it possible to imagine a bridge to the 21st century beyond the fascinations of performance styles and techniques? Attentive to the state of the art in technology and function, but also exhausting all structural logic known to date, I have tried to rethink the basic purpose of a bridge, which would be ideal for the changing needs of a growing city, but also in anticipating future changes in mobility patterns.

The simplicity of this linear neutral platform allows greater diversity in its program, embracing the needs of a growing city in terms of developments in the new configurations of all soft modes. In this case, the bridge is not the “event” in the city, but a platform that can accommodate all events in the city. It is immediately integrated into the urban landscape, a new feature of classic elegance embodied by the city of Bordeaux.

With its generous dimensions and a continuous surface, the bridge will become a new symbol; it will redefine and enhance the urban character of this emerging sector of the city. Its gentle slope allows easy pedestrian access while maintaining the required clearance heights. Thus, we propose a contemporary boulevard, a monolithic platform, 44 m wide and 545 m long, where each form of mobility has its own way, one next to the other, including cars, TCSP (tram/bus), as well as bicycles and pedestrians.



This new bridge is trying to unify the different conditions of the two banks of the Garonne, the Right Bank, strictly aligned on a lawn bordered by rows of poplars, referring to the surrounding landscape, facing the most urban landscape of the left bank in continuity with the Belcier St. John project. It aims to address the twin challenges of the aura and performance in an environment steeped in history.

Can Dense Cities Really Be Liveable?

Limin Hee

Abstract Cities are becoming denser. Not only are people moving from the countryside and outlying areas to look for better employment prospects in cities, people are also moving across international borders to live in the more competitive and connected global cities of the world. Many of the key cities in Asia have population densities 2,000–12,000 persons per sq. km, for instance, in Tokyo, Shanghai, Mumbai, and Singapore to name a few. This article discusses how dense cities can also be liveable by looking at examples across the globe.

Keywords Dense cities • Liveability • Urban development • Singapore

1 Introduction

Nearly 70 % of the world's population is expected to live in urban areas by 2050. According to UN-Habitat, cities are already home to half of humankind. More than 400 cities worldwide now have populations in excess of one million. The number of megacities—those with a population of more than ten million—is rising by the day [1].

Cities are becoming denser. Not only are people moving from the countryside and outlying areas to look for better employment prospects in cities, people are also moving across international borders to live in the more competitive and connected global cities of the world. Many of the key cities in Asia have population densities

The material in this chapter is based partially on the book by the same author in collaboration with the Urban Land Institute titled, "10 Principles for Liveable High-Density Cities: Lessons from Singapore," Centre for Liveable Cities/Urban Land Institute, Singapore, 2013.

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2,000–12,000[1] persons per sq. km, for instance, in Tokyo, Shanghai, Mumbai, and Singapore to name a few.

There is a general sentiment that high density spells the end of liveability in cities. Dense cities may face problems of overcrowding, crime, disease, pollution, poverty, and high cost of living. The oft reported negative externalities of high-density living, such as a congested cityscape, low quality of urban services, increasing competition among people amenities, and associated social conflicts, create a pessimistic view of life in a compact, highly built-up city.

The results of some international surveys, for example, the Global Liveability Survey by the Economist Intelligence Unit (EIU) or Mercer's Quality of Living Survey, have added to the perception that liveability tends to be related to cities that have a larger geographical space, low-rise developments, and low population density. In the EIU survey [2], which uses metrics for healthcare, culture and environment, education, and infrastructure, seven of the top ten scoring cities are in Australia and Canada, with population densities of 540 [3] (Melbourne) and 802 [4] (Vancouver) persons per square km, respectively. Elsewhere in the top ten, New Zealand and Finland have cities with densities of 382 [5] (Auckland) and 2,800 [6] (Helsinki) persons per square km.

Another school of thought argues that dense and vibrant cities bring about great benefits to people. Cities, especially global cities, are great agglomerations of technology, capital, talent, and ideas. The competitiveness of cities in a nation-state usually represents the overall competitiveness of the country and "failing cities lead to failing states." [7] As population grows, cities would become denser. The former Mayor of New York City Michael Bloomberg is among those who advocated high density in cities and believed "bigger is better." [8] He also contended that a good city will attract more people to move in and therefore high population density is a good indicator of the strength of the city.

> If you ask people why they move to the city, they always give the same reasons; they've come to get a job or follow their friends or to be at the center of a scene.—Geoffrey West, 2010 [9]

When a city doubles in size, researchers at the Santa Fe Institute [10] found that it would generate more than double its creative and economic output, a phenomenon known as "superlinear scaling." [11] When people come together in cities to generate, share, and develop ideas, they become much more productive and innovative [12]. Sir Peter Hall has observed that it is not by accident that

[1] The population density range is arrived at by comparing the population densities of the metropolitan regions of Asian cities such as Beijing, Shanghai, Mumbai, Osaka, Tokyo, Dhaka, etc. Metropolitan area data were used consistently for all cities. As defined in the 2009 Revision of the UN World Urbanization Prospects report, a metropolitan area is a contiguous area encompassing the city proper and additional surrounding areas that are under the direct influence of the city proper (for instance, through transport links and a commuting labor market). With cities now growing beyond their political boundaries into larger metropolitan areas, as noted in the EIU Hot Spots Report, metropolitan area definitions were felt to be more relevant.

Scandinavian cities, which often invest heavily in research and development, have high rates of innovation [12]. Today's cities are the centers of sustainability. People who live in densely populated places require less heat in the winter, travel shorter distances, and are more likely to share urban amenities. Equally important, higher density becomes an important factor or "constraint" that instigates urban planners, designers, and policy-makers to innovate and create urban solutions in land use, housing provision, mobility, resource management, and so on.

2 Why Is Singapore Relevant When Talking About Liveability?

Singapore, which has a high density of more than 7,400 persons per sq. km, has clinched high rankings in many of the world's liveability rankings. If we define a liveable and sustainable city as one that fulfills the three key outcomes of a "competitive economy," a "sustainable environment," and a "high quality of life," Singapore is one of the outliers that have combined highly dense urban environments with high measures for liveability, such as in Mercer's 2010 Quality of Living Survey (see Fig. 1). The meaning of high density is itself subjective and depends upon the society or individual's judgment against specific norms. Hence, societies or individuals of different backgrounds and under different contexts come up with different definitions of high density. For the purposes of an objective study, high density has been defined as the upper quartile of the 221 cities surveyed in the Mercer's Quality of Living Survey.

3 The CLC Liveability Framework

From its 50 years of development from independence in 1965 till today, Singapore's Centre for Liveable Cities (CLC)[2] [13] has documented and distilled some of the planning and governance Principles that have underlined Singapore's transformation. In the 1960s, the newly independent city-state had dim prospects of success—the city was resource scarce—with insufficient water even to sustain its population, its rivers and drains were polluted and stank, the lowly educated populace of mostly immigrant workers lived in slums prone to fires and disease, jobs were few to come by, and there was not much by way of an economy.

In contrast, after 50 years, Singapore is a thriving global city predicated on a knowledge economy, with a highly educated population enjoying a high quality of

[2]The Centre for Liveable Cities (CLC) is established as a knowledge center under the Ministries of National Development and the Ministry for Environment and Water Resources of the Singapore government, with a mission to distil, create, and share knowledge on liveable and sustainable cities.

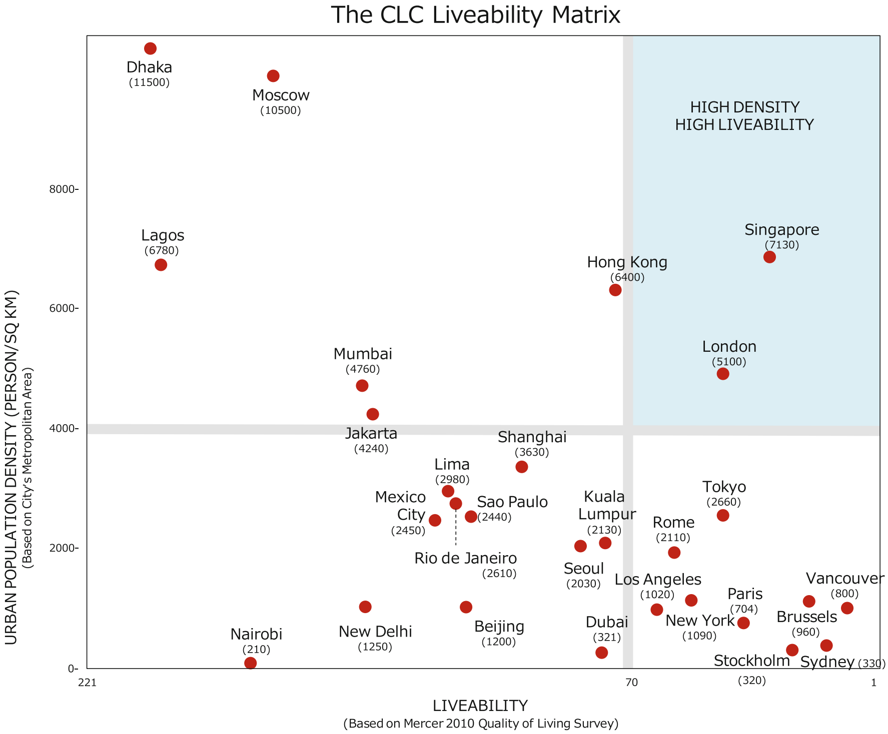

Fig. 1 The CLC Liveability Matrix derived from plotting metropolitan urban populations of cities vs. the rankings on the Mercer's Quality of Living Survey of 2010 (Source: Khoo [32])

life, and greenery lines its roads and highways, giving credence to its aspirations to be known as "a city in the garden." Singapore's standing as a highly liveable city seems to suggest that high density does not necessarily lead to disamenities in urban living. How is this achieved? The CLC has studied the urban systems framework that guided the development of the city-state, and termed this CLC's Liveability Framework. Although the framework was distilled based on Singapore's experience, its underlying lessons are seen as being relevant to cities striving to be liveable and sustainable.

As a working hypothesis, the CLC Framework assumes two components as key in understanding the institutional change of Singapore (see Fig. 2)—first, integrated planning and development, keeping the outcomes of a liveable city in view over the long term, and second, urban governance of a dynamic nature that sustains the conditions for a liveable city to thrive. Some salient points are drawn from the framework: first, city leaders have to have a vision for the city; second, cities have to develop integrated plans and mechanisms to support and implement the plans; and third, cities have to build a governance and institutional framework, both formal and informal, that will sustain the outcomes of the plan over the long term. As such,

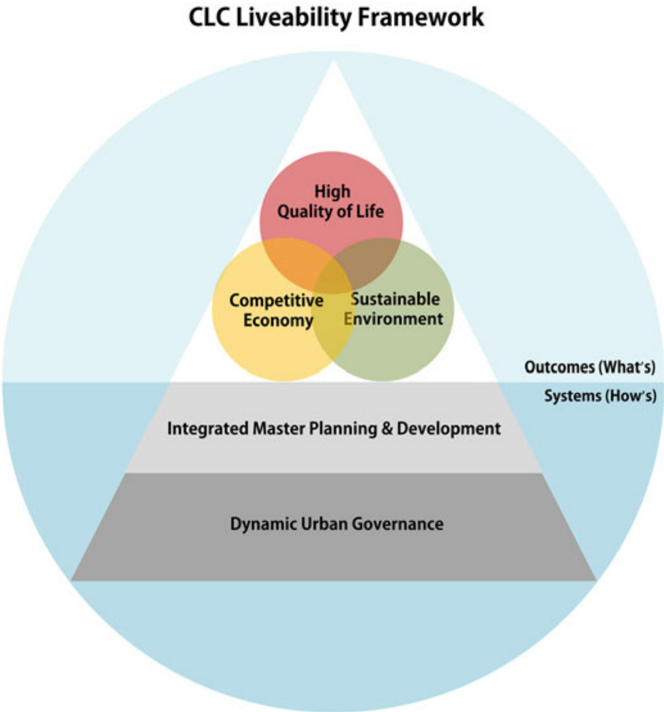

Fig. 2 CLC Liveability Framework for liveable cities (Source: Khoo [32])

the outcomes of the liveable and sustainable city, where the economy, environment, and quality of life have to be delicately balanced and decisions for any trade-offs carefully taken, have to be guided by good planning and urban governance.

CLC offers its Liveability Framework as a lens through which cities may consider their planning and development structures to achieve high liveability and sustainability. How these concepts can be applied must, naturally, respond to each city's own governance priorities and resources. In the context of high-density developments, their issues become even more important, as poor development frameworks quickly become very apparent. What are some of the urban development ideas that may apply, with reference to the framework discussed earlier? With a view to answer this question, the Centre for Liveable Cities, Singapore, and the Urban Land Institute (ULI)[3] initiated a collaborative research project to find

[3]Urban Land Institute (ULI) is a nonprofit research and education organization supported by its members. Its mission is to provide leadership in the responsible use of land and in creating and sustaining thriving communities worldwide.

examples of how liveability and sustainability are correlated to a city's highly dense environment, based on Singapore's experience.[4]

As part of this research, a series of workshops were conducted to engage experts from the public and private sectors, as well as academic and professional institutions in Singapore. The findings were published in the 2012 book *10 Principles for Liveable High-Density Cities*: *Lessons from Singapore* and are discussed in this essay. This chapter also examines the challenges that lie ahead in applying some of these ideas in cities across the world. With changing demographics, new technologies in cities, and the increasing scarcity of resources, the author aims to extend the ideas that have been embodied in the 10 Principles book, especially to contextualize the ideas and challenges in cities at different stages of development.

4 What Are the Ten Ideas for Creating Liveable, Highly Dense Cities and How Do They Work?

The ten Principles lend insights into Singapore's integrated model of planning and development, which weaves together the physical, economic, social, and environmental aspects of urban living. Many of the externalities of high-density city living can be mitigated or managed better by taking such an approach. Based on the findings from a series of expert workshops held in conjunction with the research on the Principles, this chapter distils the ten Principles not only from Singapore's experience but those of other cities as well. The chapter argues that with thoughtful planning and effective governance, a city can mitigate the negative externalities of high-density living while exploiting special opportunities to improve liveability, competitiveness, and sustainability.

4.1 Plan for Long-Term Growth and Renewal

Through land value creation, regulations, rights of use, and limited lease tenures, Singapore's land policies encourage the best use of land, proper maintenance, and optimal development cycles. City planners review Singapore's Master Plan every decade, and planners may boost land value and density in existing properties by raising plot ratios, subject to a charge levied on developers. Another strategy is the designation of "white sites." Developers may propose their preferred land use,

[4]ULI Singapore District Council and CLC were awarded an Urban Innovations Grant from the ULI Foundation to undertake a joint research initiative with the Centre for Liveable Cities (CLC). This joint initiative focused on issues of "High Density and High Liveability" and lessons learned in the Singapore context.

provided a minimum quantum mix is achieved, so as to meet market demands and encourage a range of investment strategies to boost urban growth.

Through systematic upgrading programs, older public housing flats are enlarged and improved, while new lifts, covered walkways, and better landscaping improve the public areas. This maintains good living standards for residents, despite the age of homes and neighborhoods. To optimize land use, the Selective En Bloc Redevelopment Scheme lets the government demolish some older apartment blocks, so as to rebuild them to higher densities. By encouraging affected residents to relocate to nearby flats, this scheme facilitates renewal and growth without dispersing established communities.

A combination of long-term planning, responsive land policies, development control, and good urban design has enabled Singapore to build densely. While city planners contemplate medium- to long-term planning horizons, there is a need to strike the balance between market-responsive planning with developmental needs of a city and to make sure that planning and infrastructure decisions avoid lock-in solutions that hinder future development.

Avoiding lock-in solutions in planning and infrastructure provision: In 1943, Curitiba, Brazil, had developed a comprehensive transport plan, which had envisioned exponential growth in automobile traffic. By 1965, fearing that Curitiba's rapid growth would lead to unchecked development and congested streets, a new Master Plan was drawn. Mass transit would replace the car as the primary means of transport within the city. After considering and then ruling out the building of a light-rail system, a bus rapid transit (BRT) system which depended entirely on bus services was adopted. There were several reasons for choosing BRT over subway or rail.

The first consideration was cost; building a rail system was beyond the means of the local government as the cost of a new subway system was estimated to be over $90 (USD) million per kilometer, which is much higher than the $200,000 per kilometer for construction of new BRT routes. Moreover, a bus system was a more flexible and affordable public transport solution than rail transit, allowing for route adaptations where needed.

A third reason came from the contextual consideration from the local government, which preferred a development mode that complemented the transport infrastructure with land use. The BRT system enabled good access to the housing settlements in Curitiba, while a rail system may be less flexible in serving the extant population. One of the most distinguishable features of Curitiba's BRT is the integration of transport planning with land-use planning, which is also key to its success. The fully integrated and connected bus system in Curitiba can be modified for little cost as markets change, making it very adaptable to the needs of connectivity relevant to patronage throughout the network [14].

Establishing sustainable development practices: With rapid industrial development and urbanization, Shenzhen, China, is facing land scarcity. In the earlier Master Plan of Shenzhen 1996–2010 and the Construction Plan of Shenzhen 2006–2010, it was stipulated that former urban land should be redeveloped before any greenfield sites are considered, including vacated industrial land and urban villages. As more than 45 % of the land has been taken up over the past three decades, the government was hard pressed to redevelop brownfield areas. The city was also pushing for industrial reform, with a move from low-value-added and labor-intensive industries to high-end and capital-/technology-intensive industries; some traditional industries had to be moved out, creating the potential for the redevelopment of the brownfield sites.

According to the later Shenzhen Master Plan 2007–2020, built-up land area should be limited to 900 sq. km. In 2012, newly increased allowable built-up land area and land slated for urban renewal accounted for 44 % and 56 % of the total development areas, respectively. To deter real estate speculation, the government enacted tax relief, financial subsidies, and a special supporting fund (instead of the traditional approach to waive land premium), among other incentives, to provide the push for urban renewal. The proportion of developed renewed land increased to 60 % while that of development on greenfield sites decreased to 40 % in 2013 [15].

4.2 Embrace Diversity, Foster Inclusiveness

People from diverse backgrounds often live next to each other in dense cities, which can be a cause of tension sometimes. But when embraced, demographic diversity can culturally enrich a city and boost its competitiveness. Singapore's urban conservation districts of Chinatown, Little India, and Kampong Glam let people easily enjoy varied environments and lifestyles. Dense and diverse cities allow exposure to different cultural environments, languages, and connections to diasporic networks and also bolster competiveness of cities in terms of human resources and capabilities.

Amidst diversity, inclusiveness is needed to maintain social cohesion and harmony. Among Singapore's most powerful tools in this regard is its public housing program, initiated in the 1960s. In particular, the Ethnic Integration Policy defines quotas that guide housing allocation, so that different groups share the same neighborhoods. Planners also integrate public and private housing for different income groups in the suburban new towns. This nurtures familiarity, cohesion, and trust across diverse income groups, through the sharing of space and amenities.

Density supports interaction through shared activities. Proximity, convenience, and the need to share scarce land encourage people to engage activities like community gardening (Fig. 3). Well-designed neighborhood public spaces can foster a sense of inclusiveness and community by removing barriers to movement and interaction. In Singapore's public housing estates, people traverse multiple thresholds and differentiated spaces, from ground-level public "void decks" through semipublic corridors linking high-rise apartments and then to the privacy of the home, without gates, yet without sacrificing security or privacy.

The need to balance diversity and equity is often discussed in urban and social planning. The important role of public spaces in enabling social access and the formation of networks across different ethnic and demographic groups in cities

Fig. 3 Community garden in Singapore (*Source*: *National Parks Board*, *Singapore*)

cannot be overemphasized. The creation of social infrastructure and amenities with access for all helps to flatten spatial inequalities in cities, as we can see in cities that have enacted spatial policies to encourage social cohesion.

Integrating diversity and *social equity in planning*: Vancouver, Canada, has constantly resisted two major North American urban trends—introduction of freeways into the city center and the loss of the residents to the suburbs. Instead, since the 1980s, the city has developed policies for the intensification of population density in the downtown area, pushing for higher but controlled housing intensity and diversity, with stronger neighborhood identity [16].

Based on the above strategy, the Vancouver City Council adopted housing policies and legislation that allow for diversity and inclusivity for lower-income groups. For example, the Standards of Maintenance Bylaw maintains the minimum standards in low-income housing, and the Single Room Accommodation Bylaw manages the rate of change in the low-income housing stock. An affordable housing policy requires at least 20 % of units in new neighborhoods to be designated as nonmarket housing. This mechanism is also supported by various nonprofit organizations that help social housing and social integration.

4.3 Draw Nature Closer to People

Greenery softens a densely built-up city and makes it more liveable. Satellite photographs show that, despite sustained urbanization from 1986 to 2007, Singapore's green cover grew from 36 to 47 %. Tree-lined roads, parks, and nature areas are the foundations of Singapore's garden-city reputation. Incentives also encourage building owners to invest in greenery, producing vertical green walls, sky gardens, and lushly landscaped atriums and plazas.

Under the Active, Beautiful, and Clean Waters (ABC Waters) Programme, Singapore has been transforming its functional concrete drains and canals, and restricted-access reservoirs, into naturalized and biodiverse streams, rivers, and lakes that are open to public recreation. One of the flagship ABC Waters projects is the Bishan-Ang Mo Kio Park and wetlands (Fig. 4), which was designed based on a floodplain concept. The project transformed a 2.7 km section of Kallang River that ran in a canal along the edge of the park into an attractive, recreational destination through the park. The concrete canal walls were replaced with naturalized riverbanks replete with plants and bedding materials. The waterway design allows people to venture into the steam and interact with plants and animals in and around the water [17]. The project also involved the community in playing

Fig. 4 Bishan-Ang Mo Kio Park in Singapore (*Photo courtesy of Guangming Lin*)

roles for the new waterway, through education initiatives, ensuring safety, as well as in establishing community gardens in its vicinities.

Blending nature into the city helps provide city dwellers with pockets of respite from the bustle of urban life. By adopting a strategy of pervasive greenery and by transforming its parks and water bodies into lifestyle spaces for community activities, Singapore has had many success stories in integrating nature with its dense developments. Cities like Berlin and Seoul too have demonstrated appealing initiatives in bringing nature to the urban living environment, drawing nature and greenery closer to citizens through various initiatives.

Introducing greenery in cities: Berlin, Germany, has had a long history of planning for green spaces in urban areas. The city is made up of 4,626 ha of forests, parks, gardens, lakes, and open space areas, which is around one-third of the city's territory. This is an outcome of various planning instruments and green initiatives which have been put in place since the 1960s. The Courtyard Greening Programme (1983–1996), aimed to add green space in the form of green roofs, green facades, and backyard community gardens in the most densely built-up areas of the city. The aim was to improve urban climate and introducing greenery as an urban amenity. Through the program, 54 ha of courtyard and roofs were added and 32.5 ha of facades were greened [18].

Urban water resource management and stakeholding: Cheonggyecheon was a historic stream in Seoul, South Korea, a legacy from the Joseon Dynasty in the late fourteenth century. By 1945, Cheonggyecheon stream was filled with trash, mud, and sand swept from the mountains and was severely contaminated with waste from shabby makeshift settlements built along its banks. The filthy stream was subsequently replaced with a four-lane, elevated freeway as part of a modernization process in 1977. In 2000, the Korean Society of Civil Engineering found that the road and elevated highway had severe structural problems that would cost approximately USD 95 million to fix. When the city authorities changed their focus from accelerated modernization to one of sustainable development, health, and social responsibility, the restoration of the stream was seen as an opportunity for urban transformation. From July 2003 to 2005, the freeway was dismantled and the Cheonggyecheon Restoration Project created a 5.8 km landscaped green pathway alongside the revitalized Cheonggyecheon stream [19].

The governance of the project involved the tripartite arrangement of the Project Headquarters in the City Hall, the citizens' committee, and special study or consultative groups. Despite many tensions, the governance structure worked well "by bringing a sufficient amalgam of interests within the public and private sectors, along with influential elements of civil society" [19], (p.213). Harvard professor and urbanist Peter Rowe observed that "The Cheonggyecheon project has been referred as the 'threshold event' and 'tipping' or 'turning' point in a radical public change of attitude from a narrow, production orientation toward development and urbanization to one that openly embraces high levels of amenity, lifestyle choices, and environmental sustainability. It also represents a significant milestone in the transition toward higher levels of citizen participation and from central to local levels of decision making." [19].

4.4 Develop Affordable Mixed-Use Neighborhoods

Easy access to good facilities is essential to high liveability, and one of the advantages of high urban density is that it supports the provision of varied commercial, civic, and transport amenities in convenient proximity to homes. Singapore's public housing new towns are seen as good-quality residential environments, with amenities planned within easy reach of most homes. Networks of walkways and public transport improve mobility and the accessibility of homes and amenities within towns, while promoting sustainable and affordable transport.

Housing policies, land-use planning, and financial incentives are designed to deliver a variety of affordable housing and amenities for people from different income groups. The density and population of these new towns generates economies of scale, which helps moderate cost of living. Facilities that require larger catchment populations, such as cineplexes and shopping malls, are clustered in town centers, while more localized amenities, like convenience stores, coffee shops, playgrounds, and kindergartens, are closer to homes, in the smaller neighborhoods and precincts that make up each town.

Strategies by Singapore to develop affordable mixed-use neighborhoods include the building of compact new towns with good amenities, introducing elements of mixed-use living in existing neighborhoods, and connecting neighborhoods and amenities with pedestrian walkways and nearby public transport nodes. Developing affordable mixed-use neighborhoods in cities also requires the collaboration among stakeholders with planning that is catered to shifting demographic profiles.

Planning for changing demographics: The tsunami of older residents in the United States puts new demands on housing, mobility, healthcare, and a range of other services. New York City (NYC) has emerged as a leader in innovative and holistic planning for the aging population. Age-Friendly NYC was launched in 2007 as a collaborative effort of the nonprofit New York Academy of Medicine, Mayor Bloomberg, and the City Council to make NYC one of the World Health Organization's age-friendly cities. Through the study of local seniors' needs by talking to more than 1,500 people, the city published a 2008 findings report. Additionally, all city agencies assessed their own work through an aging lens to determine what they were already doing, or could be doing, to support older residents. This assessment produced a 2009 plan that identified 59 specific issues organized in four themes (community and civic participation, public spaces and transportation, housing, and health and social services) and a corresponding city response to each issue [20].

To implement the plan, Age-Friendly NYC set up a commission of high-profile, cross-sector leaders, organized into five workgroups, to advance age-friendly thinking in numerous fields and industries that touch aging issues from a range of angles. These initiatives, piloted in three neighborhoods, include free seniors-only hours at the local public pool; school buses used during off-hours to transport seniors to the grocery store; improved access to laundry in public housing; better programming for older adults at local institutions, such as libraries, museums, and restaurants; and an age-friendly grocery guide maps stores that offer amenities valued by seniors, such as public restrooms, senior discounts, and delivery options from local stores [20].

Building healthy cities: Mariposa is a redeveloped mixed-income community in Downtown Denver, converted from a public housing project completed in 1952. In 2009, the Denver Housing Authority (DHA) prompted the use of health as a framework for Mariposa's Master Plan development. A Health Impact Assessment (HIA) highlighted the need to create more opportunities for residents to engage in physical activity, such as widening sidewalks in areas with high levels of pedestrian traffic and improving bike facilities. To build on the findings of the health assessment, DHA customized the Healthy Development Measurement Tool to evaluate and guide healthy land-use development [21].

The Mariposa Master Plan called for improved bike and pedestrian access to the station, high-performance buildings with energy-efficient features, a community garden, and a network of open spaces and parks. A mix of privately managed, subsidized affordable units and market-rate units (aimed at creating a mixed-income community) were also proposed. This increased the number of units in the Mariposa District from 270 to 800, promoting high-density residential development adjacent to the light-rail station. The community garden would provide fresh food choices on-site while the community works with an existing neighborhood store to stock fruits and vegetables [21].

4.5 Make Public Spaces Work Harder

Land is scarce in dense cities, and this calls for innovative solutions to make spaces work harder and produce synergies. For example, Singapore has transformed slivers of underused land, along roads and canals or under elevated railway tracks, into "park connectors" (Fig. 5). These are landscaped jogging and cycling tracks that link parks and let people exercise, play, socialize, commute, and enjoy nature, closer to home. The island-wide Park Connector Network is a comprehensive matrix of green spaces that promotes a healthy lifestyle, social interaction, sustainable transport, and even biodiversity.

Public spaces need not be limited to the ground level. In Singapore, many underground public passages are linked to transport nodes like train stations and bus interchanges. Beyond funneling people, these "nodes and channels" are activated public spaces lined with shops and cafes. Even rooftops are not "spared"—skyscrapers like Marina Bay Sands or Pinnacle@Duxton have rooftop gardens that provide new recreational experiences and help shape the city's identity.

Singapore maximizes the potential of dormant spaces by unlocking them for commercial and leisure activities. Measures by Singapore to achieve so include encouraging multiple uses of land by equipping parcels with features that allow land to be used in different ways, getting addition and alteration approvals for buildings so they connect underground and introducing flexible spaces in the city for people to enjoy small- to large-scale events. The innovative use of urban infrastructure and new technologies in cities has helped to make the urban experience even more enriching.

Fig. 5 Punggol Waterway Park Connector in Singapore (Photo courtesy of Rodeo Cabillan)

Turning urban infrastructure into public spaces: In 2002, French Mayor Bertrand Delanoë initiated Paris Plages (Paris Beaches). For a month in summer each year, the Georges Pompidou Expressway along the city's right bank would be closed to traffic, with the whole expressway converted into a pedestrian refuge complete with 3 km of sandy beaches, floating pools, outdoor activities, and a venue for free concerts. Paris Plages attracted about two million people during the summer of 2002. The Paris Plages is expanding year after year and there are now even more different activities to occupy the young and old. For example, there are free classes in Tai Chi, tango, and other social dances aimed at senior citizens, as well as wall climbing, trampolining, and rollerblading for youngsters [22].

New technologies to help people rediscover the public space experience: In San Francisco, United States, there are many privately owned public spaces that are maintained by businesses and free for everyone to use. However, many of these spaces are not well known. A new phone app has been created to help people discover these places using location-aware Esri technology. It uses geo-triggers to allow the users to discover privately owned public spaces near to their current locations. The intent is to pull people away from the commercial touristy area like Union Square and the waterfront into the nooks and crannies that are less well known. With a curated map of these privately owned public spaces in the city, and rankings for each space based on amenities, the application helps to highlight well-designed privately owned public spaces [23].

4.6 Prioritize Green Transport and Building Options

Dense cities are better able to support public transport. Singapore invested in an extensive, integrated, and affordable public transport network. Comprising buses, light-rail, and a mass rapid transit network, it offers good connectivity to most of the island. High-density transit-oriented development has resulted in the proximity of many homes to public transport and the viability of these systems. Meanwhile, policies, such as congestion pricing, fuel pricing, and a cap-and-trade system to limit car ownership, help discourage the use of private vehicles. This reduces congestion, as well as noise and air pollution. Covered walkways, park connectors, and intra-town cycling networks also make walking and cycling viable low-energy transport options.

To mitigate the urban heat island effect common to dense cities, Singapore tries to reduce the energy consumed by buildings, by promoting green buildings through its Green Mark Incentive Scheme. The city also invested in a District Cooling System at Marina Bay, where centrally chilled water is piped to multiple buildings for air-conditioning. This system is well suited for high-density districts, and it generates energy, water, and cost savings, besides freeing rooftop space for other uses. All new developments in Marina Bay now need to meet higher Platinum or Gold Green Mark standards and must provide sky-rise greenery and communal landscaped areas equivalent to their building footprint areas.

An overall reduction in energy consumption and dependence adds to city sustainability. Singapore has adopted a resource-conscious growth strategy that relies on planning, design, the use of low-energy environmental systems for its buildings, and an efficient transport network. European cities like Zürich and Copenhagen are leading cities in promoting green transport and building options and embracing green lifestyles.

District-level planning for green urban infrastructure: In a referendum held in 2008, three-quarters of the Zürich population in Switzerland voted in favor of achieving the 2000-watt society by 2050, making it the first city in the world to give these ambitious goals a democratic legitimacy and enshrine them in the constitution. Almost all new constructions, such as housing estates, school buildings, and retirement homes, correspond to the Minergie standard (for low-energy housing). Among the model examples for this is the construction of a new city hospital (i.e., Triemli Hospital) which was built to Minergie passive (zero-energy building) standards. Another example is the new Trotte Retirement Home, a "flagship project" for the 2000-watt society. Environmentally friendly and energy-efficient construction is not the only criterion that will contribute to its appeal. The new building will comply with the specifications of two of the City Council's legislative focal points for the 2006–2010 legislative period: “On the way to the 2000-watt society” and “Planning and building for tomorrow” [24].

In Freiburg Germany, there has been a move to use 50 % cogeneration plants for electricity and heating in the city. As such, large combined hear and power (CHP plats were constructed, for instance, in Landwasser and Weingarten by utilizing methane at landfills and employing this gas to generate power, and smaller CHP plants at the city theater and indoor swimming pools. The city has about 90 small-scale power generation units that embrace a mix of conventional and renewable sources. The availability of wood chips from the logging operations of the black forest region provides feedstock for the CHP plants. The combination of district heating and CHP (combined heat and power) plants has significantly minimized energy usage and greenhouse gas emissions in the city [25].

Alternative urban mobility solutions and infrastructure: The shift from private transport to prioritizing green transport/active transport in Copenhagen has been driven by two factors—increased congestion and energy crisis in the 1970s. Since the mid-twentieth century, Copenhagen’s development was guided by the five “Fingers Plan.” The plan directed traffic flow from the center to the outskirts. Increased population made the plan unsustainable. In the 1970s and 1980s, the energy crisis, economic recession, and traffic congestion raised public awareness of alternative transport modes such as cycling. The efforts for cycling were consolidated with the help of the Copenhagen Municipal Plan in 1993. New strategies such as the municipal Eco-metropolis plan were endorsed to develop Copenhagen into a cleaner, healthier, and more environmentally friendly city [26].

More than 410 km of cycle paths were designed and the network is expected to expand to over 500 km by 2030. The entire city is served by an efficient and convenient system of bike paths, separated by curbs from sidewalks and driving lanes (Fig. 6). The bicycle crossings in the city intersections are painted in blue and equipped with special traffic lights for bicycles that turn 6 s before cars are allowed to move forward. More and more streets have been converted into pedestrian traffic. In the period from 1962 to 2005, the area devoted to pedestrians and city life grew by the factor of seven: from approximately 15,000 m^2 to a good 100,000 m^2 [26].

4.7 Relieve Density with Variety and Add Green Boundaries

One remedy to the effect of a concrete jungle in dense cities is the “checkerboard” urban planning principle, which mixes high- and low-rise developments to create variety and physical relief. Singapore has created varied residential environments by interspersing high- and low-rise developments. Even though the city’s overall density is high, the spatial quality of specific places is therefore neither unpleasant nor overwhelming. Such distinctions and attention to design at the local scale also helps create place identities. For instance, Bishan-Ang Mo Kio Park, which separates Bishan and Ang Mo Kio towns, supplies a recreational amenity to

Fig. 6 Cycling lanes in Copenhagen (Source: Gehl Architects)

residents in both towns and provides a breather from their high-rise environments. As a strong green boundary, it also allows both towns to retain distinct identities, despite their close proximity.

The key approach is to use height gradation and density differentials to space out density and create visual relief for the physical spaces. Specifically, some strategies are designed to create pockets of low density to space out high-density developments and introduce features, which lend specific character to individual neighborhoods and position relief spaces amidst high-density built environments. Other approaches include designing mixed urban typologies to achieve effect, and helping to share the perception of density through good urban design.

Urban form and typologies for high density, *high liveability*: Vancouver has demonstrated this attribute by creating a mix of urban typologies. Most of the high-rise buildings in Vancouver are slender tower buildings. The extensive new development along the city's waterfront need to meet two key requirements: high building density and good urban qualities on street level in the new urban areas. The lower level is two to four stories high, a plateau that follows building lines along the city streets. Above the plateau rise densely built skyscrapers recessed from the lines of the street, so that they do not impact on the pedestrian landscape. The skyscrapers are designed as slender towers to avoid shielding the waterfront view from the buildings behind, as well as to reduce the impact of wind and shade on the streets below. Vancouver's plateau development provides an interesting orientation in attempts to combine large and small scales in the same development and contributes to the dreams on creating great cities at eye level while still ensuring higher building density [16] pp.77–82.

Perception of high density on the ground: Aker Brygge on the waterfront in Oslo, Norway, is a good example, demonstrating that careful consideration was given to density, mix of functions, and good city space. Despite a higher building density, the buildings do not seem tall, because those along the streets have fewer floors than those set further back. City space is well proportioned with active ground floor frontages, and thanks in great part to the good design, the area has become one of the few new urban areas in Europe where people actually enjoy spending time. Density is high, but it is the "right" kind of density [26] (p.69).

4.8 Activate Spaces for Greater Safety

Dense cities are sometimes perceived as less safe. This can be mitigated using the idea, taken from urban design and space management, of "activating" spaces to make them safer. This involves encouraging some people to linger and participate in activities in a space, and not just move through it. Spaces in Singapore's public housing new towns are designed as a system of channels and nodes, with thoroughfares punctuated by activities at the nodes, like playgrounds or seniors' corners. Having activities at different times, and the presence of the community on the ground level, keeps these spaces safe.

Having a sense of safety and security is an important quality-of-life factor. As Singapore became denser, designs of high-rise public housing estates were modified to improve the "visual access" to spaces so the community can collectively be the "eyes on the street," helping to keep neighborhoods safe. Also, by integrating activity space to encourage a continuous stream of people and activities, there will be less crime in public spaces and city residents will have a stronger sense of personal safety. Similarly, in Tokyo, a strong spirit of self-help and bottom-up initiatives in communities has been established over the years to prevent crime and prepare the mass for unforeseen events like natural disasters.

Decentralizing urban governance at community levels: There are three main strategies to ensure public safety in Tokyo: First, through the promotion of the creation of safe and reassuring communities. The Office of Youth Affairs and Public Safety supports the activities of local crime prevention volunteers through the "Tokyo-wide Crime Prevention Network" and creates subsidies for project initiatives by communities that are related to the development of crime prevention [27]. Second, the promotion of measures to ensure the safety of children. The Office trains volunteer leaders who work to promote activities aimed at watching over children in the community, distributes crime deterrent stickers to be displayed on public and private sector vehicles that are constantly patrolling the community, and prevents crime through the creation of the "Community Safety Map"—outlining safe zones in the neighborhood for children. Lastly, the Office conducts various public awareness campaigns to prevent illegal employment, which may lead to crime.

4.9 Nurture Innovations and Nonconventional Solutions

Dense, resource-scarce cities need to foster innovations so as to overcome constraints and improve their liveability and competitiveness. Singapore has turned its shortcomings to its advantage through a culture of systematic innovation. Indeed, the 2011 Innovation Cities Index ranked it among the world's 30 most innovative cities. In the integrated development called one-north, people can work, live, learn, or play in a 200-ha development designed to nurture research and innovation. With reduced commuting needs, researchers can focus on work yet easily recharge or exchange ideas at nearby gyms, cafes, and parks.

Singapore has also relied on innovations to overcome its water scarcity and develop a sustainable water supply. Water reclamation was made possible by methodically rationalizing the city's drainage and sewerage systems and then being alert to and adopting relevant technologies when these became viable. NEWater, the product of this reclamation, is now pure enough to be used for wafer fabrication factories and drinking.

As a city gets more populated and built-up, with constraints on land and resources, city leaders have to look at nontraditional solutions to get around the challenges. Modern land and resource challenges require innovative, city-specific, and nonconventional solutions. For instance, the creation of the National Research Foundation in Singapore to encourage R&D projects, the development of knowledge parks, and in-depth sector-specific research have helped in mitigating Singapore's resource constraints. In Hong Kong, where land scarcity is a big challenge, key strategies include the clustering of the bulk of development around mass transit nodes, intensifying the redevelopment of brownfield areas and exploring the utilization of underground space. Smart city initiatives enable Seoul to create citywide inclusive internet accessible to all in most public spaces.

Space optimization and the search for new space: Hong Kong is one of the densest cities in the world. Like Singapore, Hong Kong's key challenge is land scarcity. Since the 1970s, Hong Kong has conducted extensive land reclamation, mainly concentrated near the main urban area. But by the 2000s, strong public objection to land reclamation has forced the government to search for more land and space supply. Hong Kong 2030 is a strategic plan to meet the housing and economic land requirements as well as infrastructure development for the future. It recommends a continuous clustering of the bulk of development around the mass transit railway stations—such high-density compact transit-oriented development (TOD) serves as a key strategy to minimize the use of limited land. Better utilization of development opportunities in the existing built areas through urban renewal, land resumption, rezoning, rock cavern development, and use of ex-quarry sites has also been recommended in the Plan [28] (p.79).

Smart cities initiatives: In Seoul, the key pillars to planning a smart city are good ICT infrastructure, integrated city-management framework and the drive to cultivate smart-tech users. To fulfill the above criteria, Seoul began distributing second-hand smart devices, donated by other residents, to low-income families and other needy residents, providing education courses on smart ICTs, and has established “u-Seoul Net”—an inclusive network in Seoul that encompasses high-speed broadband optical wire and wireless networks that are accessible to all in most public places. Other efforts include the “Smart Work Centre” project, allowing government employees to work from a choice of ten branch offices located much closer to their homes, community mapping that enables physically disabled people to mark streets or shopping malls without wheelchair access on a map shared by a community of smart device users, and “u-Seoul Safety Service” which uses smart devices to notify authorities and family members of emergencies involving the disabled, elderly and children [29].

4.10 Forge “3P” Partnerships

Dense cities are often forced to make tough land-use trade-offs when new developments are initiated. Many different interests—of residents, businesses, landowners, and other interest groups—are at stake in the development and management of places. Consulting and working collaboratively with various groups not only improve development strategies but also increase the possibility of finding win-win solutions that enjoy smoother implementation. The Singapore River One began as a project to get stakeholders to champion place management and ownership of Singapore River. It is now becoming instrumental in the development of thriving leisure and commercial spaces along the river.

The Orchard Road mall enhancement initiative is driven by an interagency task force led by the Singapore Tourism Board, along with the Urban Redevelopment Authority, Land Transport Authority, and National Parks Board. These agencies worked with private sector design consultants as well as Orchard Road stakeholders before finalizing the design for place enhancements, such as street furniture. Planning incentives encouraged private owners to play a role by improving their building facades, so that public and private improvement works together created a more vibrant street.

Singapore actively seeks partnerships to obtain good ideas for a development or redevelopment project, manage potential tension among different interest groups, and build stakeholder support. New York City and Bilbao have also leveraged on strong 3P partnership in gathering creative ideas and support, tapping on their expertise, and engaging communities, as well as the private sector in urban management. In some cities, collective responsibilities in managing urban issues have been promoted, to ensure community ownership of the problems and urban solutions.

Balance in participatory governance: Created by Local Projects and run by the City of New York, “Change by Us” is a social networking tool meant to gather ideas and feedback from local residents on planning and sustainability initiatives. It is a platform for New Yorkers to put their ideas into action by creating projects and building teams to make NYC a better place to live. With the varied and creative ideas from the public, this initiative allows the New York City’s Office of the Mayor to implement sustainable development practices [16] (pp.22). Kishore Mahbubani, National University of Singapore professor, has remarked that, “It is perfectly natural for old, overcrowded cities to get tired and to despair of renewal. This could have happened to New York. Instead, a dynamic mayor’s team coupled with bold citizens’ initiatives brought urban renewal in many ways.” [16] (p. 22).

The Friends of the High Line (FHL), a civic group with influential members from the New York Society, played a leading role in collaborating with the New York City government and pushing forward the High Line project, which sought to conserve a disused railway track and turn it into a park. Support was garnered from business community, philanthropic individuals, and organizations to provide the funding essential for the project’s success. As has been shown, a vibrant civil society can play a big role in galvanizing projects for the greater good of the community.

Means of community engagement and building social capital: The city of Bilbao is firmly committed to civic participation as part of good governance. The Kaleidos.Red Foundation in Bilbao is a network that lends its expertise to local districts on governance matters relating to social capital development, open governance, relational administration, and citizen participation. In addition, Bilbao gets its city officials to “walk the street” to identify first-hand issues of concern to the public, as well as to work with the mass media and online social networks as means of communication. Surveys on both qualitative and quantitative issues are also carried out at least once a year to identify what people want, what they are unhappy with, as well as the service gaps and areas for improvement. Bilbao places great emphasis on transparency and on facilitating public access to information that affects the towns, local districts, and one’s immediate neighborhood [30] (pp.56–65).

5 Conclusion

By 2030, 1.4 billion more people will move to cities in the hope of a better future. How can the new urbanites be accommodated? Given that most of the cities are constrained by geographic conditions and are not able to expand, the answer would be in “building up” and many cities may have little choice but to become denser, especially in urban agglomerations that are already developing as mega-regions. Many developing cities, despite having relatively low densities, have already been plagued by poor housing conditions, traffic congestion, or poor air quality. The problems will be exacerbated if initial problems are not handled carefully or mandated with clear development strategies when these cities grow even more populous.

The CLC Framework and the research on 10 Principles of building highly dense and liveable cities strived to demonstrate various approaches through which liveability in dense cities has been increased. The discussion illustrates the interventions made at various levels of urban living in Singapore and other cities, which have together contributed to high liveability. These Principles give an insight into the need for an integrated approach to development, weaving together the physical, economic-social, and environmental aspects of urban living, to create highly liveable cities. As such, these may be seen as a useful guide for policy-makers, planners, private developers, and other practitioners in building liveable, compact cities.

The Principles particularly hold relevance when several studies indicate the inevitable trend of rising densification of cities. At a time when cities face complex challenges such as rising urban population, climate change, socioeconomic divide, etc., the density trade-offs also become more apparent. In this context, the Principles also encourage a shift in the current perceptions surrounding high-density living.

Very often the negative externalities of high-density living such as congested cityscape, low quality of urban services, increasing competition among people for use of facilities, and associated social conflicts mask the less obvious positive attributes. For instance, since land is a scarce urban resource, a high development density allows for its maximum utilization, reduces the pressure to develop open spaces, and releases more land for community facilities [31]. Similarly provision of infrastructural facilities, public transport services become more economical when high population is concentrated in a small area. The social networks forged in a dense city are also known to make the city more resilient.

The ideas discussed here emphasize that many of these negative externalities of high-density living can be managed better and places made more liveable with the support of integrated long-term planning as well as dynamic urban governance, as embodied via the CLC Framework. Moving forward, as cities grow in population, more demands are placed on the city's resources including land. Questions have been raised about the threshold level of density and its impact on the city's liveability. However, looking at the CLC Framework for liveable and sustainable cities, it is apparent that some of the key factors that would continue to play an important part in sustaining the city's liveability include its integrated, interdependent, yet flexible approach to planning and development. The ability to systematically innovate the institutions that build the city as well as the ability to work with stakeholders and markets will also be key to creating thriving cities—places for people to call home, for cultures to be celebrated, for businesses to invest, for visitors to enjoy, and for nature to thrive.

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References

1. Ng, E.: Designing high-density cities for social and environmental sustainability. Earthscan, London, UK (2010)
2. The Economist Intelligence Unit.: Global liveability survey, London, UK (2013)

3. Australian Bureau of Statistics.: 3218.0 – Regional Population Growth, Australia, 2011: Main Features. Australian Bureau of Statistics. http://www.abs.gov.au/ausstats/abs@.nsf/Products/3218.0~2011~Main+Features~Main+Features?OpenDocument#PARALINK2 (2012). Accessed 30 Nov 2012
4. Statistics Canada.: Focus on Geography Series, 2011 Census – Census metropolitan area of Vancouver, British Columbia. Statistics Canada. http://www12.statcan.gc.ca/census-recensement/2011/as-sa/fogs-spg/Facts-cma-eng.cfm?LANG=Eng&GK=CMA&GC=933 (2011). Accessed 20 Apr 2014
5. New Zealand Transport Agency.: Regional summary – Auckland. New Zealand Transport Agency. www.nzta.govt.nz/resources/regional-summaries/auckland/docs/auckland-regional-summary.pdf (2008). Accessed 30 Nov 2012
6. City of Helsinki.: www.hel.fi (2012). Retrieved on 30 Nov 2012 from www.hel.fi/static/
7. Nowak, W.: Foreword. In: Burdett, R., Sudjic, D. (eds.) The Endless City, pp. 6–7. Phaidon Press Limited, New York, NY (2007)
8. Gurian, C.: Bloomberg trumpets "bigger is better" but ignores quality of city life. Remapping Debate.http://www.remappingdebate.org/article/bloomberg-trumpets-\T1\textquotedblleftbigger-better\T1\textquotedblright-ignores-quality-city-life (2013, March 21). Accessed 20 Apr 2014
9. Lehrer, J.: A physicist solves the city. The New York Times. http://www.nytimes.com/2010/12/19/magazine/19Urban_West-t.html?pagewanted=all&_r=0 (2010, December 17). Accessed 20 Apr 2014
10. Bettencourt, L.M.A., Lobo, J., Strumsky, D., West, G.B.: Urban scaling and its deviations: revealing the structure of wealth, innovation and crime across cities. PLoS One **5**(11), e13541 (2010)
11. Florida, R.: For creative cities, the sky has its limit. Wall St J. http://online.wsj.com/news/articles/SB10000872396390443477104577551133804551396 (2012). Accessed 20 Apr 2014
12. Hall, P.: Cities are where new ideas happen. Think Cities, Centre for Cities. http://thinkcities.org.uk/cities-are-where-ideas-happen/ (2014). Accessed 28 Apr 2014
13. Centre for Liveable Cities/Urban Land Institute: 10 Principles for Liveable High-Density Cities: Lessons from Singapore. CLC/ULI, Singapore (2013)
14. Hensher, D.: Frequency and connectivity – key drivers of reform in urban public transport provision. Journeys, Nov 2008, LTA Academy, Singapore (2008)
15. Cheng, F.: Recovering urban land: a framework to improve brownfield redevelopment practices – Case of Shenzhen, China (Master's Thesis). International Institute for Geo-information Science and Earth Observation, Enschede, Netherlands (2007)
16. URA: Cities in Transformation – Lee Kuan Yew World City Prize. Urban Redevelopment Authority, Singapore (2012)
17. Tan, N.S.: Revitalising Singapore's urban waterscapes: active, beautiful, clean waters programme. Urban Solutions (1), Centre for Liveable Cities, Singapore (2012)
18. Kazmierczak, A. & Carter, J. (2010). Adaptation to climate change using green and blue infrastructure – A database of case studies. The University of Manchester. http://www.grabs-eu.org/membersArea/files/Database_Final_no_hyperlinks.pdf. Accessed 20 Apr 2014
19. Rowe, P.G., Kim, S.H., Jung, S.H.: The Cheonggyecheon: A City and Its Stream Restoration Project. Puritan Press, Hollis, New Hampshire (2010)
20. Morken, L.: New York City and Atlanta: cities plan for the aging population. Department of City and Regional Planning, Cornell University. http://s3.amazonaws.com/mildredwarner.org/attachments/000/000/181/original/c63bbcf692ec7da9f1478dc2613cf85b(2012).Accessed29 Apr 2014
21. Eitler, T.W., McMahon E.T., & Thoerig, T.C.: Ten Principles for Building Healthy Places. Urban Land Institute. http://www.uli.org/wp-content/uploads/ULI-Documents/10-Principles-for-Building-Healthy-Places.pdf (2013). Accessed 29 Apr 2014
22. Ludher, E.K., Yong, J.: Social equity through community events. Urban Solutions (4), Centre for Liveable Cities, Singapore 72–77 (2014)

23. Schwartz, A.: A new way to explore some of San Francisco's hidden public spaces. Co.Exist. http://www.fastcoexist.com/1681937/a-new-way-to-explore-some-san-franciscos-hidden-public-spaces (2013)
24. City of Zürich.: On the way to the 2000-watt society – Zurich's path to sustainable energy use. Office for Environmental and Health Protection Zurich. https://www.stadt-zuerich.ch/content/dam/stzh/gud/Deutsch/Ueber%20das%20Departement/2000-Watt/Publikationen_und_Broschueren/OnTheWayToThe2000WattSociety.pdf (2011). Accessed 20 Apr 2014
25. Hoppe, K.: Case study of City of Freiburg, Germany, European Union. Environmental Protection Office. http://www.forum15.org.il/art_images/files/72/CaseStudyFreiburg.pdf (2007). Accessed 20 Apr 2014
26. Gehl, J.: Cities for people. Island Press, London (2010)
27. Office for Youth Affairs and Public Safety.: Public Safety. Tokyo Metropolitan Government. http://www.seisyounen-chian.metro.tokyo.jp/english/public-safety.html (2013). Accessed 20 Apr 2014
28. Yeh, A.G.O.: Hong Kong – the response to population growth. Urban Solutions (2), Centre for Liveable Cities, Singapore 76–83 (2013)
29. Hwang, J.S., Choe, Y.H.: Smart cities Seoul: a case study. ITU-T Technology Watch Report. http://www.itu.int/dms_pub/itu-t/oth/23/01/T23010000190001PDFE.pdf (2013). Accessed 3 May 2014
30. Hee, L., Khoo, L.M.: Engaging communities – lessons from around the world. Urban Solution (3), 56–65 (2013)
31. Cheng, V.: Understanding density and high density. In: Ng, E. (ed.) Designing High-Density Cities for Social and Environmental Sustainability, pp. 3–18. Earthscan, London, UK (2010)
32. Khoo, T.C.: The CLC framework: for liveable and sustainable cities. Urban Solutions (1), Centre for Liveable Cities, Singapore 58–63 (2012)

The Heat Is on, Now We Must Act

William S.W. Lim

Abstract Climate change is today one of the most pressing concerns. To quote from the recent United Nations (UN) Report by the Intergovernmental Panel on Climate Change (IPCC): "Warming of the climate system is unequivocal... The atmosphere and ocean have warmed, the amounts of snow and ice have diminished, sea level has risen, and the concentrations of greenhouse gases have increased." As reported in the media, the UN Secretary-General Ban Ki-Moon has declared, "The heat is on... Now we must act."

To achieve global sustainability, we need a global mental change as an essential imperative condition to prevent the disastrous and irreversible deterioration in climate conditions. Sustainability requires complex in-depth and multi-faceted corrective processes in order to redress the broad range of unsustainability, including its ethical and value-loaded cultural dimensions.

Presently, the city-state of Singapore is deeply embedded in Modernity's dominant modes of understanding reality, with economic and technical systems narrowly defining the logical linear orientated rationality. Reaching sustainability in Singapore is therefore an ambitious target. It will take time, radical readjustments, political commitment and broad-based support of the whole community. A deeper broad-based slower transformational process is a clear option.

It is in this context that this article wishes to share some observations on Singapore – first, the selected challenges of sustainability in relation to A) a sustainable population, B) "fewer cars, fewer roads", C) Third Space and D) the dynamic serendipity of the arts; and second, examples of development strategies towards a people-oriented sustainable environmental vibrancy.

Keywords Global mental change • Fewer cars, fewer roads • Third Space • Dynamic serendipity od the arts • "No car" development • Public space for citizens • New uses for existing roads • Shifting density and new streetscapes • People oriented inclusiveness

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Climate change is today one of the most pressing concerns. This situation cannot be left unchecked, and as environmental analyst Lester Brown has emphatically stressed, “If we continue with business as usual, civilisational collapse is no longer a matter of whether but when” [1]. The recent United Nations (UN) Report by the Intergovernmental Panel on Climate Change (IPCC) is both alarming and challenging [2]. The Report categorically states: “Warming of the climate system is unequivocal . . . The atmosphere and ocean have warmed, the amounts of snow and ice have diminished, sea level has risen, and the concentrations of greenhouse gases have increased” [2]. As reported in the media, the UN Secretary-General Ban Ki-Moon has declared, “The heat is on . . . Now we must act” [3].

On the global level, we must urgently eliminate and disconnect the causal relationship between extreme poverty and unsupportable rapid population growth, notably in the low income countries. In recent decades, both objectives have been achieved particularly in East Asia. However, progress has been modest with the situation worsening in some countries and regions. Lester Brown has warned of the urgency to slow the population growth rate and to achieve stabilisation of the global population soon in order to avoid the impending disastrous food and water crisis [4]. Jomo Kwame Sundaram, an economist in the United Nations, strongly argues that this “ . . . affirm(s) the need for a shift away from the fundamentalist free-market thinking that has dominated poverty-reduction strategies in recent decades towards context-sensitive measures to promote sustainable development and equality” [5]. Environmental pollution—i.e. air and water—is now critical in many non-West countries and requires urgent action. It requires firm commitments and it will take time. London’s Great Smog of 1952 killed thousands and took more than a decade to clear [6].

To achieve global sustainability, we need a global mental change as an essential imperative condition to prevent the disastrous and irreversible deterioration in climate conditions. Sustainability is a concept for an age of hypercomplexity, continuous rapid changes and indeterminate conditions of interconnected global and local ecological, cultural and social crises. Sustainability requires complex in-depth and multifaceted corrective processes in order to redress the broad range of unsustainability, including its ethical and value-loaded cultural dimensions. An equally important point to note, sustainability is multidisciplinary. It is imperative to acknowledge architecture academic Leon van Schaik’s analysis in the restructuring of our embedded mental relationship between centre and periphery [7], and to recognise well-known sociologist Saskia Sassen’s exposition in promoting the primacy of our historical roots beyond the artificial unstable impact of neoliberal generated global substances [8]. Furthermore, sustainability must be enriched by the visions and serendipitous contribution of art, design and culture. It needs to also provide inspiring guidelines to generate sustainable vibrancy for the benefit and enjoyment of everyone.

In the last two decades, with rapid growth in its banking and commercial sectors, Singapore has strong ambitions to become a major global city. The two Integrated Resorts, annual downtown Formula 1 event, sophisticated entertainment and restaurant venues, as well as luxury brand shops in upgraded shopping malls, have collectively led to an unsustainable global theme park type of vibrancy.

Furthermore, this has increasingly provoked a clear division of the city, with vibrancy firmly based on income and affordability. In response to global and local challenges, Singapore needs to develop and enhance urgently a sustainable, affordable and accessible vibrancy for all Singaporeans.

Presently, the city-state is deeply embedded in Modernity's dominant modes of understanding reality, with economic and technical systems narrowly defining the logical linear orientated rationality. There is now a greater awareness that change, indeterminacy and uncertainty are the dominant features of our contemporary life [9]. In recent years, civil societies and activists have posed increasingly effective challenges. Furthermore, the pace of new technologies and innovation on a broad front is developing rapidly. This has generated the need for political change to happen much faster than before. It requires us to question many presently unchallengeable official conceptual guidelines, and to debate issues such as meritocracy and projected population growth, as well as the use of sovereign wealth funds for the welfare and services to the community. Government policies that refuse to face up to the current reality of unsustainability, while continuing to emphasise the ideals and development strategies of the past, are doomed to fail. However, to transform them quickly is not an easy task and cannot be quickly achieved.

Achieving sustainability in Singapore is therefore an ambitious target. This will take time, radical readjustments, political commitment and broad-based support of the whole community. A deeper broad-based slower transformational process is a clear option. However, it must not become an exercise of tokenism which will quickly result in disenchantment. To put this framework for change in perspective: "The past is owned by those who know. The present is controlled by those who think. The future belongs to those who can imagine (or dream)" [10].

It is in this context that I will like to share my observations on Singapore—first, selected challenges of sustainability in relation to (a) a sustainable population, (b) "fewer cars, fewer roads", (c) Third Space and (d) the dynamic serendipity of the arts; and second, examples of development strategies towards a people-oriented sustainable environmental vibrancy.

1 Challenges of Sustainability

1.1 A Sustainable Population

Singapore's White Paper published in January 2013 outlined a comprehensive projection up to the year 2030 [11]. It identified two current fault lines: i.e. the long-term impact of low birthrates and the subsequent excessive dependency on senior citizens. The Paper received many critical responses, particularly in relation to the large income gap and low wages. However, the projected increase in population to 6.9 million is the focus of much public controversy. Former Nominated MP and Nature Society President Geh Min's impassioned plea in her article entitled *Singapore: Home or Hotel?* has echoed the reality of Singapore. She stated that

"Without a shared sense of home, we will not achieve social cohesion in our compact city-state ... Let us not deteriorate into a city-state of convenience: a hotel rather than a home" [12]. This concern has since escalated to a much wider range of issues, and has generated positive policy response to protect the jobs and identity of Singaporeans.

Two significant population issues stand out. First: According to Alex Au's insightful blog post entitled *Population: Elemental Considerations 1*, a demographically sustainable population in Singapore similar to other developed economies will have a dependent ratio of about 2.25 [13]. Alex, a civil society activist, also warned that a short term solution with substantial increase of new citizens will have dire consequences decades later, when these citizens become seniors requiring support. Fortunately, the dependent ratio can be favourably adjusted presently, as there are large numbers of foreign workers not eligible to retire in Singapore. Second: Sociology scholar Shirley Sun in her new book analyses the reasons why Singapore has a very low fertility rate which is well below the replacement level of 2.1 [14]. As detailed in a book review, Sun argues that the cultural-ideological gaps in Singapore between the individual and the State have led to chronic popular dissatisfaction [15]. All responsibility in Singapore has been shifted to the family in the near absence of seriously redistributive and socialised welfare services. This has given rise to the failure of increasing Singapore's fertility rate even after a long period of government childbirth incentive policies.

Even with the comprehensive inclusive corrective measures taken to improve the birth rate, it will take time before results are seen. Presently a moderate input of new citizens to make up for the birth rate shortfall will correct this imbalance, and will achieve the long-term objective of a sustainable population.

1.2 "Fewer Cars, Fewer Roads"

This is the title of prominent local academic Kishore Mahbubani's dream in a recent article published in the mass media [16]. Is it real—is it realisable? Dreaming has been described as "having visions beyond what is usually considered possible" [17]. Kishore states: "The problem here is that a car remains an essential part of the Singapore dream. Yet, if every Singaporean achieves his or her dream, we will get a national nightmare" [16]. In my opinion, to realise the dream requires many interrelated complex challenges. We urgently need to expand and improve our public transport facilities. However, the extension of the MRT lines will take time. Our immediate implementable task is to actively promote cycling for commuting, as an efficient and affordable mode of transport. According to a Straits Times report: "A cycling census in London this year found that one in four road users in the morning peak period is a cyclist. For some popular roads, as many as three in five vehicles in the morning rush hour were bikes" [18]. Our roads must provide bicycle lanes, as we need to strive towards an effective national network which is green, efficient, affordable and safe for Singaporeans in all age groups. Singapore can aspire to become a self-respecting, cycling-oriented sustainable modern city.

Values and lifestyles must change to achieve sustainability, toward a richer job and work satisfaction and greater happiness. In the process, the single-minded pursuit of wealth and status of car ownership can be successfully contested.

The article has drawn attention to the danger when a single agency makes decisions, resulting in the unnecessary demolition of the much beloved National Library at Stamford Road. Kishore lamented: "The road planners who designed this tunnel had no idea that they were effectively shooting a bullet through the soul of Singapore by destroying the National Library" [16].

We are currently confronted with the decision by this same agency to construct a highway across Bukit Brown. Can this action be changed or await further analysis in the projection of economic and population growth? It is interesting to note that this article received little public and media attention. Perhaps, dreaming has yet to attract much interest for Singaporeans?

1.3 The Third Space

Singapore's policy of meritocracy has developed since independence from our overemphasis on scholastic achievement. Top scholars are nurtured through generous scholarships and handpicked for top government jobs. It has in recent years received increasing public criticism of its elitism. At the same time the authorities are now more aware of the need to redefine their scope and selection process in order to meet the rapid challenging global conditions. It is now clear that the selection process must be broadened, and must include the arts and creative cultures, as well as the sciences and sports. Furthermore, meritocracy particularly in the public service can only be justified when it is exercised with firmly committed individual social responsibility.

In a recent interview, Kwok Kian Woon, a noted social science academic, has strongly stressed that we need a Singapore Third Space which "must not be swayed or enticed by power or money; it must steer clear of politics, especially partisan politics and market forces" [19]. Third Space has now provided an effective platform for civil societies and activists with constant critical voices through social media such as Alex Au's *Yawning Bread* blog and *The Online Citizen*, as well as other independent websites and publications. A wide range of issues are raised. They include areas covering social and spatial justice, minimum wage, education, housing, healthcare, gay rights and gender equality among others. I will give two examples:

1. Bukit Brown is an important environmental site with irreplaceable collective memories. The Singapore Heritage Society (SHS) has worked hard over recent years to change the authority's mindset in constructing a major highway across the site and to develop it for low rise private housing [20]. The Society has since received strong support from the World Monuments Fund as it has listed Bukit Brown on its 2014 World Monuments Watch list. However, to date no policy change has been made yet.

2. Economist Donald Low's recent article entitled "Has 'global city' vision reached its end date?" has presented many key questions which policy makers must confront and resolve [21]. "Global city" concepts and characteristics of income inequality, spatial and social injustice as well as unsustainable theme park-like development have now been brutally exposed. He concludes "It is becoming clear that economic growth no longer creates the inclusive and just society that Singaporeans seek."

1.4 The Dynamic Serendipity of the Arts

In this age of rapid change, uncertainty and complexity, the creative art and design communities recognise their development can no longer be regulated in a fashion that is linear and inevitably Eurocentric. However, in Singapore, there is almost no fundamental mindset change yet in many institutionalised structures of power. We must contest the self-centred Modernist tradition of art as an autonomous object. Unlike politics, art begins in curiosity and proceeds as an instrument for questioning the existing order of things and as a platform for imagining alternatives. It is not bound by constraints of rational calculation and pure logic, instead requiring the challenges of tension and disruptive novelty. An example is *The Locust Wrath*, a dance project by The Arts Fission Company led by Angela Liong. The Locust Wrath was a performance strongly inspired by ecological and climate change, supported by an imaginative electro-acoustic soundscape [22]. As Nikos Papastergiadis, a cultural studies academic, has commented: "Artists have developed techniques for finding the questions with which they can cross-examine the perplexity of our common condition" [23]. Local playwright Alfian Sa'at was inspired by and responded to the overwhelming public reaction ignited by the government's Population White Paper to write the play titled *Cook a Pot of Curry* [24]. The play was based on a number of candid interviews, with critics reviewing: "Watch it if you dare . . . Because it wastes absolutely no time plunging right into the depths of Singapore's population tensions, digging up old scars, touchy topics and virtually slapping your face with them" [24]. Art is not concerned whether it appears to be useless or functional. Its creation has become increasingly both local and global. Singapore based Theatreworks' recent publication entitled *From Identity to Mondialisation* is a must read to understand its incredible ground breaking journey of 25 years [25]. Theatreworks' artistic director Ong Keng Sen has taken the risk of negotiating differences through exchanges with traditional and contemporary artists, and has successfully promoted and established a cosmopolitan dialogue between different people that can relate to the essence of local experience and the global process. Art requires a commitment towards openness and appreciation that differences really matter. Art is a vital independent creative force of visions, imagination and dreams. Art can generate unexpected and unintentional contributions to the immense challenges towards sustainability. In conclusion, Ivan Heng—the Founding Artistic Director of W!LD RICE and a recent recipient of the Cultural Medallion—has aptly stated: “I would like to create a safe and free platform where the most challenging and urgent issues of the day can be debated and discussed without fear or favour” [26].

2 Strategies Towards a People-Oriented Sustainable Environmental Vibrancy

Here I present five examples of development strategies and concepts toward an active people-oriented sustainable environmental vibrancy that may be applied in Singapore. Each of the ideas will require further in-depth studies and testing for their suitability. Some concepts, with modification, can also be applied in many other major cities in Asia’s emerging economies. The examples are:

1. A “no car” development option
2. New public space for citizens
3. Public space in shopping malls
4. New uses for existing roads
5. Shifting density and new streetscapes

2.1 A “No Car” Development Option

Presently 63 % of the population in Singapore go to work by public transport [27]. This compares unfavourably with 90 % in Hong Kong [28]. With increased demand in the future, construction of more roads cannot be the solution. Singapore needs to improve its public transport and provide a comprehensive cycling network in order to reduce the pressure of driving to work. Car ownership as a symbol of success particularly for the upward aspiring professional and middle income Singaporean must be corrected, but this will take time. It is in this context that we should examine a concept of how we can induce some Singaporeans to opt for a “no car” option.

The “no car” option will mean that no car parking facilities will be provided in selected public and private housing projects. These projects should ideally be located in close proximity to MRT stations and convenient downtown locations. Residential density can be substantially increased in response to the expanded capacity of the MRT system, without adding to road congestion. The HDB should rent single room units in downtown areas to Singaporean workers at an affordable cost. Workers in the service industries working late hours will find this option particularly appealing. It will also make urban living attractive to the higher income individuals in response to their preferred lifestyles. Furthermore, this can stimulate more varied and vibrant activities that cater to everyone, along existing minor roads after dark, in downtown Singapore.

2.2 New Public Space for Citizens

Since 1980, many emerging economies have grown at a historically unprecedented pace. Their cities are now more spatially fragmented, more socially divisive and more restrictive for the poor in the use of available public space. To achieve sustainability and social equity we need to maximise the provision and accessibility of public space and lower the barriers for interaction, enabling the citizens to choose where, when, how and with whom to interact.

To elaborate, three examples in Singapore are raised:

1. Bukit Brown needs to be preserved as a special historical public park of our collective memory. To realise a dream like Kishore's—to have fewer cars—why do we still need to build a new highway across the site? Furthermore, even if the provision of middle income housing is necessary, we should instead consider building a few high rise blocks and to leave the present exciting, chaotic and memorable landscape largely untouched.
2. Singapore has more than 20 golf courses. Some of these courses should be converted into much needed public parks and community facilities. To meet the stated quantum of use, high rise construction around the sites will be an attractive alternative solution.
3. There are many locations across expressways which are imminently suitable to construct a second level platform linking two active developed areas. The size and shape of the platform will vary to fit in the landscape of the location, and should be used for the arts and community activities. It will be a place to meet, relax and exercise, as well as to participate collectively and to celebrate festivals and other joyous events together.

2.3 Public Space in Shopping Malls

The shopping mall is among the most striking urban forms in the city centres of emerging economies. It is generated by the competition to attract foreign investments as well as local and global cosmopolitan elites. The developer's ambition to maximise profit has been allowed to become the paramount objective, disregarding any aspirations of achieving public goodwill through provision of public space. The design of malls became inclined towards limitedly serving its commercial purpose. Many areas in malls that were once public and accessible to all in the urban centres have been and still are being taken up for private usage. Today in Singapore, facilities for artistic performances and non-governmental public gathering for discourse and celebrations are clearly inadequate. They are expensive and hardly affordable particularly for the less-established experimental arts and community groups.

The mall exists in an interesting grey area: its space is opened to the public to attract trading, despite its private ownership. The key issue is how to ensure that the mall will provide a reasonable quantum of affordable public space, and how measures are taken to guarantee that it will be provided. We need to establish progressive planning codes for shopping malls specifically relevant to each city, in order to ensure the effective provision of open and non-commercial public space including spaces for art performances, exhibitions, public discourse, public libraries, non-profit design and art offices and bookshops, etc. The challenge now is for public space to be incorporated into the design of the mall with minimum rental charged to cover maintenance for the amenities.

2.4 New Uses for Existing Roads

Singapore, like many other traditional Asian cities, has streets that are bustling with life after dark. Besides serving their functions, back lanes were often occupied as community spaces. However, with the advent of rapid modernisation and urban development, street activities suffered a heavy toll from disruptions that destroyed their vibrancy. Motor vehicles have taken possession of the streets. Singaporeans are now increasingly aware that an inclusive society must include spatial justice such as the use of public space as a citizen's right. The near complete dominance by motor vehicles of existing roads must therefore be on the contesting agenda.

To introduce bottom-up arts and community activities on public roads during weekends and public holidays, with governmental support at arm's length, will be a big challenge. Outside downtown and major commercial areas, there is another level where local residents and cultural groups can wish to repossess particular streets for their special events and celebrations as well as other art-related and community activities. However, there are other obstacles to overcome. They include the acceptance of non-government, independent organisers and coordinators, together with payment to cover expenses as well as selecting the dates and level of activities. To start off, it may be advisable to select dates when businesses along major roads are not seriously affected, such as Christmas Day, Chinese New Year and National Day.

2.5 Shifting Density and New Streetscapes

The Singapore Master Plan is revised, amended and expanded every five years. In response to numerous inter-related factors, in particular the increased capacity of public transport and roads, residential density and plot ratio will be adjusted accordingly. The upward adjustment is regulated and applied to existing demarcated planning areas. Substantial increase in the last decade has led to the demolition of historical buildings as well as many sound buildings constructed in recent years. This has resulted in a homogeneous urbanscape without the much needed different historical anchorage in each location.

The theory of shifting density is to enable others to purchase and transfer the increased residential density or plot ratio from adjoining preserved buildings with a regulated payment, for upgrading as well as improving the efficiency of electrical consumption. Broadly, this is applicable to are three different areas. First, this applies along main roads, such as Beach Road. This will provide the necessary incentive for the owners of Golden Mile Complex—a historically important building—to benefit from this exercise. Second, this applies to surrounding areas of MRT stations. Many owners may take advantage of this exercise. The areas will have a complex hierarchy and a mixed development appearance that is chaotic, exciting and indeterminate. Third, this applies to a large area scheduled for redevelopment such as Queenstown. With the present planning approach, the authority has rejected the residents' wish to preserve many buildings and sites. However, by applying this tactic of shifting density it is conceivable that much can be preserved. Existing roads can be upgraded but not necessarily widened. The whole sector can be a testing ground to achieve a cycling friendly sustainable environment. Car usage should be limited. Minor roads can be enhanced for roadside and community activities. It can become a new chapter for urban redevelopment in Singapore and elsewhere in the Asian region.

3 Conclusion

Reaching sustainability in Singapore is an ambitious target. It will take time and radical readjustments to our values and lifestyles as well as the support of the whole community. The recent Draft Master Plan 2013 has shown some positive improvement in many areas, such as cycling networks, open public spaces and historical preservation. However, the paramount challenges for Singapore today are to work committedly towards achieving a people oriented inclusiveness and a sustainable, creative and vibrant society. I wish to end by quoting a review of my recent book: "Maybe in a few years' time, the unfolding picture will be clearer. It is a future we cannot easily foresee but I suspect that it is a choice of a future that many will have to make soon" [29].

References

1. Brown, L.: World on the Edge: How to Prevent Environmental and Economic Collapse, p. 10. W W Norton & Company Inc., New York (2011)
2. Climate Change 2013: The Physical Science Basis. Fifth Assessment Report by Intergovernmental Panel on Climate Change. http://www.climatechange2013.org/images/uploads/WGIAR5-SPM_Approved27Sep2013.pdf (2013). Accessed 2 Oct 2013
3. Gillis, Justin: Scientists set upper limit on safe level of emissions. International Herald Tribune (28–29 Sept 2013)

4. Brown, L.R., Planet, F.: Empty Plate: The New Geopolitics of Food Scarcity. W. W. Norton & Company, New York (2012)
5. Jomo, Kwame Sundaram: Anti-poverty 2.0. Project Syndicate, 8 Mar 2013. http://www.project-syndicate.org/commentary/rethinking-anti-poverty-programs-and-policies-by-jomo-kwame-sundaram
6. Galbrath, Kate: No quick fix for China's air pollution. International New York Times (31 Oct 2013)
7. Van Schaik, L.: Modernism and contemporaneity in architecture: peripheries & centres. In: Lim, W.S.W., Hwee, C.J. (eds.) Non West Modernist Past: On Architecture & Modernities, pp. 47–58. World Scientific Publishing, Singapore (2012)
8. Sassen, S.: The economies of cities. In: Burdett, R., Sudjic, D. (eds.) Living in the Endless City, p. 60. Phaidon, London (2011)
9. Lee, A., Wui, L.T., Hong, O.S.: Commentary on incomplete urbanism. In: Lim, W.S.W. (ed.) Public Space in Urban Asia, pp. 216–225. World Scientific Publishing, Singapore (2014)
10. Ang, Hwa Leong Charlie: Inventing the future. The Business Times Weekend (19–20 Oct 2013)
11. National Population and Talent Division. Population white paper: a sustainable population for a dynamic Singapore. http://population.sg/whitepaper/resource-files/population-white-paper.pdf (2013). Accessed 4 Nov 2013
12. Geh Min: Singapore: home or hotel? The Straits Times (4 Mar 2013)
13. Au, Alex: Population: elemental considerations 1. Yawning Bread blog. http://yawningbread.wordpress.com/2013/02/04/population-elemental-considerations-1/ (2013). Accessed 6 Nov 2013
14. Sun, S.H.-L.: Population Policy and Reproduction in Singapore: Making Future Citizen. Routledge, London (2012)
15. Song, Y.-J., Chang, K.-S., Sylvian, G.: Why are developmental citizens reluctant to procreate? Analytical insights from Shirley Sun's *Population Policy and Reproduction in Singapore* and Takeda Hiroko's *The Political Economy of Reproduction in Japan*. Inter-Asia Cultural Studies **14**(3), 481–492 (2013)
16. Mahbubani, Kishore: Fewer cars, fewer roads: I have a dream for Singapore. The Straits Times (14 Sept 2013)
17. Kagan, S.: Toward Global (Environ)Mental Change: Transformative Art and Cultures of Sustainability, p. 34. Heinrich Boell Stiftung, Berlin (2012)
18. Toh Yong Chuan: S'pore still lacks the ride stuff. The Straits Times (9 Nov 2013)
19. Hwee, Goh Sin, Fei, Lim Woan: Excessive individualism, absence of social accountability: Kwok Kian Woon on elitism and meritocracy in Singapore. Yihe Shiji, Issue 20 (June–September 2013), p. 21
20. Chong, Terence, Lin, Chua Ai: The multiple spaces of Bukit Brown. In: William S.W. Lim (ed.) Public Space in Urban Asia, pp. 26–55. World Scientific Publishing, Singapore (2014)
21. Low, Donald: Has "global city" vision reached its end date? The Straits Times (28 Aug 2013)
22. National Arts Council—Arts Education Programme: The Locust Wrath, Public Arts Programme Details. https://aep.nac.gov.sg/publicviewpp.aspxid1241. Accessed 4 Nov 2013
23. Papastergiadis, N.: Cosmopolitanism and Culture, p. 196. Polity Press, Cambridge, UK (2012)
24. Tan, Jeanette: Watch "Cook a Pot of Curry" . . . if you dare. Yahoo! Entertainment Singapore (8 Jul 2013). http://sg.entertainment.yahoo.com/blogs/going-out-by-night/watch-cook-pot-curry-dare-055731995.html. Accessed 6 Nov 2013
25. Theatreworks. From Identity to Mondialisation: Theatreworks 25. Singapore: Editions Didier Millet (2013)
26. Oon, Clarissa: On a cultural mission. The Straits Times (23 Oct 2013)
27. Land Transport Authority: Household interview travel survey 2012: public transport mode share rises to 63%. http://app.lta.gov.sg/apps/news/page.aspx?c=2&id=1b6b1e1e-f727-43bb-8688-f589056ad1c4. Accessed 4 Dec 2013

28. LTA Academy: Passenger transport mode shares in world cities. JOURNEYS 7 (2011). http://ltaacademy.gov.sg/doc/J11Nov-p60PassengerTransportModeSHares.pdf. Accessed 4 Dec 2013
29. Lee, Andrew, Wui, Leong Teng, Hong, Ong Swee: Commentary on incomplete urbanism. In: William S.W. Lim (ed.) Public Space in Urban Asia, p. 225. World Scientific Publishing, Singapore (2014)

Holistic Approach to Shape Future Cities

Ricky Tsui, Shu-Wei Wu, and Anita Siu

Abstract Cities are where majority of people are living as well as the main engines that drive our economy. People are attracted to live in cities as there are more hope for jobs, education, healthcare and better living standards. This is not a surprise that urbanisation rate keeps on increasing. With the scarcity of resources on earth and worsening of our environment, amplified further by climate change, cities have to be designed and reformed in a sustainable way and to provide safe, reliable and healthy places for their citizens to prosper. Latest ICT technologies will for sure contribute to smart living, in which convenience and enhancement are the keys. A holistic approach is required to shape our future cities as resources, constraints and requirements for growth are highly interconnected.

Keywords City • Green • Smart • Resilience • Sustainable • System • Resources

1 Need of Optimising Our Living Condition

What are the critical drivers for the development of future cities? How should we shape a future city holistically? World population has been increasing rapidly and is expected to reach over 9 billion by the year 2050 (from current 7 billion). Coupling with the accelerating rate of urbanisation, with expected rate reaching 70 % by that year (from current >50 %), together with the gradual shifting of demographics, there is an urgent need on more and well-suited infrastructures to sustain city growth. While infrastructure is a critical part, we should treat a city as an integrated system in the design as its various infrastructures, resources and requirements to support its further growth are interdependent. Sustainability has become essential in most city development or urban regeneration projects driven by scarcity of resources

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and environment issues, and at the same time, these infrastructures and systems shall have to be resilient to many risks and remain proper functioning throughout their design life. Climate change increases the severity and frequency of those adverse events, imposing more constraints and requirements to their design. Sustainability and resilience are the basic "push" factors to shape future city development.

The convenient means of communication and information exchange offered by recent matured technologies, such as ICT, cloud, IOT and RFID, drive the implementation of various smart initiatives in cities that improve city operation efficiency, encourage government and citizen collaboration, save resources, provide more business opportunities and, above all, enhance convenient and high-quality living of city dwellers. This is the key "pull" factor for cities to become smart and subsequently knowledgeable to maintain their competitiveness. To retain talents to work and live, a city shall need to have distinctive culture, environment, identity and prosperity to be liveable and as their preferable home to thrive.

2 Vision of Future City

The ideal future city will be one that is sustainable, resilient, smart, knowledgeable and highly liveable, and it will have a stable political environment combined with reasonable economic prosperity. Talents will be attracted to work and utilise their skills and creativity to differentiate. A supportive environment with systems and services will be designed to optimise the city around those highly skilled, innovative and knowledgeable citizens and communities.

The future smart eco-city is envisioned that it will provide an intelligent lifestyle built upon innovative eco-design utilising (1) intelligent urban planning, with utilities and infrastructures linked as an integrated and interconnected system, and (2) sustainable strategies based on new and innovative technologies regarding energy, water, waste, transportation and buildings aiming at high performance, good resilience and low/zero carbonemission.

A good future city will be well designed under a unified framework with various utilities and infrastructures linked as the basic system as shown in Fig. 1.

Various assets of the city, namely, social capital, people, economy, natural environment, manufactured assets and politics and governance, are linked to these infrastructures/utilities. Integrated resource management (IRM) modelling (Fig. 2) shall be deployed in every stage of planning to correlate their interconnectivity, and quantitative performance outputs can be delivered against the sustainability appraisal framework, which can then facilitate decision making with regard to different design options. As such, true optimal conditions can be derived to satisfy various sustainability objectives.

A future city shall be capable to reduce vulnerability. Resilience can be defined as the degree to which a system can continue to function, or adapt and evolve, effectively in a changing environment, which can have immediate or long-term effects, caused by a wide range of hazards, trends and threats such as natural hazards, urbanisation, depletion of resources, etc. The five characteristics of describing

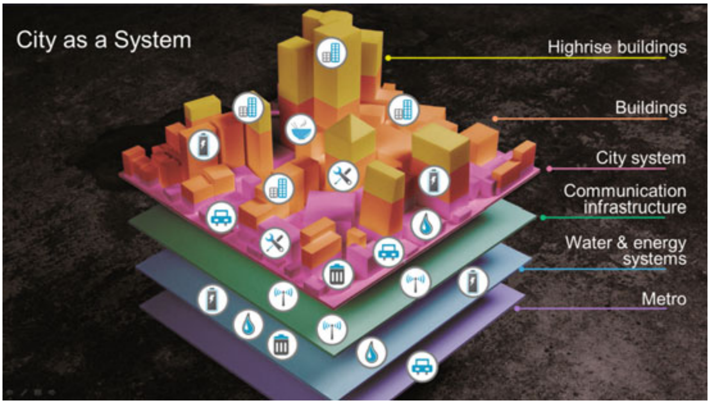

Fig. 1 City as a system (©Arup)

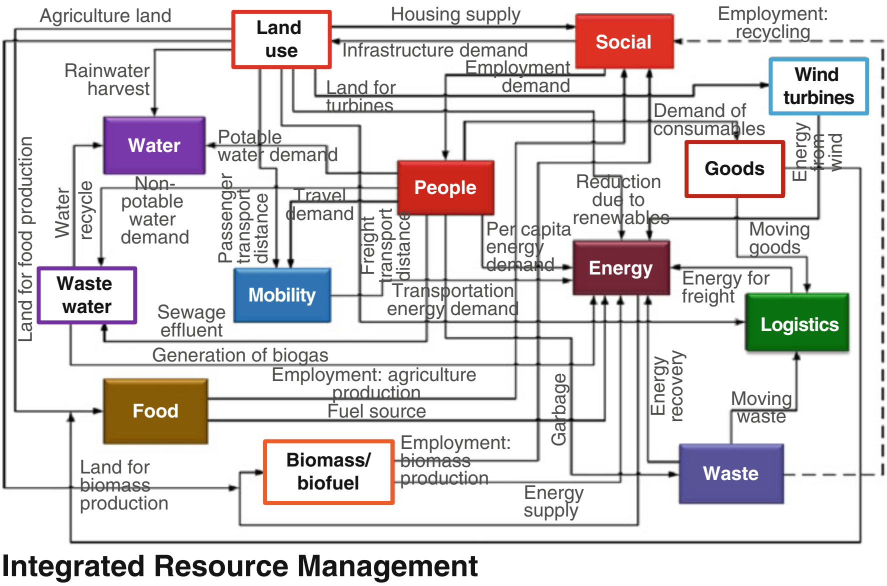

Fig. 2 Integrated resource management model is a performance framework linking the proposed technical solutions to sustainability objectives by integrating spatial and resource flow parameters (©Arup)

the resilience of an urban system refer to flexibility, redundancy, resourcefulness, responsiveness and capacity to learn [1]. A framework to evaluate the resilience of urban systems is shown in Fig. 3. By identifying those threats, hazards and trends that might affect various urban systems of a city (itself as an integrated system), these systems can be assessed, one by one, to determine the implications of

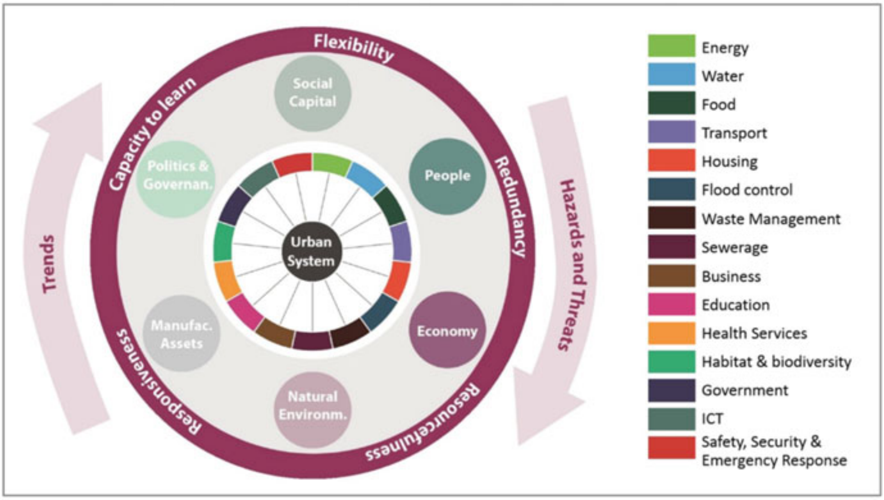

Fig. 3 Resilience framework for planning (©Arup) source [1]

their failure and interconnectivity with other systems and subsequently to identify feasible options for building city resilience.

A future city shall also be smart, in which the seams and structures of the various urban systems are made clear, simple, responsive and even malleable via contemporary technology and design. Citizens are not only engaged and informed in the relationship between their activities, their neighbourhoods and the wider urban ecosystems but are actively encouraged to see the city itself as something they can collectively tune, such that it is efficient, interactive, engaging, adaptive and flexible, as opposed to the inflexible, mono-functional and monolithic structures of many twentieth-century cities. It is expected that latest information and communications technologies will provide new business opportunities and contribute to its economic growth.

3 First Step: Green and Resilience

The city system is a complex feat of engineering. Infrastructure in the city system is similar to the processor in a smartphone; it supports applications running in a mobile operating system environment, and that is a fundamental indicator of the phone's power. To shape a better future city, our "processor" shall be carefully specified. Two elements are essential—green and resilience. History and statistics have already shown they underpin the successful development of a city.

Superstorm Sandy in October 2012 caused $19 billion damage and 43 tragic deaths to New York City and US$50 billion damage for the whole United States [2].

Hong Kong, with 7 million residents, is dumping 13,844 tonnes to landfills every day, costing more than US$180 million on operating landfills, waste collection and operating waste transfer service every year [3, 4].

Although green and resilience are not new subjects, it is worth looking into each of them closely to identify a holistic approach to upgrade the infrastructure to the highest standard as being the “processor”.

3.1 Green

A “green” system functions in optimal efficiency with lowest resource consumption and minimum waste production, so as to produce least impact to the environment and ecology system; ultimately the system can sustain by itself. This objective is not unrealistic. There are already many good examples in different parts of the world.

3.1.1 Case Examples

Transport. All major cities now rely heavily on mass transit system that efficiently and effectively moves people around with low pollution emission. Hong Kong, like other highly dense cities, is much more relying on mass transit, yielding a daily average patronage more than 4 million [5]. Many governing bodies are strengthening fuels and vehicle emission standards, while promoting more electric cars and bicycles on the road. Copenhagen, as an exemplar, has a high proportion of working class—36 %—riding bicycle to work [6]. All these significantly improve the air quality in urban area.

Water. With the fact that 68 countries are facing high or extremely high level of baseline water stress [7], water conservation projects have been rolling out in many cities in the world, and water reclamation system becomes one of the fundamental features in “green buildings”.

On the other hand, developed cities are modernising their sewage systems. For instance, treating 75 % of the sewage discharged into the Victoria Harbour, Stage 1 of the Harbour Area Treatment Scheme (HATS) in Hong Kong, has increased

Fig. 4 Upgrading work at Stonecutters Island Sewage Treatment Plant under HATS Stage 2A increases its chemically enhanced primary treating capacity from 1.7 million m^3 to 2.45 million m^3, serving 5.7 million people (DSD 2010) (©Arup)

the dissolved oxygen in Harbour water by 10 % [8]; this allows the cross-harbour swimming race to resume after being suspended for 32 years (Fig. 4).

Energy. 10 % of the global energy consumption comes from renewable energy. In several countries, renewables have already achieved a high level of penetration, like wind power met 33.2 % of electricity demand in Denmark and 20.9 % in Spain in 2013 [9].

Apart from seeking more reliable and cost-effective green energy sources (supply side), people are driving different initiatives to reduce energy consumption (demand side), like district cooling and district heating. The Pearl Qatar district cooling plant is the world's largest district cooling plant and has 130,000-ton seawater cooling capacity to replace electricity-generated cooling [10]. The world's largest district heating system is at Copenhagen and produces approximately 33,000 terajoules of heat per year [11], through waste heat from refuse incineration plants and combined heat and power plants.

Waste. Many cities are aiming at minimising their waste production and implementing new strategies for effective waste management. In Taiwan, the kitchen waste collection regulation reinforces citizens' involvement in domestic waste reduction and separation. In 2012, 835-kilotonne kitchen waste (equivalent to 3.3 % of total waste generation) was recycled and used as pig feed after high-temperature sterilisation (about 71 %) or as organic fertiliser after composting (about 29 %) [12]. This also helps extend the expected life of landfills and improve the efficiency

Fig. 5 The Hong Kong Sludge Treatment Facility adopts fluidised bed incineration technology to decompose sewage sludge at 850 °C in order to meet with the highest environmental requirements on air emission control. The plant is currently under construction (©Marcel Lam Photography)

of garbage incinerators. (The amount of food waste is equivalent to the volume of waste processed daily in two 900-tonne incineration plants.)

In Hong Kong, a new world-class sludge treatment facility can decompose up to 2,000 tonnes of sewage sludge per day by incineration process. The thermal energy recovered from the process will be turned into electricity to support the facility operation, and approximately 2-MW surplus will be exported to the grid [13] (Fig. 5).

Buildings. Buildings consume 32 % of the world's total energy [14]. "Zero carbon (or energy)" buildings, which we are gradually seeing more in our cities, aim at reducing the energy demand throughout the whole life cycle by active and passive design, in addition to utilise more renewables and other low-carbon energy sources. Active design refers to the adoption of low-energy-consumption mechanical and electrical devices, e.g. LED lighting, while passive design involves proper design of the building configuration, for example, to reduce solar gain in summer while increasing solar gain in winter. Also, there are many benchmarking systems in different parts of the world, like LEED (Leadership in Energy and Environmental Design) Certification by the US Green Building Council, to help recognise and promote the design of green buildings (Fig. 6).

City. City planning is moving from auto-oriented to transit-oriented development (TOD) nowadays. The core of our new communities is the mass transit station,

Fig. 6 China Resources Building green retrofit is the first building renovation project in Hong Kong that achieved LEED® Core and Shell Gold rating. Key features include reusing the existing structural frame, adopting high-performance façade, increasing indoor ventilation rate and upgrading the electrical and mechanical equipment (*left* and *right*: building before and after renovation) (©Arup)

surrounded by a relatively high-density mixed-use residential and commercial area, which was gradually followed by low-density development. This strategy can maximise access to green transportation—walking within the community and mass transit to rest of the city (Fig. 7).

How people feel being in a city is also crucial. With the help of microclimate study, the most comfortable living environment can then be defined. Microclimate study adopts a holistic approach integrating external wind environment, natural ventilation, daylight provision, solar heat gain, indoor air quality, outdoor thermal comfort and urban heat island effect, with an ultimate objective to increase living standard of the citizens (Fig. 8).

Fig. 7 Kowloon MTR Station in Hong Kong is an exemplar of TOD. The complex consists of office buildings, residential buildings and a shopping mall. The Olympic MTR Station follows also a similar concept (©Arup)

3.2 Resilience

A resilient system can effectively respond to sudden disruption or changing environment so as to reduce immediate impact. It shall have adopted mechanisms to allow fast recovery or adapt accordingly in long term. Origins of disruption and changing environment can be, for example, from natural hazards (like earthquake, flooding and drought), system failures (like blackout and derailment) and global trends (like scarcity of resources and urbanisation).

3.2.1 Characteristics of Resilience

A resilience system usually has one or more, even all, of the following characteristics:

- A redundant system has spare capacity to absorb sudden increase in demand or partial loss of supply.
- A robust system can survive impacts without significant loss of function; it refers to either a robust physical system or a resourceful system that is capable to identify problems, establish priorities and mobilise resources.
- A system has diversified sources or service routes which provide flexible alternatives when a part of the system fails.

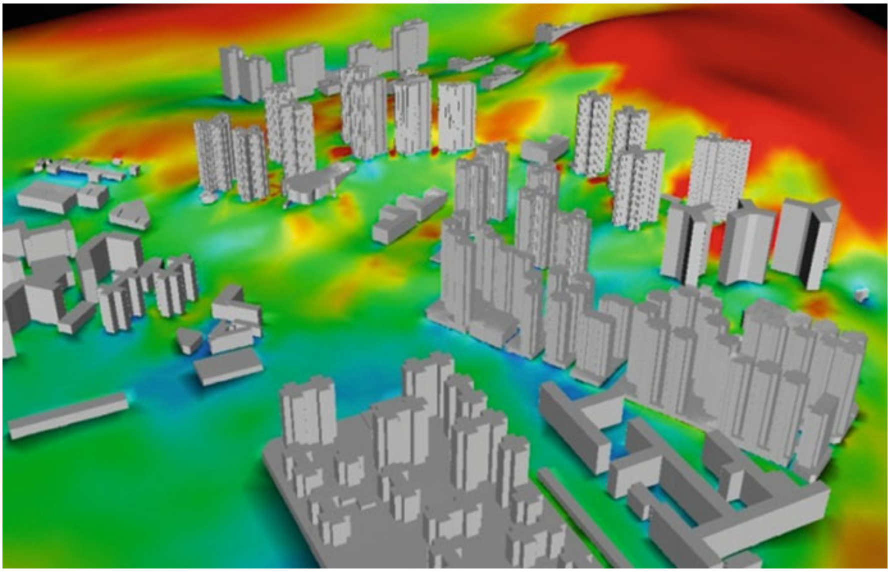

Fig. 8 Microclimate study can apply to community development as well as single building development. By simulating the windflow and solar access, engineers can improve natural ventilation and thermal comfortability (©Arup)

- An automated monitoring system with quick responsive plan ensures short feedback time to sudden impact.
- Knowledge is shared between systems, and the populace, to provide integrated responses; it includes continuous learning from experience and failure [1, 15].

The resilience strategy shall compose of detailed analysis of possible risk, effective and sustainable resilience measures and the anticipated cost of implementing and maintaining the measures. There is no easy guide suitable for all cities; however, successful cases can provide good references for new city planning or old city regeneration.

3.2.2 Case Examples

Transport. The London Underground operates using grid-supplied electricity, and the network is backed up by a separated power supply at Greenwich Power Stations, which generates power specifically for the Underground in emergency cases. This secondary power supply ensures continuity of subway service in the city.

Water Supply. New York City and Cleveland in the United States rely on redundant provision of pipe connections and strategically placed valves to isolate damaged pipes and minimise the areas of lost service [16]. Similarly in Hong Kong, a ring configuration concept is used to improve the reliability of salt water supply in

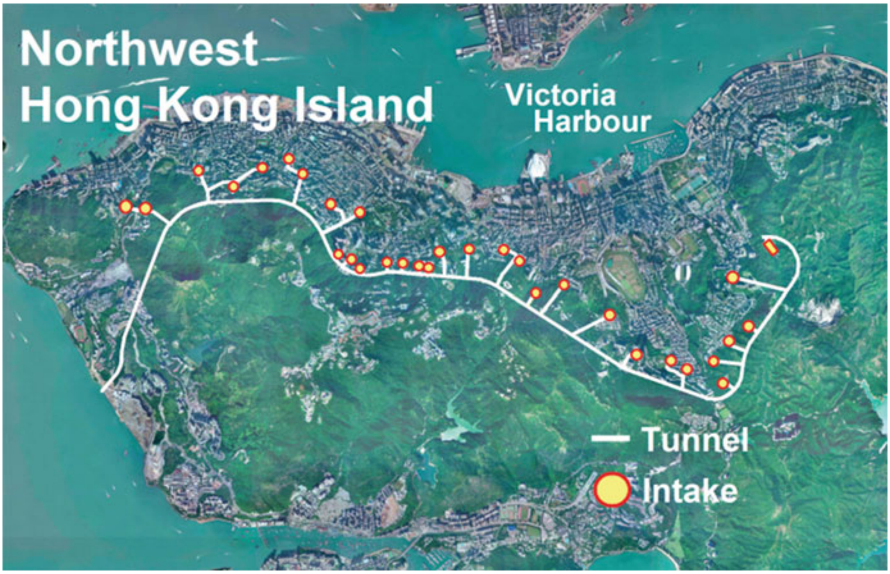

Fig. 9 West Drainage Tunnel is about 10.5 km long, diameter from 6.25 m to 7.25 m with 34 intakes and a total of about 8-km adits connecting the intakes with the drainage tunnel (©Arup)

the eastern Kowloon areas; either side of the ring main system is able to deliver salt water even if the other side is shut down [17].

Flooding. To alleviate flooding in the low-lying Hong Kong central business district due to an annual average rainfall of about 2,200 mm, the West Drainage Tunnel collects rainwater along the hillside and discharges to the sea. This substantially improves the overall flood protection level of the Hong Kong Island (Fig. 9).

Energy. In Munich, Germany, a virtual power plant has brought together 8 MW in distributed small-scale cogeneration stations, together with 12 MW in renewable hydroelectric and wind power plants to form a distributed and flexible energy management system, which allows diversified and decentralised generation facilities to be operated as a single system, or independently to serve local networks as required; this improves the reliability of planning and forecasting [18].

Buildings. Many of the building resilience measures are already mandatory in regulations, e.g. power backup system, to provide redundant supply of building services in case of system failure.

Nowadays, the advanced computer analysis software allows us to simulate possible human behaviour during emergency; thus the building management team can be more responsive in planning and directing the evacuation routes far before the actual event happens (Fig. 10).

Of course, buildings should be robust enough to withstand any natural hazards, e.g. earthquake and typhoon, or any possible human impact, like blasting in a terrorist attack. A comprehensive multidisciplinary risk assessment is therefore

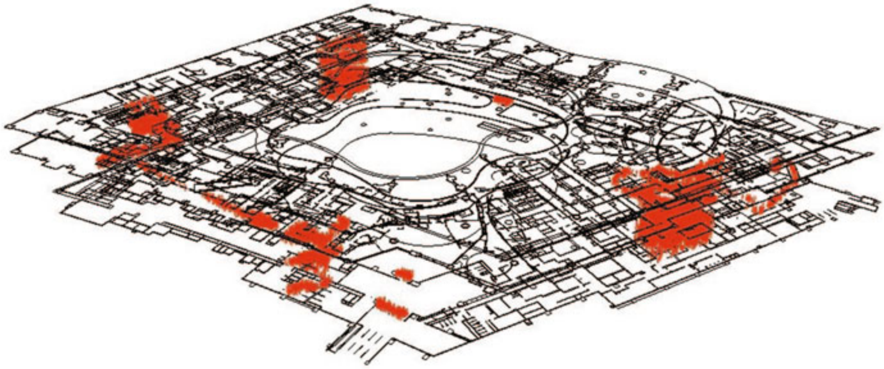

Fig. 10 In the Marina Bay Sands, Singapore, fire evacuation modelling effectively estimated the safe evacuation time across a large range of fire scenarios, and this greatly influenced the fire safety design and systems required for the entire development (©Arup)

required to ensure the building owner can anticipate all possible risks and develop an effective resilience plan accordingly.

3.3 Creating a Green and Resilience City

Every city has its own planning constraints related to the stage of its economic development, demography, topography, ownership or tenure, land values, etc. Since there is no guaranteed formula for success, each city shall have to address its own needs and risk on implementing specific green and resilient strategies.

3.3.1 Understand the Needs, Risk and Available Resources

Many of these topics have been discussed before and people begin to neglect their implications and importance. For instance, everyone knows fire is a risk and believes it has been taken care of by the regulations. It should be noted that regulations aim at protecting life, but not at continuous business operation. We learnt from history that almost all businesses closed after fire. Therefore, a comprehensive evaluation of sustainable needs and risk is always required. It shall assess how much risk the city can take and what resources are allowed, in terms of investment, physical space, manpower intelligence and citizens' support. An IRM approach may be helpful.

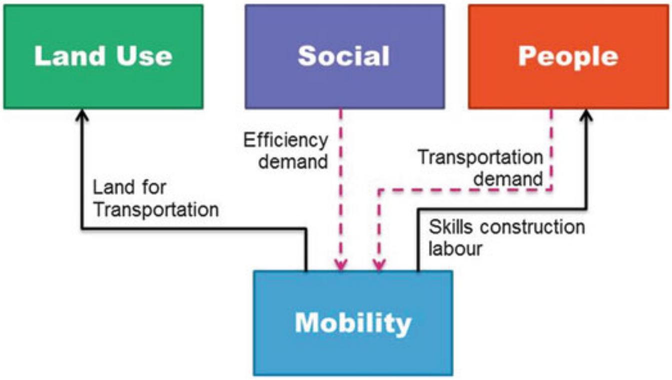

Fig. 11 Examining urban mobility using IRM

3.3.2 The IRM Approach

There is no one city that has unlimited resources. To maximise the effectiveness in resource utilisation, the “IRM modelling” and the concept of “city as a system” mentioned in Sect. 2 may be deployed. Below is a simple example of their application in reducing traffic congestion.

Urban subway is always considered as an effective solution for relieving traffic congestion. However, its required capital cost and skilled labour demand are huge. A more low-cost solution is the bus rapid transit (BRT), which provides dedicated lanes or specialised vehicles on roadways to efficiently transport passengers to their destinations. For example, BRT in Bogotá Transmilenio has successfully reduced travelling time by 32 %, cut gas emissions by 40 % and decreased accident rates by 90 % [19]. But BRT does require sufficient land on ground to implement.

In most cases, cities in developed countries are often very crowded. As such, no more above-ground space is available for mobility solutions; mayors may only seek solutions at other layers of the city system—flyover or underground (Fig. 11).

4 Smart

4.1 Uniqueness of a City

Smart initiatives applying on green and resilient cities are expected to address many problems and challenges that occur during the process of city development and can bring new prospects. However, every city is unique and the development needs and priorities vary for different cities. In addition, their resources, affordable budget, infrastructure and people readiness are not the same. (This applies also to implementing previously discussed green and resilient strategies.) But, it doesn’t imply that a city should be very "green" and "resilient" before kick-starting any smart initiatives.

4.1.1 Cities in Developed and Developing Countries

For cities in developed countries, they have comparatively more resources and flexibility to adopt different smart concepts, but for cities in developing countries, it is largely dependent on their development priorities as often confined by their limited resources.

As a developed city (country), Singapore is putting significant investment into smart city development, especially to smart transport. In Singapore, every person owns 1.6 vehicles on average, causing huge pressure on its city transport system. Traffic congestion resulted in low efficiency and environment pollution. Starting from 1998, an electric road pricing system was implemented with sensors and infrared devices installed and city road networks connected with traffic signal system and electronic scanning system further optimised; the city's traffic condition can then be predicted in predetermined periods of 10, 15, 30, 45 and 60 min. The accuracy of the prediction within the next 1 h can reach 85 %, and it can reach 90 % within the next 10 min [20]. Citizens can obtain expected traffic condition in the next one hour through their smartphones and select appropriate travel routes accordingly.

For the city of Nairobi, Kenya (a developing country), with 320 million population and 0.3 million vehicles [21], driving during peak period is mayhem. Commuters cram roads that were designed for a city 10 times smaller, and congestion costs Nairobi US $17,000 per day for lost productivity, fuel consumption and pollution, putting the city at the world's 4th worst for commuting [21, 22]. With very limited resources, the city implemented a smart solution based on "frugal innovation" in collaboration with a number of organisations. "Frugal innovation" for transport implies leverage on existing sensors, like web cameras, with the aid of sophisticated analytics, rather than relying solely on a comprehensive network of expensive roadside sensors. Combining advanced analytics on various traffic parameters with image processing and simulation, various what-if scenarios can be generated for smarter decision making.

4.1.2 Well-Established and New Cities

A different approach on smart city development between well-established and new cities may have to be adopted. For well-established cities, they need to consider relevant smart initiatives based on the current framework. For example, with the total budget of 8.67 million euro, Santander (in Spain) initiated a citywide experimental research facility that is sufficiently large, open and flexible to enable the integration of new and relevant smart applications with the current urban systems including parking and traffic, lighting, parks and gardens, participatory sensing, energy, environment and tourism, etc. Stakeholders involved the government, developers, citizens, researchers and private organisations.

For new cities, it is relatively easier to adopt a holistic approach to drive different smart initiatives. As an example, the New Songdo City (South Korea), starting from scratch, attracted around 35 billion US dollars and is expected to be completed by the end of 2015. By that time, there will be 65,000 citizens in this one of the smartest cities in the world. A good ICT framework will be in place and a common information sharing platform will exist among the new city's community, government departments, private companies, etc. One smart card will allow residents to make payments easily, check medical records and enhance daily life activities. The smart system will seek full coverage and provide smart services to residents at anytime and anywhere in the city, which will greatly improve the effectiveness of the city management and resource utilisation.

4.2 Examples of Smart Initiatives

Connectivity is the main prerequisite for driving various smart initiatives in different cities. The 3 "I"s are crucial: interconnected, in which people are connected through the Internet (cellular communication, broadband and wireless communication, etc.); instrumented, in which devices are connected (the Internet of Things, GPS, cloud computing, etc.); and intelligent, in which smart living and smart city can be achieved. Quite often, the first approach is to ensure that the city has a good ICT framework. With this, various smart initiatives can be adopted according to the needs of each city. Examples of smart initiatives are given below with particular reference to those cases from the Greater China.

4.2.1 Efficiency and Convenience

Smart Transport to Improve City Mobility. Taipei's "Hao Xing" system in Taiwan refers to its smart transport system, including items such as "news", "bus", "event", "parking lot", "speed", "taxi", "MRT", "YouBike" and "river cruise". It has been used more than 100 million times in the year of 2013, and the main purpose of the system is to provide full and complete real-time traffic information services supported by integrating ICT, time and spatial information. As such, the issue of "last mile" can be better handled.

For example, bus information system, providing dynamic information and travel route optimisation, is normally used for more than 2.21 million times per day, and 91 % of the users said that the system has been helpful for minimising the waiting time.

For parking guide system, 90 % of the users said that it could enhance efficient parking. The system could save 9 min for parking and 92 % of the interviewees suggested the expansion of the system.

YouBike programme started from 2009 and provided 500 bikes for demonstration in 11 points in Xinyi District. It was then extended to the whole Taipei in 2011. The number of the bike point reached 129 by the end of 2013 with altogether 4,335 bikes [23]. The use of bike keeps increasing.

Smart Logistics to Improve Efficiency of Port Management. The main idea of smart logistics in Taipei, Taiwan, is to automate the process of managing containers so as to improve work efficiency, lower maintenance cost, improve safety level on site, enhance the image of its quick connection with others through sea and air transportation and ultimately improve the competitiveness of Taipei Port.

Taipei Port is the first one to use "two-way wireless sensing technology" to schedule vehicles, which can overcome the disadvantages (one-way transmission) of using RFID. As such, ID recognition rate has reached 99.5 %, and the loading operation of vehicles with containers can be fully automated.

Through patented scheduling algorithm, the operation/management of the pier has been improved, the efficiency of loading and unloading in the Taipei Port has been increased by about 50 % and the overall revenue has been increased about 20 % [24]. Smart logistics in Taipei Port was granted the award of United States R & D 100 in 2013.

Smart Government to Improve Service Efficiency. The city of Wuxi in China has made a huge progress in the development of smart city since its first initiative of "Sensing Wuxi" in 2009 and ranked the first at the evaluation of "Outstanding Government Website in China" in 2012 [25] and also the first at the evaluation of "Smart City Development in China" in the year of 2013 [26]. Now, Wuxi's government website has become the benchmark, namely, "Wuxi Model", for the e-integration of government departments, which is characterised by:

1. Under the unified planning, "online government" platform for various departments was established with unified standard and unified technical architecture and managed by unified service provider. It consists of clusters with similar operation model and service code. Those clusters have connectivity, sharing information and coordinating with each other so as to effectively integrate various information resources. By breaking down "information silos", different departments are collaborating with others more efficiently.
2. It has been developed from "simple service" to "comprehensive human services", with four languages at portal website: Chinese, English, Korean and Japanese. With mobile version, e-government services can be accessed through smartphones. The Wuxi's accessibility website was completed and launched in 2010, providing barrier-free services to different groups.

The operation efficiency of government website (for various departments) has been increased by more than 60 %. The amount of annual information disclosure at government portal has been increased by 40 %. The average monthly portal visit is over 5 million with an annual growth rate of over 22 %, and the public satisfaction level on interaction between government and citizens is over 90 % [27] (Fig. 12).

Smart Water to Improve Resource Efficiency. There were more than 2,000 leakage or burst accidents annually before year 2010 in Hong Kong, which wasted

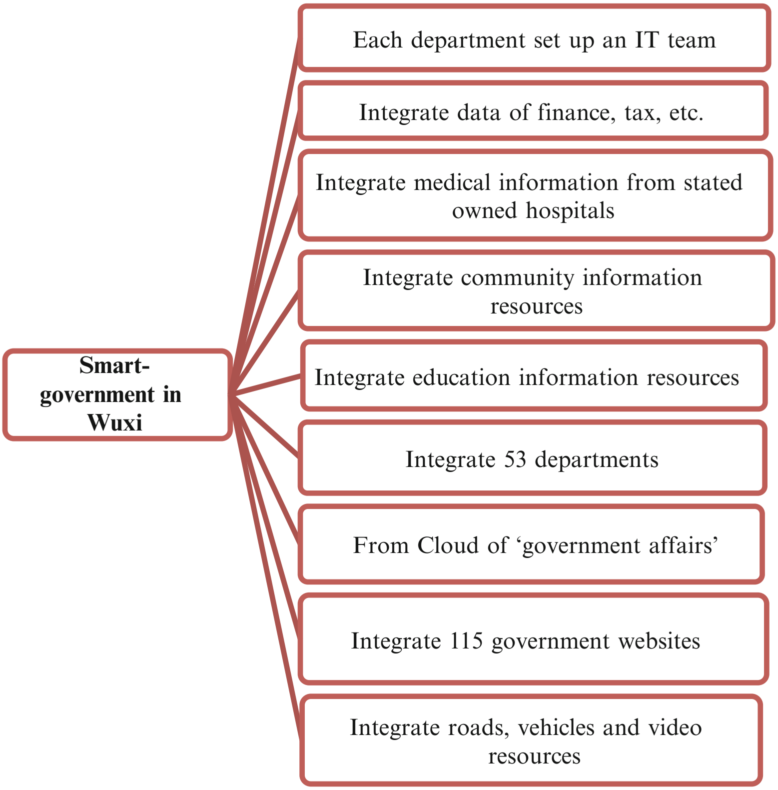

Fig. 12 Smart Wuxi: e-government

20–30 % of the water supply and seriously affected the stability of water supply and sustainable development of water resources in Hong Kong [28]. In order to improve water utilisation efficiency, the government is deploying new technologies to strengthen water leakage control including "telemetric district metering" (TDM) and "comprehensive pressure management" (CPM). By using TDM (e.g. electromagnetic flowmeter and global system for mobile communication), the flow and pressure data can be sent to control centres for early detection of leakage and further for remedial actions. Through CPM (e.g. installation of flow-modulating pressure-reducing valves and flowmeters), the water main pressure can be optimised to further reduce leakage [29]. The water resource is utilised more efficiently through these technologies and programmes, which can be reflected by the figures below showing that the "no. of leaks detected" and "estimated quantity of fresh water saved (cubic metres/day)" are decreasing (data from [30]) (Figs. 13 and 14).

Smart Wind Turbine to Improve Resource Efficiency. The County Rudong, in Jiangsu Province in China, has rich offshore wind resource with the largest number of wind turbines installed in intertidal zones. In order to improve the efficiency

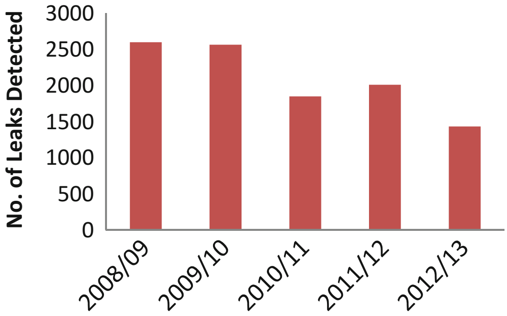

Fig. 13 Number of leaks detected in Hong Kong

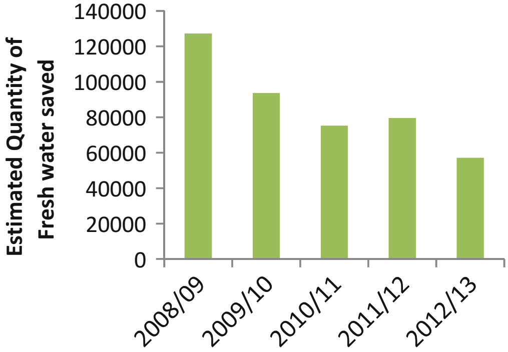

Fig. 14 Estimated quantity of fresh water saved in HK

of wind resource utilisation, smart offshore wind turbines have been adopted with the following characteristics: "high reliability, smart control and optimal cost". The wind turbines can sense proactively, think and make judgement and decision. They can analyse data and respond to two issues: "what is the current wind condition?" and "how the wind condition may change soon?" They can perceive their own status and external environment accurately and adjust operation model and strategy to keep the best performance even with very high speed wind [31].

This type of smart wind turbine, through smart control, can lower the cost of offshore wind power by more than 20 % and increase the power generation efficiency by about 20 % [32]. It makes possible the development of large-scale offshore wind farm. The control system of each turbine can be connected with cloud technologies. By sharing information with each other, each wind turbine not only can perceive its working condition but also determine the interaction with each other. As such, smart coordination enables optimal power generation for the whole wind farm.

Smart Card to Improve Convenience of Daily Life. Octopus card is a famous "electronic toll collection system", being utilised everywhere in Hong Kong. This can be used to make various payments or pay for different services such as transport fares (e.g. railway, bus, minibus, ferry and car park), telecommunication bills, supermarkets, convenience stores, fast-food shops, vending machines and kiosks, photo booths, cinemas, etc. Many commercial or residential buildings even use Octopus card for their access control system.

At present, there are more than 25 million cards in circulation, and more than 99 % of the citizens aged between 15 and 64 in Hong Kong own at least one Octopus card [33]. The number of daily transactions is over HK$13 million with a total daily turnover of more than HK$140 million, and each transaction only takes less than 0.3 s [33, 34]. The benefits of using "Octopus" include:

- Improving convenience of daily life
- Eliminating the trouble of using coins
- Easy to recharge up to HK$1,000
- Allowing debts up to HK$35, which avoids emergency cases such as insufficient balance, no time to recharge, etc.

Smart Healthcare to Facilitate Healthy Life. "Medical Wizard", as a smart assistant, was launched by New Taipei City Government in Taiwan to improve healthcare services based on a mobile platform. The "Wizard" coordinates many healthcare services including latest news, healthcare websites, hospitals and clinics, common registration inquiries, real-time information on patient queuing, health-checking information, vaccination, health education and lists of doctor [35].

Citizens can also add relevant events into their own calendar and set up reminders to important events such as revisiting doctor and children vaccination. Through this "Medical Wizard", citizens can manage their health/hospital activities in a smart way and enjoy a more convenient life.

4.2.2 Smart Security to Make Safer Cities

Mitigating the Shortage of Police. Every policeman in New Taipei City in Taiwan is serving at least 500 or more citizens and the rate (number of policeman/citizen) is the lowest, comparing with other cities like Taipei, Taichung, Tainan and Kaohsiung. In order to reduce the shortage pressure and serve citizens more efficiently, New Taipei City made a huge investment on smart city security system to enable a safer city. This system consists of expert database, geographic information system (GIS), M-Police toolkit, 110 system, security and record systems, smart image recognition system, joint defence systems by policeman/citizen, etc. For example, the handheld M-police toolkit designed particularly for a policeman is shatterproof, shockproof and waterproof and is able to connect with database and face recognition system so as to help search missing persons.

Improving the Efficiency of Crime Investigation. The "security governance decision programme" in New Taipei City includes information integration centre, database and platform, geographic information system (GIS) of crime, visualisation of crime analysis, etc. For example, the police can integrate their information with those from citizens through database and platform and make image and video analysis or connect with GIS and make correlation analysis in order to support crime investigation, prevention and prediction. E-sky eye programme can help monitor the city and make record, which improves the crime detection efficiency [36].

4.2.3 New Business Opportunities

Smart Tourism to Attract More Visitors. The city Guilin, Guangxi Province in China, has made a good progress in smart tourism including setting up of more than 1,000 tourism websites, a public tourism information platform and an e-commerce platform for tourism. For example, all hotels and guest houses (residential) in the county Yangshuo (under Guilin) can be booked online, and a number of personalised guest houses and boutique hotels have been attracting a stable customer flow through online marketing. In addition, an e-sky eye system has been launched to monitor all tourist spots in Guilin which can provide (1) real-time information on visitors and traffic flows and (2) timely and accurate tour guide services.

At present, there are a few smart tourism initiatives ongoing in Guilin, for example, improving smart tourism system, building comprehensive smart tourism data centre, building smart terminal system on tourism information and promoting more collaboration between tourism enterprises and domestic famous e-commerce enterprises. In particular, Guilin is building the national demonstration area, where tourists can swipe their cards with full accessibility, and launching the Communication Bank-Guilin Card which can provide tourists with more convenience on enjoying food, accommodation, transportation, shopping and entertainment.

"Being smart" is strongly promoted for the development of tourism industry in Guilin. For example, Guilin was awarded with "2012 China's best tourist city", and the total tourism revenue in 2012 reached 25.5 billion RMB, accounting for 17 % of Guilin's GDP [37]; the total tourism revenue in 2013 reached 34.6 billion RMB with an increase of 35.7 %, and the number of serving tourists reached 35.8 million with an increase of 9 % [38].

Smart Agriculture to Promote Economy. Smart agriculture involves the integration of ICT applications with the whole industrial chain process from cultivation (e.g. optimising environment to increase productivity), marketing (e.g. apps on price information, crop epidemic early warning and production forecasts), to product tracking (e.g. using RFID to track product for security reasons). In particular, smart cultivation can directly increase crop's productivity through integrating various sensors and cultivation management system to optimise cultivation environment. Based on the information collected by sensors of light, temperature, water, fertiliser, humidity and crop ecology, the system can simulate and monitor crop growth process and control and change these parameters dynamically in the optimisation model so as to achieve the best yield. By further integrating cameras and connecting with the Internet and smartphones, remote growth monitoring and pest control can be realised (Fig. 15).

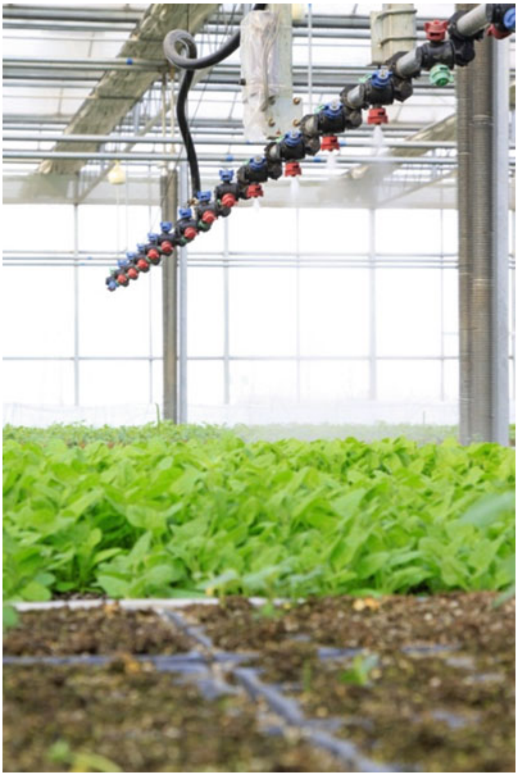

Fig. 15 Upgrading to smart agriculture

Taiwan has mature agriculture technologies and already made exploration on smart agriculture. For example, the Connected Context Computing Centre in National Taiwan University did a pilot study on orchid planting that used a smart remote monitoring system and various sensors to precisely control the growth environment. By planting orchid smartly, the yield can be improved, and florescence can be prolonged with lower impacts caused by diseases, bugs and viruses. If orchids in Taiwan can all be planted in this smart way, 10 % increase in yield can be realised, i.e. US $0.5 billion according to US $4–5 billion for Taiwan on orchid annual export, which can thus largely strengthen local economy [39].

5 Summary and Insights

The world is under unprecedented level of urbanisation. More new cities are needed while existing cities shall have to reform to house more city dwellers. Resources will of course be limited and constraints will inevitably exist. Cities shall need to be attractive to the knowledge-based population such that they can create and innovate, deploying their skills to drive further economic growth.

An ideal city would be one that is green, resilient, smart, knowledgeable and liveable. With such vision, a framework to holistically design a new city or reform an existing city is proposed. A city is best regarded as an integrated system with many urban subsystems interconnected with each other. Infrastructures and utilities that form these subsystems shall be carefully designed within affordable resources according to our set sustainability objectives. An IRM model can be deployed to consider various options based on quantitative measures. Different city resilient initiatives shall have to be considered to reduce its vulnerability, but these are very city specific as each city is unique with respect to its stage of development, available resources and constraints. Examples of various green and resilient initiatives are given as best practices to inspire and inform.

Technology can always provide the driving force for disruptive changes. Deployment of latest ICT technologies will improve our cities and enhance smart and high-quality living. Examples are given on how various cities, with particular reference to those from Greater China, deploy smart initiatives to facilitate their development. Again, these are all city specific but can serve as examples to provide useful stimulus to shape a better future city.

Liveability can be enhanced if a city has distinctive culture, identity and environment that attract talents to live and contribute. This subject has not been touched upon here but will be a topic worth to further explore.

References

1. Macmillan S., Collier, F., Hambling, J., Kernaghan, S., Kovacevic, B., Miller, R., Paya, A., Richardson, E.: Tomorrow's cities – a framework for building resilience. Proc ICE Urban Des Plann. **167**(2), 79–91 (2012)
2. The City of New York Mayor Michael R. Bloomberg.: A Stronger, More Resilient New York, NYC, USA (2013)
3. Environmental Protection Department, Hong Kong Special Administrative Region: Monitoring of Solid Waste in Hong Kong – Waste Statistics for 2012. HK EPD, Hong Kong (2014)
4. Environment Bureau, Hong Kong Special Administration Region: Hong Kong Blueprint for Sustainable Use of Resources 2013–2022. Environment Bureau, Hong Kong (2013)
5. MTR Corporation.: Patronage Updates. http://www.mtr.com.hk/eng/investrelation/patronage.php (2014). Accessed 26 June 2014
6. Arup.: Copenhagen: Solutions for Sustainable Cities, Arup, UK (2011)
7. Reig, P., Maddocks, A., Gassert, F.: World's 36 Most Water-Stressed Countries. World Resources Institute. http://www.wri.org/blog/2013/12/world%E2%80%99s-36-most-water-stressed-countries (2013). Accessed 26 June 2014
8. Drainage Services Department, Hong Kong Special Administration Region.: Harbour Area Treatment Scheme FAQ. http://www.dsd.gov.hk/others/HATS2A/en/FAQ/ (2010). Accessed 26 June 2014
9. Ren21. Renewables 2014 Global Status Report (2014)
10. Qatar Cool. The Pearl Qatar. http://www.qatarcool.com/thepearl.html (2014). Accessed 26 June 2014

11. New York City Global Partners. Best Practice: District Heating System. http://www.nyc.gov/html/unccp/gprb/downloads/pdf/Copenhagen_districtheating.pdf (2011). Accessed 26 June 2014
12. Environmental Protection Administration Executive Yuan, R.O.C. (Taiwan).: 2012 Annual Report on Resource Recycling (101年度資源回收再利用年報), EPA, Taiwan (2014)
13. Environmental Protection Department, Hong Kong Special Administrative Region.: Sludge Treatment Facility. http://www.epd.gov.hk/epd/english/environmentinhk/waste/prob_solutions/WFdev_TMSTF.html (2014). Accessed 26 June 2014
14. International Energy Agency.: FAQs: Energy Efficiency http://www.iea.org/aboutus/faqs/energyefficiency/ (2014). Accessed 26 June 2014
15. Arup, R.P.A., Siemens.: Toolkit for Resilience Cities – Infrastructure, Technology and Urban Planning, USA (2013)
16. U.S. Environmental Protection Agency's National Homeland Security Research Center by American Water Works Association and CDM.: Planning for an Emergency Drinking Water Supply, USA (2011)
17. Legislative Council Panel on Planning, Lands and Works, Hong Kong Special Administrative Region.: 36WS CB(1)885/04-05(01) Ring Mains for Cha Kwo Ling, Salt Water Supply System (2005)
18. Siemens Press Release.: Stadtwerke München and Siemens Jointly Start Up Virtual Power Plant. http://www.siemens.com/press/en/pressrelease/?press=/en/pressrelease/2012/infrastructure-cities/smartgrid/icsg201204017.htm&content[]=ICSG&content[]=EM&content[]=EMSG (2012). Accessed 30 July 2014
19. C40Cities.: Case Study – BRT System Reduced Traveling Time 32 %, Reduced Gas Emissions 40 % and Reduced Accidents 90 %. http://www.c40.org/case_studies/brt-system-reduced-traveling-time-32-reduced-gas-emissions-40-and-reduced-accidents-90. Accessed 30 July 2014
20. Jianbo Cheng.: Comparing Strategies of Smart City Internationally, Modern Industrial Economy, (2013)
21. IBM East Africa.: A vision of smarter city: how Nairobi can lead the way into a prosperous and sustainable future. https://www.google.com.hk/url?sa=t&rct=j&q=&esrc=s&source=web&cd=1&cad=rja&uact=8&ved=0CBsQFjAA&url=http%3A%2F%2Fwww.foresightfordevelopment.org%2Fsobipro%2Fdownload-file%2F46-155%2F54&ei=NvnKVOOuNcn38QXAq4CwCw&usg=AFQjCNFPoW9mm80ItkpIlmODFAmWBczSCw&sig2=F3m_rSiXlUXE0zsxCnnW2w&bvm=bv.84607526,d.dGc (2012). Accessed 30 Jan 2015
22. Sachiko Yoshihama.: Frugal Innovation for Smarter Transportations in Developing Countries, IBM Research – Tokyo. Accessed 26 Apr 2013
23. Huang Junjia.: Smart Transport: Taipei "Hao Xing", at Smart City Development and Collaboration Forum Between Mainland China and Taiwan. (2014)
24. 资讯工业策进会, *台湾智慧联网产业及应用之发展*, at Smart City Development and Collaboration Forum between Mainland China and Taiwan. (2014)
25. 无锡模式"政府网站群整合助推智慧政府建设, http://www.wuxi.gov.cn/zt/itzxzl/6272874.shtml. Accessed 1 Aug 2014
26. 无锡蝉联智慧城市第一, http://www.wuxi.gov.cn/zxzx/wxyw/6636398.shtml. Accessed 1 Aug 2014
27. 张克平, *无锡智慧城市建设实践与思考*, at Smart City Development and Collaboration Forum Between Mainland China and Taiwan. (2014)
28. 李行伟, 蔡宇略, 香港—从智能城市迈向智慧城市, http://www.cnscn.com.cn/news/show-htm-itemid-8178-page-2.html. Accessed 29 Jan 2015
29. Water Supplies Department of Hong Kong.: Total Water Management in Hong Kong. (2008)
30. Water Supplies Department of Hong Kong.: Annual Report 2012/13
31. 薛辰, 远景能源的4兆瓦海上智能风电机组近期屡获订单, 风能, http://news.bjx.com.cn/html/20140616/518814.shtml (2014). Accessed 23 July 2014
32. 喻思娈, 御风追梦智慧能源, 人民日报, http://paper.people.com.cn/rmrb/html/2013-12/08/nw.D110000renmrb_20131208_8-04.htm (2013) Accessed 23 July 2014

33. 統 計 數 據 一 覽, http://www.octopus.com.hk/octopus-for-businesses/benefits-for-your-business/tc/. Accessed 28 July 2014
34. 香港智慧城市应用案例, http://www.ningzhe.net/article/3246.html. Accessed 29 Jan 2015
35. 醫療精靈-醫療照護全掌握, http://focus.www.gov.tw/subject/class.php?content_id=180. Accessed 29 July 2014
36. 智慧警政安全城市-新北構築科技防衛城, http://www.digitimes.com.tw/tw/b2b/Seminar/shwnws_new.asp?CnlID=18&cat=99&product_id=051A30417&id=0000376902_FQM8C1W41XABNA1NCNHUI#ixzz33BH1wSCs. Accessed 29 July 2014
37. 朱桂萍, 城市旅游信息化服务产业发展研究, Estate Observation. 2014/9
38. 莫月华, 桂林市智慧城市建设的思考与建议, *企业科技与发展*, 2014 年第8期(总第372期)
39. Yen-Kuang Chen.: Connected context computing: challenges & opportunities (presentation), National Taiwan University. http://www.ari.iii.org.tw/2013EUIOT/slide/09%20Intel%20%E9%99%B3%E5%BD%A5%E5%85%89%E3%80%90%E9%97%9C%E9%8D%B5%E8%B6%A8%E5%8B%A2%E3%80%91%E6%99%BA%E6%85%A7%E8%81%AF%E7%B6%B2%E5%8F%8A%E6%83%85%E5%A2%83%E6%842%9F%E6%B8%AC%E9%81%8B%E7%AE%97%E7%9A%84%E6%A9%9F%E6%9C%83%E8%88%87%E6%8C%91%E6%88%B0.pdf. Accessed 30 Jan 2015

Building Resilient Cities to Climate Change

Matheos Santamouris and Constantinos Cartalis

Abstract Several publications have been made regarding the state of the environment in cities, especially in light of new challenges such as climate change [1–6]. In particular the International Council for Local Environmental Initiatives (ICLEI) speaks about the urgent need to build resilient cities to natural hazards and prioritizes the development of resilience plans by local authorities, especially with respect to climate change and the associated impacts to local societies [3]. In the same wavelength, the Intergovernmental Panel for Climate Change (IPCC) [5] refers to the increasing burden to local societies due to climate change and claims that the occurrence of extreme weather events, with the potential to affect cities, has not only increased since its latest assessment [4], but is also estimated to further increase in the following years. IPCC [5] also refers to the impacts of climate change to cities, mostly in terms of the increase of temperature, as well as of the occurrence of tropical days and heat waves. The European Environment Agency (EEA) in its publication on the impacts of climate change [6] also refers to the impact of climate change in the European continent and combines the increase of heat waves in Europe and the spatial and temporal enhancement of thermal heat islands in several European cities, to the urbanization trend in Europe (80 % of the population is expected to live in cities by 2020), and to the vulnerability of the population, especially elderly people.

Keywords Climate change • Cities • Resilience

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1 Cities and Climate Change

Several publications have been made regarding the state of the environment in cities, especially in light of new challenges such as climate change [1–6]. In particular the International Council for Local Environmental Initiatives (ICLEI) speaks about the urgent need to build resilient cities to natural hazards and prioritizes the development of resilience plans by local authorities, especially with respect to climate change and the associated impacts to local societies [3]. In the same wavelength, the Intergovernmental Panel for Climate Change (IPCC) [5] refers to the increasing burden to local societies due to climate change and claims that the occurrence of extreme weather events, with the potential to affect cities, has not only increased since its latest assessment [4], but is also estimated to further increase in the following years. IPCC [5] also refers to the impacts of climate change to cities, mostly in terms of the increase of temperature, as well as of the occurrence of tropical days and heat waves. The European Environment Agency (EEA) in its publication on the impacts of climate change [6] also refers to the impact of climate change in the European continent and combines the increase of heat waves in Europe and the spatial and temporal enhancement of thermal heat islands in several European cities, to the urbanization trend in Europe (80 % of the population is expected to live in cities by 2020), and to the vulnerability of the population, especially elderly people.

2 The Quest for Resilient Cities

The quest for resilient cities is not new. ICLEI [3] considers that “A resilient city is low risk to natural and man-made disasters. It reduces its vulnerability by building on its capacity to respond to climate change challenges, disasters and economic shocks”. The meaning of resilient cities has been discussed and examined in particular with respect to the difference between definitions relating to the equilibrium and nonequilibrium views of resilience [7, 8]. In the first view, resilience is regarded as the ability of systems to return to their stable equilibrium point after disruption, whereas in the second view resilience is the capacity of a system to adapt and adjust to changing internal or external processes.

An examination of climate change adaptation and mitigation plans for modern megacities demonstrates clearly the differences between the two views. In the first view (equilibrium), the city needs to be designed and planned so as to “bounce back” after disruption. In the second view (nonequilibrium), the city needs to define multiple (internal) states and secure that the interaction of processes will facilitate their stability.

The heat wave event in Paris (2007) has demonstrated that Paris complied to the equilibrium view; although the terminal point was exceeded, the city managed to “bounce back” despite the fact that the urban system had limited capacity to adapt and adjust. In other words Paris failed to comply to the nonequilibrium view. Similar cases may be examined for the vast majority of world cities, with more negative assessments recognized in fast-growing cities, mostly in the developing world [9].

In practical terms, a city which promotes the nonequilibrium view for its design and planning accepts that city processes are dynamic, interdependent, and interactive. Such approach facilitates the definition of internal stable states for each of the processes as well as the preconditions to be met so as the terminal points of each stable state not to be reached. In the event that a terminal point is reached, the effort to ameliorate the situation is carried not only by adjustments or adaptation within the disrupted process but within other processes as well. In such a case, the city operates as a "living organism," with its components dynamically influencing each other as well as controlling the final state of the city.

Resilience reflects not only how well environments respond to shocks (for instance, those related to climate change) but also how they capitalize opportunities.

In addition to the above, people are by definition a part of the city system as they are individually and institutionally responsive and reactive components of the metropolitan ecosystem [10]. The inclusion of people in the city system results in a number of "new" needs to be considered for an integrated plan toward a resilient city. These include, among others, health as related to air pollution and thermal comfort as influenced by excessive temperatures and heat waves. To this end the integration of the "human" dimension reflects a major improvement in drafting a plan toward a resilient city.

3 Cities, Climate, and Resilience

In recent years, widespread attention is given in developing plans for climate change adaptation and mitigation [11, 12] as well as for plans for resilient cities. Plans need to be interrelated so as to describe the threefold relationship between climate change and cities: (1) Cities are major contributors to CO_2 emissions, (2) climate change poses key threats to urban infrastructure and quality of life, and (3) how cities grow and operate matters for energy demand and thus for greenhouse gas emissions. The understanding of the elements and factors which control this relationship is considered essential for developing climate change resilient cities as well as for supporting sustainable urban planning.

In particular, plans for resilient cities to climate change demand up-to-date and area-wide information on the characteristics and development of the urban system, both regionally and locally. Key information in this context is the detailed assessment of such urban parameters as (a) land use/land cover changes, including changes in urban green, (b) local wind circulation patterns, (c) air temperature and land surface temperatures, and (d) presence and strength of the urban heat island and heat waves.

It should be mentioned that the role of land in resilience, climate change, and the mitigation of greenhouse gases has received less attention than energy systems [12].

This is despite the fact that evidence from urbanized regions, where land use activities have resulted in significant changes to land cover, suggests land use to be a significant and measurable driver of climate change as well as one that operates through a physical mechanism independent of emissions of greenhouse gases. In light of the above, a plan for a climate-resilient city should increase the ability of a city to survive a climate change-related shock as well as to change in the event of outside shocks which are due to climate change.

Plans for resilient cities need to include actions that touch on awareness raising, capacity building, infrastructure, ecosystems, and development of knowledge and institutions [13]. An important question in urban resilience is how to plan robust infrastructural solutions in the face of climate change and how to integrate these solutions in city planning.

Plans for resilient cities to climate change need to also identify vulnerable social groups and deal with the disproportionate exposure to climate risk of vulnerable groups [14–17]. Such exposure may be due to such factors as poor-quality building stock, poor infrastructure at the neighborhood scale, low-income households, poor spatial planning, etc.

4 Building Resilient Cities to Climate Change

Cities need be designed with the strength to resist natural and technological hazards, the flexibility to accommodate extremes without failure, and the capacity to recover quickly from disaster impacts [18]. A set of principles of resilient systems that need to be taken into account for the design and planning of cities are provided in [19]. The set refers in particular to such principles as redundancy, diversity, efficiency, autonomy, strength, interdependence, adaptability, and collaboration. Special weight needs to be given to redundancy and interdependence. The former is associated to a system design with multiple nodes so as to ensure that failure of one element or component of the system does not result in the entire system to fail. The latter is linked to an integrated system with its components supporting each other.

In line with the above, city administrators need to record and assess city operations and define the multiple subsystems as well as their stable states and their respective terminal points. They also need to define the “communication corridors” between the subsystems, in an obvious effort to recognize the parameters and factors which by controlling or affecting the stability or instability of a subsystem may also influence the state of another subsystem. To this end, the recognition of the internal (interaction) patterns and processes within the city system is considered a major precondition for designing a system capable to adapt and adjust to changing internal or external processes. In most cases, cities are approached as a collection of structures, that is, with limited consideration to the internal patterns and processes from social, economic, ecological, environmental, and development points of view.

5 Cities' Overheating: The Case of the Urban Heat Island

Heat island is the more documented phenomenon of climate change in cities. Studies have started at the beginning of the twentieth century, and data exists for almost all major cities in the world. Heat island is the phenomenon where ambient temperature in specific parts of the city is higher than the corresponding temperature in rural or suburban areas. Higher urban temperatures are associated with a more positive heat balance in the urban areas compared to the heat balance in the surrounding rural areas.

The magnitude of the urban heat island is expressed using a parameter called urban heat island intensity which is the average maximum difference of the recorded ambient temperature between the urban and the rural stations. In many heat island studies, heat island intensity is defined as the average annual temperature difference or the absolute maximum recorded temperature difference. The intensity of the urban heat island is a function of many parameters. The most important are:

(a) The synoptic climatic conditions in the concerned area and in particular the wind speed and cloud cover. It is usually reported that heat island takes its maximum intensity during calm and clear days. However, this is not always the case as local phenomena like sea breezes influence the thermal balance of a place not in a similar way.
(b) The local topographical characteristics, like the presence of mountains or water bodies close to the area.
(c) The city characteristics, like the urban density, the urban form, the type of materials used, the sky view factor in the urban canyons, the anthropogenic heat released, etc. Areas using dark absorbing materials, having a high thermal capacity, tend to absorb and store heat during the daytime, while heat is released during the night increasing the urban temperature. Also, in urban canyons with a low sky view factor, infrared radiation emitted by the various surfaces in the canyon cannot escape to the space, and the near-surface canyon temperature is increasing.
(d) The characteristics of the considered rural station. In many studies reporting the urban heat island characteristics, the selected "rural" station is highly influenced by the urbanization process and is not really representative. In other cases, the selected rural station is highly influenced by local phenomena like sea breeze and does not reflect in reality the temperature conditions in the considered rural area.

To measure the characteristics of the urban heat island, three monitoring procedures are used and applied:

(a) The use of conventional and standard meteorological stations. This type of stations presents usually a very high accuracy; however, they cannot be placed in dense urban zones, where heat island takes its maximum.
(b) Miniature temperature sensors placed in meteorological boxes. Their advantage is that they can be placed almost everywhere; however, attention has to be taken to avoid problems of thermal disturbance of the stations by the surrounding environment.

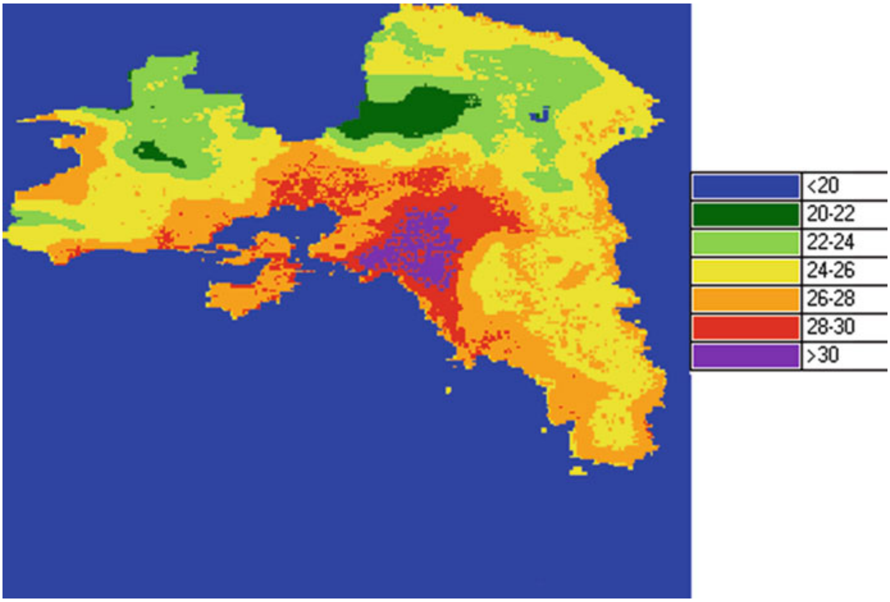

Fig. 1 Spatial distribution of land surface temperature (deg Celsius) in the Attica region during nighttime. The presence of the surface urban heat island is easily recognized

(c) Measurements performed by mobile stations during specific periods. Such a monitoring procedure offers a very good coverage of the considered zone; however, it is usually performed for a limited period of time.

More information and data about the characteristics of the urban heat island may be found in [20].

It should be also mentioned that in several studies, the surface urban heat island (SUHI) may be used reflecting the distribution of land surface temperature (LST) instead of ambient temperature. LST varies in cities, as materials used in construction reflect differences in heat capacity, heat conductivity, albedo, emissivity, and permeability. On the other hand, rural surfaces present totally different properties depending on the types of land they are composed. For instance, rural surfaces mostly occupied by dry bare soil are characterized by a low thermal inertia, meaning that they exhibit large changes in diurnal surface temperature (Fig. 1).

To measure the strength of the SUHI phenomenon, the SUHI intensity (ΔT) is used, generally defined as the difference between the maximum urban surface temperature and the background rural one [21]. Under calm and clear weather conditions, daytime ΔT usually acquires its largest values as solar radiation affects LST. In addition the nocturnal urban–rural differences in LST are much smaller than in daytime, as strong solar heating can lead to larger temperature differences between dry surfaces and wet, shaded, or vegetated surfaces.

Daytime ΔT may be weak after sunrise or even negative at midday, meaning that urban surfaces are cooler than those of the surrounding countryside ("cool island"). The main reason for the development of a "cool island" over a city near the midday hours is a lag in urban surface warming due to the heat storage capacity of the building materials and the extensive shading of some parts of the city by tall buildings or other natural structures located in the surrounding fields (i.e., mountains). On the other hand, SUHIs on calm, cloudless nights are considered most pronounced, with the effects of street canyon geometry on radiation and of thermal properties on heat storage release, being the primary and almost equal causes on most occasions.

SUHI studies are performed with the use of satellite data in the thermal infrared part of the electromagnetic spectrum. Data need to be of relatively high spatial resolution so as to understand the spatial intra-urban variability of SUHI through LST mapping. This requirement is of particular importance in the case where the study area reflects an urban area of moderate size or a region of particular concern within a city. Moreover, satellite SUHI studies require high revisit time so as to estimate SUHI intensities at a frequent basis as well as to estimate and map the thermal inertia of the urban landscape, which helps to understand the roles that individual components of the city (such as parks, industrial complexes, etc.) play in the thermal patterns of the city [22]. This requirement is particularly important if the link between SUHI intensity and air pollution is to be explored [23] or if satellite-derived LST is used to calculate energy parameters, such as the cooling degree days [24], or bioclimatic parameters, such as the thermal discomfort index [25, 26].

The impact of the urban heat island on the human thermal comfort is important. In urban environments, the commonly prevalent high temperatures, especially during the summer period, that produce the urban heat island effect also tend to worsen the comfort conditions of the city dwellers [26]. Human discomfort can be evaluated through a number of theoretical and empirical biometeorological indices usually requiring such input parameters as air temperature, wind speed, air humidity, etc. Figure 2 shows the spatial representation of thermal comfort in the wider urban agglomeration of Athens, as estimated during days with high ambient temperatures, in summer months. Areas with poor thermal comfort practically coincide with the urban agglomeration of Athens. The improvement of thermal comfort—or the avoidance of episodes of poor thermal comfort especially in the city centers or suburbs—reflects a major precondition for a resilient city to climate change.

6 On the Energy and Environmental Impact of Urban Heat Island

Increased urban temperatures have a serious impact on the energy consumption of buildings used for cooling purposes. In parallel, they support the increase of the concentration of urban pollutants and in particular of tropospheric ozone, while they

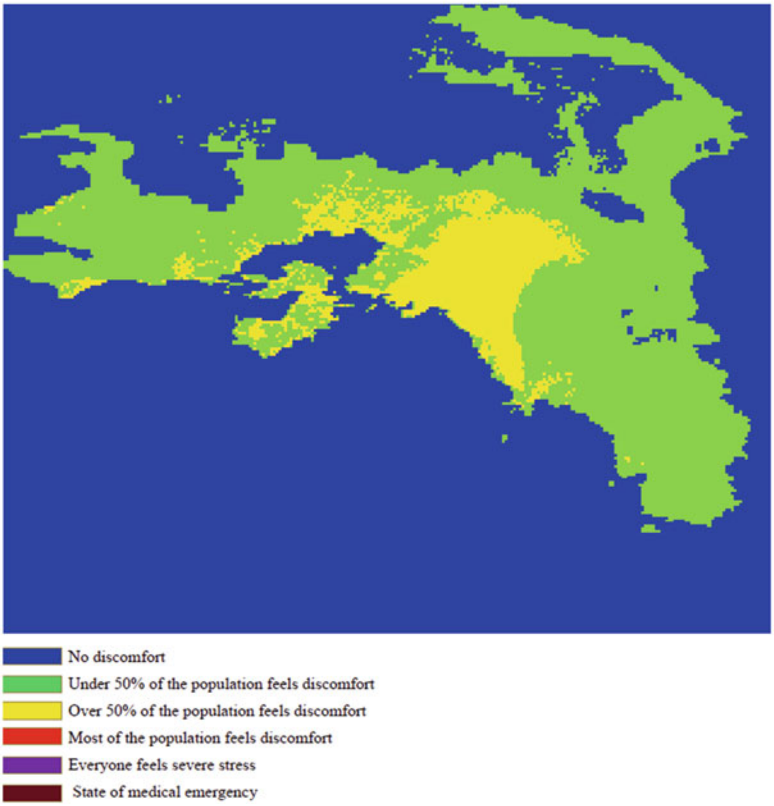

Fig. 2 Spatial distribution of thermal comfort in the Attica region during nighttime

deteriorate thermal comfort conditions in open urban zones [27]. In parallel, recent research has shown that urban heat island has a serious social impact on low-income population as it increases extensively indoor temperatures during the summer period [28]. Finally, UHI has an important impact on the global environmental performance of cities increasing considerably their ecological footprint [29].

The energy impact of urban heat island is very well documented. Urban overheating increases the peak electricity demand for electricity and the absolute electrical energy consumption in cities. It is well known that urban overheating increases substantially the peak electricity demand. In particular, it is reported that for each degree of temperature rise, the corresponding increase of the peak electricity load is between 0.45 and 4.6 %. This is equivalent to an additional electricity penalty of about 21 (±10.4) W per degree of temperature increase and per person [30]. At the same time, it is found that the actual increase of the electricity demand per degree of temperature increase varies between 0.5 and 8.5 %.

Apart from the important increase of the electricity demand, higher urban temperatures increase the cooling load of individual buildings, and in parallel, it decreases their heating demand. Analysis of most of the existing studies aiming to evaluate the energy penalty induced by the urban heat island to individual buildings has shown that in cooling-dominated climates the energy penalty during the summer period is much higher than the corresponding decrease of the heating demand [31]. As expected, in heating-dominated climatic zones, the decrease of the heating demand because of the ambient temperature increase is significant and counterbalances highly the possible increase of the cooling demand. The overall analysis has shown that for all the reported studies, involving many types of individual buildings, the average increase of the cooling load induced by the urban heat island is close to 13 % [31]. The exact cooling penalty is a function of many design and operational characteristics of the considered buildings, and for sure, the average figure reported previously may change when additional studies are carried out and reported.

7 On the Health Impact of Urban Heat Island

Average annual temperatures estimated for the period 2070–2100 indicate that urban population in European cities will feel as if the climate of the city has moved southward [5]. Heat waves are likely to increase in severity, frequency, and duration in the future, resulting in heat mortality in cities in both developed and developing countries. In particular the urban heat island effect can have negative public health effects in urban areas. For instance, in the 2003 European heat wave, most casualties occurred in cities [32]. In addition, urban heat island may affect local atmospheric cycles and may result in the increase of the concentrations of air pollutants such as the ozone which can exacerbate chronic respiratory diseases and cause problems in lung functions [33].

8 Urban Heat Island Mitigation Techniques

Important mitigation technologies aiming to decrease urban ambient temperatures are proposed and applied all around the work. The main objective of the specific mitigation techniques is to reduce the heat surplus in a city by decreasing the sensible and latent heat produced and generated or by dissipation to urban heat to an environmental sink of lower temperature.

Among the most known urban heat island mitigation techniques are [34]:

(a) The use of cool materials applied in buildings and urban structures
(b) The use of additional urban green in cities and buildings
(c) The reduction of the anthropogenic-generated heat
(d) The use of heat sinks like the ground or the water to dissipate the excess urban heat

(e) The use of advanced and traditional urban solar control devices to decrease the surface temperature of the urban fabric
(f) The use of urban ventilation techniques to enhance the airflow in cities and promote passive ventilative cooling

Most of the above techniques and technologies are applied in many projects around the world and have delivered very significant results.

In particular, the use of cool/reflective materials in building roofs or in pavements seems to be the more promising technology [35]. Reflective materials are characterized by a high reflectivity in the solar spectrum together with a high thermal emissivity. Reflective materials can be white or colored. Cool colored materials present a high reflectivity in the near infrared compared to conventional materials of the same color [36]. Comparative assessment of the surface temperature of high reflective white materials against conventional white materials has shown that it is possible to reduce surface temperatures up to 10 K [37]. Almost a similar surface temperature reduction is achieved when cool colored reflective materials are used [38].

Cool colored reflective materials are extensively used on the roof of buildings to increase solar reflectance and reduce the thermal input to the buildings. The possible energy benefits depend highly on the characteristics of the building and or the region; however, the maximum indoor temperature during the summer period may reduce by 1–5 K [39]. The possible reduction of the cooling load in air-conditioned buildings may vary between 10 and 40 % as a function of the building and local climate characteristics. In parallel, the possible increase of the heating penalty induced by cool roofs is much lower that the cooling benefit, at least in the cooling-dominated climates. As it concerns the possible contribution of reflective roofs on the city scale, detailed calculations on the possible impact of cool roofs on the energy balance of a city have shown that an extensive use of cool roofs technology may reduce the maximum ambient temperature in a city up to 1.5 K [39].

Recent research aiming to develop new advanced cool materials presenting a higher capacity for thermal mitigation has resulted into the development of thermochromic materials [40]. These materials are able to change their color as a function of their surface temperature. Thus, they may present a very high albedo during the summer period and also a low albedo during the winter period. Intensive research is actually carried out to improve the durability of the materials.

In parallel, in order to increase the thermal capacitance of the reflective materials and their surface temperature, phase change nano-ingredients are integrated into the existing reflective materials [41]. Testing of nano-PCM doped reflective materials has shown that it is possible to further reduce the surface temperature by 1.5–2 K compared to the conventional reflective materials.

The use of reflective materials for pavements has gained a very increasing acceptance during the last years. Cool pavements decrease the surface and ambient temperature and improve comfort in open spaces. Cool pavements may have the form of concrete tiles or asphaltic surfaces or other types, and they present a much lower surface temperature compared to conventional materials [42, 43]. The

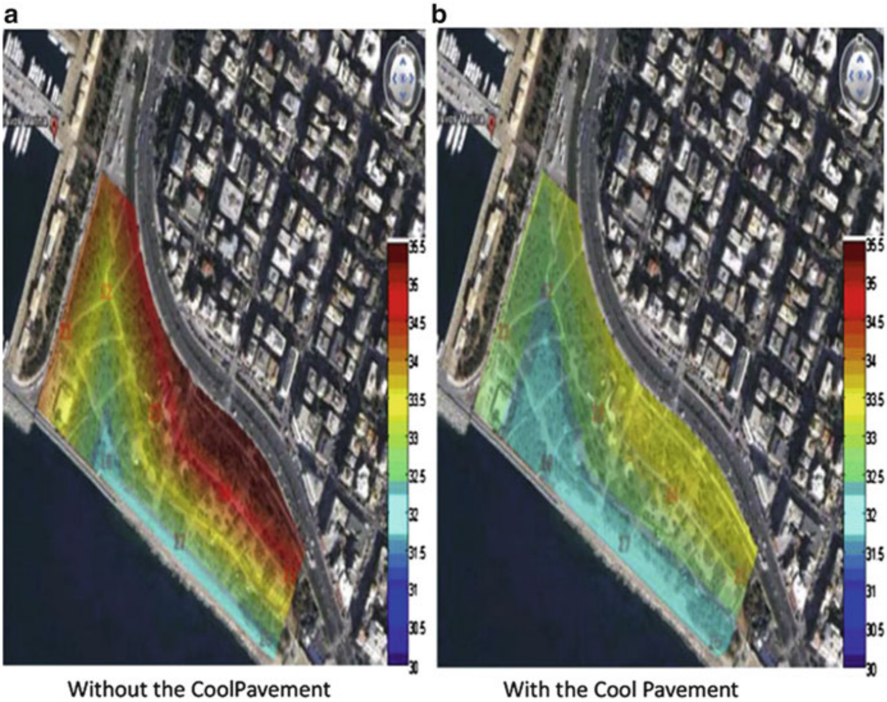

Fig. 3 Spatial distribution of the ambient temperature in the rehabilitated coastal park, before and after the use of cool pavements [43]

extensive use of reflective tiles in a coastal urban park in Athens has permitted to decrease substantially the maximum summer ambient temperature [44]. Extensive monitoring of the rehabilitated zone has shown that the maximum summer ambient temperature is reduced up to 2 K. Figure 3 shows the distribution of the ambient temperature in the considered zone under the same climatic conditions before and after the application of the reflective pavements [44, 45].

Reflective pavements are used in many projects around the world, but few of them are monitored and the results are reported. Analysis of all the published cases has shown that cool pavements can reduce the average ambient temperature up to 1.0 K (Fig. 4) and the maximum ambient temperature up to 3.5 K (Fig. 5) [44].

Green roofs are fully or partially covered by vegetation and plants growing in a medium over a waterproof membrane. Two types of green roofs are available: intensive roofs that are covered by shrubs and small trees and extensive roofs which are lighter and are covered by a thin layer of vegetation. Green roofs present many important advantages like decreased energy consumption, better management of the rainwater, better air quality and noise management, etc. [45]. Several studies carried out have shown that green roofs installed in buildings may reduce significantly the peak summer temperatures and the cooling load of the building [45]. In general, the

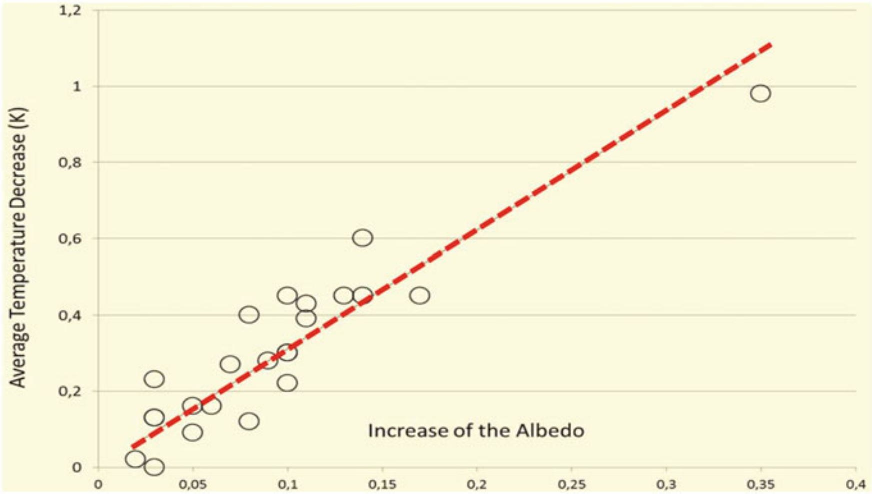

Fig. 4 Relation between the increase of the albedo in a city and the corresponding decrease of the average ambient temperature. Data are from existing projects reported in [44]

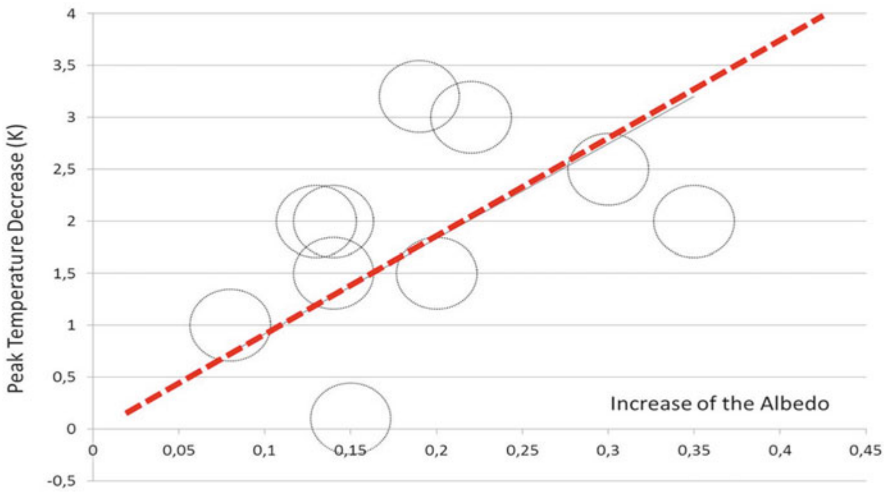

Fig. 5 Relation between the increase of the albedo in a city and the corresponding decrease of the peak ambient temperature. Data are from existing projects reported in [44]

mitigation potential of green roofs is high and contributes significantly to reduce urban ambient temperatures.

A comparison of the mitigation potential of green and reflective roofs is performed in [45]. It is reported that when the albedo of the cool roofs is higher than 0.7, then the mitigation potential of cool roofs is always higher. For lower

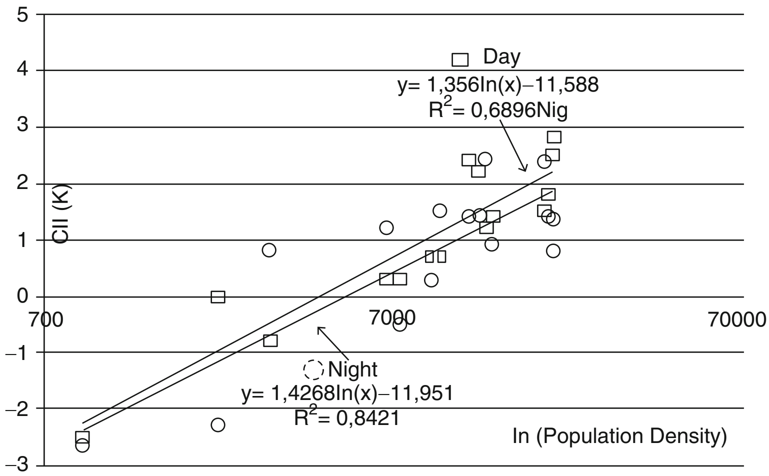

Fig. 6 Relation of the daytime and nocturnal cool island intensity with the population density [46]

albedo values, it seems that well-irrigated green roofs present a higher potential. Green roofs may present a higher or similar mitigation potential than the cool roofs when the latent heat losses are higher than 400 W per square meter. However, the impact of weatherization on the thermal performance of reflective roofs has to be considered as well.

Urban trees provide solar protection and decreased ambient temperatures mainly because of the evapotranspiration mechanism. At the same time, urban trees and parks filter pollutants, mask noise, and prevent erosion. Several studies are available concerning the specific climate inside and around urban parks. A recent review is given in [46].

The specific temperature decrease inside urban parks may vary as a function of the characteristics of the park and the properties of the surrounding zones. The reported nighttime cool island developed inside parks varies between 0.5 and 10 K, while the corresponding daytime cool island varies between 0.3 and 7 K [47]. A statistically significant relation between the nocturnal and daytime cool island in a park and the corresponding urban density is found and reported in [46], Fig. 6. As shown, the higher the urban density in a place, the higher the cooling island of an urban park.

The climatic impact of urban parks in the surrounding zones depends highly on the size of the park, the density of the urban areas around it, the anthropogenic heat generated, and the specific weather conditions. In many cases, the impact of a park is reduced just in some meters. In general, it is accepted that under average conditions, the thermal impact of a park is extended between 300 and 400 m. Figure 7 shows the specific temperature distribution along two different traverses in an urban park in Athens, Greece. As shown, the temperature distribution varies considerably as the density and the weather conditions were very different.

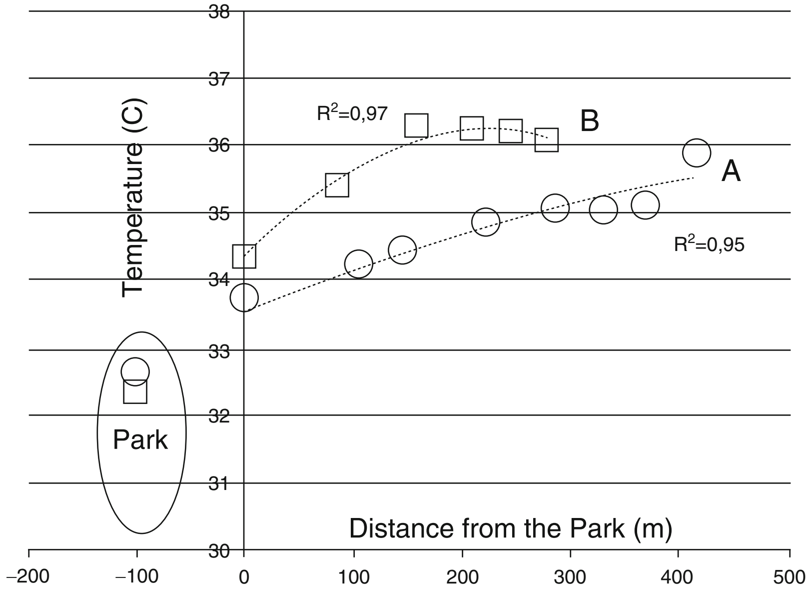

Fig. 7 Distribution of the average ambient temperature along two different traverses around a park in Athens [46]

The use of cool heat sinks to dissipate the excess urban heat and thus decrease urban ambient temperatures is discussed in [47]. Evaporative techniques using injection of very small water droplets is a well-known technique widely used in dry climates. The use of the ground for heat dissipation is considered in many case studies as well. This is achieved through the use of earth to air heat exchangers buried at a certain depth and where the ambient air is circulated and cooled. The use and the performance of such a system are described in [48].

9 The Role of Spatial Planning in Strengthening Urban Resilience

The link between urban heat island and urban sprawl is considered critical as the more urbanized an area becomes, the higher the intensity of the heat island and consequently the demand for electricity (cooling needs). Figure 8 shows the urban sprawl as defined in the Attica region from 1988 to 2007 [49]. In the left part of the figure, the extent with years of the urban area in km^2 is provided, whereas in the right part of the figure, a depiction of the urban sprawl is provided as areas in red reflect additions to the urban web of Athens in the course of the years from 1988 to 2007.

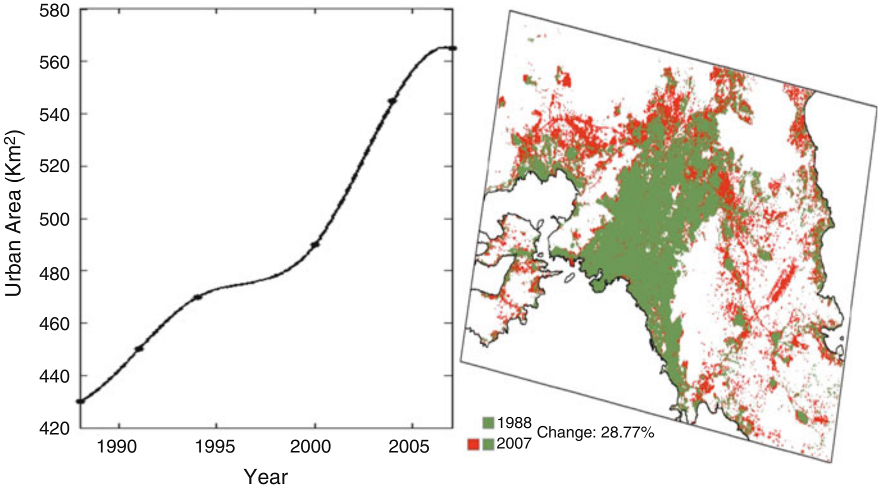

Fig. 8 Expansion of Athens with years in km^2 (*left image*) and urban sprawl for the period 1988–2007 [49]

It is interesting to note that as density (population/km^2) increases in urban areas (a process described as densification), both per capita electricity demand [33] and total energy demand in urban areas decrease [50, 51]. For instance, Denmark's urban areas are denser than Finland's by a factor of four, and people there consume around 40 % of the electricity consumed by the people in Finland.

In general terms, building resilient cities to climate change is associated to spatial planning as the latter gives geographical expression to the economic, social, and environmental policies of local societies [11, 52–54]. Therefore, spatial planning is one of the fields which provide the infrastructures that are necessary for resilient cities and at the same time controls or even restricts urban sprawl. Spatial planning systems in Europe are fragmented [11, 54], a fact which weakens the potential for a uniform plan toward urban resilience at the regional scale. This implies that urban resilience needs to be built by means of a wide set of interventions at the city scale. Such interventions have to be closely related so as to maximize their potential and allow for synergies to be developed. Spatial planning has been linked to climate change adaptation strategy [11] in terms of the measures to be taken for land use/land cover, control of urban sprawl, flood management, etc., and also encouraged European cities to move toward more compactness on the basis of environmental and quality of life objectives. In 2009, the Japanese Government (Ministry of Land, Infrastructure, Transport and Tourism) introduced the concept of "Eco-Compact City" as one of the top priority urban policies. The compact city strategy aims to intensify urban land use through a combination of higher residential densities and centralization, mixed land uses, high degrees of street connectivity, high degree of impervious surface coverage, and development limits outside the urban area concerned [55].

10 Strategic Urban Planning for Climate Change

Long-term strategic planning needs to take into consideration the vulnerabilities of urban areas to climate change. The basic elements of strategic urban planning are to periodically document the type and significance of vulnerabilities of urban areas due to climate change, to analyze urban pressures, to identify local capacity to act, to link city growth plans to climate change, to introduce mitigation technologies in city planning, and to assess long-term impacts and benefits of policy options [56, 57]. Yet, a number of barriers to climate resilience in cities do exist.

The incapacity of cities to integrate in their resilience plans the needs of the most vulnerable and marginalized in the urban community is discussed in [58]. Urban areas with weak governance systems—as a result of political instability, immature local government structures, lack of services of metropolitan character, limited coordination between the public and private sectors, exclusion of climate change from the local or central government political agenda, favoring of short-term, over long-term, planning, etc.—demonstrate limited capacity to introduce resilience in urban planning [59]. In addition urban resilience may not be met if coordination between local governments and local economic institutions is not achieved. The need to develop urban development models which will be inclusive for all parts of the population, thus promoting equity, needs to be recognized. This is considerably important as the globalization patterns developed in the last two decades shift power from the state to the private sector, a fact which may result in spatial segregation in the event that private interest is concentrated in some parts of the city only. To this end, a potential barrier to building resilient cities to climate change may be the reduction of the range and extent of state policies for the poorest and the most vulnerable ones.

As an example the increasing rates of households experiencing energy poverty in the western suburbs of Athens have been well documented [58]. It has been also documented [60] that Athens may be considered a “dichotomized” city, in the sense that a NW to SE axis traverses the urban agglomeration, separating municipalities in two main categories (in terms of their gross domestic product, the prevailing environmental conditions, the job opportunities, etc.): those which rank high in environmental, economic, and social parameters and those which rank low. In this case, the plan for resilience cities to climate change should also include measures supporting convergence and cohesion so as it has the potential to last in time and any social and economic drawbacks to be effectively challenged.

References

1. International Council for Local Environmental Initiatives.: http://resilient-cities.iclei.org/resilient-cities-hub-site/about-the-global-forum/resilient-cities-2011/ (2011)
2. International Council for Local Environmental Initiatives.: http://resilient-cities.iclei.org/resilient-cities-hub-site/about-the-global-forum/resilient-cities-2012/ (2012)

3. International Council for Local Environmental Initiatives.: http://resilient-cities.iclei.org/resilient-cities-hub-site/about-the-global-forum/resilient-cities-2013/ (2013)
4. Intergovernmental Panel for Climate Change.: In: Core Writing Team, Pachauri, R.K., Reisinger, A. (eds.) Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, p. 104. IPCC, Geneva, Switzerland (2007)
5. Intergovernmental Panel for Climate Change.: Climate Change 2013 The Physical Science Basis, Working Group I Contribution to the Fifth Assessment Report of the Intergovernmental Panel for Climate Change (2013)
6. European Environment Agency.: Climate Change, Impacts and Vulnerability in Europe 2012 an Indicator-Based Report, Report No 12/2012, p. 300 (2012)
7. Pickett, S.T.A., Cadenasso, M.L., Grove, J.M.: Resilient cities: meaning, models, and metaphor for integrating the ecological, socio-economic and planning realms. Landsc. Urban Plann. **69**, 369–384 (2003)
8. Cartalis, C.: Towards resilient cities – a review of definitions, challenges and prospects, advances in building energy research. (2014)
9. OECD: Environmentally Sustainable Buildings: Challenges and Policies. OECD, Paris (2003)
10. Berkowitz, A.R., Nilon, C.H., Hollweg, K.S. (eds.): A New Frontier for Science and Education. Springer, New York (2003)
11. European Commission: An EU strategy on adaptation to climate change. COM **216**, 11 (2013). Final
12. European Environment Agency.: Adaptation in Europe – Addressing Risks and Opportunities from Climate Change in the Context of Socio-Economic Developments, Report No 3/2013, p. 136, (2013)
13. Tyler, S., Reed, S., Maclune, K., Chopde, S.: Planning for urban climate resilience: framework and examples from the Asian cities climate change resilience network, Boulder, ISET Working Paper, p. 68, (2010)
14. Baccini, M., Biggeri, A., Accetta, G., Kosatsky, T., Katsouyanni, K., Analitis, A., Anderson, H.R., Bisanti, L., D'Ippoliti, D., Danova, J.: Heat effects on mortality in 15 European cities. Epidemiology **19**, 711–719 (2008)
15. Confalonieri, U., Menne, B., Akhtar, R., Ebi, K.L., Hauengue, M., Kovats, R.S., Revich, B., Woodward, A.: Contribution of working group II to the fourth assessment report of the intergovernmental panel on climate change. In: Parry, M.L., Canziani, O.F., Palutikof, J.P., van der Linden, P.J., Hanson, C.E. (eds.) Human Health. Climate Change 2007: Impacts, Adaptation and Vulnerability, pp. 391–431. Cambridge University Press, Cambridge, UK (2007)
16. Laurent, F., Cassadou, S., Médina, S., Fabres, P., Lefranc, A., Eilstein, D., Le Tertre, A., Pacsal, L., Chardon, B., Blanchard, M., Declercq, C., Jusot, J.F., Prouvost, H., Ledran, M.: The relation between temperature, ozone, and mortality in nine French cities during the heat wave of 2003. Environ. Health Perspect. **114**(9), 1344–1347 (2006)
17. Hemon, D., Jugla, E.: The heat wave in France in August 2003. Rev. Epidemiol. Sante Publique **52**(1), 3–5 (2004)
18. Santamouris, M., Argiroudis, K., Georgiou, M., Livada, I., Doukas, P., Assimakopoulos, M.N., Sfakianaki, A., Pavlou, K., Geros, V., Papaglastra, M.: Indoor air quality in fifty residences in Athens. Int. J. Vent. **5**(4), 367–380 (2007)
19. Henstra, D., Kovacs, P., McBean, G., Sweeting, R.: Background Paper on Disaster Resilient Cities. Institute for Catastrophic Loss Reduction, Toronto/London, ON (2004). http://www.dmrg.org/resources/Henstra.et.al-Background
20. Santamouris, M. (ed.): Energy and Climate in the Urban Built Environment. James and James Science Publishers, London (2001)
21. Mihalakakou, G., Santamouris, M., Papanikolaou, N., Cartalis, C., Tsagrassoulis, A.: Simulation of the urban heat island phenomenon in Mediterranean climates. J. Pure Appl. Geophys. **161**, 429–451 (2004)
22. Stathopoulou, M., Synnefa, A., Cartalis, C., Santamouris, M., Karlessi, T., Akbari, H.: A surface heat island study of Athens using high resolution satellite imagery and measurements

of the optical and thermal properties of commonly used building and paving materials. Int. J. Sustain. Energ. **28**, 59–76 (2009)
23. Lo, C.P., Quattrochi, D.A.: Land-use and land cover change, urban heat island phenomenon, and health implications: a remote sensing approach. Photogramm. Eng. Rem. Sens. **69**, 1053–1063 (2003)
24. Statophoulou, M., Cartalis, C., Keramitsoglou, I.: Thermal Remote Sensing of Thom's Discomfort Index (DI): Comparison with In Situ Measurements. SPIE Symposium, Brugges (2005)
25. Stathopoulou, M., Cartalis, C., Chrysoulakis, N.: Using midday surface temperature to estimate cooling degree-days from NOAA-AVHRR thermal infrared data: an application for Athens, Greece. Sol. Energ. **80**, 414–422 (2005)
26. Polydoros, A., Cartalis, C.: Assessing thermal risk in urban areas – an application for the urban agglomeration of Athens. Adv. Build. Energ. Res. (2014)
27. Santamouris, M., Kolokotsa, D.: On the impact of urban overheating and extreme climatic conditions on housing energy comfort and environmental quality of vulnerable population in Europe. Energ. Build. In Press (2014)
28. Sakka, A., Santamouris, M., Livada, I., Nicols, F., Wilson, M.: On the thermal performance of low income housing during heat waves. Energ. Build. **49**, 69–77 (2012)
29. Santamouris, M., Paraponiaris, K., Mihalakakou, G.: Estimating the ecological footprint of the heat island effect over Athens. Greece Clim. Change **80**, 265–276 (2007)
30. Santamouris, M., Cartalis, C., Synnefa, A., Kolokotsa, D.: On the impact of urban heat island and global warming on the power demand and electricity consumption of buildings – a review. Energ. Build. In Press (2015)
31. Santamouris, M.: On the energy impact of urban overheating on buildings. Energ. Build. **82**, 100–113 (2014)
32. Hallegate, S., Henriet, F., Corfee-Morlot, J.: The economics of climate change impacts and policy benefits at city scale: a conceptual framework, Environment Working Paper, No. 4, OECD, Paris (2008)
33. OECD.: Cities, climate change and multilevel governance, Environmental Working Papers, OECD, Paris (2009)
34. Santamouris, M., Adnot, G. (eds.): Cooling the Cities, Editions des Ecoles des Mines, Paris. Distributed by Eyrolles, France (2004)
35. Santamouris, M., Synnefa, A., Kolokotsa, D., Dimitriou, V., Apostolakis, K.: Passive cooling of the built environment – use of innovative reflective materials to fight heat island and decrease cooling needs. Int. J. Low Carbon Tech. **3**(2), 71–82 (2008)
36. Santamouris, M., Synnefa, A., Karlessi, T.: Using advanced cool materials in the urban built environment to mitigate heat islands and improve thermal comfort conditions. Sol. Energ. **85**, 3085–3102 (2011)
37. Synnefa, A., Santamouris, M., Livada, I.: A study of the thermal performance of reflective coatings for the urban environment. Sol. Energ. **80**(8), 968–981 (2006)
38. Synnefa, A., Santamouris, M., Apostolaki, K.: On the development, optical properties and thermal performance of cool colored coatings for the urban environment. Sol. Energ. **81**, 488–497 (2007)
39. Kolokosta, D., Santamouris, M., Zerefos, S.C.: Green and cool roofs' urban heat island mitigation potential in European climates for office buildings under free floating conditions. Sol. Energ. **95**, 118–130 (2013)
40. Karlessi, T., Santamouris, M., Apostolakis, K., Synnefa, A., Livada, I.: Development and testing of thermochromic coatings for buildings and urban structures. Sol. Energ. **83**(4), 538–551 (2009)
41. Karlessi, T., Santamouris, M., Synnefa, A., Assimakopoulos, D., Didaskalopoulos, P., Apostolakis, K.: Development and testing of PCM doped cool colored coatings to mitigate urban heat island and cool buildings. Build. Environ. **46**(3), 570–576 (2011)
42. Santamouris, M.: Using cool pavements as a mitigation strategy to fight urban heat island — a review of the actual developments. Renew. Sustain. Energ. Rev. **26**, 224–240 (2013)

43. Santamouris, M., Gaitani, N., Spanou, A., Saliari, M., Gianopoulou, K., Vasilakopoulou, K.: Using cool paving materials to improve microclimate of urban areas – design realisation and results of the Flisvos project. Build. Environ. **53**, 128–136 (2012)
44. Santamouris, M.: Cooling the cities – a review of reflective and green roof mitigation technologies to fight heat island and improve comfort in urban environments. Sol. Energ. **103**, 682–703 (2014)
45. Sfakianaki, E., Pagalou, E., Pavlou, K., Santamouris, M., Assimakopoulos, M.N.: Theoretical and experimental analysis of the thermal behaviour of a green roof system installed in two residential buildings in Athens, Greece. Int. J. Energ. Res. **33**(12), 1059–1069 (2009)
46. Skoulika, F., Santamouris, M., Boemi, N., Kolokotsa, D.: On the thermal characteristics and the mitigation potential of a medium size urban park in Athens, Greece. Landsc. Urban Plann. **123**, 73–86 (2014)
47. Santamouris, M., Kolokotsa, D.: Passive cooling dissipation techniques for buildings and other structures: the state of the art review article. Energ. Build. **57**, 74–94 (2013)
48. Fintikakis, N., Gaitani, N., Santamouris, M., Assimakopoulos, M., Assimakopoulos, D.N., Fintikaki, M., Albanis, G., Papadimitriou, K., Chryssochoides, E., Katopodi, K., Doumas, P.: Bioclimatic design of open public spaces in the historic centre of Tirana, Albania Original Research Article. Sustain. Cities Soc. **1**(1), 54–62 (2011)
49. Chrysoulakis, N., Mitraka, Z., Stathopoulou, M., Cartalis, C.: A comparative analysis of the urban web of the greater Athens agglomeration for the last 20 years period on the basis of Landsat imagery. Fresen. Environ. Bull. **22**, 2139–2144 (2013)
50. Kamal-Chaoui, L., Alexis, R. (eds.): Competitive Cities and Climate Change, OECD Regional Development Working Papers No 2, 2009, OECD Publishing (2009)
51. IEA.: World Energy Outlook 2009, OECD/IEA, Paris (2009)
52. Grazi, F., van den Bergh, J., van Ommeren, J.: An empirical analysis of urban form, transport and global warming. Energ. J. **29**(4), 97–122 (2008)
53. Ruth, M., Coelho, D.: Understanding and managing the complexity of urban systems under climate change. Clim. Pol. **7**, 317–336 (2007)
54. Council of Europe.: European Regional/Spatial Planning Charter (1983)
55. Churchmann, A.: Disentangling the concept of density. J. Plan. Lit. **13**(4), 389–411 (1999)
56. Tyler, S., Reed, S., Maclune, K., Chopde, S.: Planning for urban climate resilience: framework and examples from the Asian cities climate change resilience network, Boulder, ISET Working Paper, p. 68 (2010)
57. Godschalk D.R.: Urban hazard mitigation: creating resilient cities. Plenary paper presented at the Urban Hazards Forum, John Jay College, City University of New York (2002). http://www.arch.columbia.edu/Studio/Spring2003/UP/Accra/links/GodshalkResilientCities.doc Accessed 22–24 Jan 2002
58. Santamouris, M., Paravantis, J.A., Founda, D., Kolokotsa, P., Michalakakou, A.M., Papadopoulos, N., Kontoulis, A., Tzavali, E., Stigka, K., Ioannidis, Z., Mexil, P., Matthiessen, A., Servou, E.: Financial crisis and energy consumption: a household survey in Greece. Energ. Build. **65**, 477–487 (2013)
59. United Nations.: Cities and Climate Change: Policy Directions, Global Report on Human Settlements, United Nations Human Settlements Program, Earthscan, London (2011)
60. Stathopoulou, M., Iacovides S., Cartalis, C.: Quality of life in Metropolitan Athens. Using satellite and census data – comparison between 1991 and 2001. J. Heat Island Inst. Int. (2012)

Evaluation and Reliability of Shape Grammars for Urban Planning and Network Design

Basil J. Vitins and Kay W. Axhausen

Abstract Shape grammars are increasingly applied in urban simulations and are promising tools for urban design, e.g., in procedural modeling. Shape grammars are interdisciplinary, straightforward, understandable planning tools, which potentially have the chance to overcome the complexity of urban design. Applications of grammars and rule-based methods could be found in cognate fields of architecture, urban and transport planning, geometry, and also in mathematics, and computer sciences.

Applications of shape grammars are described exemplarily for various fields of science. It is found that often a profound evaluation of the effect of certain shape grammar rules is missing in literature. Therefore, a set of four approaches is proposed in this chapter (1) to establish theory of grammars and rule-based approaches, (2) to evaluate existing shape grammar rules, (3) to generate and extract new shape grammars, and (4) to verify complex system wide shape grammars. The four approaches are exemplarily applied in the field of road transport network design; however, migration to urban planning and architecture seems promising for future applications. Reliability is addressed in the evaluation methods to tackle uncertainties in planning.

Keywords Shape grammar • Rule • Intersection type choice • Urban Simulation • Delay • Reliability • Network • Optimization • Meshedness

1 Introduction

This chapter focusses on advances in the development of shape grammars for urban planning, in particular for transport network design. Network design and urban form strongly interact with each other. Shape grammars are applied in various cognate fields of urban planning and are potentially able to overcome the complexity and interdisciplinary in urban design. March [30], Stiny and Mitchell [38], Lehnerer

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[29], and Duany et al. [14] already applied shape grammars to a certain extent in cognate fields of network design such as architecture and urban planning. An overarching theoretical approach and evaluation methods are proposed in this chapter for shape grammars. The approaches and methods are verified in network design; however, it is claimed that they are also applicable in an urban planning and architectural environment.

There is clear evidence that our current society relies on efficient transport systems [e.g., 5, 46]. Scaling effects increase productivity and social welfare of our society. However, transport networks are complex and interdependent, e.g. with urban planning, architecture, information, and energy supply networks. Thus, society aims at a reliable and robust transport system to absorb changes in demand without major infrastructure changes. The importance of reliable networks has increased even more for transport systems due to their limited capacity in parallel with their crucial function as a backbone for our economic system. So, the current transport systems have to fulfill two major tasks: The system should be as efficient as possible, while at the same time reliable and robust to short- and long-term changes.

To fulfill these tasks, authorities and responsible organizations face major challenges due to the characteristics and complexity of urban networks. The first important characteristic is the decentralization in any given network topology. With some exception graphs such as radial trees with root nodes (hub-and-spoke network), or Cayley trees with root nodes and hierarchical levels [12], transport networks lack predefined hierarchies within the set of elements of a graph G, such as nodes (v) and edges (e), e.g. the definition of centralized objects [28]. A priori, v and e lack of an order or relevance, also, e.g., for reliability and robustness improvements [e.g., 17]. Peripheral or minor edges might be as relevant, regarding reliability and robustness, as centralized and major edges [e.g., 26]. The lack of order or relevance differs from many biological networks with tree graphs, described, e.g., in [47]. Biological networks, such as vascular systems in plants, generally are more affected at a disfunction of an edge e closer to the root node. Lämmer et al. [28] confirm these findings and state that for transport networks the "topological organisation is less obvious and a hierarchical structure similar to a Cayley tree is not found at all" [28, p. 95]. The second characteristic is the lack of decomposition of a given urban network into independent subnetworks (subgraphs G_n) similar to the decomposition of a mathematical formula, and therefore the potential reduction in complexity. This holds again for most graphs, except, e.g., radial graphs with root nodes. The second characteristic implies that network elements and their attribute (a_{v_n}, a_{e_n}) might depend on other attributes $\{a_{v_n}, a_{e_n}\} = f(\mathbf{a})$. An example of the potential dependencies of the attributes is the nonlinear problem of travel demand assignment under intersection delay considerations [33, p. 213]. Another example is the design and choice of road types, which might depend on urban densities. Overall, both characteristics might be obvious, but explain the vast complexity arising in network design.

Knowing about the ever increasing relevance of transport systems in conjunction with their complexity, plans and recommendations are required and expected for proper and improved transport system and urban designs. Recommendations are essential for planners, and authorities for settlement development. Moreover, recommendations can be bequeathed to future generations, adapted, and improved for future changes and increasing efficiency.Often, design recommendations can be formulated as rules. Rules are more adaptive in their application, compared to, e.g., predefined rigid design patterns. In the following, they are referred to as shape grammar rules as a general expression, which includes recommendations. The definitions of shape grammar rules for planning are relevant research tasks, due to the required interdisciplinary and fundamental knowledge, and potential universal applications of the new recommendations.

Following paragraphs sketch existing results on shape grammar rules in academia and practice. Drawing on existing academic literature, at least six major research directions can be identified with examples, in urban planning and cognate fields. (1) An architectural example is provided, e.g., by Stiny and Mitchell [37], who developed and applied grammar rules for the Palladian villa style. Lehnerer [29] described elements, building blocks, and corresponding grammar rules for building plans. (2) In transport network design, Marshall [31] focusses on streets and patterns and underlying grammar rules, e.g. for road type choice. Van Nes [44] evaluated and optimized road and public transportation networks and characteristics, such as road spacings and densities. (3) In urban planning, Duany [14] focussed on an urban code, related to the New Urbanism movement [e.g., 21]. Southworth and Ben-Joseph [34] presented qualitative designs for a functional, livable, and economic city. (4) In geometry, Stiny [36] implemented shape grammars for paintings and sculptures. Prusinkiewicz and Lindenmayer [32] proposed the L-System, which consists of rules and an alphabet of symbols, making larger and more complex systems possible through recursion, such as plant morphologies. (5) Mathematics and operations research have focussed on rules for a longer time. Logic defines an alphabet, which consists of terms, symbols, and rules, such as the "=" symbol. In operations research, e.g. evolutionary algorithms apply rules for optimization. (6) In computer science, an increasing number of urban models and simulations have been developed in recent years [e.g., 18, 43] based on procedural methods to simulate and visualize urban areas. The seminal books of Alexander et al. [3] and Alexander [2] cover aspects of (1), (2), (3), and can be seen as a cornerstone in the development of grammars, also for future development, maybe even in (6).

Beside academic literature, norms and design guidelines are well-known platforms for recommendations about network design for both transport and urban planning for practitioners and authorities. Network design guidelines [e.g., 1, 20, 22, 23, 52] discuss only some aspects of urban design and network topology. The "Urban Street Geometry Design Handbook" [23] focusses on road types and hierarchical design, conflict points at intersections, and intersection spacing. "A Policy on Geometric Design of Highways and Streets" [1] proposes hierarchical designs and a focus on technical design and road geometry. The "Planning and Urban Design Standards" [4] elaborates also on hierarchies and connectivity within network design. High connectivity is recommended for future city design and discussed for multiple urban network layouts. Both the “Urban Street Geometry Design Handbook” and “Planning and Urban Design Standards” contain elements of the new urbanism movement [e.g., 15].

Multiple advantages occur when applying a rule-based approach in urban and transport planning. Shape grammar rules can be efficiently applied by network designers and spatial planners without extensive transportation knowledge. Shape grammar rules require low computational costs and are more adaptive in their applications. They have the potential to overcome the complexity of transport networks. Moreover, shape grammar rules of various disciplines can be joined for completeness and for an encompassing design language.

Despite the various past developments and vast expert knowledge in network design, the consensus on “best practice” in urban network design is currently vague. It is found that also some of the planning recommendations are vague, while others merely rely on past examples and are incomplete. Often, recommendations for dense or congested urban road network design are not covered in the guidelines, even though networks are faced with high demands in urbanized areas. There is a lack of fundamental knowledge about the effect of different network designs. Especially the new urbanism movement proposes new design ideas, but often relies on qualitative data for research and practice. Recommendations on reliability and robustness improvements are often missing in the guidelines. A lack of knowledge is problematic especially due to the issues discussed above, namely the increasing number of applications and the complexity of network design. Especially, there is a lack of methodology in the actual development and evaluation of rules, despite their increasing applications in e.g., urban simulations.

This chapter contributes to the fundamental knowledge on urban design and shape grammars. It claims that quantitative evaluations of shape grammar rules shed more light on the effect of shape grammar rules. Therefore, theory on the language concept is elaborated for shape grammar rules as well as three approaches for quantitative evaluation and derivation of shape grammar rules. The approaches are able to crystallize potential grammars and evaluate rules for network design. Additionally, it could be found that during evaluation of shape grammar rules, more insights are gained for network design, serving as additional knowledge for future planning.

2 Applications of Shape Grammar Rules

Example applications of design rules can be found worldwide in new districts and growing cities. Many applications are due to the large ongoing urbanization around the globe and growing urban centers. Additionally, after natural disasters, such as earthquakes or tsunamis, economies and transport supply need to recover as quickly as possible. Beside designing new districts, existing urban areas are under constant changes regarding demand and supply. Existing areas have to address new or changing requirements in living or commercial areas, such as changing travel demand. In existing urban areas, authorities are urged to maintain the level of service in the light of changing requirements, and therefore have to rely on planning recommendations.

Researchers and practitioners have applied shape grammar rules in urban planning and cognate fields, sometimes to an increasing extent in recent years, e.g. in urban simulations. Some fields have overlapping aspects, such as transport network design, which are considered in both urban planning and transportation. Shape grammars are applied to simulate urban growth [e.g., 45, 56] or urban redesign [e.g., 9, 57]. Figure 1 shows examples of shape grammar rules, each corresponding to plans which are visualized in Fig. 2. Both Figs. 1 and 2 are explained in the following. An encompassing list of shape grammar rules and additional examples are provided in [48].

Figures 1a and 2a refer to rules available for transport planning and network design. The Swiss norm for transport network design [51] specifies a strong hierarchical design for road types, in which adjacent road links differ in one

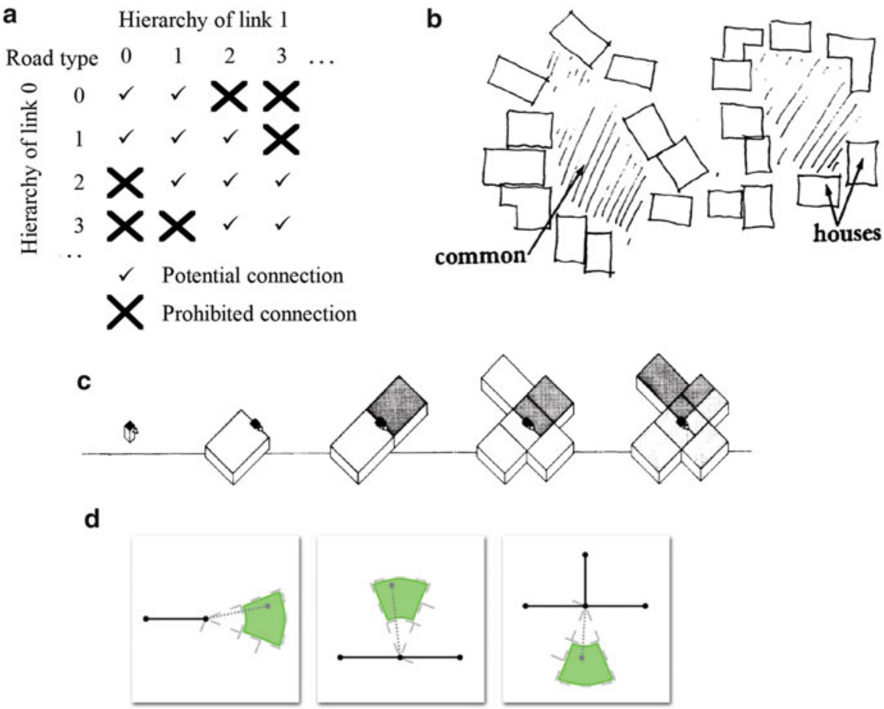

Fig. 1 Examples of shape grammar rules in transportation, urban planning, architecture, and computer science. (**a**) Shape grammar rule for hierarchical network design, adjacent road links should differ in one hierarchy at most. (**b**) Clustering of about 8–12 houses around some common land and paths [3, p. 202]. (**c**) The beginning of a prairie-style house, with a center fire place and rooms adjacent in a butterfly shaped composition [35, p. 13]. (**d**) The design and geometry of a new road element [56, p. 5]

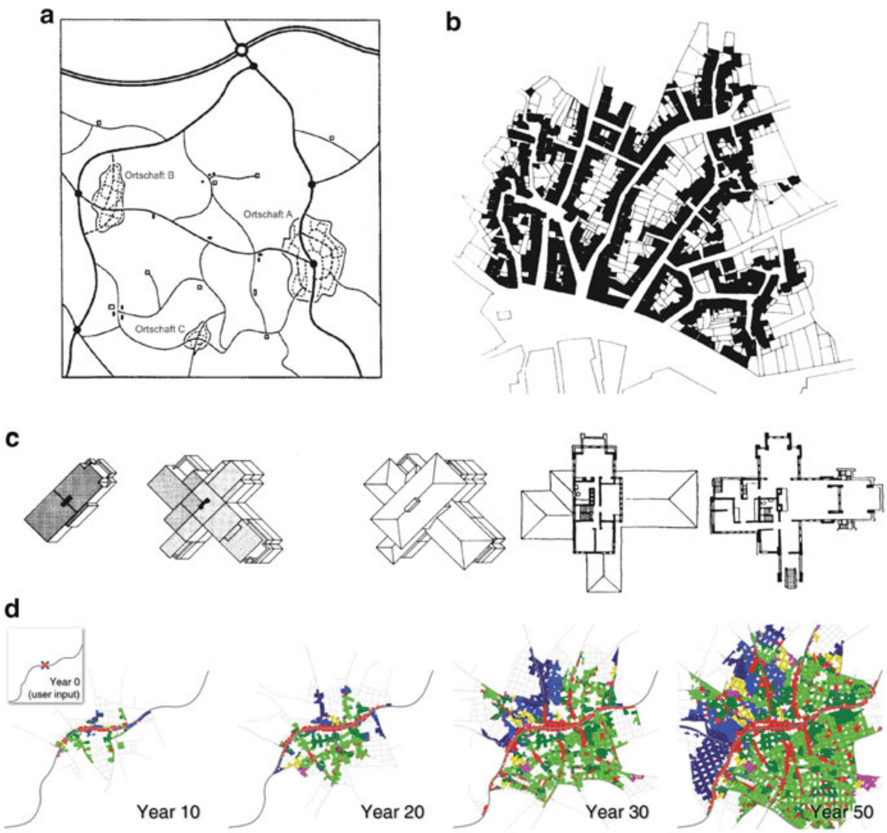

Fig. 2 Examples of grammar rule applications in transportation, urban planning, architecture, and computer science, related to the rules in Fig. 1. (**a**) The Swiss norm for road network design [51, p. 5]. (**b**) Example city design of Alexander et al. [3, p. 190]. (**c**) Prairie house from Stiny [35, p. 12] built on grammar rules. (**d**) Simulation of a city and its growth, including various land use types [56, p. 4]

hierarchy level at most (Fig. 1a). Figure 2a shows an example network of the current Swiss norm for network design. Figure 1b refers to urban planning and visualizes the recommendation of housing clusters around some common land, to support quality of the neighborhood, and increase comfort of the inhabitants. Figure 2b exemplarily shows a city quarter after the application of multiple rules of Alexander et al. [3], among others the clustering rule.In architecture, similar approaches are applied when comparing to urban planning above. Rules are defined for the design and construction of new buildings, such as the specification of rooms and their spatial relation. Figure 1c visualizes the design grammar of a prairie house, based on the ideas of Lloyd Wright [35], and Fig. 2c shows the final building and floor plan. In computer science, rule-based approaches are widely applied especially in programming languages. Grammar rules can be directly implemented in computer codes. Figure 1d shows an example schema which defines direction and length of new roads, related to the road design of the previous development steps. The outcome of this and additional grammar rules is displayed in Fig. 2d.

3 Potential Study Designs for Grammar Evaluations

This chapter improves the understanding of the effect of shape grammar rules. Different study designs are proposed and explained for the evaluation of shape grammar rules. Figure 5 shows a schematic overview of four proposed study designs, whereas study design 0 covers the underlying theory and theoretical requirements. Multiple study designs are proposed because shape grammar rules can be diverse in their content and complexity. Some rules describe the overall and general topology, like the T-junction rule of Alexander et al. [3], while others describe very specific designs, such as boulevards, which implies specific design on very limited space. Obviously, the definition and validation of one rule might differ from the validation of the other rule. Four study designs are proposed separately to overcome the diversity of shape grammar rules and corresponding verification problems.

3.1 Study Design 0: Theoretical Foundation

Study design 0 aims at a discussion of the theoretical aspects of shape grammars for a complete and sound definition of shape grammar rules for urban planning. The goal of study design 0 is to evaluate if the concept of shape grammar rules is sound and feasible in a theoretical and qualitative way (Fig. 5a), and that prerequisites for shape grammars and the necessary definitions are known. Study design 0 is required as a theoretical foundation, for further quantitative evaluation methods.

3.2 Study Design 1: Straightforward Application of Shape Grammar Rules

Study design 1 focusses on existing and defined shape grammar rules, which lack evaluations. In study design 1, shape grammar rules are applied and evaluated systematically in different network scenarios, and eventually compared with a reference scenarios without rules (Fig. 5b). This allows a quantitative comparison of scenario 1 (after implementation) and scenario 0 (before implementation). Therefore, evaluation can be conducted based on the differences between scenarios 1 and 0. The methodology of study design 1 is similar to standard scenario

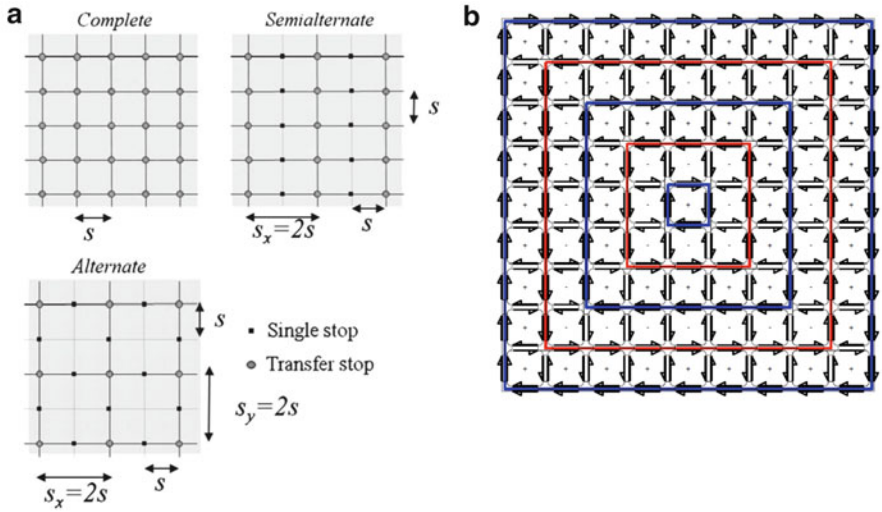

Fig. 3 Implementation of specific network rules, including evaluation, according to study design 1. (**a**) Public transport network design and different stop types [19, p. 940]. (**b**) Specific intersection types and turn restrictions [16, p. 10]

evaluations. However, study design 1 focusses primarily on rules, their effect, and the enhancements of rules. It is important that rules are not evaluated themselves as stand-alone rules, but their effects on networks or study areas.

Two examples of an application of study design 1 are provided in Fig. 3. Figure 3a refers to the design of public transport networks (also described in, e.g., [44]). Public transport networks consist of many variables, such as stop type and spacing, or line densities. Figure 3a shows three public transport networks designed according to certain rules [19]. The three networks are evaluated and compared regarding an objective function. Additional parameters, such as spacing, are evaluated as well in the mentioned research. Figure 3b refers to Eichler et al. [16], who determined specific intersection types and turn configurations, and evaluated network patterns in multiple example gridiron networks. Eichler et al. [16] applied study design 1 and evaluated the resulting network regarding travel distance changes. Both examples in Fig. 3 describe network conditions with implemented infrastructure changes. This allows a comparison between condition 1 (after implementation) and condition 0 (before implementation).

3.3 Study Design 2: Optimization and Derivation

Study design 2 extracts rules from already designed networks. Study design 2 is only applicable if it is known which networks are efficient and already optimized. Study design 2 assumes that optimized networks feature certain characteristics, which can be determined and extracted for future recommendations and shape grammar rules. Then, the designed and optimized networks are statistically evaluated regarding potentially significant characteristics. Multiple networks are needed to be evaluated for statistical analyses and significance. New rules are extracted and statistically justified under various transport conditions. Figure 5c shows a scheme of the proposed study design 2.

Figure 4 shows existing applications of study design 2. Figure 4a,b refers to spatial optimization methods, whereas Fig. 4c,d refers to statistical evaluations. Two examples for spatial optimization are provided in Fig. 4a,b. Figure 4a refers to the project [27]. The software developed in this project simulates and evaluates iteratively urban scenarios. The software is applied in parcel relocation and optimization, dependent on certain changeable parameters. The software designs and optimizes urban scenarios, but excludes grammar rule extraction. Figure 4b shows a network on a featureless plane with self-evolutionary structures, evaluation and

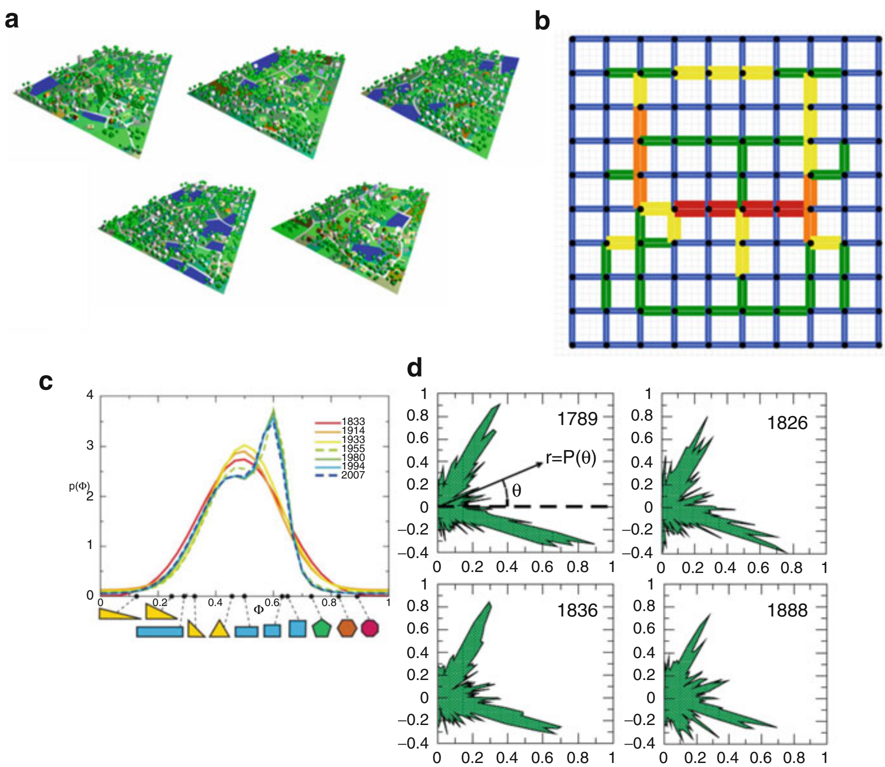

Fig. 4 Implementation and optimization methods for spatial planning. (**a**) The software Kaisersrot [27] generates and optimizes parcel distributions. (**b**) Self-evolutionary networks design and their evaluation, e.g., at evolution of ring structures [57]. (**c**) Distribution of parcels and its changes over time [39, p. 4]. (**d**) Angle distribution and historical evolution of the network of Paris [7, p. 6]

investment models for optimized road and intersection type choice. Both examples in Fig. 4a,b optimize scenarios based on infrastructure changes. In study design 2, it is additionally suggested that network characteristics are extracted from the optimized scenarios. Figure 4c,d depicts two example approaches from literature, each focussing on statistical evaluation of network characteristics. Figure 4c shows the evaluation of a real-world parcel shape distribution, based on multiple existing road networks. Figure 4d depicts the angle distribution of a descriptive evaluation.

Two issues potentially occur applying study design 2. First, the problem of increasing complexity hampers the design and optimization of large networks considerably. Therefore, reasonable assumptions are necessary to narrow down the vast search space size. Second, study design 2 lacks reference networks similar to study design 1. Therefore, approach study design 2 does only allow statistical analyses of a set of networks under consideration.

3.4 Study Design 3: Implementation and Comparison

Study design 3 focusses on more complex shape grammars compared to study design 1, such as road type choice and design (e.g., Fig. 1a). While certain shape grammars can be implemented and evaluated right away, other shape grammars are less concrete in their implementation (e.g., hierarchical network design). Especially rules, which affect the entire network topology, are more complex and study design 1 cannot be applied right away for evaluation. In study design 3, the shape grammar rules are defined first and then applied and implemented within a network design method. Network scenarios are designed and optimized based on the designated shape grammar rule and an underlying design method, e.g. as shown in Fig. 4a,b. Study design 3 proposes to apply shape grammar rules during the scenario design and optimization, and therefore contrasts study design 2.

Quantitative and statistical evaluation measures compare the network designs with a comparison set of reference networks designed without the designated shape grammar rule, or with a set of networks designed with a different shape grammar rules. Examples of network evaluations are given in Fig. 4c,d. Furthermore, the evaluations take places under various patterns, such as variable travel demand, to gain additional insights. However, it is emphasized that shape grammar rules are not evaluated in isolation but after application in different network conditions. Figure 5d depicts the comparison method of Study design 3 schematically.

3.5 Objective Function

Objective functions are needed for evaluation purposes in the proposed study designs methods (Sects. 3.2–3.4). This chapter focusses on shape grammar rules and evaluations for transport network design. Objective functions for transport planning

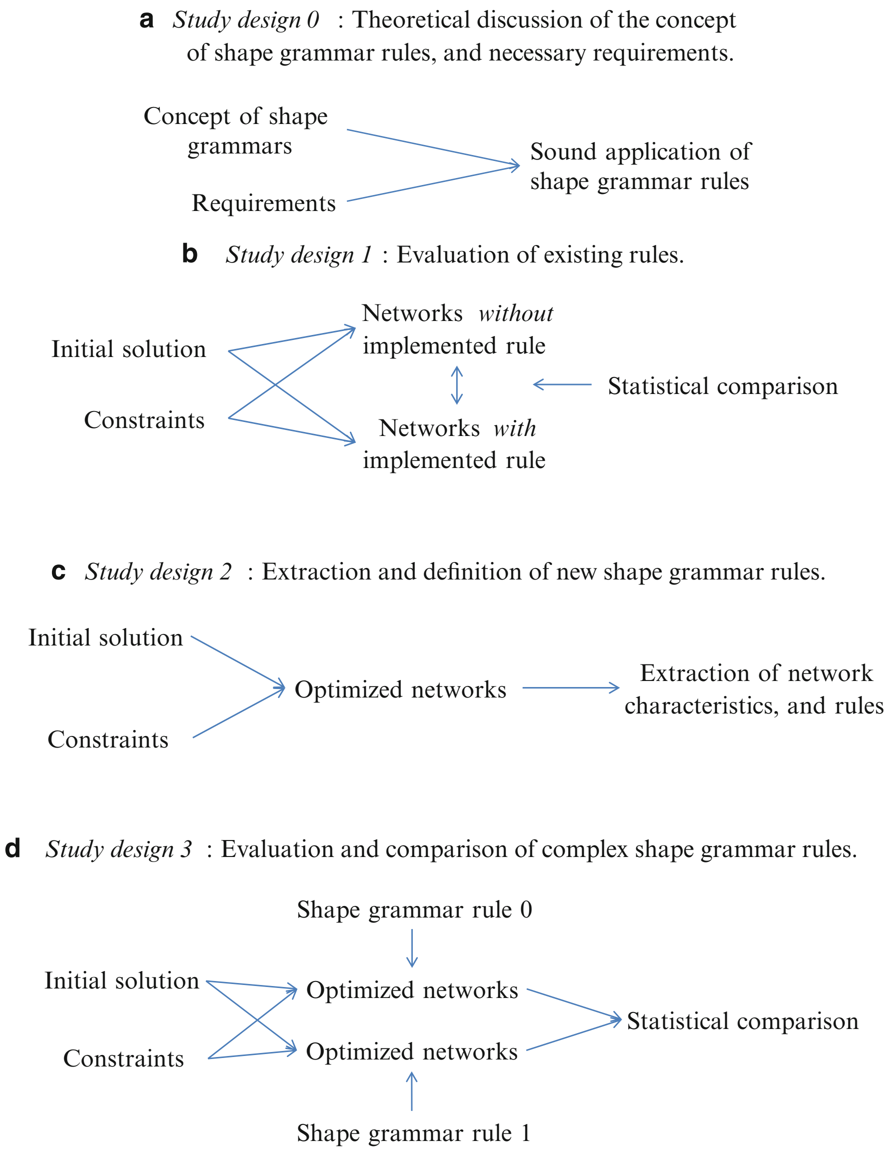

Fig. 5 Applied study designs to tackle research questions 0–3

purposes are relatively straightforward. However, evaluations can be extended with additional functions. For example, Bramley and Power [9] evaluated social sustainability regarding urban form and housing types.

Transport economics and guidelines for cost–benefit analyses (CBA) propose a large set of evaluation methods and corresponding parameters mainly for infrastructure changes [e.g., 54]. CBA considers user costs, infrastructure costs, and additional impacts discounted for a reference year. Focussing on the external effects, existing studies and norms define costs for noise, air pollution, and climate changes [53], or car accidents [55]. Also based on economics, accessibility A is a widely accepted and applied measure [e.g., 6]. A can be calculated for location i, for example, as $A_i = \sum_{\forall j} \cdot X_j \cdot e^{-\beta c_{ij}}$ with X_j as attractiveness of location j, $\beta = 0.2$ and c_{ij} = travel time between i and j.

Three objective functions are used in Sect. 4. The first function is based on the CBA and contains generalized travel costs. The second function contains accessibility based on population and job densities. The third function is based on the external costs, namely noise, air pollution, climate effects, and accidents.

3.6 Maximum Supply Approach

Multiple methods and measures exist for network reliability, robustness, resilience, etc. This section focusses on one aspect in urban planning, which is particularly uncertain and mostly varies over time: the level of travel demand. The uncertainty is due to gradually or unexpected changes in urban densities, e.g. population, jobs, leisure facilities, or changes in travel behavior due to cost or technological changes.

The proposed method especially accounts for unknown future travel demand (similar to, e.g., [19] or [8]), and shape grammar evaluation (Sect. 3). Therefore, the method assesses the maximum increase in urban density a network could cater for, without unacceptable travel time increases $\Delta d_{\text{structuraldata}}\left(\Delta t^{x\%}\right)$, when d is the urban density (jobs, population, ...) and $\Delta t^{x\%}$ the travel time difference. The focus is on travel time due to its importance in economic measures. An upper bound is assumed for travel time changes $\left(20\,\%\text{inthefollowing}, \rightarrow \Delta d_{\text{structuraldata}}\left(\Delta t^{20\,\%}\right)\right)$, which is achieved by gradually increasing urban densities. An average peak hour demand is defined for each density based on census data. Obviously, travels demand depends on other activities, daytime, mode share, car occupancy, which are ignored in this evaluation for simplicity. The aim is to determine how much urban densities can be increased with a given area and network design, but without an unacceptable increase in travel time. The major advantage of this approach is its focus on the relative difference and reduced dependence on transport infrastructure density, such as total lane length, as seen below in Sect. 4.4.

4 Study Designs for Road Network Design

Four study designs were described in Sect. 3 for the evaluation of different shape grammar rules. They are applied and discussed in the following.

4.1 Language Approach for Urban Design (Study Design 0)

This section focusses on the theoretical justification of shape grammars. Grammar $\mathcal{G}$ consists of rules $\mathcal{R}$, similar to a syntax. $\mathcal{R}$ are responsible for the "mechanics" of a certain language $\mathcal{L}$. For example, Stiny and Gips [36] described rules for geometric shapes and provided an abstract definition. However, it is stated that grammars do not only consist of rules. In addition to rules, $\mathcal{G}$ consists of semantics $\mathcal{S}$. In transport and urban planning context, $\mathcal{S}$ is basically responsible for all the information except the rules itself. In particular, $\mathcal{S}$ contains information about the effect of $\mathcal{R}$, such as effect on efficiency, safety, livability, etc. This is regarded as essential for the definition and improved application of rules. Moreover, $\mathcal{S}$ defines the application range in which the grammar rules $\mathcal{R}$ can be applied for reasonable design. For example, certain rules might be defined for urban environments, while others for rural environments.

It is assumed that the planners and designers act rationally and follow a certain overall intention, e.g. a sustainability goal or cost minimization, which are explicitly defined, or implicitly followed. The expression "objective" is deployed to define the intention in a qualitative or quantitative manner. Additionally, it is supposed that planners act in a spatially defined area, called "site," which they intend to change directly, or indirectly, through structural changes. Obviously, the phrases, clauses, or sentences are buildings, neighborhoods, or transport networks in the case of urban shape grammar applications. Figure 6 visualizes the proposed language approach. The two elements in the bottom of Fig. 6 refer to the application of shape grammars, and therefore include planners objective, site, and the resulting urban design.

Alexander et al. [3] showed an entire set of rules, and corresponding application and background information. Another example is the hierarchical network design approach of Marshall [31], which defines rules of how adjacent roads of the same or different type might be added to each other. In addition to these rules, adjacent urban land use types are defined for meaningful planning. Information about the context

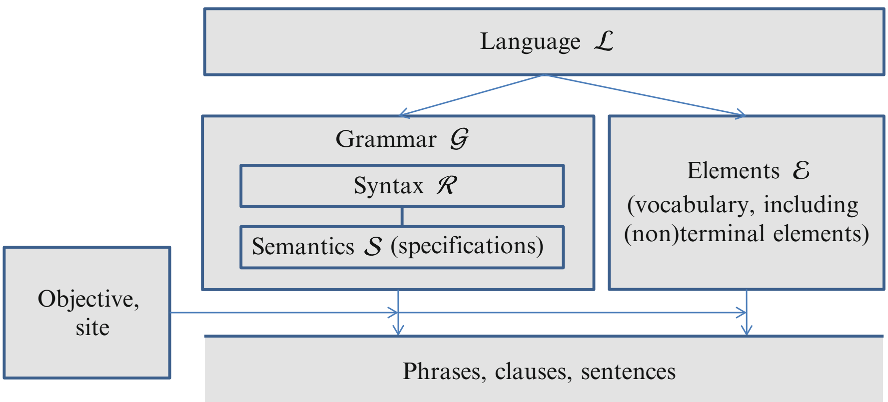

Fig. 6 Contextualized language setup for shape grammars with exogenous planner's objective

and effect of shape grammar rules seems reasonable for the definition of future shape grammar rules, and successful applications. These theoretical considerations additionally support the evaluation methods, which are presented in this chapter, and the applied underlying objective function (Sect. 3.5).

4.2 Example Shape Grammar Application (Study Design 1)

Here, a boulevard design is exemplarily evaluated for potential shape grammar rules on boulevards. For example, Jacobs et al. [25] describe multiple boulevards worldwide, with different designs. The initial boulevard design is sketched in Fig. 7a. It is implemented in a gridiron transport network model, with $100 \cdot 100$ [m^2] block size and standard road and intersection parameters [42]. Urban densities and travel demand are based on an average four-story perimeter block development of Zurich and the census data [40]. Vitins and Axhausen [48] elaborate additional evaluations and boulevard types, in addition to the design in Fig. 7a.

Figure 7b–d depicts the results of the evaluation according to the three objective functions (Sect. 3.5), depending on various boulevard lengths l. Figure 7b–d indicates overall nonlinearity of the functions. Data are therefore approximated with

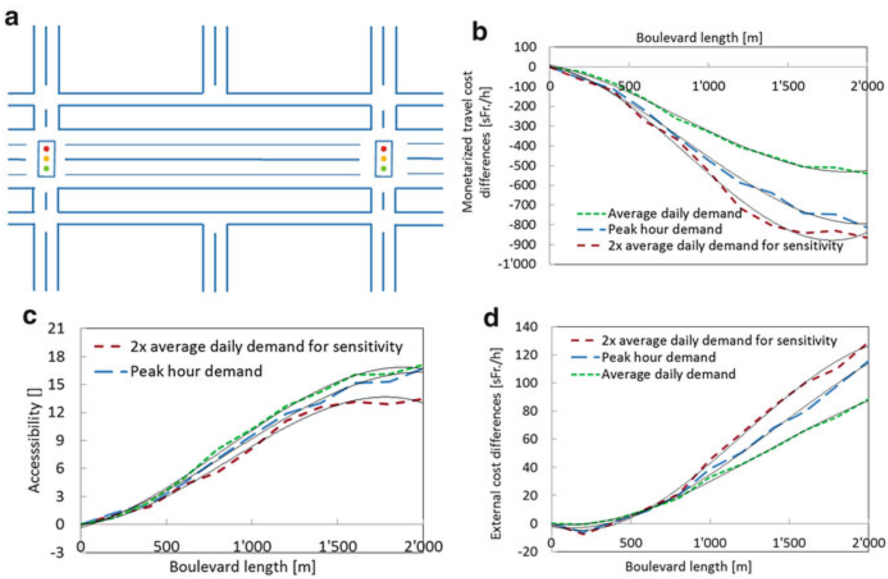

Fig. 7 Boulevard design, and the evaluation outcome as total monetarized travel time savings, accessibility changes and external effects for different boulevard lengths and network size $2 \cdot 2$ [km^2], including polynomial approximation (degree = 3). (**a**) Design of the boulevard integrated in a gridiron network. (**b**) Monetarized travel costs. (**c**) Accessibility. (**d**) External costs

a polynomial function $f(l)$. Polynomials of degree 3 are able to account for slope changes at both ends, to avoid overestimation of the data points, and still achieve a high fit (R^2). The highest slope values $f''(l_{max}) = 0$ are determined, based on polynomials of s-shapes like in Fig. 7. Figure 7 shows delimited linear intervals, allowing elasticity calculation based on linear assumption. A two-sided application range $\{l_{min}, l_{max}\}$ is proposed, in which values close to the highest slope values can be expected. An approximated elasticity ϵ^s is calculated for the subset s of the data, which is inside the interval l_{min}, l_{max}. External costs have the highest elasticities (1.7–1.9), followed by accessibility (1.3–1.4), and travel costs (1.3–1.4).

Multiple issues occurred during modeling and evaluation, which are valuable for future design recommendations and the improvement of shape grammar rules. This additional information is added in the form of shape grammar rules including application specifications, and listed below. Vitins and Axhausen [48] add additional details regarding these rules.

Rule 1: Boulevards should have a certain minimum length to achieve noticeable travel cost reduction and increasing accessibility: The minimum length is 2–3 blocks. Longer boulevards reduce travel costs and increase accessibilities.

Rule 2: Boulevards with signals at the center road have the highest travel cost and accessibility elasticities $\epsilon^{s,T}$, $\epsilon^{s,A}$.

Rule 3: Travel speed on the boulevards has to be higher than on parallel roads, even when implementing signals with uniform waiting time.

Rule 4: The capacity of the center road has to be high enough to serve the flows. At least two center lanes for each directions are advisable.

Rule 5: Boulevards reduce generalized travel costs of urban traffic if the major intersections at the center road provide enough capacity and low turn delays for the required flows. This holds also for the crossings of the boulevard, which might be bottlenecks for crossing traffic. At least 3 approaching lanes for the major intersections are advisable.

Rule 6: Boulevards have a benefit-to-cost ratio of $\frac{b}{c} > 1.0$ only if the land prices are relatively low for acquisition. Obviously, boulevards as proposed above should be designed in an early stage of urban design. If not, additional economical studies and effects [e.g. 46] might be considered, beyond a standard cost–benefit procedure.

The above rules were derived with the following assumptions and evaluation methods (application specifications).

- A static model is used for all evaluations with detailed intersection delay calculations [HCM, 42], but ignoring spill-over effects.
- Urban density of 15,068 [pers/km^2] and 6,685 [jobs/km^2] are assumed, including peak hour and sensitivity flows which correspond to a 4-story perimeter development. Travel behavior is based on the Swiss census and travel diary [41].
- The boulevard is modeled in a gridiron network of $2 \cdot 2$[km^2], and $3 \cdot 3$[km^2], respectively.

4.3 Optimized Networks (Study Design 2)

Study design 2 requires optimal networks to extract shape grammar rules. Therefore, optimal networks are defined first which conform to the planning needs, such as efficiency, minimized infrastructure costs, safety, or other attributes. Two approaches are suggested to obtain these networks: First, it is possible to define real-world networks, which conform to the planning objectives. For example, Cardillo et al. [11] extracted network characteristics from multiple real-world networks. Second, artificial network models can be generated and optimized regarding the planning objectives. Detailed available models and underlying methods are available for transport simulation, some of them covering also urban simulations. Independent of these two approaches, it is required to have a large enough set of networks for statistical evaluations.

The second approach is applied in the following, and therefore, artificially designed networks are required for evaluations. For this purpose, a network design algorithm is applied, as described in [49, 50]. The algorithm deals with the nonlinear road assignment and complexity of the road network graph and therefore implements an integrated genetic and ant colony algorithm. The algorithm designs road networks or a limited spatial area, connecting demand generating blocks. Assumptions are required for the design process on the demand side, especially urban densities, and on the supply side, in particular infrastructure expenditures.

Study design 2 enables multiple evaluations, e.g. on topology or network element choice and densities. Exemplarily, the focus is on network meshedness in this section. The meshedness coefficient M (also in [10, 13]) is a sensitive graph topology measure which is defined in the following: $M = F/F_{\max} = F/(2N-5)$, where F is the number of faces of a network graph, and $F_{\max}$ the maximum possible number of faces in a maximally connected planar graph ($F_{\max} = 2N-5$), proportional to the number of nodes N [11, p. 5]. Compared to network element densities (nodes, links), and node degree, M focusses on the topology of networks by accounting for the face densities. Regarding the meshedness coefficient M, Cardillo et al. [11] found major differences on real-world networks. For example, networks of New York, Savannah, and San Francisco have values of $M > 0.3$, and in contrast to Irvine and Walnut Creek with $M < 0.1$, as shown in Table 1.

The upper half of Table 1 shows values of M for multiple network patterns. M differs considerably between the different patterns. The lower half of Table 1 shows values of M for optimized networks. These networks are modeled similar to the networks described in Sect. 4.2; however, the featureless plane is smaller ($1 \cdot 1$ [km^2]) due to the complex optimization. These networks were designed with different urban densities, travel demand, and infrastructure costs and optimized regarding low generalized user costs. Despite different intersection types, high values of M are achieved through the optimization process, including low standard deviation σ. There is evidence that networks with high M values correlate with low user costs (see also Sect. 4.4).

Table 1 Example networks (1·1 [mile^2]) and their meshedness coefficient M, based on [11], the figures in [24], and evaluations of the optimized networks

Design	Examples	M	σ	Example network
Real-world networks:				
Gridiron	Barcelona, Los Angeles, New York, Richmond, Savannah, San Francisco	0.291	0.0435	 Manhattan
Medieval	Ahmedabad, Cairo, Bologna, London, Venice, Vienna	0.229	0.0374	 Venice
Baroque	New Delhi, Washington	0.224	0.0695	 Washington
Modernist	Brasilia, Irvine (1)	0.116	0.0310	 Brasilia
Dentritic	Irvine (2), Walnut Creek	0.049	0.0350	 Irvine
Optimized networks:				
Ignoring turn delays		0.259	0.0450	
With signals		0.265	0.0411	
Right-of-way		0.266	0.0728	
With roundabouts		0.264	0.0258	

4.4 Rule Implementation (Study Design 3)

Exemplarily, this section focusses on a straightforward application of study design 3 on intersection type choice. Different intersection types are separately applied in the design of networks already mentioned in Sect. 4.3. One intersection type is applied in a single network, and entire networks with different implemented intersection types are designed similar to Sect. 4.3, and compared with each other (Fig. 5d).

Beside the rather straightforward intersection type evaluations, further examples can be found, e.g., for road type choice in network design [50].

Signals, right-of-way intersections, and roundabouts are considered in the following. All-way stop controlled intersections are ignored due to their general absence outside the USA. All intersection types are modeled with two approaching lanes for comparison reasons. Conflicting flows increase turn delays, and are considered in the delay calculations, which are based on the HCM [42].

Intersection types are sensitive to flow changes. On the supply side, variable infrastructure expenses lead to various network densities which will be considered in the following. In addition, the maximum supply approach is applied (Sect. 3.6), which means that structural densities (jobs, population) are increased until the additional travel time has reached 20 % of the free flow travel times $\left(\Delta d_{\text{pop,jobs}}\left(\Delta t^{20\,\%}\right)\right)$. Table 2 shows the relevant independent variable after a stepwise regression, when considering $\Delta d_{\text{pop,jobs}}\left(\Delta t^{20\,\%}\right)$ as dependent variable. Additionally, 2 scenarios are defined for road and intersection type sensitivity. Scenario 1 consists of street types with doubled capacity compared to scenario 0, scenario 2 consists of intersection types with an additional approaching lane; calculations are based on the HCM [42].

As shown in Table 2, d_r and M contribute significantly to high supply, in scenario 0 and 1. Again, low multicollinearity is expected between d_r and M due to higher VIF values. Additionally, the implementation of signals is significant. Right-of-way intersections only have a positive significant influence in scenario 1, but still lower than signals. The positive influence of right-of-way intersections mirrors that roundabouts might have higher delays at increasing densities. In scenario 2, right-of-way intersections have negative influence, indicating that capacities of right-of-way

Table 2 Regression result of optimized networks for $\Delta d_{\text{pop,jobs}}\left(\Delta t^{20\,\%}\right)$ as a dependent variable

Scenario	Parameter	Significance	Stand. β	Variance inflation factor (VIF)
0	Meshedness M	0.009	0.286	1.310
	Network density d_r	0.000	0.409	1.357
	Dummy signal	0.000	0.665	1.060
Significance: 0.000				
Adj. R^2: 0.688				
1	Meshedness M	0.011	0.273	1.310
	Network density d_r	0.000	0.434	1.362
	Dummy right-of-way	0.000	0.493	1.197
	Dummy signal	0.000	0.707	1.266
Significance: 0.000				
Adj. R^2: 0.705				
2	Meshedness M	0.000	0.621	1.002
	Dummy right-of-way	0.011	−0.307	1.193
	Dummy signal	0.043	0.239	1.193
Significance: 0.000				
Adj. R^2: 0.586				

intersections cannot increase to the same extent than at roundabouts and signals. Right-of-way intersections are therefore less efficient with additional lanes, and increasing flows, which also comports with the following results on intersection type choice.

In Table 2, scenario 2 shows significant values for M, signals, and right-of-way intersections. Additionally, d_r is significant even after the stepwise linear regression. However, the standardized β value of d_r is negative, in combination with M, which seems unreasonable. M and d_r are slightly correlating, as shown in scenario 0 and 1. Therefore, d_r is excluded in Table 2 in scenario 2 due to low standardized β and lower significance, compared to M.

It is therefore concluded that signals produce lower turn delays at high flows. At lower flows, right-of-way intersections have low turn delays. No significant correlation could be found for 3 and 4 arm intersections, even though they were considered in the evaluation. However, a detailed evaluation of signal delays at an isolated intersection shows lower delays at 4 arms, due to a more optimized phase allocation.

5 Conclusion

It is necessary to consolidate fundamental knowledge of shape grammars for future advances in urban planning, due to their advantages in application, and the already increasing number of shape grammar implementations. For this purpose, evaluations are required to measure the effect of rules. This chapter shows that it is possible to evaluate the effect of certain shape grammars in planning, based on well-defined, but exchangeable objective functions. The proposed maximum supply approach applied in shape grammar rule evaluation accounts for variable urban densities and reliability. Knowledge about the application perimeter and limitations of the grammar rules is fundamental for future and meaningful applications. Both aspects, the evaluation and the limitations of the rules, comports with theory and the general concept of the language approach. In the future, evaluations of additional rules will be necessary. Moreover, evaluations on urban design and architectural rules are required to increase the understanding in cognate fields.

References

1. AASHTO: A Policy on Geometric Design of Highways and Streets. American Association of State Highway and Transportation Officials, Washington (2004)
2. Alexander, C.: The Timeless Way of Building. Oxford University Press, New York (1979)
3. Alexander, C., Ishikawa, S., Silverstein, M.: A Pattern Language: Towns, Buildings, Construction. Oxford University Press, Oxford (1977)
4. American Planning Association: Planning and Urban Design Standards. Wiley, Hoboken (2006)

5. Axhausen, K.W.: Accessibility: long-term perspectives. J. Transp. Land Use **1**(2), 5–22 (2008)
6. Axhausen, K.W., Dolci, C., Fröhlich, P., Scherer, M., Carosio, A.: Constructing time-scaled maps: Switzerland from 1950 to 2000. Transp. Rev. **28**(3), 391–413 (2008)
7. Barthélemy, M., Bordin, P., Berestycki, H., Gribaudi, M.: Self-organization versus top-down planning in the evolution of a city. Sci. Rep. **3**(2153), 1–7 (2013)
8. Bell, M.G.H.: A game theoretic approach to measuring performance reliability of transport networks. Transp. Res. B Methodol. **34**(6), 533–545 (2000)
9. Bramley, G., Power, S.: Urban form and social sustainability: the role of density and housing type. Environ. Plann. B **36**(1), 30–48 (2009)
10. Buhl, J., Gautrais, J., Solé, R.V., Kuntz, P., Valverde, S., Deneubourg, J.L., Theraulaz, G.: Efficiency and robustness in ant networks of galleries. Eur. Phys. J. B Condens. Matter Complex Syst. **42**(1), 123–129 (2004)
11. Cardillo, A., Scellato, S., Latora, V., Porta, S.: Structural properties of planar graphs of urban street patterns. Phys. Rev. E **73**(6), 1–8 (2006)
12. Clark, J., Holton, D.A.: A First Look at Graph Theory. World Scientific, Teaneck (1991)
13. Courtat, T., Gloaguen, C., Douady, S.: Mathematics and morphogenesis of cities: a geometrical approach. Phys. Rev. E **83**(3), 1–12 (2011)
14. Duany, A., Sorlien, S., Wright, W.: SmartCode Version 9.2. New Urban News Publications Inc., Ithaca (2009)
15. Dutton, J.A.: New American Urbanism. Skira, Milan (2000)
16. Eichler, D., Bar-Gera, H., Blachman, M.: Vortex-based zero-conflict design of urban road networks. Netw. Spat. Econ. **13**(3), 229–254 (2013)
17. Erath, A.: Vulnerability assessment of road transport infrastructure. Ph.D. Thesis, ETH Zurich, Zurich (2011)
18. ESRI: CityEngine. http://www.esri.com/software/cityengine/ (2012). Accessed April 2012
19. Estrada, M., Roca-Riu, M., Badia, H., Robuste, F., Daganzo, C.F.: Design and implementation of efficient transit networks: Procedure, case study and validity test. Transp. Res. A: Policy Pract. **45**(9), 935–950 (2011)
20. FGSV: Richtlinien für integrierte Netzgestaltung, Norm, vol. 121. Forschungsgesellschaft für Straßen- und Verkehrswesen, Cologne (2008)
21. Haas, T.: New Urbanism and Beyond. Rizzoli, New York (2008)
22. IHT: Transport in the Urban Environment. Institution of Highways and Transportation, London (1997)
23. ITE: Urban Street Geometry Design Handbook. Institute of Transportation Engineers, Washington (2008)
24. Jacobs, A.: Great Streets. MIT Press, Cambridge (1993)
25. Jacobs, A., MacDonald, E., Rofé, Y.: The Boulevard Book. MIT Press, Cambridge (2002)
26. Johnson, D.S., Lenstra, J.K., Rinnooy Kan, A.H.G.: The complexity of network design problem. Networks **8**(4), 279–285 (1978)
27. Kaisersrot: Kaisersrot—Solutions you cannot draw. http://www.kaisersrot.com (2011). Accessed Nov 2011
28. Lämmer, S., Gehlsen, B., Helbing, D.: Scaling laws in the spatial structure of urban road networks. Physica A **363**(1), 89–95 (2006)
29. Lehnerer, A.: Grand Urban Rules. NAI010 Publishers, Rotterdam (2009)
30. March, L.: A boolean description of a class of built forms. In: March, L. (ed.) The Architecture of Forms, pp. 41–73. Cambridge University Press, London (1976)
31. Marshall, S.: Streets and Patterns. Spon Press, London (2005)
32. Prusinkiewicz, P., Lindenmayer, A.: The Algorithmic Beauty of Plants. Springer, New York (1996)
33. Sheffi, Y.: Urban Transportation Networks: Equilibrium Analysis with Mathematical Programming Methods. Prentice Hall, Englewood Cliffs (1985)
34. Southworth, M., Ben-Joseph, E.: Streets and the Shaping of Towns and Cities. Island Press, Washington (2003)

35. Stiny, G.N.: Computing with form and meaning in architecture. J. Archit. Educ. **39**(1), 7–19 (1985)
36. Stiny, G.N., Gips, J.: Shape grammars and the generative specification of painting and sculpture. In: Freiman, C. (ed.) Information Processing, chap. 6, vol. 71, pp. 1460–1465. North-Holland, Amsterdam (1972)
37. Stiny, G.N., Mitchell, W.J.: The palladian grammar. Environ. Plann. B **5**(1), 5–18 (1978)
38. Stiny, G.N., Mitchell, W.J.: The grammar of paradise: on the generation of mughul gardens. Environ. Plann. B **7** (2) 209–226 (1980)
39. Strano, E., Nicosia, V., Latora, V., Porta, S., Barthélemy, M.: Elementary processes governing the evolution of road networks. Sci. Rep. **2**, 1–8 (2012)
40. Swiss Federal Statistical Office (BFS): Mikrozensus Verkehr 2010. http://www.bfs.admin.ch/bfs/portal/de/index/infothek/erhebungen__quellen/blank/blank/mz/01.html (2010)
41. Swiss Federal Statistical Office (BFS): Mobilität in der Schweiz—Ergebnisse des Mikrozensus Mobilität und Verkehr 2010. Swiss Federal Statistical Office (BFS), Neuchatel (2012)
42. Transportation Research Board: Highway Capacity Manual. Transportation Research Board, Washington (2010)
43. UrbanVision: Urbanvision home, software. http://www.cs.purdue.edu/cgvlab/urban/urbanvision-system.html (2012)
44. van Nes, R.: Design of multimodal transport networks. Ph.D. Thesis, Technical University Delft, Delft (2003)
45. Vanegas, C.A., Aliaga, D.G., Benes, B., Waddell, P.A.: Interactive design of urban spaces using geometrical and behavioral modeling. ACM Trans. Graph. **28**(5), 1–10 (2009)
46. Venables, A.J.: Evaluating urban transport improvements. J. Transp. Econ. Policy **41**(2), 173–188 (2007)
47. Viana, M.P., Strano, E., Bordin, P., Barthélemy, M.: The simplicity of planar networks. Sci. Rep. **3**(3495), 1–6 (2013)
48. Vitins, B.J., Axhausen, K.W.: Shape grammars in transport and urban design. Paper presented at the world symposium on transport and land use research, Delft, June 2014
49. Vitins, B.J., Garcia-Dorado, I., Vanegas, C.A., Aliaga, D.G., Axhausen, K.W.: Evaluation of shape grammar rules for urban transport network design. Paper presented at the 92nd annual meeting of the transportation research board, Washington, January 2013
50. Vitins, B.J., Schüssler, N., Axhausen, K.W.: Comparison of hierarchical network design shape grammars for roads and intersections. Paper presented at the 91st annual meeting of the transportation research board, Washington, January 2012
51. VSS: Projektierung, Grundlagen - Strassentypen, Norm, SN 640 040b. Swiss Association of Road and Transport Professionals (VSS), Zurich (1992)
52. VSS: Projektierung, Grundlangen, Norm, SN 640 040b. Swiss Association of Road and Transport Professionals (VSS), Zurich (1994)
53. VSS: Kosten-Nutzen-Analysen im Strassenverkehr: Externe Kosten, Norm, SN 641 828. Swiss Association of Road and Transport Professionals (VSS), Zurich (2006a)
54. VSS: Kosten-Nutzen-Analysen im Strassenverkehr; Grundnorm, Norm, SN 641 820. Swiss Association of Road and Transport Professionals (VSS), Zurich (2006b)
55. VSS: Kosten-Nutzen-Analysen im Strassenverkehr: Unfallraten und Unfallkostensätze, Norm, SN 641 824. Swiss Association of Road and Transport Professionals (VSS), Zurich (2010)
56. Weber, B., Müller, P., Wonka, P., Gross, M.: Interactive geometric simulation of 4d cities. Eurographics **28**(2), 1–12 (2009)
57. Yerra, B.M., Levinson, D.: The emergence of hierarchy in transportation networks. Ann. Reg. Sci. **39**(3), 541–553 (2005)

Using Policy Instruments to Drive Optimal Living and Sustainable Consumption in the Built and Natural Environment

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Abstract In order to drive optimal living and sustainable consumption in the built and natural environment, there is the need to develop more sustainable, less energy-intensive systems and approaches that offer economic advantages, better operational performance, environmental merits and social acceptability. Measures to achieve these objectives including low-carbon technologies such as renewable energy generation technologies and energy efficiency measures are widely available today. Current focus on these technologies to reduce operational energy requirements has led to the neglect of embodied energy. This may result in obscuring the actual or net environmental gain for a given technology. Understanding the actual life cycle environmental gains is therefore necessary if a holistic effort in achieving sustainable built environment is to be attained. Furthermore, these environmental measures (operational and embodied) must be considered within an economic context. Against this backdrop, this chapter illustrates how policy instrument such as Marginal Abatement Cost Curve (MACC) can be used as a mechanism for evaluating low-carbon technologies taking into account both operational and embodied emissions and financial cost. The implication of emissions embodied in international trade flows within a MACC framework is also discussed.

Keywords Building • Environment • Economics • Policy instruments • Decision making • Optimisation

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1 Introduction

Whether it is based on current emission data or future projections of further growth, the building sector currently represents the largest and singular most important contributor to greenhouse gas (GHG) emissions globally [1, 2]. For instance, the Fifth Assessment Report (AR5) by the Intergovernmental Panel on Climate Change [3] under its Working Group III reported that greenhouse gas (GHG) emissions from the building sector have more than doubled since 1970 to reach 9.18 $GtCO_2e$ in 2010 representing 25 % of total emissions excluding the Agriculture, Forestry and Land Use (AFOLU) sector and 19 % of all global 2010 GHG emissions [4]. Furthermore, they account for approximately one-third of black carbon emissions (GEA [7]) and one-eighth to one-third of F-gas emissions, depending partially on the accounting convention used [4–8]. As such, improving the energy efficiency of buildings has become a top priority worldwide. A significant majority of buildings that exist now will still exist in 2050 and beyond; therefore, the greatest energy savings and carbon footprint reductions can be made through retrofit of existing buildings. This requires the development of sustainable as well as less energy-intensive systems and methods that are environmentally friendly, offer economic advantages and are socially acceptable.

Fortunately, measures for reducing GHG emissions that are most appropriate for building retrofit, including low-carbon technologies such as renewable energy generation technologies and energy efficiency measures, are widely available today. This suggests that there is an expectation that substantial savings in greenhouse gas (GHG) emissions can be achieved in the construction and operation of buildings through the application of these low-carbon technologies. Current concentration on low-carbon technologies to reduce operational energy requirements has ignored the less significant gains possible in embodied energy. However, as benefits from operational energy reduction are achieved, embodied energy arising from the extraction of raw materials, processing, manufacture, transportation, on-site delivery, construction, maintenance, renovation, final demolition as well as all the activities and processes along the supply chain that constitute these solutions will become increasingly important in making further progress. In the future, legislation (which places a price on carbon, using cap and trade schemes) and innovative technologies and knowledge will trigger aggressive operational emission reductions, while the large existing building stock will prompt major refurbishment and/or rebuild effort. This may further lead to increase in overall emissions and suggest that embodied emissions are likely to become one of the key metrics to be addressed in whole-life building emission assessment. As such, future regulations may require embodied emissions to be considered by the installer in attempts to achieve the best-value retrofit plan.

Consumption of energy results into environmental impacts in two different ways. The first way relates to direct environmental impacts resulting from consumption when consumers directly burn fossil fuels, and the second pertains to significant environmental impacts that arise indirectly in the production of consumable goods.

When production occurs in the same country as consumption, then it is relatively easy to formulate government policy to regulate environmental impacts. However, increasing competition from imported products has led to a large share of production occurring in a different country to consumption. The production of goods and services is becoming increasingly global with countries depending on each other in terms of export and import. For instance, in 2001, the production of commodities traded internationally was responsible for about 22 % of global CO_2 emissions [10]. As such, regulating the resulting emissions embodied in international trade is becoming critical to stem global emission levels. Due to increased globalisation of production networks, there is increasing interest in the effects of trade on the environment [11, 12]

In the UK, for example, recent history has led to the shift in the production of a range of building retrofit options to overseas markets, and although this has, to a certain extent, led to reductions in GHG emissions occurring on the UK territory, in reality, the consumption of materials has grown and global GHG emissions have risen as the needs are met through imports. For instance, Barrett et al. [13] reported that the UK territorial-based emissions indicated a 19 % reduction between 1990 and 2008, whereas consumption-based emissions show a 20 % increase during the same period and are driven by GHG embodied in imported products. This assertion is supported by a consumption-based perspective to GHG reporting [14, 15]. Given this imbalance in the UK emission pattern, it is pertinent to understand the energy systems, consumption and emission patterns of the UK industry especially as it relates to retrofit decisions and highlights implications for policy formulation and development. This can trigger innovations in product development processes and sustainable business models.

Against this backdrop, this chapter discusses how the environmental–economic input–output (EIO) model [16, 19] based on the 2-region (e.g. the UK and the rest of the world) multiregional input–output (MRIO) framework [19–20] can be used to estimate the environmental loads and emission implications of consumption associated with some selected building energy retrofit options. This allows for comparison between emissions associated with products manufactured in the UK, for example, and the rest of the world (RoW) with the view to facilitate better understanding consumption pattern and identify policy, business and consumer triggers that will lead to an overall emission reduction within the built environment. The chapter then illustrates how the results of embodied emissions can be integrated with operational emissions and costs within a Marginal Abatement Cost Curve (MACC) framework as a mechanism for evaluating intervention options.

The development of an integrated policy instrument (i.e. MACC) which takes a whole-life environmental and economic assessment viewpoint can highlight how value is delivered across different parts of the techno-economic system, specifically on financial gains, embodied and operational emission reduction potential. Such an approach, when integrated with other top-down policy approaches, could play a role in improving policy discussions in the building sector and provide better insights (for instance, through the creation of an efficient and standardised decision-making process) and drives the move towards optimal living and sustainable consumption in the built and natural environment.

2 Structure and Significance of the Chapter

The chapter is organised into six parts. Section 3 provides a brief description of the underlying principles of the Marginal Abatement Cost Curves on how it can be used to identify options which deliver the most economically efficient reductions in GHG emissions and prioritise mitigation options. A description of the multiregional input–output framework in terms of its advantages and how it can be adopted to evaluate emissions embodied in international trade flows is presented in Sect. 4. A description of the methodology adopted to evaluate the operational emission saving potential and embodied emissions incurred by the option is presented in Sects. 5 and 6, respectively. In Sect. 7, analysis and results of integrating the three key variables of emission mitigation options, financial costs, operational and embodied emissions, within a MACC framework are presented. This is then followed by a discussion of findings which is presented in Sect. 8. Finally, summary and conclusions are drawn in Sect. 9.

3 Using Marginal Abatement Cost Curves

The use of Marginal Abatement Cost (MAC) curves is a standard policy approach for appraising and indicating emission abatement potential and associated costs [21]. They are also widely employed in the economics of the environment as well as domestic and international policy on climate change for the assessment of costs associated with CO_2 emission reduction [21]. In combination with a marginal damage function, MACCs are used for the analysis of static and inter-temporal cost–benefit to appraise an optimal level of environmental discharge and to show the prioritisation of certain emission policies under uncertainty [22]. Essentially, MACCs are employed to prioritise the CO_2 emission reduction options of an abatement project (i.e. a project to reduce net GHG emissions) based on a set of criteria.

The MAC expressed in cost per tonne of GHG emissions saved is the additional cost of abating an additional tonne of GHG above what would be achieved in a ‘business as usual’ context. A MACC is a graphical device that combines the MACs of available abatement projects to facilitate decision making. A MACC therefore shows the connection between the marginal quantity of CO_2 reduced and the related marginal costs per unit of CO_2 saved through the application of a range of abatement options into the energy system, replacing parts of the baseline emissions [23]. The cost curve illustrates the abatement options for CO_2 emission reduction by considering a range of technologies and the costs associated to them. The associated costs are computed using conventional investment appraisal techniques such as net present value (NPV) or internal rate of return (IRR).

In MACC, emission reduction options are ranked according to their cost-effectiveness or cost of CO_2 abatement (i.e. cost per unit of CO_2 saved). The cost-effectiveness for each emission reduction option is computed using the relation [24]

$$C_{\text{eff}}\ (\text{£}/\text{tCO}_2) = \frac{\text{Cost of energy saving (£/kWh)}}{\text{CO}_2\ \text{savings made}\ \ (\text{tCO}_2/\text{kWh})} \tag{1}$$

Equation (1) can also be written as

$$C_{\text{eff}} = \frac{\text{Total Investment Cost}\ \ (\text{£}) - \text{NPV of the cost of enery saved}\ \ (\text{£})}{\text{CO}_2\ \text{saved per year}\ \ (\text{tCO}_2\text{e}) \times \text{Number of years}} \tag{2}$$

Equations (1) and (2) represent the Marginal Abatement Cost (MAC) which is the cost per tonne of GHG emissions of the abatement project (i.e. a project to reduce net GHG emissions). In Eq. (2), if the total investment cost is greater than the net present value of the cost of energy saved, it indicates that the intervention option under consideration reduces emissions but incurs a positive cost. Similarly, if the NPV of the financial savings in energy cost exceeds the investment cost, this indicates that the intervention option under consideration reduces emissions and saves money.

As an example, assume that the capital cost of implementing an abatement measure is £35,000 and the NPV of the annual energy savings is £20,000. If the total CO_2 abatement resulting from the implementation of the measure is 1,200 tCO_2, by applying Eq. (2), we have, for a single year,

$$\text{Cost of CO}_2\ \text{abatement} = \frac{\text{£}35,000 - \text{£}20,000}{1,200\ \text{tCO}_2} = \frac{15,000}{1,200} = \text{£}12.5/\text{tCO}_2$$

The calculation above is repeated for all the measures being considered. Some measures (e.g. options A–D in Fig. 1) have negative costs (i.e. the NPV of the financial savings in energy cost exceeds the capital cost), so that their implementation produces a net gain/savings over the time frame considered (i.e. the measures reduce emissions and save money). Some other measures, for example, options E–H in Fig. 1, show positive costs (as in the example above), which means that they do not pay back their investment even if they do save CO_2 (i.e. the measures reduce emissions but incur a positive cost). The MACC therefore allows different abatement options under consideration to be compared in terms of their cost-effectiveness relative to their CO_2 emission reduction potential. As shown in Fig. 1, option A is considered the most economically attractive option, indicating lower capital costs and a considerable CO_2 reduction with reference to the baseline. This is then followed by the analysis of the MACC results, from which the most interesting mitigation options can then be chosen by the decision and policymakers.

As indicated in Fig. 1, all measures with a negative cost-effectiveness can be safely ranked before those with a positive cost-effectiveness, but there exists a

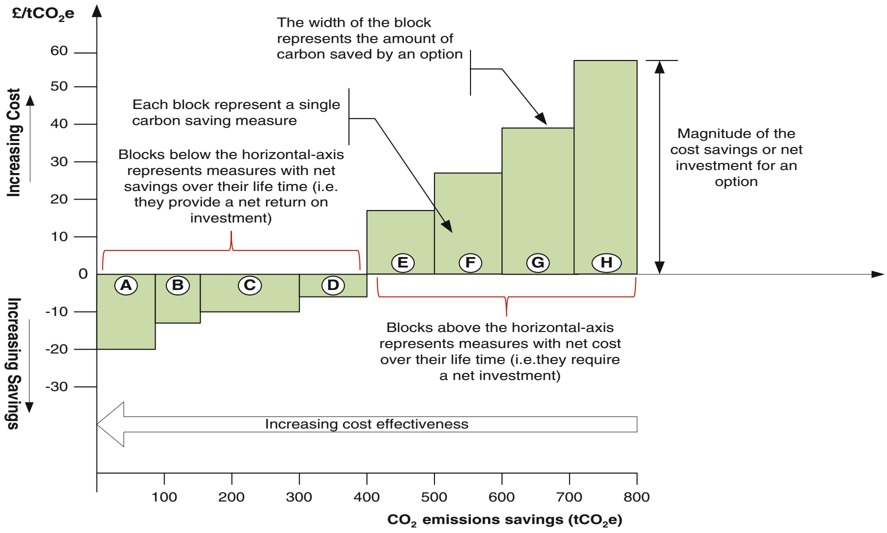

Fig. 1 Marginal Abatement Cost Curve for CO_2 abatement

mathematical flaw in the standard ranking criterion (C_{eff}) which prevents a relative ranking from being assigned to these negative cost measures. For energy efficiency options with economic net benefits (e.g. options A–D in Fig. 1), the concept leads to wrong priorities. In particular, a meaningful comparison between heat-based and electricity-based options is not possible. For instance, consider two CO_2 abatement options, one heat-based (gas) and the other electricity-based. If both options yield a negative cost of −£300 and save 20 kWh of energy/year. For simplicity, let the CO_2 emission factor (cf. in kg CO_2/kWh) of gas equal to 1 and that of electricity equal to 3 (e.g. since in actual sense, cf of electricity is thrice that of gas, in the UK). Also assume cost of gas equals cost of electricity for illustration sake. Therefore, CO_2 savings will be 20 kg CO_2/year for the heat-based (gas) option and 60 kg CO_2/year for the electricity-based option.

So, based on the standard ranking criterion (C_{eff}), the cost-effectiveness is −£15/kgCO_2e for gas (i.e. −£300/20) and is −£5/kgCO_2e (i.e. −£300/60). The ranking criterion prioritises the heat-based option (−£15/kgCO_2e) over the electricity-based option (−£5/kgCO_2e) which is a faulty decision based on the inherent flaw in the ranking criteria. The decision is faulty because the only difference between the two cases is the amount of CO_2 saved, and the ranking process suggests that the one that saves less CO_2 is more cost-effective. Detailed mathematical analysis and further illustrative examples of the identified flaw and suggested approach for an alternative ranking approach are provided in Taylor [25] and Ibn-Mohammed et al. [26]. Against this backdrop, this chapter focuses on positive cost options where the concept of MACC is still valid.

4 Multiregional Input–Output (MRIO) Model

The distinctive feature of the MRIO framework is that it allows for the tracking of the production of a given product in a given economic sector, quantifying the contributions to the value of the product from different economic sectors in various countries or regions captured in the model [10]. It therefore gives an account of the global supply chains of products consumed. The application of MRIO model for the estimation of greenhouse gas emissions provides the following advantages (Wiedmann et al. [17]; [10]):

- The MRIO framework is globally closed and sectorally deeply disaggregated. As such, using a model with such a high disaggregation of sectors will facilitate international supply chain tracking and produce more accurate results.
- MRIO framework is in tune with the current United Nations Accounting Standards (UNAS [10]). Developing the MRIO framework in conjunction with the current normalisation of the carbon footprint methodology has the capacity to strengthen and provide credibility to a footprint accounting standards.
- Implementing an MRIO will assist in overcoming uncertainties in energy or emission intensities of imported goods and services. This is achievable, since links from all international trade, including direct and indirect, are potentially accounted for. This will further add to the accuracy and comprehensiveness of emissions associated with international trade.
- MRIO framework combines, in a robust way, the matrices of domestic or local technical coefficient with the matrices of import from numerous countries or regions into one big coefficient matrix. This has the overall influence of capturing the supply chains associated with trade between all the participating trading partners as well as provide feedback pathways and effects.

4.1 Embodied Emissions in International Trade Flows

Possessing knowledge of how much energy is needed to produce building energy retrofit intervention options and their associated emissions can prove useful in assessing the overall environmental impacts of buildings. This knowledge can in effect assist consumers, businesses and even regulators to make informed choices regarding the environmental consequences of different choices. Countries all over the world depend on one another through imports and exports of manufactured goods and services as well as biophysical resources. As such, many countries, due to mounting pressure to cut down on their overall emissions, are increasingly interested in establishing the extent and the origin of the environmental implications of their imports and dependencies (Peters and Hertwich [30]). To gain a deeper understanding of the wider impacts of sustainability relating to consumption, in the hopes of promoting and implementing sustainable consumption and production policies, there is the need to track the entire life cycle impacts of goods and services across international supply chains [25]. The MRIO methodological framework can be used to achieve this.

5 Evaluation of Cost-Effectiveness of Options: Consideration of Operational Emissions Only

Five retrofit intervention options including biomass boiler, wind turbine, ground source heat pump, photovoltaic and solar hot water are analysed. The emission saving potential of the selected low-carbon technologies is based on performance calculation methods using standard algorithms for low-carbon energy sources [26–28]. The capital costs of each option were based on a range of publicly available cost information. The financial costs–benefits of each low-carbon retrofit intervention option are evaluated using an investment appraisal technique based on the calculation of net present value. The abatement costs (i.e. the additional cost of abating an additional tonne of GHG above what would be achieved in a 'business as usual' context) of the emission reduction options are calculated based on total costs (mainly investment costs) and benefits (fuel savings and CO_2 emission reductions) over the time period considered. The cost-effectiveness of each measure is calculated using Eq. (2). The estimated energy and indicative CO_2 savings (operational emissions only) from the options under consideration and cost-effectiveness are shown in Table 1.

The MAC graph plotted as a function of £/tCO_2 against cumulative CO_2 savings (tCO_2e) over 15 years is shown in Fig. 2.

6 Evaluation of Embodied Emissions Incurred by Options

The environmental–economic input–output (EIO) model, based on the 2-region (the UK and the rest of the world) MRIO framework, was used to estimate the environmental loads and emission implications of consumption associated with the low-carbon technologies under consideration. This is carried out to compare emission results associated with products manufactured in the UK and the rest of the world (RoW). For a detailed description of the robust methodological 2-region (the UK and the rest of the world) MRIO framework adopted, see Ibn-Mohammed et al. [24]. The results of the embodied emissions incurred by each option are presented in Table 2.

In the section that follows, the way in which the results of both embodied emissions incurred and operational emission saving potential of a range of options and cost are integrated within a MACC (positive cost measure only) framework is

Table 1 Estimated energy and indicative CO_2 savings from options and cost-effectiveness

Intervention option	Capital cost (£) *C*	Cost of energy saved (£)	NPV of energy saved (£) *E*	Net savings or net cost (£) {*N*} [*C* − *E*]	tCO_2e saved over 15 years {*S*}	Cumulative savings (tCO_2e)	£/tCO_2 saved {*M*} [*N*/*S*]	Ranking
Positive cost measures								MAC
Biomass boiler	120,000	8,826	91, 611	28,389	634.15	634.15	44.77	1
Wind turbine	60,000	1,625	16, 867	43,133	127.75	761.90	337.63	2
GSHP	300,000	14,659	152, 162	147,838	321.78	1, 083.68	459.43	3
Photovoltaic	200,000	3,482	36, 142	163,858	274.17	1, 357.85	598.02	4
Solar hot water	10,000	63	653.92	9,346	4.56	1, 362.41	2, 049.58	5

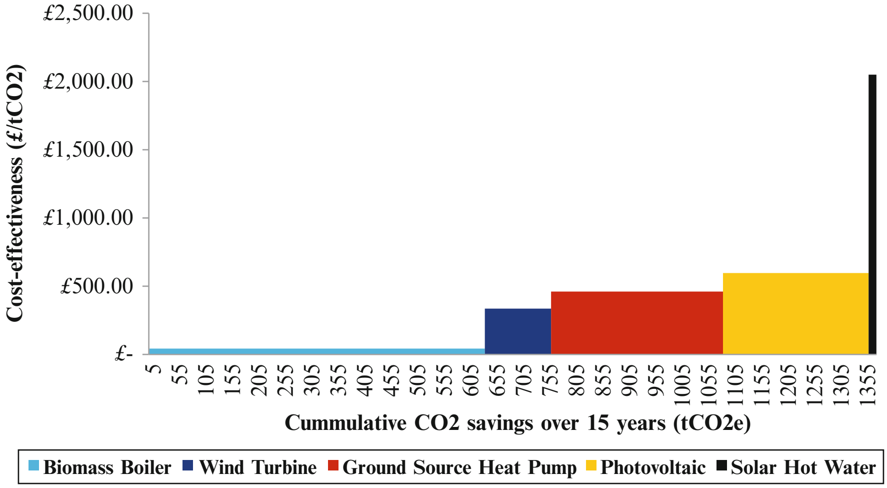

Fig. 2 MACC for positive cost measures without consideration of embodied emissions

Table 2 Embodied emission results, UK vs. RoW

Low-carbon technologies	Embodied emissions (tCO_2e) [Imports – RoW]	Embodied emissions (tCO_2e)[Domestic – UK]
PV system	104	91
Micro-wind turbine	39	33
Solar hot water	6	5
Ground source heat pump	258	221
Biomass boiler	128	85
Total	535	435

illustrated. This is then followed by a discussion on how such an integrated approach can be used to drive policy decisions to encourage sustainable consumption and optimal living.

7 Integrating Both Embodied and Operational Emissions Within a MACC Framework

This section describes how economic considerations are integrated with operational and embodied emissions within the positive regime of a MACC. Based on the embodied emission results related to each of the low-carbon technologies shown in Table 2, the net emission gain in terms of the embodied emissions of a low-carbon intervention measure and the corresponding operational emission savings after its implementation is evaluated. In this context, net emission savings is the difference between the operational emission savings of a measure across the time period considered (15 years in this case) and the initial embodied emissions incurred in the production of the measure. For example, if the operational emission saving potential of an option across 15 years is 200 tCO_2e and the initial embodied emissions incurred by the option is 20 tCO_2e, then the net emission savings is 180 tCO_2e.

Considerationof embodied emissions implies that the formula for cost-effectiveness would now become

$$\text{£}/\text{tNetCO}_2 = \frac{\text{Total Investment Cost (£)} - \text{NPV of the cost of enery saved (£)}}{E_{\text{net}}\,(\text{tNetCO}_2)} \tag{3}$$

Equation (3) suggests that the cost-effectiveness of a measure would increase in numerical value (i.e. becomes worse) when embodied emissions are taken into consideration. It follows that the consideration of embodied emissions decreases the emission reduction potential of an option. For a mathematical proof to show the validity of the effect of embodied emissions on the cost-effectiveness of a positive cost measure within a MACC framework, see Ibn-Mohammed et al. [24]. Table 3 shows the estimated CO_2 and net emission savings from options and their corresponding cost-effectiveness, assuming the low-carbon technologies are manufactured in the UK.

The MAC graph plotted as a function of £/tCO_2 against cumulative net CO_2 savings (tCO_2e) over 15 years is shown in Fig. 3.

Table 4 shows the estimated CO_2 and net emission savings from options and their corresponding cost-effectiveness, assuming the low-carbon technologies are imported from the rest of the world (RoW).

The MAC graph plotted as a function of £/tCO_2 against cumulative net CO_2 savings (tCO_2e) over 15 years is shown in Fig. 4.

8 Discussion and Analysis

As shown in Table 1, the cumulative operational CO_2 emission potential of the low-carbon technologies under consideration is 1,362.41 tCO_2e. Also, as indicated in Table 2, if all the retrofit options were manufactured in the UK, the total embodied emissions incurred is 435 tCO_2e, and if they were imported from the RoW, the total environmental loads and emissions amount to a total of 535 tCO_2e. The embodied emissions associated with international flow trade, therefore, far surpass the emissions from the UK by a value of 100 tCO_2e. It follows that the cumulative net CO_2 emission potential of the low-carbon technologies under consideration is 927.41 tCO_2e if they are manufactured in the UK and 827.41 tCO_2e if they were imported from the RoW.

The results presented above clearly demonstrate how the consideration of embodied emissions can affect the overall picture of a climate change abatement project. As shown, the consideration of embodied emissions leads to a decrease in the total

Table 3 Estimated CO_2 and net emission savings from options assuming the place of manufacture is the UK

Intervention option	Net savings or net cost (£)N	tCO_2e saved over 15 years S	Embodied emissions incurred, UK (tCO_2e)e	Net emission savings (net tCO_2e) $G = S - e$	Cumulative net savings (net tCO_2e)	£/net tCO_2 saved $C'_{eff}[N/G]$	Ranking
Positive cost measures							MACC
Biomass boiler	28,389	634.15	85	549.15	549.15	51.70	1
Wind turbine	43,133	127.75	33	94.75	637.90	455.23	2
Photovoltaic	163,858	274.17	91	183.17	821.07	894.57	3
GSHP	147,838	321.78	221	100.78	921.85	1,466.94	4
Solar hot water	9,346	4.56	5	−0.44	–	–	–

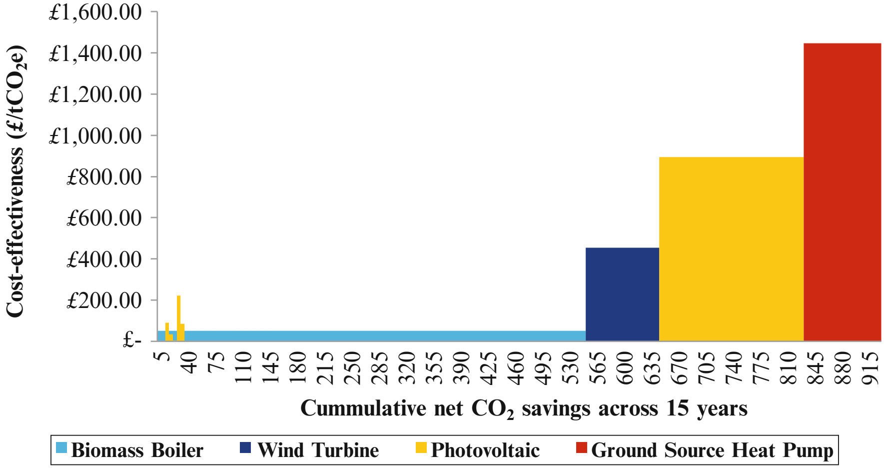

Fig. 3 MACC for positive cost measures with the consideration of embodied emissions, assuming the place of manufacture is the UK

emission reduction available from an option and the cumulative emission savings. Similarly, the consideration of embodied emissions worsens the cost-effectiveness of an option. For instance, as shown in Table 1 and Fig. 2, the cost-effectiveness of biomass boiler without the consideration of embodied emissions is £44.77/tCO_2e. But when embodied emissions are considered, cost-effectiveness worsens (i.e. it becomes £51.70/tCO_2e if it was manufactured in the UK (see Table 3) and £56.09/tCO_2e if it was imported from the rest of the world (see Table 4)). This suggests that a great deal of attention need to be paid to it. Similarly, based on Figs. 2 and 3, it is interesting to see how the environmental performance of photovoltaic system now appears to be better than that of GSHP when embodied emissions are considered.

Also, under the time frame of 15 years, the implementation of solar hot water is found not to have a net emission savings as its initial embodied emissions exceed its total operational emission savings. This explains its disappearance in the MACC curve as shown in Figs. 3 and 4. This suggests that, depending on the scenario and the estimated value of embodied emissions depending on the place of manufacture, the order and sequence of the abatement options can be significantly altered. As such, an understanding of the relationship between embodied and operational emissions of a given set of abatement options as depicted in Figs. 3 and 4 can be useful in providing detailed information which can form the basis for the formulation of effective policies to cover wider scopes in emission reduction strategies.

The knowledge of the comparison between products manufactured in the UK and the RoW can be used in policy analysis to ascertain the environmental impacts of international trade flows between different countries with the view to understand the consequences that the relocation of a given industrial sector within the UK to

Table 4 Estimated CO_2 and net emission savings from options assuming the place of manufacture is the RoW

Intervention option	Net savings or net cost (£)N	tCO_2e saved over 15 years$S$	Embodied emissions incurred, UK (tCO_2e) e	Net emission savings (Net tCO_2e)$G = S - e$	Cumulative net savings (net tCO_2e)	£/net tCO_2 saved $C'_{eff}[N/G]$	Ranking
Positive cost measures							MACC
Biomass boiler	28,389	634.15	128	506.15	506.15	56.09	1
Wind turbine	43,133	127.75	39	88.75	594.90	486.01	2
Photovoltaic	163,858	274.17	104	170.17	765.07	962.91	3
GSHP	147,838	321.78	258	63.78	828.85	2,317.94	4
Solar hot water	9,346	4.56	6	−1.44	–	–	–

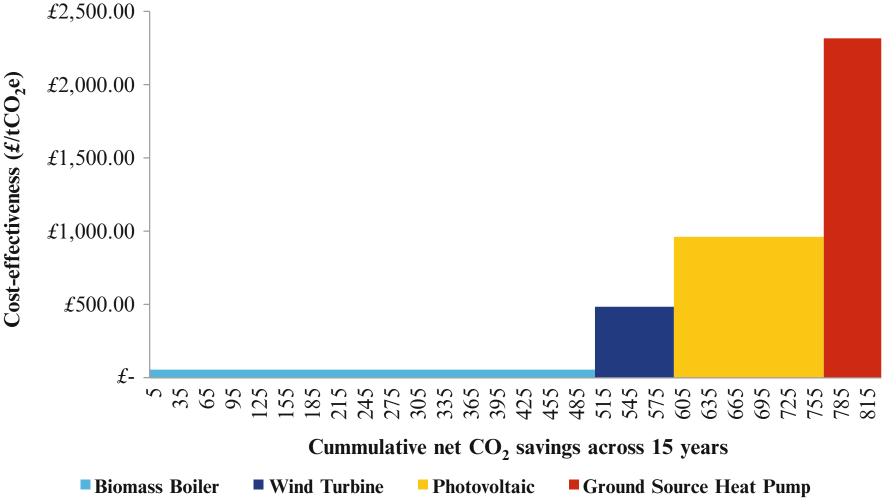

Fig. 4 MACC for positive cost measures with the consideration of embodied emissions, assuming place of manufacture is the ROW

the RoW has on emissions. For instance, consider the case of biomass boiler, for example, as shown in Table 2; the embodied emissions associated with it when imported from the RoW (128 tCO_2e) are much higher than when manufactured in the UK (85 tCO_2e). From production-based perspective to GHG reporting [13], it will appear better if the manufacturing of biomass boiler is done in the UK rather than importing them from the RoW.

The results of the comparison of embodied emissions between the UK and the RoW based on the MRIO framework when integrated within Marginal Abatement Cost Curves (MACC) as a mechanism for evaluating intervention options as demonstrated in Figs. 3 and 4 can trigger innovations in product development processes and sustainable business models. This in turn can be useful in providing detailed information which can form the basis for the formulation of effective policies towards decarbonisation efforts. Extending the use of MACCs in a way which integrates financial considerations with both embodied and operational emissions into a single model as illustrated can facilitate a more holistic view of the environmental impact of emission abatement options. For example, consider the case of biomass boiler based on its cost-effectiveness as mentioned earlier. With the consideration of embodied emissions, its cost-effectiveness is £51.70/tCO_2e, assuming the place of manufacture is the UK (case 1) and £56.09/tCO_2e if it was imported from the RoW (case 2). From a policymaker's point of view, there is more scope to regulate in case 2 as compared to that of case 1 since embodied emissions in international trade flows are taken into consideration. In doing so, a better understanding of the consumption pattern can be facilitated and can assist in identifying robust policy framework, business and consumer triggers that will lead to an overall emission reduction.

9 Summary and Conclusion

In this chapter, we illustrate how the results of embodied emissions can be integrated with operational emissions and costs within the Marginal Abatement Cost Curve (MACC) framework as a mechanism for evaluating low-carbon technologies to identify options which deliver the most economically yet efficient reductions in GHG and prioritise mitigation options within the built environment. Underlying limitations of the MACC approach regarding a mathematical flaw associated with the ranking of cost-effective options were illustrated with an example and suggest why the chapter focuses on the positive cost measures only. The integration of the three key variables of cost and both operational and embodied emissions indicates that a decrease is seen in the total emission reduction available from an option. For positive cost measures, the cost-effectiveness becomes worse due to the consideration of embodied emissions, corresponding to a smaller emission reduction for a given amount spent. The overall ranking of some of the options is also significantly altered when embodied emissions are considered.

The development of an integrated policy instrument such as the use of MACC which takes a whole-life environmental and economic assessment viewpoint as discussed in this chapter highlights how value is delivered across different parts of the techno-economic system, specifically on financial gains, embodied and operational emission reduction potential of low-carbon technologies. Such an approach, when integrated with other top-down policy approaches, could play a role in improving policy discussions in the building sector and provide better insights (e.g. through the creation of an efficient and standardised decision-making process) and drives the move towards optimal living and sustainable consumption in the built and natural environment.

References

1. International Energy Agency [IEA]: World Energy Consumption by Sector. http://www.iea.org/stats/index.asp (2009). Accessed 26 Jan 2013
2. United States Green Building Council, [USGBC]: The LEED reference Guide for Green Building Design and Construction for the Design, Construction and Major Renovations of Commercial and Institutional Building (2009)
3. Intergovernmental Panel on Climate Change [IPCC]: Working Group III – Mitigation of Climate Change. IPCC Technical Chapter 9. http://report.mitigation2014.org/drafts/final-draft-postplenary/ipcc_wg3_ar5_final-draft_postplenary_chapter9.pdf (2014). Accessed 20 May 2014
4. IEA: CO_2 Emissions from Fuel Combustion. Beyond 2020 Online Database, 138 pp. International Energy Agency, Paris (2012a). http://data.iea.org. Accessed 15 May 2014
5. UNEP: HFCs: A Critical Link in Protecting Climate and the Ozone Layer. United Nations Environment Programme, Nairobi, Kenya. 35 pp. http://www.unep.org/dewa/portals/67/pdf/HFC_report.pdf (2011a). Accessed 15 May 2014
6. EEA: Production, imports, exports and consumption of Fluorinated gases (F-gases) for years 2007-2011 in the EU-27 (Mt CO_2e, GWP TAR), European Environ-

ment Agency. http://www.eea.europa.eu/data-and-maps/figures/production-imports-exports-and-consumption (2013). Accessed 15 May 2014
7. GEA Global Energy Assessment - Toward a Sustainable Future, Cambridge University Press, Cambridge, UK and New York, NY, USA and the International Institute for Applied Systems Analysis, Laxenburg, Austria (2012)
8. US EPA: Overview of Greenhouse Gases. Emissions of Fluorinated Gases. United States Environmental Protection Agency. http://epa.gov/climatechange/ghgemissions/gases/fgases.html (2013). Accessed 15 May 2014
9. United Nations Handbook of National Accounting: Integrated Environmental and Economic Accounting 2003. United Nations; European Commission; International Monetary Fund; Organisation for Economic Co-operation and Development; World Bank (2003)
10. Hertwich, E.G., Peter, G.P.: Multiregional Input-Output Database. One Planet Economy Network [OPEN] EU-Technical Document. http://www.oneplaneteconomynetwork.org/resources/programme-documents/WP1_MRIO_Technical_Document.pdf (2010). Accessed 20 Feb 2013
11. Copeland, B.R., Taylor, M.S.: Trade and the Environment: Theory and Evidence. Princeton University Press, Princeton (2003)
12. Jayadevappa, R., Chhatre, S.: International trade and environmental quality: a survey. Ecol. Econ. **32**, 175–194 (2000)
13. Barrett, J., Scott, K., Roelich, K., Peters, G., Wiedmann, T., Lenzen, M., Le Quéré, C.: Consumption-based GHG emission accounting: a UK case study. Climate Policy **13**(4), 451–470 (2013)
14. Larsen, H.N., Hertwich, E.G.: The case for consumption-based accounting of greenhouse gas emissions to promote local climate action. Environ. Sci. Policy **12**, 791–798 (2009)
15. Kanemoto, K., Moran, D., Lenzen, M., Geschke, A.: International trade undermines national emission reduction targets: new evidence from air pollution. Glob. Environ. Chang. **24**, 52–59 (2014)
16. Acquaye, A.A., Duffy, A.P.: Input–output analysis of Irish construction sector greenhouse gas emissions. Build. Environ. **45**, 784–791 (2010)
17. Wiedmann, T., Lenzen, M., Turner, K., Minx, J., John, B.: Multiregional Input-Output Modelling Opens New Opportunities for the Estimation of Ecological Footprints Embedded in International Trade. International Ecological Footprint Conference, Cardiff, 8-10 May 2007 (2007)
18. Wiedmann, T., Wood, R., Minx, J.C., Lenzen, M., Guan, D., Harris, R.: A carbon footprint time series of the UK – results from a multi-region input–output model. Econ. Syst. Res. **22**(1), 19–42 (2010)
19. Kanemoto, K., Lenzen, M., Peters, G.P., Moran, D.D., Geschke, A.: Frameworks for comparing emissions associated with production, consumption, and international trade. Environ. Sci. Tech. **46**, 172–179 (2012)
20. Kanemoto, K., Lenzen, M., Geschke, A., Moran, D.: Building Eora: a global multi-region input output model at high country and sector. 19th International Input-Output Conference, Alexandria, USA, 13–17 June 2011 (2011)
21. Kesicki, F., Strachan, N.: Marginal abatement cost (MAC) curves: confronting theory and practice. Environ. Sci. Policy **14**, 1195–1204 (2011)
22. Kesicki, F.: What are the key drivers of MAC curves? A partial-equilibrium modelling approach for the UK? Energy Policy **58**, 142–151 (2013)
23. Toke, D., Taylor, S.: Demand reduction in the UK-with a focus on the non-domestic sector. Energy Policy **35**(4), 2131–2140 (2007)
24. Taylor, S.: The ranking of negative-cost emissions reduction measures. Energy Policy **48**, 430–438 (2012)
25. Ibn-Mohammed, T., Greenough, R., Taylor, S., Ozawa-Meida, L., Acquaye, A.: Integrating economic considerations with operational and embodied emissions into a decision support system for the optimal ranking of non-domestic building retrofit options. Build. Environ. **72**, 82–10 (2014)

26. Wiedmann, T., Wilting, H.C., Lenzen, M., Lutter, S., Palm, V.: Quo Vadis MRIO? Methodological, data and institutional requirements for multi-region input–output analysis. Ecol. Econ. **70**(11), 1937–1945 (2011)
27. Building Regulations: Low or Zero Carbon Energy Sources: Strategic Guide. http://www.planningportal.gov.uk/uploads/br/BR_PDF_PTL_ZEROCARBONfinal.pdf (2006). Accessed 20 May 2012
28. RETScreen® International: Clean Energy Project Analysis: RETScreen® Engineering & Cases Textbook. 3rd edn. http://www.retscreen.net/download.php/ang/1016/0/Textbook.pdf (2005). Accessed 27 Oct 2013
29. London Renewables: Integrating renewable energy into new developments: toolkit for planners, developers and consultants (2004). ISBN 1 85261 660 1.
30. Peters, G.P. and Hertwich, E.G.: CO_2 Embodied in International Trade with Implications for Global Climate Policy. Environmental Science and Technology. **42**(5), 1401–1407 (2008)

Hidden Surface Effects: Radiant Temperature as an Urban and Architectural Comfort Culprit

Forrest Meggers

Abstract The movement of heat throughout our built environment by transmission of radiation between surfaces is often overlooked in the operation, performance, and comfort of buildings. The temperature of a surface determines the amount of blackbody radiation it will emit, and thus controls the radiant exchange of heat in the environment. The heat exchange by radiation is important for systems and can dramatically influence the energy efficiency and the perceived comfort of a building. We discuss the physical mechanisms for measuring and understanding the heat transfer by radiation in buildings as well as the important connections to system performance and operation. The historical perspective on comfort, operation, and radiation is discussed. Finally, some novel concepts that take advantage of an understanding of radiant heat transfer potential are explored.

Keywords Exergy • LowEx • Thermal comfort • Bioclimatic design • Systems thinking • Integrated design

1 Introduction

Walking down the street, feeling a bit warm you gaze ahead and see a bank clock with its trusty display of the temperature. It displays a comfortable 24 °C (76 °F). You wonder why you feel so warm at a seemingly acceptable temperature. The sun has just dipped behind the building across the street, and you have moved into its shade, yet you still feel warm. You resolve yourself that the bank clock thermometer must be off.

This is a common error in society. We are surrounded by measurements of the ambient temperature from bank clocks to the weather report to the thermostats running our building systems. In fact the ambient temperature is only one of many factors affecting our comfort. In some cases the ambient temperature is actually playing a minor role in our comfort. Nevertheless, in reference to the thermostat,

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it is the factor that universally controls nearly all building comfort systems, and subsequently a major portion of building energy demand.

In terms of outdoor comfort condition is even more complex, but still often reduced down to a single ambient temperature, always displayed prominently as the only key indicator of conditions. Of course, reading further into the weather forecast, one soon finds important other factors such as wind speed, humidity, pressure, precipitation, etc., which play important roles in more recent indicators such as wind chill and heat index that help indicate how comfort and the resulting perception of temperature will be changed by wind speed and humidity.

1.1 Mean Radiant Temperature

An even more hidden influence on the perception of temperature is the radiant heat emitted from the surfaces around you. If I change the average temperature of the surfaces around you by 1 °C, it is like changing the ambient air temperature around you by 1.4 °C [1]. Although this may not seem obvious, it had been studied with similar results in the 1940s [2] and was a core part of the bioclimatic chart developed by Victor and Aladar Olgyay at Princeton in the 1950s [3].

This is why in the scenario with the seemly incorrect bank clock, the temperature measurement is actually correct. As you stand on the street where the sun has just dipped behind the other buildings, the thermal mass in the brick and concrete recently in the sun, and now standing adjacent to you, is still very warm. Its surfaces are radiating heat at you, causing you to feel warm even though the ambient temperature you observe is low. The surfaces radiate infrared radiation based on Planck's law of blackbody radiation causing heat transfer between you and the material, independent of the heat transfer more commonly felt through the convection as air moves over your body. This is the same kind of radiation as we receive from the sun, only at a much smaller temperature scale. Clearly you can feel the radiation of the sun, and this is also why an outdoor café can still be crowded on a 40–50 °F day when it is sunny. Also, this is the heat you feel as you stand near a bonfire. But in terms of the small temperature differences in the surfaces near you on the street, it is difficult to differentiate the source of the heat, and it only becomes significant if there is a significant amount of warm surface surrounding you.

The heat transfer phenomenon by radiation is not entirely overlooked in building design. The primary term used in building design is the concept of mean radiant temperature (MRT). All surfaces, including the surfaces of the occupants of a space, are radiating heat in the form of blackbody radiation. The temperature of the surface defines the amount of radiation, and thereby the amount of heat exchange. Therefore, an average of the temperatures of surfaces viewed from a certain position defines the MRT at that position. At typical building conditions this radiation is in the infrared (IR) spectrum, for which glass is no longer transparent, but rather a source of emission. Generally because most surfaces around us are at a relatively close equilibrium with the surroundings, it only considers specific circumstances, like when large window in winter might create a large surface at a low radiant temperature. If an occupant stood close to the window, that surface would make up a large fraction of their average view and could significantly impact their MRT. This is why people often feel a chill near windows even if a radiator is located below them keeping the air temperature warm.

In the example walking down the street, the warm surfaces of the pavement and walls that had just been in the sun are an example of surfaces not at equilibrium. They have thermal mass that keeps them warm after the sun moves away, causing them to maintain high surface temperatures and increase MRT, which results in the perception that the bank clock temperature is incorrect.

These phenomena, although often experienced in the built environment, are not frequently addressed in planning, design, and engineering. There are many ways that we can control the temperature of surfaces rather than presume they are generally at equilibrium. These techniques can range from simple shading analysis to embedded piping and reflecting systems. Tools exist to simulate radiation exchanges and are part of many energy-modeling packages. Most radiation calculations deal with solar gains coming in through windows, but there is potential to extend analysis to better understand, predict, and mitigate scenarios of poor thermal comfort due to MRT, both indoor and outdoor.

2 Heat Exchange Fundamentals for the Built Environment

2.1 Heat Transfer

The physics of the heat exchanges that influence comfort in an urban or building setting are governed by the three modes of heat transfer: conduction, convection, and radiation. Conduction and convection are related to one's direct contact with the surfaces and air in the environment, whereas radiation is the less tangible remote exchange of photons released as a part of blackbody emission. Blackbody emission is governed by Wien's Law, which relates the emission of an ideal source that is completely black (meaning it radiates equally and completely at all frequencies) to the amount of energy emitted, and is related to the absolute temperature (in Kelvin) to the fourth power. Conduction and convection are governed by thermal conductivity and heat transfer coefficients respectively, which linearly relate the temperature difference to the amount of heat transferred. Equations (1)–(3) show the relationships of heat transfer, Q, for conduction, convection, and radiation exchange between a hot temperature, T_{H}, and a cold temperature, T_{C}.

$$Q = kA\left(T_{\mathrm{H}} - T_{\mathrm{C}}\right) \quad \text{Conduction} \tag{1}$$

$$Q = hA\left(T_{\mathrm{H}} - T_{\mathrm{C}}\right) \quad \text{Convection} \tag{2}$$

$$Q = \epsilon\sigma A\left({T_{\mathrm{H}}}^4 - {T_{\mathrm{C}}}^4\right) \quad \text{Radiation} \tag{3}$$

The equations all have a similar appearance. They all are adjusted by coefficients: conduction by the thermal conductivity of the material, k; convection by the heat transfer coefficient, h, a more complicated factor influenced by fluid movement and boundary conditions between fluids solids; and then for radiation the emissivity, ε, which defines ratio of the real material surface to that of an ideal perfectly emitting blackbody, and the Stefan–Boltzmann constant, σ, a physical constant for blackbody radiation. All the equations also demonstrate the importance of the surface area, A, of the heat exchange in governing the amount of heat that can be transferred. Finally and most importantly for the operation of buildings, they are all governed by the temperature difference. This is the driving force of heat exchange just as height is the driving force of a waterfall. Unlike convection and conduction, the driving gradient for radiation is not linear.

2.2 Radiation

The radiant exchange of energy is governed by the temperatures to the fourth power (in Kelvin). Unlike for conduction and convection where a doubling of the difference between hot and cold temperatures causes a doubling of the heat transfer, a doubling of the temperature in a radiant exchange causes a different change in heat transfer. If the difference is doubled by increasing the warm surface temperature emitting radiation, then the heat transfer is more than doubled, whereas if the difference is doubled by reducing the cool absorbing temperature, the heat transfer is less than doubled. This fundamental difference makes the radiant heat exchange more difficult to address with simple ambient temperature factors. Changes in radiant temperature cause shifts in heat transfer in different proportions than ambient temperature changes do, leading to a difference in perception.

The heat exchange by radiation is a separate flow of heat operating independent of convection and conduction, and relating only to the temperature and surface properties of a material. It can be calculated when these temperatures and properties are known. Unfortunately both our built and natural environment is filled with a complex range of surfaces, making control of radiant heat exchange difficult to predict. In small applications two surfaces exchanging heat by radiation can be easily understood, but in a nonuniform room full of people, windows, heaters, and sunlight the radiation exchanges are often dynamic and difficult to evaluate. Experimentally a small device can be used to approximate the radiant heat in a complex space by measuring the temperature inside an insulated black ball, whose surface interacts with the complex radiant conditions as shown in Fig. 1. Inside a temperature sensor in the middle of the sphere reports back mean value, giving the mean radiant temperature.

The mean radiant temperature is the average radiant temperature received by an insulated blackbody, or as more commonly estimated: the average temperature of the surrounding space weighted by the view angle from the point of measurement. This temperature indicates what the average difference in radiant temperature is

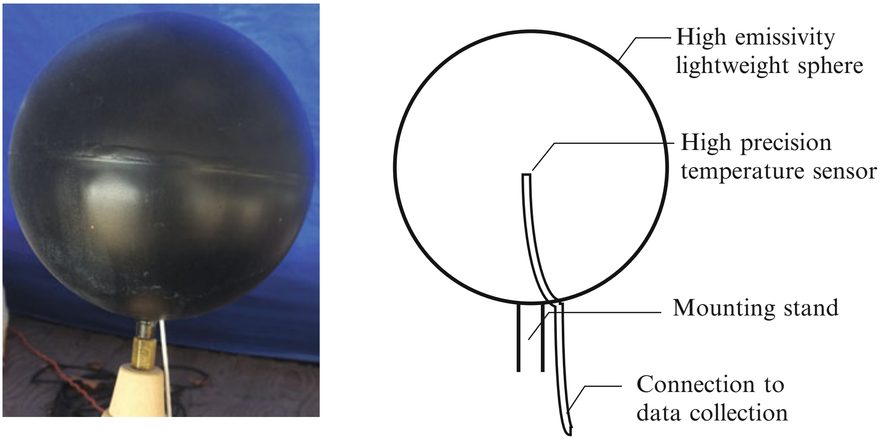


Fig. 1 Mean radiant temperature black bulb or globe sensor system photo (*left*) and diagram (*right*)

as viewed from a point in space. It is used to make estimates of the difference in surface temperatures that would drive radiant heat exchange. Unlike with convection and conduction where the temperatures and exchanges are explicitly related to the temperature, the mean radiant temperature is only an approximation of the temperature. It is the key variable for estimating the impact of surface temperatures and the resulting radiant heat exchange with occupants in a space.

The mean radiant temperature is approximated by the averaging the surface temperatures and their view angles given in Eq. (4) where n surfaces are viewed from a point in space, and each surface subtends a solid angle of Ω with a surface temperature of T, giving the MRT by averaging these values across the viewable sphere solid angle of 4π steradians.

$$\text{MRT} = (\Omega_1 T_1 + \Omega_2 T_2 + \Omega_3 T_3 + \cdots + \Omega_n T_n) \,/\, (4\pi \text{ sr}) \tag{4}$$

In general, the MRT is simplified to substitute the solid angles by simple angles representing the perspective of walls or ceiling and floor through 2D sections of the space, thereby substituting the Ω with θ, and finding the MRT by taking an average over 360° or 2π radians. This is the standard practice in architecture texts [1], allowing students to estimate MRT, but generally focusing on the effects of cold surfaces like large windows or doors with little insulation. These approximations are necessary and accepted due to the fact that users expand across larger areas than single points, and that surfaces are often not static and are made up of many variable components ranging from plants to walls to chairs. Although MRT is often overly simplified, it plays a key role in building operation. It is a critical approximation that can inform our understanding of a large range of phenomena, influencing the design, operation, and perception of building spaces.

3 Thermal Comfort

3.1 Origins

Thermal comfort is the primary objective of conditioning of our indoor environment, but more often than not it is simply associated to a temperature range that is considered acceptable. The phenomena such as radiant temperature along with air movement and humidity demonstrate the need for a more holistic view of the concept. Particularly for the built environment, we must consider the many variables that influence comfort if we are to find the most reliable, energy-efficient, and environmentally appropriate solutions.

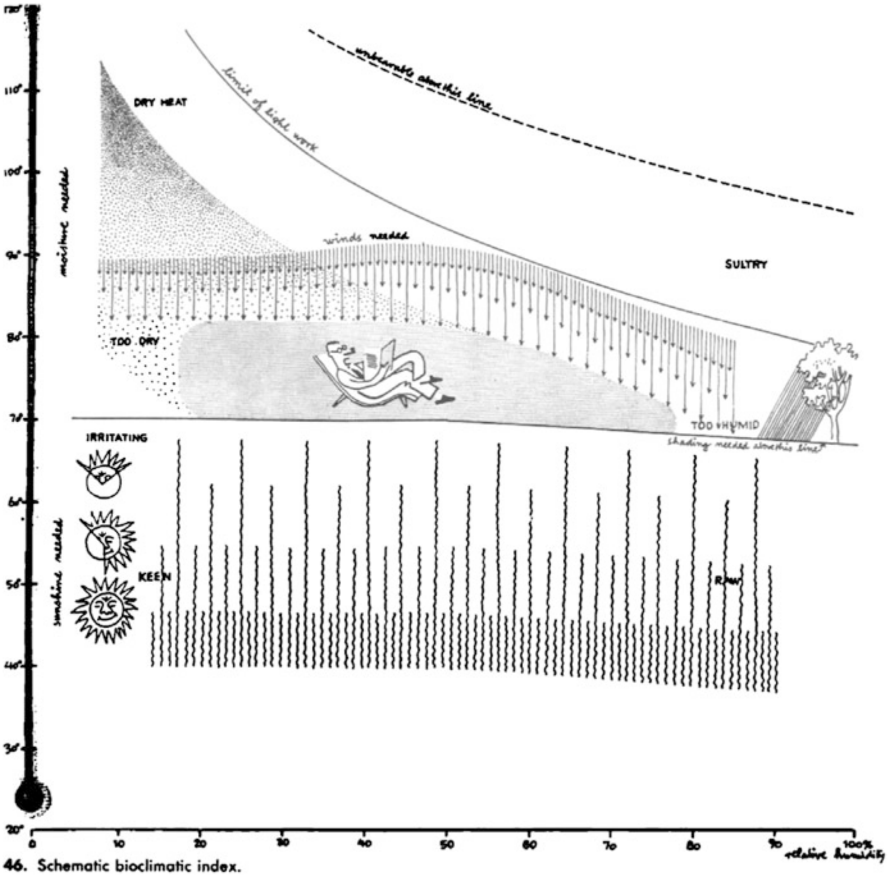
Thermal comfort is a topic of extensive study, although it does not fall under the same regime of fundamental physics, thermodynamics and heat transfer, as is the case for mechanical operation of buildings. The most significant body of work by Fanger created an extensive set of experimental analyses of occupants perceived comfort under various conditions, which resulted in the Predicted Mean Vote (PMV) giving a function of $+3$ to -3 level of comfort that is related to the Predicted Percentage Dissatisfied (PPD) that indicates if people are comfort or not [4].

The work of Fanger was a significant shift from a range of subjective criteria for thermal comfort to a standard model. The model was subsequently adopted by large agencies such as ASHRAE (American Society of Heating Ventilation Refrigeration and Air-conditioning Engineers). These led to a central acceptance of these comfort calculations and the resulting criteria for building design and for many codes in the USA and abroad.

3.2 Definitions

Although the comfort definitions had previously been less explicit, the standardization resulting from the Fanger work made much of it strictly explicit. Aspects such as MRT were obfuscated by the focus on temperature and humidity. This focus on temperature and humidity was largely connected to the operation of the central air-conditioning systems and their connection to the psychrometric chart a tool defining temperature and humidity interdependencies. With cheap energy in the 1950s and 1960s, new air-conditioning systems were designed to be able to control any environment, removing any humidity load or heat wave and heating during the coldest months; all is achieved with a large central chiller and boiler connected to ducts and pipes moving the conditioned air into the spaces around the building. It was not an elegant practice, but it was a powerful one, and it changed the perception, and more importantly the expectation of the indoor climate condition globally.

Today people expect to feel a very specific level of thermal comfort. Complaints arrive quickly if one moves outside of the Fanger comfort criteria. The building systems are designed to insure these criteria are met.



46. Schematic bioclimatic index.

Fig. 2 Thermal comfort as expressed by architects Victor and Aladar Olgyay in their book and from their teachings in 1963, [3] Permission from PU received. Figure is from 1963 so it should look like it is from 1963

Still, there remain other ways to change the human thermal condition such as radiant exchange. This was also not lost historically to researchers like the Victor and Aladar Olgyay in the 1950s. They recognized the significant shift to a command-and-concur mentality of universal central air-conditioning systems. They promoted a concept of Bioclimatic Design in which the human condition and the environmental condition are central rather than the air-conditioning system. They worked with a more holistic view of thermal comfort as described in the book *Design with Climate* [3]. Figure 2 shows the chart developed by Olgyay, and the MRT plays a clear role in determining a comfortable condition.

3.3 Bioclimatic Design

In bioclimatic design, the human comfort is considered for the actual thermal equilibrium that it must achieve with the existing environment. This is influenced by the wind speed, solar load, and the MRT besides the temperature and humidity. Working with all these variables results in a less explicitly defined concept of comfort as there are more independent variables, but they can be used to set reasonable limits and their influences on each other can be considered rather than neglected to facilitate large system operation.

The simplification of comfort to only focus on temperature and humidity was in no way linked to the work of Fanger, it was more to the way that the work of Fanger was leveraged. The work of the Olgyays did not contribute to making universal specifications for system operation. Instead, it was a holistic perspective that recognized the way that MRT should be interpreted in the design of building space in various environments.

Today there is a shift to new comfort models that also appreciate the nuances of thermal exchange, the environment, and the human body. Adaptive comfort was developed in the 1970s [5]. It was a reaction to the fixed comfort conditions that had grown along with the prevalence of large central building systems. It helped recognize that there are also predictable dynamic scenarios where typical comfort will not be achieved due to the movement between different environments, and to changes in the type of activity or stress.

The shift today to an improved perspective on comfort also helps expose the importance of surface temperature and the potential of building operation with active thermal surfaces [6]. These systems improve thermal comfort by recognizing and leveraging the heat exchange by radiant transfer. A holistic understanding of the exchange of heat between a person and the surrounding climate can greatly inform design processes. Leveraging radiant exchange techniques can simultaneously improve comfort and operation of the system by responding to both the climatic and the human condition.

4 Operation of Building Systems

4.1 Function Fundamentals

The core function of building systems is to deliver comfort. In its implementation it often seems like a complex task, but in fact it can be captured in a single practice: maintaining comfortable indoor conditions that may be different from the outdoor environmental conditions. This can take the form of artificial heating, cooling, or humidity management in a number of technical forms, as well as artificial lighting and fresh air delivery.

The differences maintained by building systems from outside conditions actually represent a fundamental thermodynamic potential. Nature does not want this potential to exist. Nature tends toward equilibrium, i.e., hot flows to cold, actions and reactions balance, and energy and mass are conserved. These fundamental rules hold true for building systems, and therefore, the potential that is created by our desire for an indoor condition not in equilibrium with the outdoor condition requires a constant input of energy to maintain that potential.

The input of energy to maintain temperature and humidity at desirable levels in a building is simply defined by a combination of the gradients of temperature and humidity across the boundary of the building façade and the resistance of this boundary to heat and moisture transport. Therefore, in the design of building heating and cooling systems for example, the engineer must simply use an energy balance based on the heat losses and gains of the building through walls, windows, doors, roofs, etc. during cold outside conditions. The conduction and convection given in Eqs. (1) and (2) show the dependency on the temperature difference, the material thermal conductivity, and the airflow.

Unfortunately, although this procedure has facilitated the design of all modern building heating and cooling systems, it overlooks the systems themselves. It focuses on the optimization of the passive façade and roof construction and insulation, and the minimization of the energy necessary to deliver comfort into a space. It does not fully consider the effectiveness of the delivery of that comfort through the building systems. In order to move heat into or out of building spaces, internal systems with specific temperature gradients must be designed to generate the internal potentials that add or remove heat from the space. Energy analysis alone only tells us about the amount of energy moved across these potentials, but not about the effectiveness of these potentials in transferring that energy. This additional quality of energy being transferred is captured by the concept of *exergy*, which gives us a metric for this additional quality that is defined by the second law of thermodynamics.

4.2 Exergy Perspective

The concept of exergy has been extended recently to the field of building design and construction [7, 8]. It does an excellent job of exposing some aspects of wastefulness in buildings that are not uncovered by energy analysis alone. These are often cases where the temperature needed to provide heating or cooling is not properly matched to the temperature used to generate the heating or cooling.

Exergy combines the fundamental energy balance defined by the first law of thermodynamics with the entropy balance defined by the second law [9]. This is done by defining a term that was originally called the “loss of available work” by Ahern [10], which is the combination of the change in entropy, Δs, of a system with the temperature of the environment, T_0, within which that system is operating. The loss of available work is subtracted from the “energy” term, Q, which for the majority of our analysis of buildings is heat and can also be defined as a change in enthalpy, h. This defines the exergy for heat transfer processes shown in Eq. (5).

$$\mathrm{Ex} = Q - T_0\,\Delta s \tag{5}$$

This equation is used to define the maximum potential of a heat transfer process. This is useful because it also captures the added loss of value for heat transfers across large temperature differences. These will generate larger changes of entropy and thus a larger reduction to the exergy term. For our purposes a constant specific heat is often used to calculate the exergy term for heat transfer as given in Eq. (6)

$$\mathrm{Ex} = c_p\,(T - T_0) - T_0\left(c_p \ln\left[\frac{T}{T_0}\right] - R\ln\left[\frac{p}{p_0}\right]\right) \tag{6}$$

where c_p is the specific heat and R is the universal gas constant. The temperature of the process is T and again the environmental temperature is T_0. The pressure of the process is p and the environmental pressure is p_0, but for the analysis of buildings there is rarely a significant pressure difference from the atmospheric pressure, and thus, this last pressure-term usually drops out. Using this equation the exergetic performance of building systems can easily be evaluated [8].

Exergetic efficiency can also be defined as the ratio of the maximum potential of a system to its actual output. Exergy defines this maximum "available work" [10], which is limited by irreversibility in thermodynamic cycles. Therefore, a better picture of the actual performance of a system relative to a feasible maximum is obtained from an exergetic efficiency. The most common exergetic efficiency is the simple ratio of actual output to the maximum available exergy that was input. This can be evaluated for the maximum exergetic potential of chemical inputs such as primary energy fuels or also for heat inputs into a system along with other potential energy inputs. Some refinements have been made to exergy efficiency where certain parts of the output of a system are utilized and other parts simply pass through the system, as shown by Brodyansky [11].

4.3 LowEx Buildings

In buildings for example, a boiler can combust some fuel like natural gas with great energy efficiency. We may use a highly efficient combustion boiler capturing heat with 95 % efficiency, but the temperature generated by the combustion is around 1,000 °C, while a building temperature is around 20 °C. Even with a 95 % efficient combustion boiler system, the exergetic efficiency is less than 10 % when taking into account the desired room temperature at which the heat is delivered. In this case 95 % of the heat may be going into the room, but the high temperature at which it was generated could have been used much more effectively for processes that can utilize the high temperature. It could have been used to do more "useful" tasks like generate electricity or drive a machine. Even for typical radiator system with temperatures above 60 °C there is a significant waste of exergy. A radiant heating or cooling system focuses on low temperature heating surfaces on the order of 30 °C and high temperature cooling surfaces around 18 °C. Radiant heating and cooling is key for low exergy (LowEx) systems.

Not only does exergy analysis allow for better building design, but it also helps to generate more comfortable buildings. Shukuya has shown how the exergy of the human body can describe the optimal room conditions for human body operation. These can then be matched to the low exergy building systems. This analysis generates optimal operating conditions for heating and cooling of rooms relative to human body exergy production [12].

There are many examples of LowEx buildings and building systems. These are based on the principles described above and have a reduced consumption of valuable high-exergy-content primary energy sources, which are mostly greenhouse-gas-emitting fossil fuels. There has been an extensive review of the exergetic performance of renewable energy-based climatization systems, which describes a wide range of studies demonstrating the application and implementation of exergy analysis for the improvement of building systems [13].

The implementation of low exergy building systems provides a significant potential for integrated design that leads to a much higher performance [14]. The idea of matching temperature levels within the different levels of climatization systems goes hand in hand with the concept of design integration. This means the integration itself leads to better exergetic performance.

4.4 Pumping Heat

The principal part of any LowEx heating or cooling system in a building is the generation system. We have determined that a heat pump has by far the highest potential performance. A heat pump can move multiple units of heat with only a small input of exergy, usually in the form of electricity to drive a compressor (for vapor compression heat pumps most commonly used in buildings). A heat pump can move heat either into or out of a building, and therefore, it can act both as a heating system and as a cooling system. For heating, heat pump performance is measured by this ratio of heat supplied (Q) to exergy input, called the coefficient of performance (COP) as shown in Eq. (7), and for cooling the heat supplied is simply replaced with the heat removed.

$$\mathrm{COP} = \frac{Q_{\mathrm{heat}}}{\mathrm{Ex}_{\mathrm{in}}} \tag{7}$$

Combustion-driven heating systems are limited by the energy content in their fuel, so the “COP” of any boiler or furnace type of system cannot physically be higher than 1. A typical heat pump operates with a COP greater than 3 and when combined with a LowEx building system the COP will easily be greater than 5. When low exergy heat and cooling systems are implemented that have temperatures close to the room temperature such at radiant heating and cooling surfaces, we have found that a COP of greater than 8 is achievable [14]. That means more than 8 units of heat would be created for each unit of electrical exergy.

These improvements are due to the inherent relation of the heat-pump cycle to the second law of thermodynamics. As determined by Carnot [15], and similar to heat engines, there is a maximum theoretical performance of a heat pump. The maximum performance possible is limited by the temperature difference between which the cycle operates. This Carnot COP is given in Eq. (8) for heating, where the temperatures must be in Kelvin. Equation (9) shows how an exergetic efficiency, g, can be used to relate real COP to the maximum potential.

$$COP_{Carnot} = \frac{T_{Hot}}{T_{Hot} - T_{Cold}} \tag{8}$$

$$COP = g \times COP_{Carnot} \tag{9}$$

The COP of the heat pump is thus directly related to the temperature lift it must provide to move the heat from the colder source to the hotter sink. Here we see directly the link between the low temperature lift demanded by low exergy buildings and the benefit to the heat pump performance. The COP increases hyperbolically as the temperature lift decreases.

If one looks at data-sheets for various heat-pump manufacturers widely available online, one can see that heat pumps typically operate with an exergetic efficiency in the range of roughly 0.4–0.6. This number remains relatively constant over the heat-pump operating range so the COP can be calculated using Eq. (5). This is done in Fig. 3 to show the dramatic increase in COP as the temperature lift of heat pump is changed.

Currently, the heat pumps and chillers offered on the market are designed for higher temperature lift building systems such as traditional high-temperature radiators or forced air systems with cold central air-conditioning systems. They operate at higher lifts at the far left of Fig. 3.

4.5 Radiant Performance Lever

Radiant heating and cooling systems that are integrated into large building surfaces transfer the heating or cooling demand into the space at temperatures much closer to the ambient due to the physics of radiant heat transfer discussed previously from Eq. (3). This facilitates operation of the heat pump or chiller system to the far right of Fig. 3.

Still, it is necessary to use a heat generation system that can take advantage of the lower temperature differences achieved by radiant systems. When current

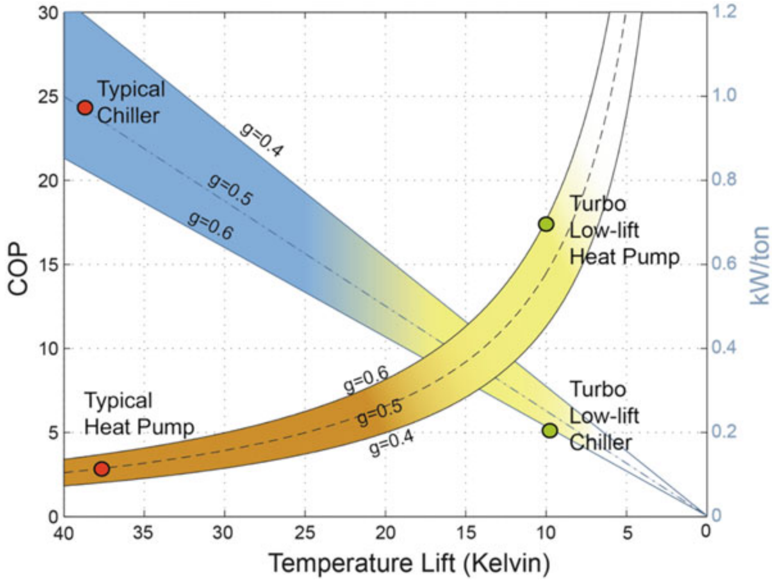


Fig. 3 Relationship between performance of a heat pump (COP: kW/kW) or chiller (kW/ton) compared to temperature-lift that the system has to deliver from the source to the supply. Low exergy systems aim for Low-lift as employed by the Turbo heat pump system being developed by external collaborators from BS2 and ETHZ

heat pump or chiller technology is operated across temperature differences less than 20 °C, the exergetic efficiency is decreased [16]. New systems are currently being developed that take advantage of turbo compressor technology. A turbo heat pump system is being developed through a collaboration between ETH Zurich, Lucerne University of Applied Science and Arts, and a turbo power electronics spinoff, Celotron. The main component is a new compressor with RPM > 100,000. The first prototypes have shown a machine efficiency of 0.6 maintained all the way down to a 10 K (18 °F) temperature lift, leading to a COP of 18 at that operational point [17], as shown in Fig. 4. As mentioned typical heat pumps cannot operate below temperature lifts of 15 K and have exergetic efficiencies that fall below 0.5 for any lift below 20 K.

The reason that heat pumps and chillers have not been designed to operate at these low temperature lifts is due to the nature of standard heating and cooling installations. Instead of being integrated with the design of a space, historically they were designed to fit into standard spaces, with an independent objective of reducing size. Reducing size means limiting heat exchange area, necessitating larger temperature gradients to drive the heat transfer needed to meet the heating and cooling demands.

Radiant heating systems have been around for decades, but the supply of low temperature heat was usually done by mixing combustion-boiler temperatures down to around 30 °C. Radiant cooling systems struggle against problems of condensation

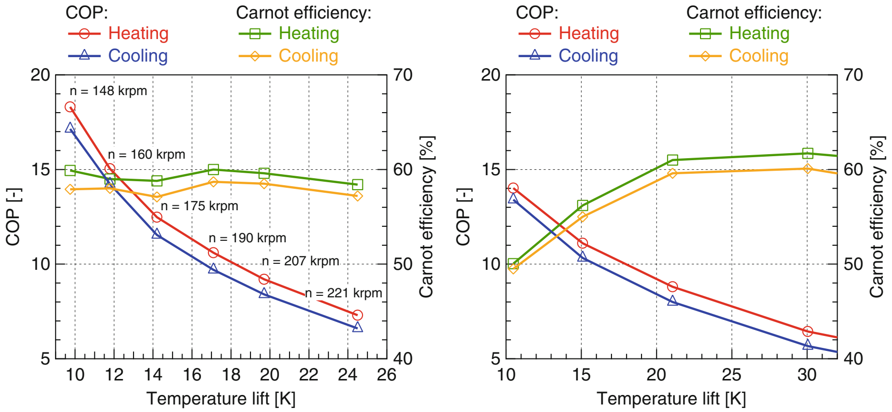


Fig. 4 Performance of standard low-lift heat pump limited by standard compressor operating conditions (*left*) with excellent performance for COP (*red line*: heating, *blue line*: cooling) but still limited at low temperatures in exergetic Carnot efficiency, (*green line*: heating, *yellow line*: cooling). The turbo compressor (*right*) shows excellent exergetic efficiency down to a temperature lift to 10 K with heating COP of 18 and an exergetic efficiency of 60 % [17]. Verdampfungstemperatur: Condenser Temp. and Tempearturhub: Temp. lift

in humid environments and are often supplied by the same chiller used for low-temperature mechanical dehumidification of air, which requires temperature below 10 °C while the radiant system could operate at 18 °C.

Radiant systems provide the opportunity to achieve low temperature-lifts for heat pumps and chillers, but it requires intelligent integration of the system in the building design. The surfaces need to be placed in good locations. The heat exchanges and distribution must be optimized. Finally, the exchange between the heat pump refrigerant and heating or cooling loop must be designed.

4.6 Elegant Operation

Not only are radiant surfaces critical for the operation of the a heat pump or chiller system, maximizing the system performance, but radiant systems also operate with a more ideal control dynamic. The system operates much closer to the room temperature, which benefits the performance of the systems, but also increases comfort and results in a very convenient response to changing demands in the space.

Figure 5 shows the reaction of a cooling system to an increase in temperature of the space. Imagine sitting in a room and the sun suddenly comes out from behind a cloud significantly increasing the cooling demand in the space. If the room was initially at 21 °C (70 °F) and the sun increases the temperature to 24 °C (75 °F) a typical control system would have a control thermostat that only reacts when the temperature at the wall reaches the higher value. The typical central air system

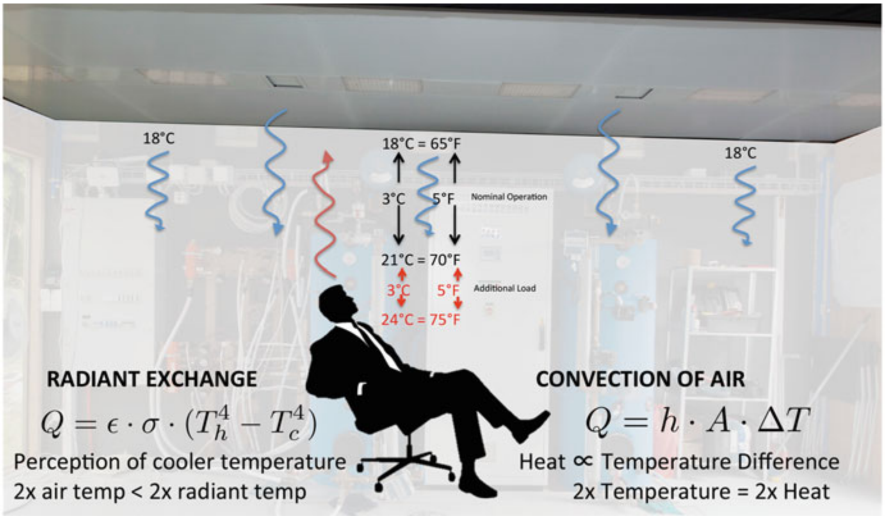


Fig. 5 The operation of buildings with radiant heating, or in this case cooling, is much more elegant. Because the system operates very close to the air temperature, a small increase in air temperature causes an automatic shift in the cooling or heating power without any complex control system. Additionally, the user experiences shifts in radiant comfort that more effectively influences comfort

would then turn on and force chilled air across a cooling coil generally designed at a temperature of 6–10 °C (42–50 °F). This air is prone to supply at temperatures too low or requires wasteful reheat. Also, the delayed reaction can lead to problematic hysteresis in the control response, and the location of the thermostat sensor can lead to nonuniform distribution.

In contrast to typical air-based systems, a radiant cooling system connected to adequate thermal mass as the cooling panel connected to a concrete ceiling in Fig. 5 would be, do not require any control system to respond to the temperature increase heat demand and the temperature rise. The physics of the high-temperature radiant cooling system allow it to respond automatically. At a cooling temperature of 18 °C (65 °F), the nominal cooling demand is covered by the panel being 3 °C (5 °F) cooler than the space. When the space increases to 24 °C (75 °F), the temperature difference has doubled. For the convection occurring at the panel, the heat transfer is linearly dependent on the temperature difference, and therefore, the cooling power is doubled. As the load increased causing an increase in the space temperature, the cooling power of the system doubles without any sensors, fans, or control algorithm. Additionally, the radiant cooling demand has more than doubled, due to the nonlinear relationship mentioned previously.

The radiant system connected to thermal mass, otherwise known as a thermally activated building system (TABS), has high thermal inertia. It has a large heat capacity and wants to stay at the same temperature even when the space temperature increases due to a sudden change in thermal load. Therefore, the resulting increases in temperature difference are substantial relative changes from standard operation.

The result is a very elegant operation of the radiant system. It responds naturally to shifts in indoor conditions. It also delivers a higher level of comfort by managing both the air temperature and more importantly the MRT. In turn, the management of the MRT can allow for more flexible conditions for air temperatures, minimizing losses associated with the air infiltration and related heat transmission in the building. It provides a simple solution for building conditioning.

Still, it is not without caveats. The surfaces must be relatively extensive to generate adequate heating and cooling supply. Also, in humid locations where dew point temperatures rise above a radiant cooling panel operating temperature, there is risk of condensation, and the system cannot act as a direct dehumidification system. For cooling, the latent loads for dehumidification must still be managed in a controlled ventilation system, for which research in the tropics has been carried out [18].

4.7 Integration Impacts

The physics of the operation of radiant systems provide a foundation for an improved performance, but by exploring aspects of design integration a new dimension of performance is revealed. As described, this performance of radiant systems is due to the operation with low temperature gradients. But both the radiant part and the convective part of any heating or cooling provided are dependent on an adequate surface area. For radiant systems both the heat transfer surface area and the visible view-factor are important for the operation. Therefore, the integration into active surfaces for heating and cooling becomes another interesting part of the design process.

Conveniently, a system of active surfaces is ideal for the replacement of typical large air-based system volumes. By removing excessive plenum spaces, long tracts of ducting, and enormous air handing units, the volumes of buildings become open and accessible, which facilitates the incorporation of active radiant surfaces. In traditional residential buildings radiant floor heating systems have been common since the 1950s, but the largest potential for integration lies in the large commercial buildings where currently architects accept a de facto responsibility for providing plenum spaces, ducting shafts, and huge mechanical rooms for air heating and cooling systems.

A more informed design is achieved with an awareness of radiant systems and the integration of hydronic piping systems in surfaces. There has been recent expansion in the awareness of thermally active surfaces in design [6], but much of the design potential is still not recognized.

Piping systems such as capillary tube mats, which can be simply tacked onto walls and ceilings and then plaster over provide simple methods of implementation. Chilled ceiling systems are also common either in the form of panels fixed to the ceiling or pipes embedded in dropped ceiling systems. Imbedding hydronic piping into concrete structure generates a truly integrated structure that can serve as load carrier, space divider, and shell system.

These are just a few of the ways that radiant systems can be integrated into a building. The important aspect is that the integration process is embedded within the architectural design, and the results lead to expanded design potential rather than a more constrained one. The de facto spaces that would usually be reserved for large air-based systems become free for creative implementation of more open spacious designs. The surfaces for heating and cooling ask to be exposed and to be part of the design, rather than tucked away in mechanical rooms or closet. This gives the architect direct involvement in the mechanical implementation, briding what is usually a separate and often incompatible design processes. How surfaces interact with people visually and radiantly are both a result of electromagnetic radiation emission and reflection. Therefore, design challenges for the view and arrangement of interior surfaces can be simultaneously explored.

4.8 Re-radiation

Research into novel implementation of radiant systems in building structures opens up explorations in how the aspects of the three important material surface characteristics of reflection, emission, and absorption of radiation play off each other. Some materials reflect longer and shorter wavelengths differently. Point any thermal imaging camera at a typical dry-erase white board and instead of diffuse reflection of white that is apparent in the visible, there is a spectral reflection of infrared radiation in the thermal imaging spectrum. The reflection of radiation in the infrared steered by composite material design for special bidirectional emission and absorption properties can facilitate interesting reflection and heat transmission phenomena [19].

Building surfaces can also be given interesting geometries that reflect IR and also guide a novel form finding process as shown in Fig. 6 at Princeton University. These projects explore the ability of shapes to converge and concentrate both emission and absorption of thermal radiation. The absorption is a particularly interesting challenge as the emission sources, most office space occupants, are large oblique surfaces that emit diffusely, and therefore, generating a radiant heat exchange with this space requires intelligent programing of the surface geometry.

The radiant umbrella project in Fig. 6a explored the ability of a simple reflective sheet to interact with a set of small radiant piping to expand the otherwise small radiant surface access of the piping. The Thermoheliodome in Fig. 6b derived a thermally reflective form through a structural and fabrication form finding process. It was optimized around a ray tracing process to maximize diffuse radiation absorption on a cool bulb at the focus of a cone. Figure 7 shows the resulting images from a thermal camera of the surfaces.

Fig. 6 Radiant Umbrella experiment (**a**) and Thermoheliodome experiment (**b**) at Princeton University: by shifting the radiant temperature of the surface using reflection of pipe surface temperatures onto the user, the MRT is shifted and we can experimentally play with the perception of comfort in the outdoor environment. In this case evaporative cooling is used because this eliminates the possibility to go below the dew point and cause condensation on the pipes

These projects are clearly theoretical tests of experimental concepts that may not apply directly in typical building projects. But they still expose a novel method of manipulation of heat transfer and comfort of occupants of a space. By experiencing the phenomena of heat transfer through radiation by means of exploratory design methods, new opportunities arise for system development. Research in reflection and redistribution of radiation not only helps us to gain a better understanding of the operation of the systems but also provides the ability to develop and test new systems.

Radiation has many aspects that can be researched, and in the field of physics and electromagnetic radiation, it represents a fundamental building block for the way our

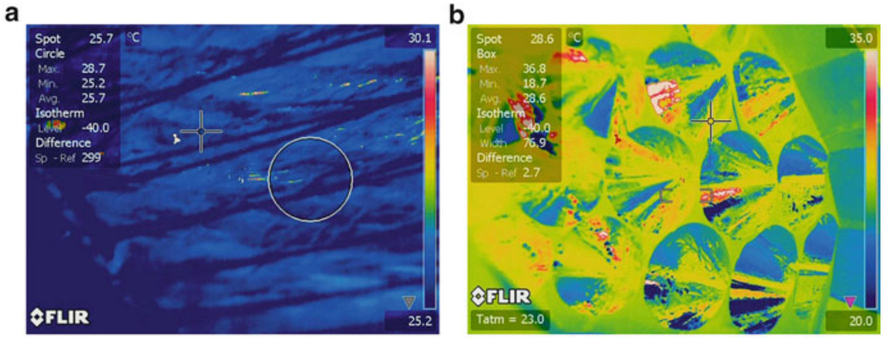


Fig. 7 The Radiant Umbrella (**a**) shows the expansion of the surface area of the pipes with a lower temperature by reflection, and the Thermoheliodome (**b**) shows the ability of the conic form to produce cooling even at off-axis angles

universe works. As we design and develop our own built environment, it would be a significant oversight to neglect the many ways in which it can be studied, controlled, and designed to generate better thermal, operational, and aesthetic performance for buildings.

5 Summary and Conclusion

Mean radiant temperature and the variety of forms of heat transfer that take place in the built environment are not fully appreciated by standard architecture or engineering conceptual design practices. There are opportunities to allow these phenomena to shape and encourage new ways of thinking about energy, comfort, and a more sustainable built environment.

There is enormous potential in the operational characteristics and the performance potential of activating surfaces for radiant heat exchange to strategically shift MRT. This potential is overlooked in large centralized air-based heating and cooling systems. Finding these hidden surface effects and exploiting them in design practice can enable new paradigms for interfaces between systems and spaces, allowing architects to take a central role in the materialization, placement, and geometry of not only the building space but also its heating and cooling systems. In this role, standard rules for mechanical system spaces will fade into a clean slate of design freedom to express both conceptual appearance and performance.

References

1. Wujek, J.B.: Mechanical and Electrical Systems in Architecture, Engineering, and Construction, 5th edn. Prentice Hall, Upper Saddle River (2010)
2. Yaglou, C.P.: Radiant Cooling - Investigated in Texts at Harvard and Discussed at New York Meeting by Dr. Yaglou. Heating and Ventilating, pp. 102–104 (1947)
3. Olgyay, V.: Design with Climate. Princeton University Press, Princeton (1963)
4. Fanger, P.O.: Thermal Comfort. McGraw-Hill, New York (1973)
5. Nicol, J.F., Humphreys, M.A.: Thermal comfort as part of a self-regulating system. Build. Res. Pract. **1**, 174–179 (1973). doi:10.1080/09613217308550237
6. Moe, K.: Thermally active surfaces in architecture, 1st edn. Princeton Architectural Press, New York (2010)
7. Shukuya, M.: Energy, Entropy, exergy and space heating systems. In: Bánhidi, L. (ed.) Presented at the Healthy Buildings ’94. Proceedings of the 3rd International Conference, Technical University of Budapest, pp. 369–374 (1994)
8. Shukuya, M.: Exergy: Theory and Applications in the Built Environment, Green Energy and Technology. Springer, Dordrecht (2012)
9. Moran, M.J., Shapiro, H.N.: Fundamentals of Engineering Thermodynamics, 6th edn. Wiley, Hoboken (2008)
10. Ahern, J.E.: The Exergy Method of Energy Systems Analysis. Wiley, New York (1980)
11. Brodyansky, V.M.: The Efficiency of Industrial Processes: Exergy Analysis and Optimization. Elsevier, Amsterdam (1994)
12. Shukuya, M., Saito, M., Isawa, K., Iwamatsu, T., Asada, H.: Human-Body Exergy Balance and Thermal Comfort. IEA ECBCS Annex 49 - Low Exergy Systems for High-Performance Buildings and Communities (2010)
13. Torio, H., Angelotti, A., Schmidt, D.: Exergy analysis of renewable energy-based climatisation systems for buildings: a critical view. Energy Build. **41**, 248–271 (2009)
14. Meggers, F., Ritter, V., Goffin, P., Baetschmann, M., Leibundgut, H.: Low exergy building systems implementation. Energy **41**, 48–55 (2012). doi:10.1016/j.energy.2011.07.031
15. Carnot, N.L.S.: Réflexions sur la puissance motrice du feu (1824)
16. Wyssen, I., Gasser, L., Wellig, B., Meier, M.: Chiller with small temperature lift for efficient building cooling. In: Proceedings of Clima 2010. Presented at the 10th REHVA World Congress “Sustainable Energy Use in Buildings,” REHVA, Antalya, Turkey (2010)
17. Wyssen, I., Gasser, L., Wellig, B.: Effiziente Niederhub-Wärmepumpen und -Klimakälteanlagen, in: News aus der Wärmepumpen-Forschung. Presented at the 19. Tagung des BFE-Forschungsprogramms “Wärmepumpen und Kälte,” Burgdorf, Switzerland, p. 14 (2013)
18. Bruelisauer, M., Chen, K., Iyengar, R., Leibundgut, H., Li, C., Li, M., Mast, M., Meggers, F., Miller, C., Rossi, D., Arno Schlueter, E., Tham, K.: BubbleZERO—design, construction and operation of a transportable research laboratory for low exergy building system evaluation in the Tropics. Energies **6**, 4551–4571 (2013). doi:10.3390/en6094551
19. Zhu, L., Raman, A., Fan, S.: Color-preserving daytime radiative cooling. Appl. Phys. Lett. **103**, 223902 (2013). doi:10.1063/1.4835995

Weather Data and Solar Orientations

Mojtaba Samimi

Abstract As we approach the end of 2014, what is the public's interpretation of advances in "solar architecture"? Is it still, in many cases, limited to an installation of solar thermal collectors or photovoltaic panels on building roofs and facades? And in the area of improving "energy efficiency" of buildings and their interiors, are the choices for materials and high-tech systems generally considered as the final objectives for some leading building industries? Are these the only things we should consider as the means towards an environmentally oriented and healthy design?

A comprehensive integration of solar and weather data (including long-term historical weather records, recent observations, nowcasting, deterministic and probabilistic weather forecast scenarios) into all aspects related to structures (including architectural and urban plans as well as city flow management and decision-making processes) cannot be treated as an option we choose to ignore or drop along the way.

This chapter tries to discuss some key parameters such as global and local challenges observed by the author, namely, in 2014. It also strives to demonstrate the creative process of actively questioning, finding and developing adaptive solutions in urban/architectural decision-making environments.

Keywords Solar performance • Environmental approach • Data processing • Urban impact • Integrated design

1 Introduction

Around the biosphere of planet earth overflowing with a variety of contextual complexities, the indoor and outdoor qualities for building and city dwellers could be improved significantly if we appreciated design and performance standards according to global and local environments which, it should not to be forgotten, are our major actors or firsthand realities of the solar system.

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A more comprehensive consideration of surrounding forces, of energies and materials which themselves are the result of the many interactions of the earth's atmosphere and the sun can allow these areas to be studied and applied more systematically. This is vital, namely, towards developing efficient neighborhoods and cities, where the issues concerned with living spaces, whether outdoors and indoors can lead to immediate or long-term impacts on human safety, health, comfort, meditation, social interaction, and thought.

As achieved in a number of former instances of architecture and urban fabrics, in order to live in solar houses of the future, people should dream, vote and look forward to solar cities as well. Long-lasting building structures and volumes involve long time horizons. And in order for the dream of solar cities to come true, people need more than solar technologies to be installed on site. To accomplish this we need a vision, a language, a culture, and a desire to interact more in unity with our surrounding and immediate universe.

2 Weather Data and Its Application Question Marks

Each society needs to train and trust solar-environmental decision makers including but not limited to the architects and urban designers to address, shape, and fashion a good future for all. To progress and build on this basis, reliable data is needed and there should be always an updated chapter for weather data.

In respect to the issues concerning limited energy resources and their rising prices, energy efficiency is being highlighted every day. In terms of building design, building energy simulation tools must be generally used to determine the energy performances of some different building designs and systems.

But does all the necessary information for sustainable planning exist in a typical meteorological weather file? The answer is of course "No"! These weather files are a great piece of information appropriate for building energy simulation, whereas they cannot introduce the full range of weather patterns that are probable or likely to happen in the real world including extreme weather and environmental patterns for each location.

Let's continue to put even more question marks on some of our present plans where we want to stay or live for a number of decades into the future.

Does every well-promoted architectural or urban design project effectively apply climate information starting from the early stages of the design process?

If the answer is "Yes," what is the distance between the site where the observed weather data was collected and the actual building's site? Is the data interpolated or extrapolated from two/three other station locations? Are those reference observation stations providing reliable data? How are the direct and diffuse solar components estimated?

What are the expectations of future scenarios including and considering climate and urban changes as well as the changes likely to happen needs, ongoing projects and functionalities required by those who will be using and living in the building?

Can the weather forecast play a role and if so, what is the role of the weather forecast? Is such data reliable? How reliable should it be? Can weather forecast data be made more useful as input considerations in a building's planning and operation phases? Are all weather parameters available to use? Are there weather parameters missing?

Exploring the question even further, one could ask why are zenith angles of the sun and moon not included in our current daily observations. Should such parameters be calculated and provided? This information is not necessarily easy or familiar yet for all to consider.

Whereas the orbital path of the earth around the sun is actually very close to a circle (the relation between the short and long diagonal is 0.999), did ellipse related forms are used in Baroque architecture to exaggerate Kepler's laws of planetary motion?

Do successful design firms today use big volumes of weather data in practice? If not yet or no more: what are the short and long-term impacts on humans as well as on the built and natural environments?

How big could be the impact of a well-designed small-scale project in the city, houses in suburbs and those who use buildings? How much schools and communities can help in raising awareness and upgrading future regulations towards sustainable design?

To approach practical solutions and bring the interaction between weather data and design research to the next level, a new version of the SOLARCHVISION tool was designed by the author in 2014 and is still undergoing development at the R.M.M. Solarch Studio. By integrating several high quality datasets provided and maintained by Environment Canada, including long-term climate files, weather observations, and deterministic and ensemble regional and global model weather forecast files, this platform tries to improve a number of great applications of real-time weather data, namely, in buildings and cities [1].

3 A Robust Solar-Based Approach

> Solar-climatic studies during the processes of building skin and urban design can improve many aspects including the potentials and performances in terms of energy production, energy demand, daylight, health, comfort, and safety for long periods of time, with the added benefit that most of these architectural rearrangements and improvements do not necessarily increase the construction costs.

Bearing in mind the fact that there are always just limited resources available to improve the quality and performance of outdoor spaces, the responsibility of the city and decision makers as well as the time allocated to planning should be allowed to be long enough in order to extract the full potential benefits from these important early stages. As opposed to current development trends who tend to ignore or postpone performance analysis in the design process, improving the early planning stage is a more efficient sustainable approach and allows the design team to take their time and the initiative to study different parameters of interest and many critical impacts right from the very early stages of planning.

In this way, a robust solar-based approach could help to incorporate all the complexities of architecture and city management applied simultaneously on a variety of scales and in different contexts and climates.

On the other hand, to efficiently interact with changing external conditions and indoor needs, several required support systems could be developed, called upon, and integrated in a beautiful responsive form. In addition, to resist, react, and adjust efficiently in a changing world, a number of environmental oriented concepts (e.g., adaptation, hibernation, migration) can help, namely, in architectural design as well as urban planning. Nevertheless; the intention of future plans should be to ingeniously manage and solve the problems and not to create new major ones.

To bring and maintain good qualities associated with the full life cycle, health, comfort, and safety measures, it is therefore essential to "integrate comprehensively the environmental considerations and weather data details as early as possible in the planning and design processes and also in the construction and operation phases" [2].

4 Solar Studies for Design in Cold Climates of Canada: Montréal

Contrary to popular belief, in many cases, extreme low temperature conditions happen in clear sky and not on cloudy and snowy days. This simple fact highlights the importance of solar optimizations in architectural and urban design in cold climates such as those in Canada where the coldest and warmest temperatures most often likely occur on sunny days. Besides, applying a solar-climatic approach as early as possible in the planning/design stage is essential to improve, create, and fashion more comfortable and sustainable spaces (Figs. 7 and 8).

To provide a few examples, some modest studies on proposed future architectural/urban developments in Montréal, Quebec, were completed then presented at the Office de Consultation Publique de Montréal (OCPM), and these are listed here (Figs. 1 and 2):

2014, March: ocpm.qc.ca/sites/ocpm.qc.ca/files/pdf/P73/8a9.pdf
2014, February: ocpm.qc.ca/sites/ocpm.qc.ca/files/pdf/P72/8a4.pdf
2013, September: ocpm.qc.ca/sites/ocpm.qc.ca/files/pdf/P70/9a20.pdf [3]

The studies presented in Figs. 3, 4, 5, and 6 illustrate the annual solar radiation and impact analysis of proposed future towers in a Montréal downtown area and are used to give one example here. The building on the right is Bell Centre while the Windsor tower is the high-rise building under construction on the left. In addition to this tower there are two proposed towers on the south-east side of Bell Centre (Projet immobilier sur la rue St-Antoine Ouest).

Fig. 1-2 Presence of the sun on the pedestrian path in cold times of winter (9:00 a.m., 16 February 2014, air temperature: −15 °C)

But as discussed on February 2014, "the proposed arrangement of buildings in this area could most likely lead to the creation of an undesirable and unsafe pedestrian path in the future when considered in terms of solar-climatic aspects" (see red area on Fig. 6). "In addition, the current layout of tower in Site #2 also interferes with the important view axis line and blocks the perspectives in the spaces between Saint-Jacques and Des-Canadiens-De-Montréal streets."

After analysis of these studies as well as the rest of information presented by other participants to OCPM (Office de Consultation Publique de Montréal), the Commission summarized that its recommendation to not approve amendments to the Urban Plan for Tower 2 would not unduly delay start of the project, given the developer's intention to build in phases. *This would allow for coherent planning of the sector, to take into account all issues and all the historic, urban, environmental, and social elements of the district, in order to better plan its future development*.

The commission also highlighted in "Concerns, Expectations and Opinions of Participants" the participant's request that the Borough modify its regulations to incorporate solar and climate analysis in order to take into account the climate impacts of the buildings to be constructed. "Among the elements he raised were falling ice in winter and urban heat islands in summer, which could be minimized by designing projects using analyses of seasonal solar radiation effects" (translated form Rapport de consultation publique, [4]).

As can be read further from the OCPM Final Reports as well as from Tracey Arial's View Island Report (see ref. 5), such studies can result in not only updating the regulations to account for some new challenges but also raising awareness

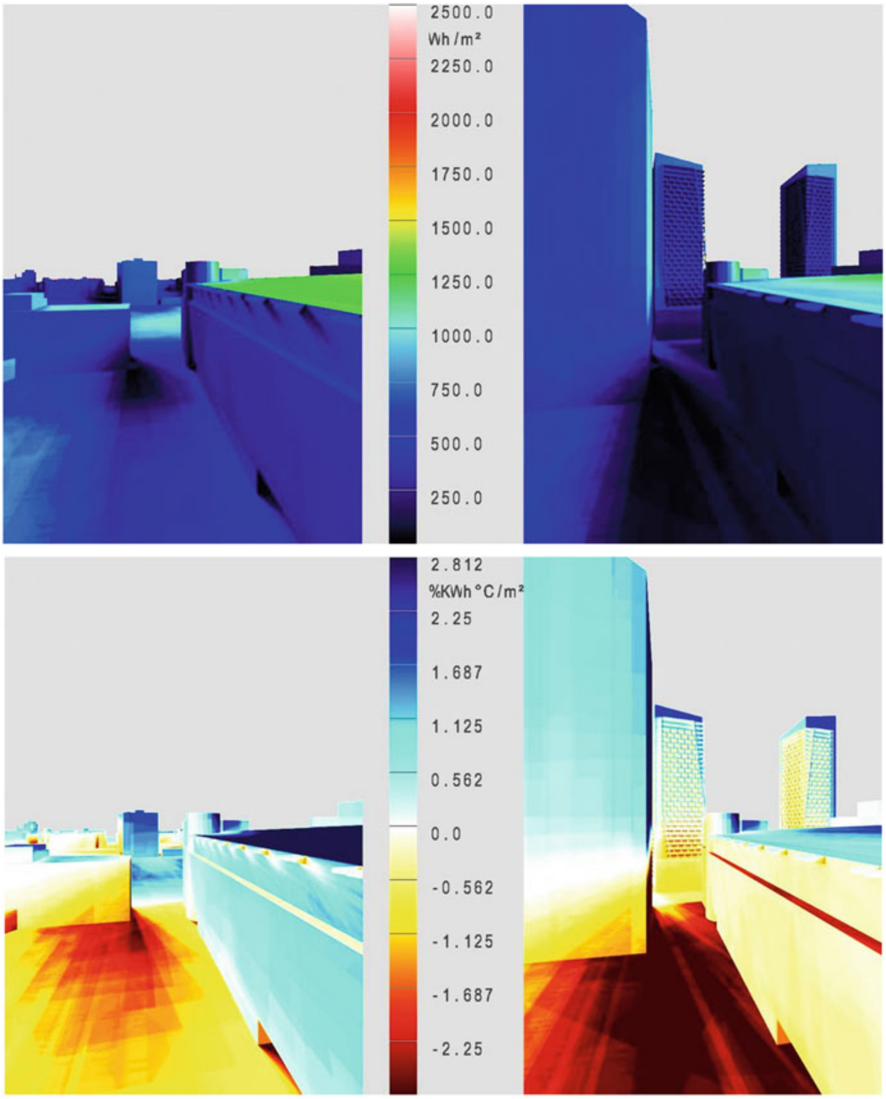

Fig. 3-6 Before/After graphs of annual solar radiation (*above*) and impact analysis (*below*) based on SOLARCHVISION models, *red*: remarkable undesirable impacts highlighting negative design performance (see ref. 7 for detailed clarifications)

and the will to consider the sun and the realities of a changing climate and urban environments in future developments among both decision-makers and the people who will use the buildings and urban spaces.

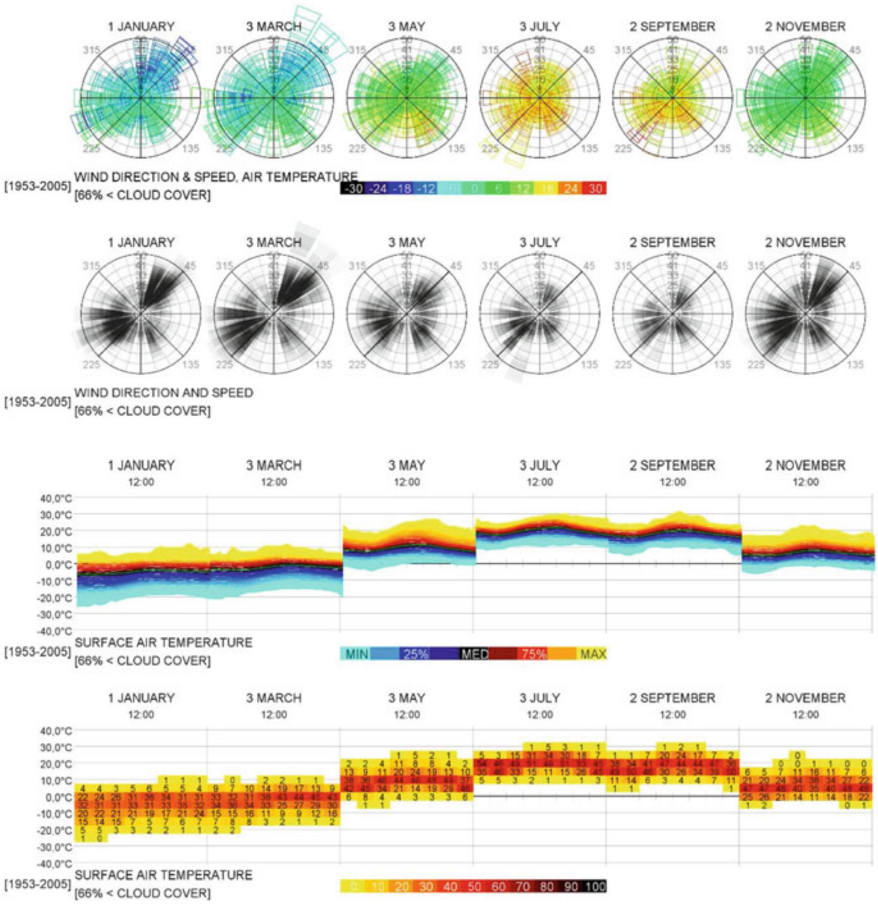

Fig. 7 Montréal climate distributions and probabilities in overcast sky: hourly air temperature and monthly wind patterns (SOLARCHVISION graphs based on CWEEDS, Montréal, Dorval, 1953–2005)

5 Smooth Transition from Past to Future

Approaching "A Golden Thread" and reading through the book with the same title that discusses 2500 years of solar architecture and technology in the West, one can see solar cities and solar architecture as deep-rooted subjects which planed and built in the ancient Greece. Moreover; solar design in different climates and *Sun-Rights Laws* demonstrate impressive civilization back to the Romans [6].

A recent book titled "Intelligent design using solar-climatic vision" also demonstrates a few aspects of ingenious ancient architectural and urban instances in the Middle-East region and, namely, those in diverse climates of Iran [7]. It can help

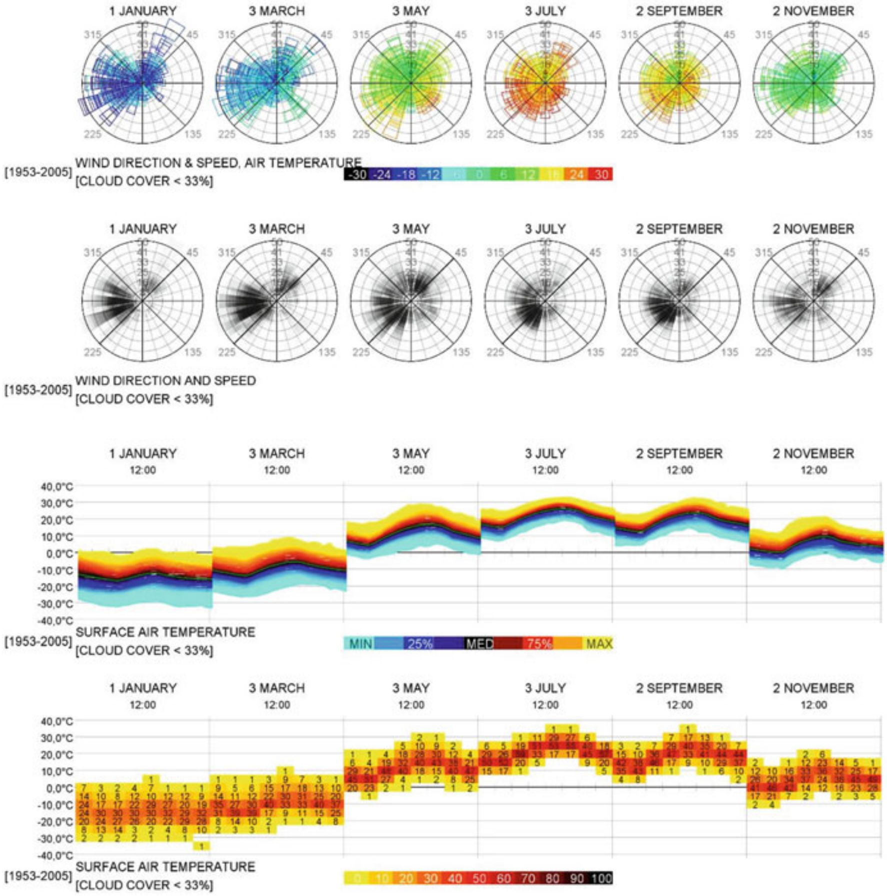

Fig. 8 Montréal climate distributions and probabilities in clear sky: hourly air temperature and monthly wind patterns (SOLARCHVISION graphs based on CWEEDS, Montréal, Dorval, 1953–2005)

to mention again that the state of art in architecture is to adjust both internal and external living spaces in a coordinated and balanced way [8].

To have better view of the future scenarios and the level of impacts, one can look first in what happened in the past. In terms of application of weather data in planning, it is therefore helpful to study a variety of parameters from the long-term climate files in hourly and daily time steps and through different months. The graphs presented in Figs. 9 and 10 illustrate distribution and probabilities for direct beam solar radiation as well as its positive and negative impacts using CWEEDS (1953–2005) [9], every other month. The extreme and average scenarios for each simulation category (e.g., active/passive) were identified by SOLARCHVISION algorithms and the solar studies were performed to calculate the potentials and

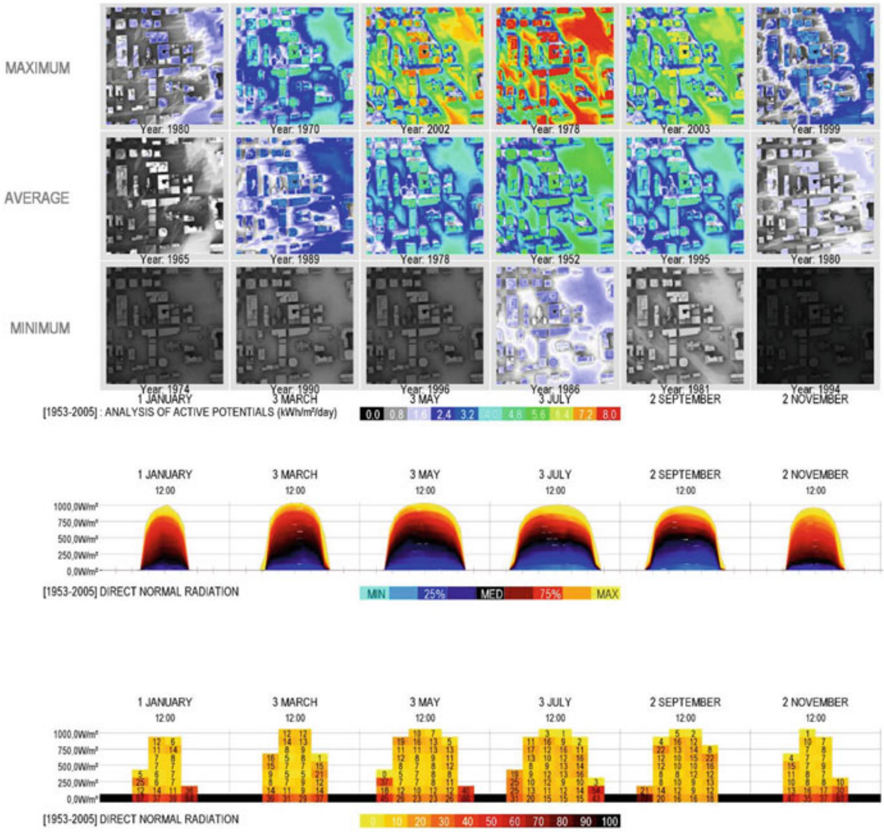

Fig. 9 Hourly and daily SOLARCHVISION graphs for distribution, probabilities and active solar energy potentials/impacts in different months using Montréal 1953–2005 data (CWEEDS)

impacts in complex urban forms (i.e., Montréal downtown from Place-des-Arts on top right to Rue University on the left).

Figures 11, 12, and 13 present Montréal observations data (station: CWTQ) with hourly SOLARCHVISION post-processing (based on cloud cover and air temperature at 6-h intervals) for global horizontal radiation and air temperature using deterministic (GDPS) and ensemble (GEPS) models. The graphs contain forecast data issued on the October 03, 2014, 00Z Environment Canada numerical weather prediction (NWP) models.

It must be noted here that the NAEFS xml files made available to the public by the Meteorological Service of Canada's Canadian Center for Meteorological and Environmental Prediction (MSC-CCMEP, formerly MSC-CMC) do not presently contain forecast data of solar flux though such forecasts may be made available at a later date. Therefore, in diagrams below solar direct and diffuse components were derived using a post-processing algorithm applied to the available data for each of

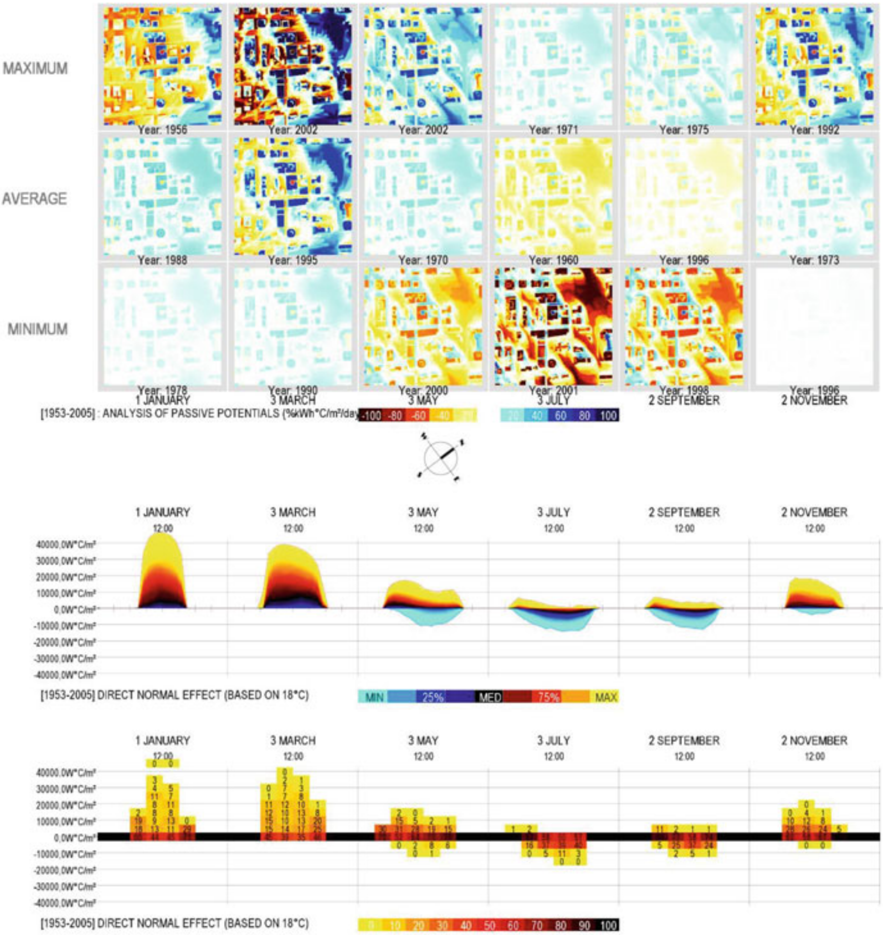

Fig. 10 Hourly and daily SOLARCHVISION graphs for distribution, probabilities and passive urban solar potentials/impacts in different months using Montréal 1953–2005 data (CWEEDS)

the 21 forecast members (GEPS). Also for air temperature models, as the original GEPS forecast data is made available at 6 h interval SOLARCHVISION was able to appropriately interpolate and infer hourly forecasts from this data based on pattern recognition using the long-term hourly climate file (CWEEDS).

Figure 14 introduces an example of probabilistic solar-weather impact analysis produced using the SOLARCHVISION-2014 integrated platform based on CCMEP's forecast. These graphs can be used to determine what can be considered as desirable and undesirable urban spaces.

Similar passive/active analysis can help assess and optimize the performance of structures and systems including but not limited to shading devices, solar thermal collectors, and PVs. Figure 15 presents plots with different scenarios for changes in

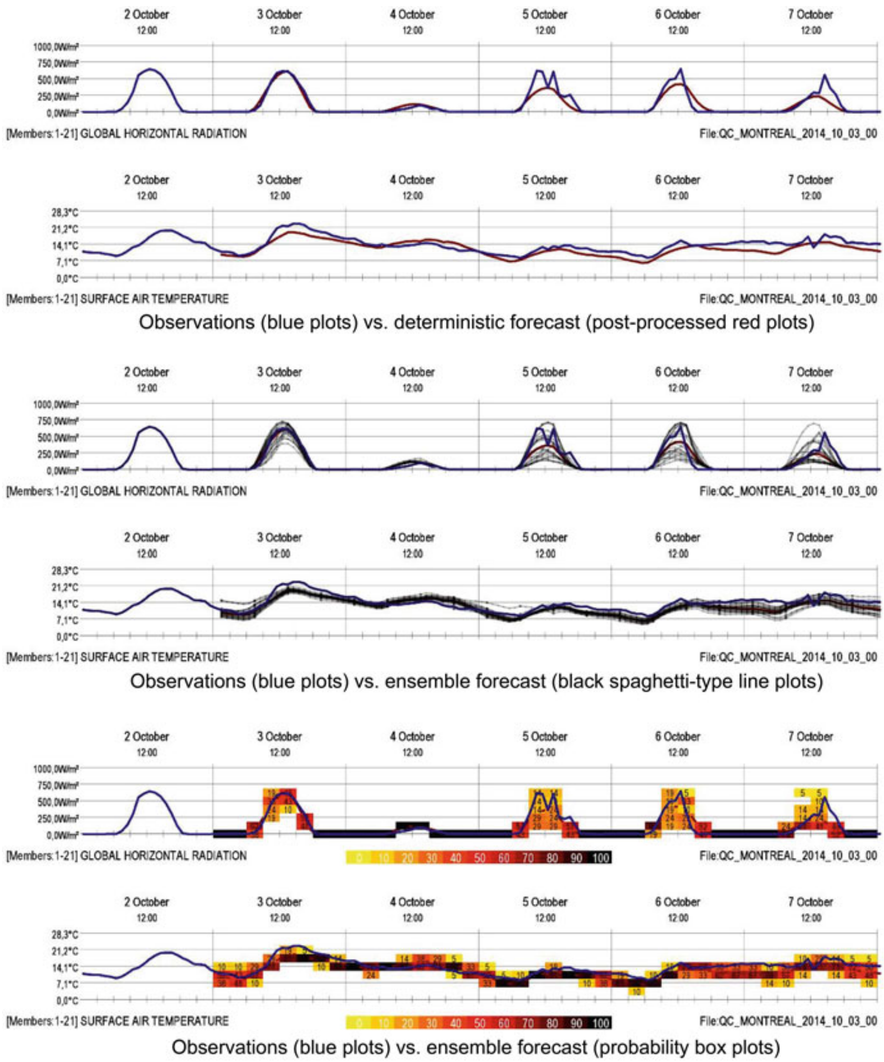

Fig. 11-13 Observations (*blue plots*) vs. deterministic forecast (post-processed *red plots*)

cloud cover parameter in six following days according to GEPS (21 members). This forecast data is issued at 00Z on September 14, 2014 at 6 h interval. After estimating direct and diffuse components of solar flux based on this parameter, the incidence angles for a surface (in this case a horizontal surface) could be applied to compute global horizontal flux. Similar task can be performed to calculate daily gains on different surface orientations and inclinations. This can be useful to find out which surfaces would receive more solar energy. As is also presented the amounts can be

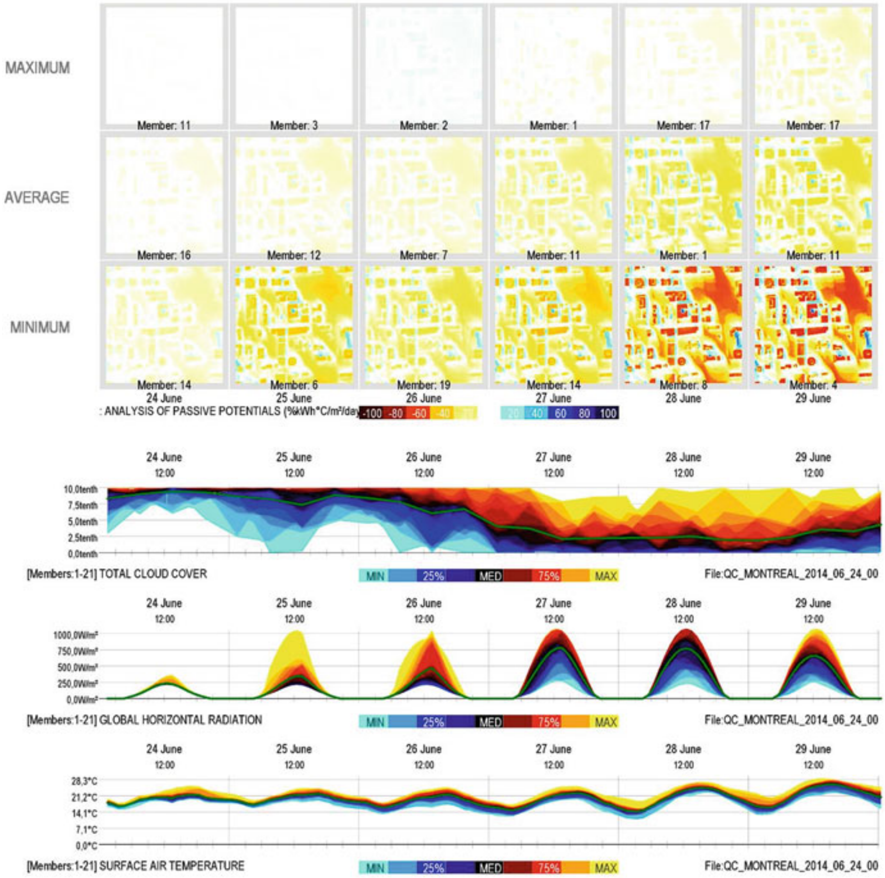

Fig. 14 Ensemble scenarios for building and urban applications produced using weather forecast data from the June 24, 00Z 2014 model integrations (NAEFS, GEPS, Montréal)

calculated for a solar tracking system and can be mapped on building and urban surfaces.

As is described on the SOLARCHVISION website, *architects as well as urban planners always need an analysis to find out the effect of each architectural element on building skin and urban areas in regard to the varied effects of the sun in different cycles*. Figure 16 introduces some different parameters of interest that can be applied by both passive and active strategies. The urban and building models generated by SOLARCHVISION illustrate solar potentials and impacts that associated with energy and comfort measures. The wind patterns demonstrate different scenarios for wind direction and wind speed on each day. It followed by plot of air temperature that includes interpolations for each hour according to climatic patterns. Finally scenarios for precipitation are presented in an accumulative plot.

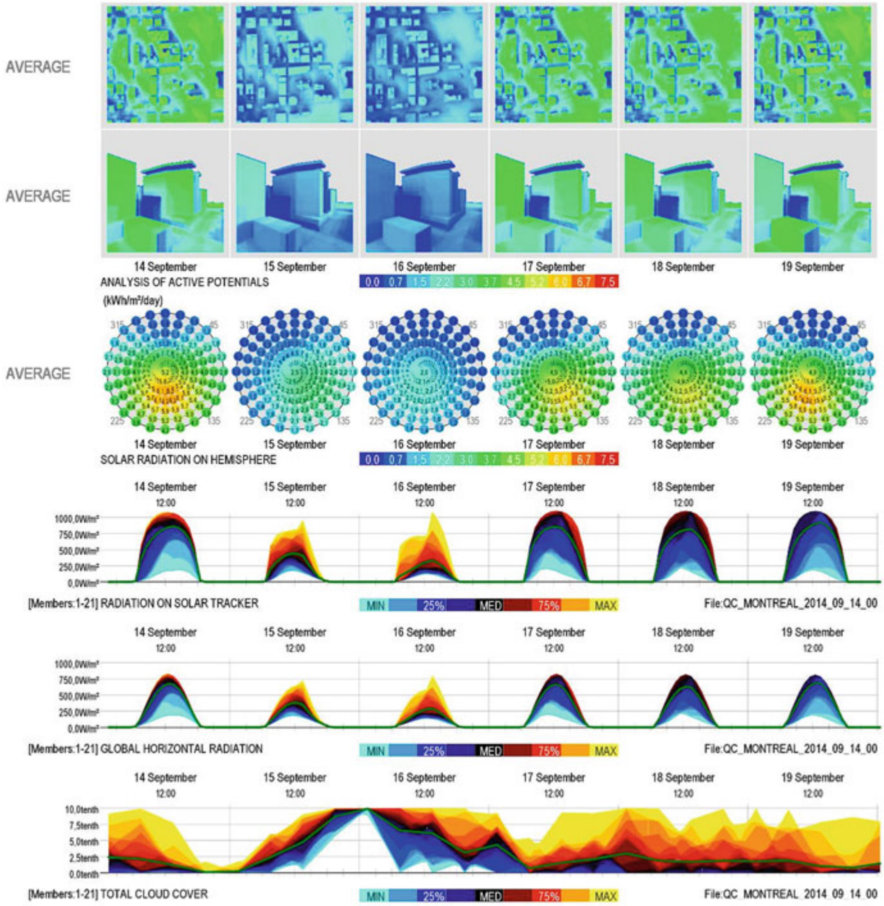

Fig. 15 Ensemble scenarios for active solar applications produced using weather forecast data from the September 14, 00Z 2014 model integrations (NAEFS, GEPS, Montréal)

Consequently the 2014 version of SOLARCHVISION platform tries to stimulate a wider range of renewable energy considerations along with the ability to target, study, control, and manage even more specific impacts of interest to sustainable buildings, liveable spaces, and cities [1].

6 Local and Global Horizons

In terms of architecture and urban plans, consideration of such trends and integrated changes in environmental parameters is necessary. Applying such information is not limited to new project design stages; and should be considered in *developing a*

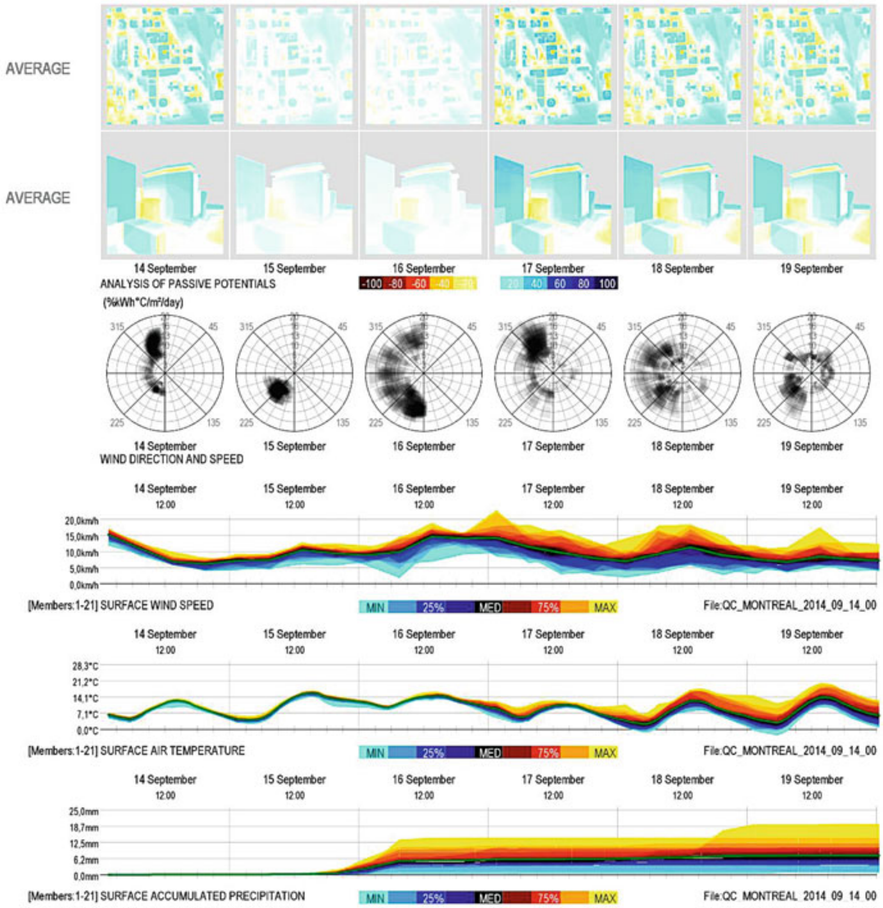

Fig. 16 Ensemble scenarios for building and urban applications produced using weather forecast data from the September 14, 00Z 2014 model integrations (NAEFS, GEPS, Montréal)

mitigation plan to adapt existing buildings and urban spaces in each city for future scenarios [12, 13]. According to the OCPM 2014 report on the consultation held on the draft Montréal Development Plan, after analysis of all the information presented by many participants, "the commission considers that Montréal cannot escape three challenges," where "Adapting the city to climate changes" is the first one noted [3].

But it is correct to consider Montréal future scenario only as warmer times both in summers and winters?

While some studies suggest a change in general temperature patterns in the past decades; RMMSS studies also highlight the fact that *as time goes by, Montréal appears to be experiencing sunnier scenarios* [12]. For instance, by comparing Figs. 17 and 18, it appears that the average amount of direct beam radiation has been significantly increasing in the past decades.

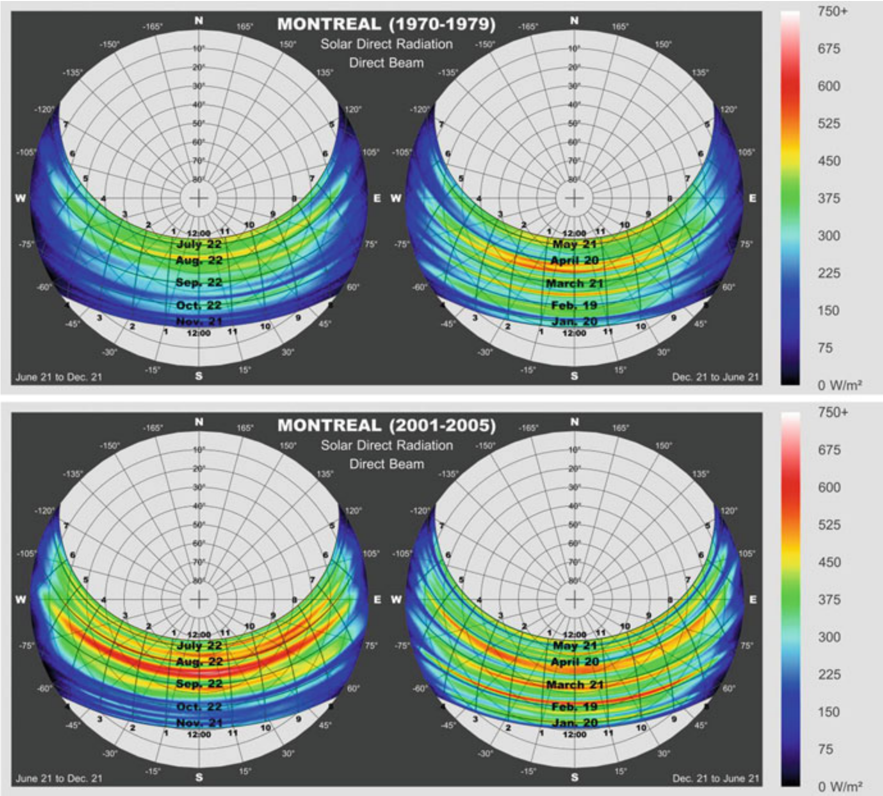

Fig. 17-18 Changes in direct beam radiation patterns in Montréal, above: 1970s, below: 2000s, *left*: June 21 to December 21, *right*: December 21 to June 21 (SOLARCHVISION standardizations based on CWEEDS)

Therefore, the increase in the number of sunny days both in summer and winter would likely result in having more extreme air temperatures in future, i.e., more cold days in winters and more warm days in summers. Figures 19 and 20 illustrate an integrated impact of the changes in air temperature as well as solar radiation in Montréal in different decades. As is illustrated in red, the undesirable impact of the sun[1] is improved notably in the past decades.

And the changes of this kind can be accelerated if we continue not actively following news. To clarify this a bit further, it can be noted here that today architects and planners have two critical options. One is to accept all this probable bad news and design the shelters that can resist thanks to appropriate shading devices and so

[1]Resulted from direct beam multiplied by the difference between base temperature and outdoor temperature, see "Intelligent design using solar-climatic vision" for more detailed clarifications regarding this index.

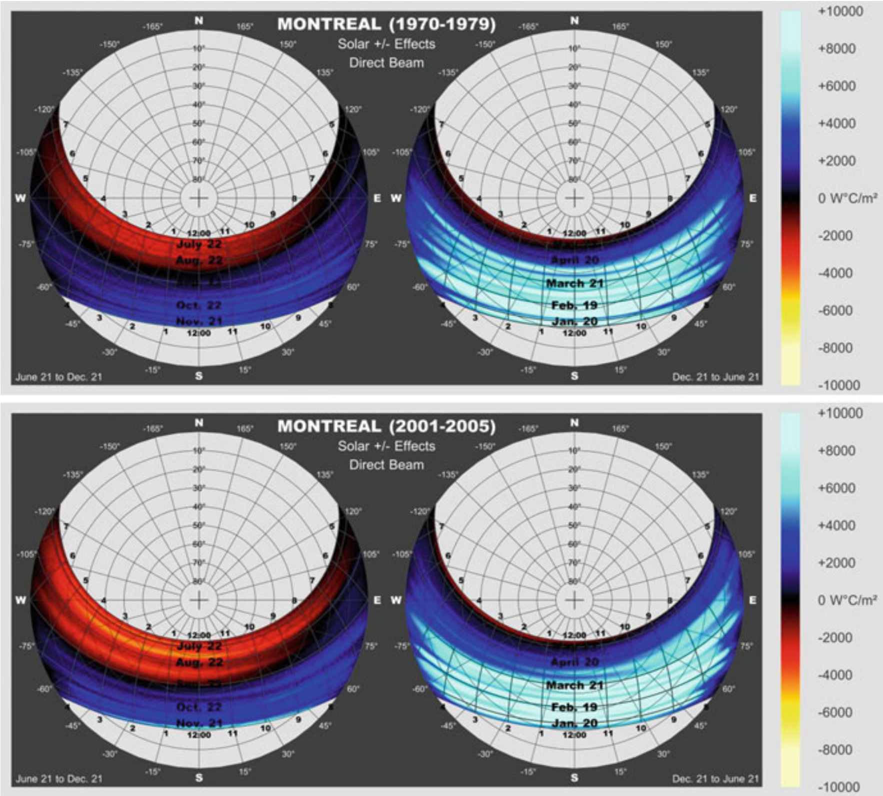

Fig. 19-20 Changes in positive and negative effects of direct beam radiation in Montréal, *above*: 1970s, *below*: 2000s, *left*: June 21 to December 21, *right*: December 21 to June 21 (SOLARCHVISION standardizations using +18 °C as the base temperature)

on. The other option is to fight against these global changes. In addition to all the great benefits[2] the sun as well as climate data details can provide when they are considered effectively, it is vital to interact efficiently in the environment. And this is of course not possible if we still consider building as systems that have no hear to listen, no eye to observe, no mind to orient, no skin to reflect, and no initiative to act in future (Figs. 21 and 22).

As was described earlier in ref. 8: looking to architecture as a tool in the design of places for living well, we cannot be indifferent to the result of events which occur around us and on this planet. Therefore, an "Active Solar Architecture" should watch out for and listen carefully to the general patterns as well as to the changes in a variety of parameters and their integrated impacts in different time scales, i.e.,

[2]In the areas of improving efficiency, comfort, health, and safety factors inside and outside buildings.

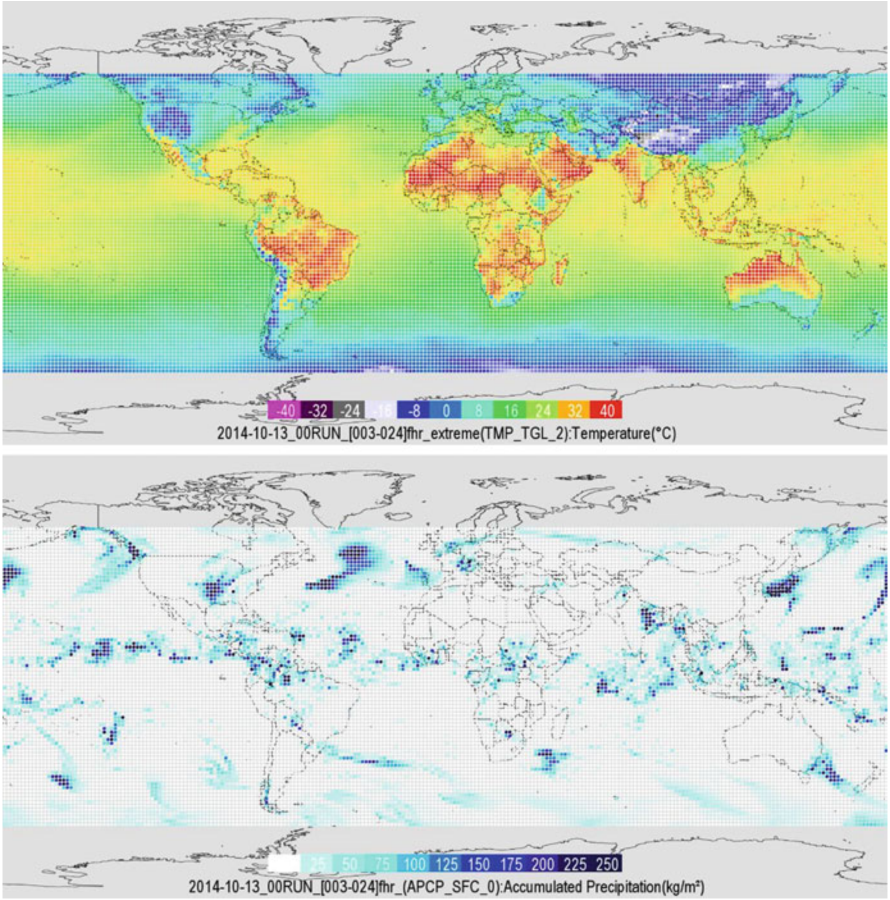

Fig. 21-22 SOLARCHVISION visualization and initial post-processing on Global Deterministic Prediction System (GDPS), *top image*: extreme daily air temperature (using +18 °C as the base temperature), *lower image*: daily accumulated precipitation

instantaneous, hourly, daily, annual, and in decades. Such processes on the various timelines are the basis which bring and maintain good qualities associated with life cycle, health, comfort, and safety measures.

In terms of environmental parameters, different weather forecast datasets including global and regional models are being updated every hour and every day. Deterministic and ensemble forecast can be used to have a better view of the future events in short and longer time periods, or lead times, into the future (Figs. 23 and 24) (also see ref. 11).

As can be highlighted by the SOLARCHVISION process, one of the focal points is how the activation of the senses at building skin/neighborhood/city management/decision-making levels can result in developing more efficient, com-

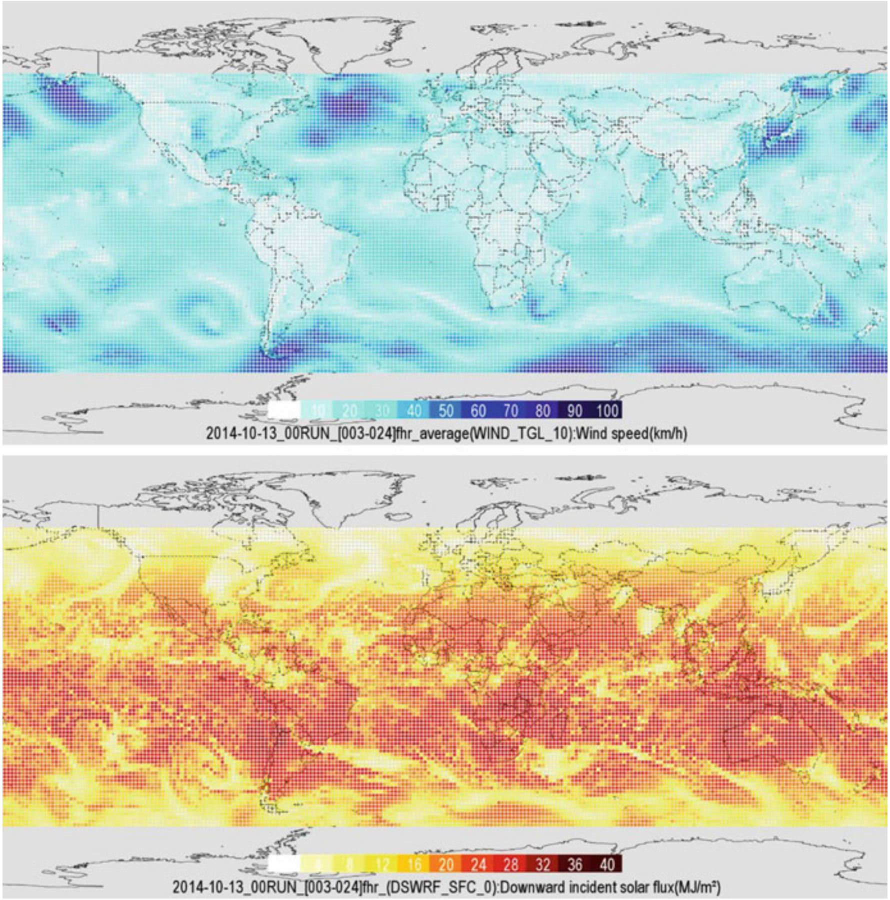

Fig. 23-24 SOLARCHVISION visualization and initial post-processing on Global Deterministic Prediction System (GDPS), *top image*: average daily wind speed, *lower image*: daily downward incident solar flux

fortable, safer, and more sustainable spaces for all. On the other hand, an integrated and optimized use of increasingly advanced technologies as well as renewable systems needs a vast and deep knowledge in different areas of science which cannot be handled without interdisciplinary work and collaboration among many environmental scientists, building engineers, architects, landscape architects, urban planners, municipalities, clients, and building and city dwellers [1].

Oh brother sun, dear brother sun please shine down on me!
Oh brother wind where have you been?
Dear sister moon tell us what you see.
Oh little star, far away into the night . . .
Grant us our wish tonight . . . [14]

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The author also acknowledges the assistance from Mr. Lewis Poulin of the Quebec National High Impact Weather Laboratory of Environment Canada for his help in learning more about the availability and application of deterministic and ensemble weather forecast datasets, summarized in part in one of his presentations made at the International Conference for Enhanced Building Operations (ICEBO), Montréal, 2013.

References

1. RMMSS: Raz Mehr Mehraz Solarch Studio (2014). SOLARCHVISION website: solarchvision.com,
2. Samimi, M.: A draft solar-climatic and impacts analysis of the proposed towers added to Montréal's Downtown (2014). Office de Consultation Publique de Montréal, Canada. ocpm.qc.ca/sites/ocpm.qc.ca/files/pdf/P72/8a4.pdf, ocpm.qc.ca/sites/ocpm.qc.ca/files/pdf/P72/8a4a.pdf
3. Plan de Développement de Montréal (2013–2014): Office de Consultation Publique de Montréal, Canada. Project info: ocpm.qc.ca/pdm, PDM Report Overview: ocpm.qc.ca/sites/ocpm.qc.ca/files/pdf/P70/pdm-presse-eng.pdf
4. Projet immobilier sur la rue St-Antoine Ouest (2014): Office de Consultation Publique de Montréal, Canada, Project info: ocpm.qc.ca/node/4080, Final report: ocpm.qc.ca/sites/ocpm.qc.ca/files/rapport-saint-antoine.pdf
5. Tracey Arial T.: Montréal developers must consider the Sun (2014). View Island Report. traceyarial.com/blog/tag/mojtaba-samimi/,
6. Butti, K., Perlin, J.: A Golden Thread: 2500 Years of Solar Architecture and Technology. Van Nostrand Reinhold, Cheshire Books, USA (1980)
7. Samimi, M., Nasrollahi, F.: Intelligent design using solar-climatic vision: Energy and comfort improvement in architecture and urban planning using SOLARCHVISION (2014). Book, Young Cities Research Paper Series, Volume 09, Technische Universität Berlin, Germany. opus4.kobv.de/opus4-tuberlin/files/4717/young_cities_research_paper_series_9.pdf
8. Rassia, S.T., Pardalos, P.M.: Sustainable environmental design in architecture—impacts on health (2012). Springer. springer.com/mathematics/applications/book/978-1-4419-0744-8,
9. Environment Canada: Weather website, https://weather.gc.ca/. CWEEDS: Canadian Weather Energy and Engineering Datasets; GDPS: Environment Canada's Global Deterministic Prediction System; GEPS: Environment Canada's Global Ensemble Prediction System; NAEFS: North American Ensemble Forecast System; CCMEP: Canadian Center for Meteorological and Environmental Prediction formerly CMC (Canadian Meteorological Centre)
10. Poulin, Lewis: Renewable energy forecasts for solar water heaters (2008). Article in the Canadian Meteorological and Oceanographic Society's CMOS Bulletin SCMO, Vol.36, No.4, August 2008. collaboration.cmc.ec.gc.ca/cmc/cmoi/product_guide/docs/REFcsts/, REFcst_SolarH2O_Concordia_200808.pdf
11. Poulin, Lewis: Weather Forecast Data an Important Input into Building Management Systems (2013). Paper, The International Conference for Enhanced Building Operations (icebo.tamu.edu). Montréal, Canada, collaboration.cmc.ec.gc.ca/cmc/cmoi/product_guide/docs/REFcsts/

12. Samimi, M.: The sun and the city of Montréal (2013). Proposal for PDM (Montréal Development Plan). ocpm.qc.ca/sites/ocpm.qc.ca/files/pdf/P70/9a20.pdf, ocpm.qc.ca/sites/ocpm.qc.ca/files/pdf/P70/9a20a.pdf
13. Samimi, M.: A draft solar-climatic and impacts analysis of the proposed complex in Villeray–Saint-Michel–Parc-Extension (2014). Office de Consultation Publique de Montréal, Canada. ocpm.qc.ca/sites/ocpm.qc.ca/files/pdf/P73/8a9.pdf, ocpm.qc.ca/sites/ocpm.qc.ca/files/pdf/P73/8a9a.pdf
14. Poulin, Lewis: Brother Sun Sister Moon: homegrown songs to help change the world (2001). An independently produced music CD, copyright Lewis Poulin 2001

Analysis and Classification of Public Spaces Using Convex and Solid-Void Models

José Nuno Beirão, André Chaszar, and Ljiljana Čavić

Abstract Urban planning and design are increasingly often supported by analytical models of urban space. We present a method of representation for analysis and classification of open urban spaces based on physical measures including three-dimensional data to overcome some observed limitations of two-dimensional methods. Beginning with "convex voids" constructed from 2D plan information and 3D data including topography and building facade heights, we proceed to "solid voids" constructed by aggregation of *convex voids*. We describe rules for construction of both *convex voids* and *solid voids*, including basic forms and their adjustment for perception. For analysis we develop descriptive characteristic values such as *enclosure, openness, granularity* and *connectivity*, derived from more basic geometric properties of the void representations. We also show how combinations of these values can be correlated with urban open space typologies, including commonly accepted traditional ones as well as previously unnamed classes of space. Concluding with discussion of some future planned developments in this work, we also propose that such methods can contribute to better understanding of the relations between urban forms and their perception and use, so as to guide urban transformations for improved urban quality.

Keywords Urban open public space • Urban spatial analysis

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1 Introduction

Public space analysis and classification is essential to any urban design or local planning process. Objective data and measures obtained from models representing public space provide essential information needed to support decisions regarding design questions involving transformations of the urban space. The idea of measuring properties of the urban space is not a new one, but their meanings are very much dependent on the models used to produce those measures. In fact, the representation of space seems to be one of the most fragile aspects regarding urban analysis [1]. Many insufficiencies and inconsistencies are found in the initial representations defining the analytical models, and they usually reflect the ambiguities in characterising and classifying urban space and the elements which compose and define it. A typical limitation is the lack of tridimensional information in the geometric models. A common criticism of spatial analysis methods, especially *space syntax*, points out the absence of tridimensional information as an important flaw in the analytical model preventing it from capturing reasonably consensual aspects of human experience in public space such as feelings of enclosure and containment or the opposites such as spaciousness or openness. Even more, the classification of public space types captures patterns in properties of spatial arrangements, such as distinguishing streets as “channelled containment” from squares as being composed of “wider and flatter convex space” with “lower containment” as we describe in subsequent sections.

In this paper we present a method for the development of public space models that are able to capture tridimensional properties of open urban space. We start from a theoretical elaboration on the representation of tridimensional urban space (A); then we describe the proposed method, showing how to generate such representations from GIS data (B), and finally we present several properties of the representational models and their meanings in terms of the relation between tridimensional features of spaces and how they are perceived or contribute to an individual’s perception and opportunities for action within open urban space (C).

Regarding the issue of representation, Sect. 2.1 starts from a critical view on the “convex space” concept, then elaborates on the concepts of “convex-voids” (Sects. 2.2 and 2.3) and “solid-voids” (Sect. 3) as an alternative means for representing public space, including tridimensional data. Moreover, Sects 2.3 and 3.1 describe the technical aspects of the model, analytical platform, and tools used to support the generation of the analytical models, and it sets out the primary variables from which several properties of urban open space can be calculated. Sections 2.4 and 3.2 elaborate on the mathematics of urban space properties taken from the geometric representation of public space and on how the measurements of such properties taken from either convex-void or solid-void representations contribute to enhancing the interpretation of how we perceive public space. Section 4 explains the modular structure of the generative model. Section 5 details theory by showing results obtained from a model of central Lisbon, and Sect. 6 discusses a theory on perceived properties of public space in relation to urban quality. Section 7 concludes on the needs for further studies relating the properties of formal models of representation with specific qualities of public space. The table in appendix summarises all the measures that model is generating.

2 Representations of Public Open Space

2.1 Convex Spaces: Representations of Convex Spaces and Their Ambiguities

Most of the critiques pointed toward urban analysis systems are targeted at the primary representations of urban space. This criticism has been particularly intense in the case of *space syntax*: namely, the critiques pointed at "axial line" and "convex space" representations [1]. Although rebuttals have been offered (e.g. [2]) doubts remain.

Focusing on the representation of convex space several issues have been raised. The topic of granularity is one of those, and the topic of topology is another. As regards to granularity: How much detail should be considered in the representation of the public space? To what extent should irregularities in façade alignments and niches be considered? Or how should the ambiguities of modern urban space be represented? For instance, open spaces merging with street continuity and differently elevated public spaces raise many questions regarding their representation. Also, intermediate spaces like front gardens or "semi-public" areas which constitute steps in privacy or in territorial depth [3] between streets (the public space—Y) and building entrances (the private space—X)[1] contribute to introduce ambiguity in the identification of such spaces. Furthermore, the representation of curved streets also raises issues of granularity involving a simplification of concave curves into segments.

Clearly the level of detail, granularity or "resolution" in representation of urban space will also depend on the purpose, scale and scope of analysis. While for a global spatial observation the resolution of the model could be lowered with fewer details and higher degree of abstraction, for more localised place analysis the resolution should increase. Several attempts at development of tools for simplifying representations of spatial arrangements have already been done [4] using gestalt principles for reducing the number of displayed elements while maintaining the semantic structure of geometric information.

The herein presented study of central Lisbon has been done on the urban design scale (c.1:500), and for that reason the established drawing tolerance was 1 m. This

[1]Hillier and Hanson propose a notation identifying steps in territorial depth from the most global or public as Y to the most local or private as X. Steps in public space towards the most global are denoted as y steps in y space; and steps in private space towards the most private are x steps in x space.

Fig. 1 Minimal drawing tolerance of 1 m used in straight (**a**) and curved (**b**) urban spaces

means that all the changes in shape or alignments of the built environment which are inferior to 1 m did not influence the definitions of convex spaces (Fig. 1a). The drawing tolerance is a consequence of the scale of spatial observation that is intended to be done, and it directly influences the resolution of the representation emerging for that purpose. In the case study of Lisbon that we are presenting, the same tolerance of 1 m was used for definition of the convex spaces within the curved streets (Fig. 1b).

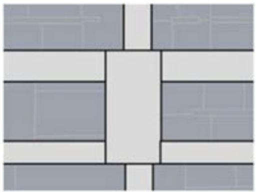
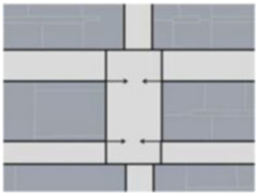
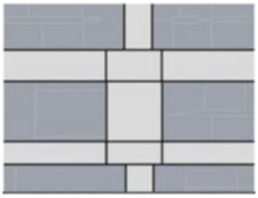
Turning now to topology, the most important critique comes from the representation of "convex space" in orthogonal street grids where one direction tends to superimpose the other by connecting street segments in one direction while subdividing streets into fragmented spaces in the other direction, hence destroying the perceived integrity of the street in the latter direction [5]. We elaborate further on this point in Sect. 3, where we describe the aggregation of convex-voids into solid-voids.

Taking into consideration the above mentioned critiques regarding granularity and topology (e.g. streets' crossings), we have developed a method that by overcoming those limitations improves urban and architectural description and analysis. The drawing method for convex spaces can thus be described in the following steps:

The last step about the need for local interpretation and group work which is presented in our method (Table 1, 5) addresses the issue of spatial interpretation already faced by space syntax. Even though the algorithm developed by Hillier and Hanson [6] for tracing convex spaces seems reasonably objective[2] practice shows that reality easily presents ambiguities that can lead two different persons to prepare

[2]Hillier and Hanson describe an algorithmic procedure for drawing the convex map as: «(. . .) find the largest convex space and draw it in, then the next largest, and so on until all the space is accounted for.» (page 98).

Table 1 Proposed procedure for drawing of convex spaces

1. Draw the typical space syntax convex space representation following instructions given by Hillier and Hanson—see footnote 2	
2. Consider all street junctions as separate convex spaces respecting the visual continuity of adjacent convex spaces	
3. Subdivide the minimum number of elements that allow the maximum number of possibilities for aggregation	
4. Spaces with significant differences in elevation should be distinguished as separated convex spaces	
5. Each situation should be interpreted locally and discussed within several working groups	

two different *convex maps*. Despite this fact, after discussion several individuals may agree on a common representation and henceforth use a common working representation. One could argue that the larger the number of people working on a common representation the greater the reliability of the model. Once agreed, the common representation can be used to perform several analytical routines that, being based on the same premises, produce comparable results. A similar comment was put forward by Stephen Marshall in regard to his route structure representation [7]. In any case, such an agreed common representation should only be applicable for problems of similar scale.

2.2 Convex-Voids: From Convex Spaces to Convex-Voids—Need for Three-Dimensional Information

As previously explained, for development of our analytical tool we began by adopting and improving *space syntax*'s reasonably objective way of representing

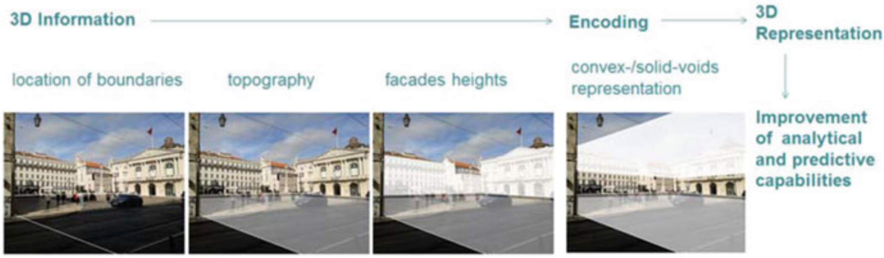


Fig. 2 From 3D realm to 3D representation

open urban spaces: *convex spaces*. However, these convex spaces are produced in a two-dimensional realm and do not account for any changes in the height of the surroundings. This would be sufficient if our ultimate objective was to analyse the influence of maximum horizontal visual fields in perception and cognition of an urban tissue (although even then it would misconstrue some important cases). But as we want to understand the character of those visual fields or of the open urban space itself and its performance, the height and topological elevations must be taken into consideration. Thus, a three-dimensional representation is needed. In that sense, our method begins from the improved *convex map* of *space syntax* by adding to it relevant information from three-dimensional realms, such as changes in height of the built surroundings and topography. It does this by encoding them in order to capture and calculate significant qualities of spaces (see Fig. 2), thus improving the model's analytical and predictive potential by describing spatial characteristics such as the feeling of containment as opposed to the feeling of spaciousness. The method for generating the analytical 3D representation at suitable resolution is presented in more detail in the following Sect. 2.3.

2.3 Convex-Voids' Height: Construction of Tridimensional Representation

2.3.1 Convex-Voids' Height

The basic representation of convex-voids is made through the extrusion of convex spaces. The height of extrusion ${}_{\mathrm{cv}}H$ is derived from the average height of surrounding buildings (Fig. 3a, b) and it is calculated as:

Convex-Voids' Height Equation

$$ {}_{\mathrm{cv}}H = (\Sigma A_{\mathrm{f}})/P_{\mathrm{s}} $$

A_{f}: Areas of buildings' façades
P_{s}: Perimeter of space ($=\Sigma L_{\mathrm{fo}}$)
L_{fo}: Length (on ground) of façades (incl. "0-height") or façade segments

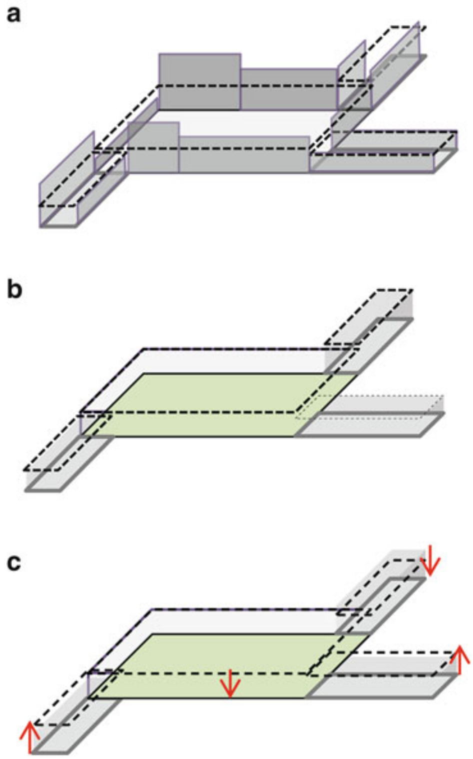


Fig. 3 Construction of convex-voids. (**a**) Boundaries and façade heights > containment value. (**b**) Containment value > convex-voids. (**c**) Perceived convex-voids

The perimeter of spaces includes façade segments and segments connecting convex spaces which have 0 height (e.g. street crossings). For computational reasons the latter segments, were given a negligible height of 5 cm. This serves to avoid issues arising from computations with "zero" values or extremely small ones affecting numerical accuracy in mathematical operations, as well as allowing visual checking of the model without adversely impacting the spatial characteristics developed.

2.3.2 Convex-Voids' Height Correction

The first model built using the above described methodology shows a few spaces that, although logical in terms of methodological consistency, fail to capture human perception in those spaces. For instance, the convex-voids representing street crossings within the regular grid clearly show a very shallow convex-void. If we consider that these spaces connect street segments on every side, corresponding to a space that has total connectivity with the neighbouring spaces (openness = 1, see Sect. 2.4) this means that such space should be perceived as totally open and not as enclosed space. Still, in narrow streets the street crossing enclosure is not so much defined by the openness to the neighbouring street segments but perhaps more by the edges of the buildings defining those street segments. Such perception of containment obviously reduces as the size (area) of the space rises; let us say that in a street crossing between two very large streets the closure effect of buildings with the same height would be obviously much lower than in the narrower streets. Considering this we defined an adjustment factor that raises or lowers the "convex-void" height depending on the convex spaces' area A_g. Such a factor typically raises the height of street crossings and lowers the height of enclosed street segments, while having only a minimal effect on larger spaces (Fig. 3c).

Corrected Convex-Voids' Height—Equation

$$_{cv}H_c = {}_{cv}H + {}_{cv}H_{adj}$$

$_{cv}H_{adj}$: Height adjustment ($= {}_{G}H \times (3/\mathrm{Sqrt}(9 + A_g))$)
$_{G}H$: Gross height correction value ($(A_f - A_{fn})/P_s$)
A_g: Ground area of space
A_{fn}: Areas of neighbours' façades

The corrected convex-void height $_{cv}H_c$ is given by the sum of convex-void height with the height adjustment value ($_{cv}H_{adj}$) which can be positive or negative depending on the characteristics of the surrounding spaces. The height adjustment $_{cv}H_{adj}$ is calculated using the gross height correction value $_{G}H$ which is given by the difference between the areas of the faces of a space A connecting other neighbouring spaces (A_f) and the area of the faces of neighbouring spaces connecting space A (A_{fn}). The faces considered here are the vertical faces of convex-voids which are coincident with an opening towards another space. Henceforth, when considering a space with very little permeability or small openings towards neighbouring spaces, the value of gross height correction $_{G}H$ given by the expression $(A_f - A_{fn})/P_s$ will tend to be small while in street crossings which are totally opened to neighbouring spaces the same expression will tend to achieve high values either positive or negative depending on which spaces have "taller" convex-voids—respectively space A or the neighbouring spaces. The gross height correction $_{G}H$ is then affected by the size (area) of the space A to which the correction is applied. The final height adjustment $_{cv}H_{adj}$ is given by the expression $_{G}H \times (3/\mathrm{Sqrt}(9 + A_g))$. This expression decreases the gross height correction when applied. The decreasing curve guarantees that decrease is small in small spaces and becomes more expressive as the considered space gets bigger.

Starting from this volumetric representation of open urban spaces (Fig. 4), we extracted several spatial characteristics and properties. Characteristics are basic measures such as size and shape, while properties refer to combined measures such as containment and spaciousness where the measure relates to a property perceived through human cognition.

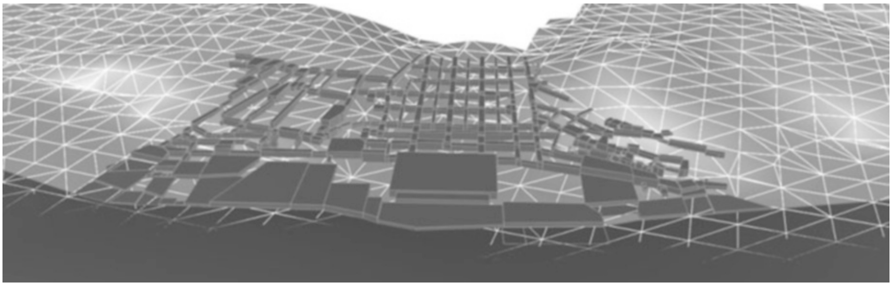


Fig. 4 Convex-voids' model

2.4 Convex-Voids' Characteristics and Properties: Characteristics and Properties of Urban Space and Their Mathematical Foundations

2.4.1 Size and Shape

Size and *shape* are categories of various basic properties of convex-voids. *Size* properties used in our work include lineal metrics such as length, width, height and perimeter, as well as more complex varieties of length, width and height for more complex shapes (e.g. length and width of bounding box). The *size* category of metrics also includes areas (e.g. of plan, of individual vertical faces, and of aggregates of faces) and volume. *Shape* properties are many and various, but here we have limited our focus to regularity/symmetry and aspect ratios, as described further in Sect. 5.2, where we use them as part of our analyses for classification of open space types and for characterisation of city districts.

2.4.2 Spaciousness/Containment: ${}_{\mathrm{cv}}S$

Spaciousness/containment represents the relation between the area of the convex-void façades and its floor area. This means that the sensation of spaciousness tends to be stronger when the area of space is bigger. The smaller spaces and ones with the higher built environment thus higher convex-voids façades would accordingly produce the feeling of spatial tightness and containment. A rise in the value of ${}_{\mathrm{cv}}S$ means a rise in the feeling of spaciousness.

Spaciousness/Containment—Equation

$$ {}_{\mathrm{cv}}S = A_{\mathrm{g}}/A_{\mathrm{fv}} $$
$$ {}_{\mathrm{cv}}C = A_{\mathrm{fv}}/A_{\mathrm{g}} $$

A_{g}: Ground area of space
A_{fv}: Area of vertical faces of convex-voids

2.4.3 Enclosure/Openness: $_{cv}$EV

Enclosure/openness to vision encodes the proportion of *open* (*or closed*) vs. *total perimeter* as a dimensionless, single (scalar) value. It is derivable from 2D (plan) data where open sides of spaces are assumed fully open and all others fully closed. It shows us the level of openness of the space perimeter, that is, the degree to which it prevents or permits vision (and possibly also movement) to an adjacent space.

Enclosure/Openness—Equation $_{cv}\mathrm{EV} = P_{ev}/P_{scv}$

$$\mathrm{OV} = 1 - {}_{cv}\mathrm{EV}\ (P_{ev} + P_{ov} = P_s)$$

P_s: Total perimeter of space
P_{ev}: Length of perimeter closed to vision $(= \Sigma L_f)$
P_{ov}: Length of perimeter opened to vision
L_f: Length (on ground) of façades (excl. "0-height")

2.4.4 Perceived Enclosure/Openness: $_{cv}\mathrm{EV}_p$

Perceived Enclosure/Openness to Vision is a percentage of a convex-void's faces that is overlapped by (the open sides of) surrounding ones. The value of enclosure 1 would indicate that the space is surrounded only by buildings while a value of 0 that it is completely open, i.e. surrounded by other convex-voids. This measure not only shows the relation of a space to its immediate neighbour(s) but also the potential of the space to be experienced as separate and distinct (if enclosure is high) or as a "transitional space" and a part of the spatial sequence (if enclosure is low).

Perceived Enclosure/Openness—Equation

$${}_{cv}\mathrm{OV}_p = \left(\Sigma A_{fv} - \Sigma A^{**}_{fvadj}\right)/\Sigma A_{fv}$$

A_{fv}: Area of vertical faces*
A_{fvadj}: Area of vertical faces of adjoining convex-voids*
*using perception-adjusted void heights
**using only the overlapping areas, where adjoining faces are higher than main convex-void

Proceeding from the observation that not all places we can see are places we can go (nor can we see all places where we can go)—in contrast with enclosure/openness where visibility from a particular space to adjacent spaces is the primary consideration, and movement is assumed to be unobstructed wherever vision is unobstructed—we are also developing a metric that will take into account obstacles to movement which may not be obstacles to vision and vice versa. The method(s) of calculation are in the first place congruent with those for simple enclosure/openness (to vision), based on a ratio of free to obstructed perimeter, but

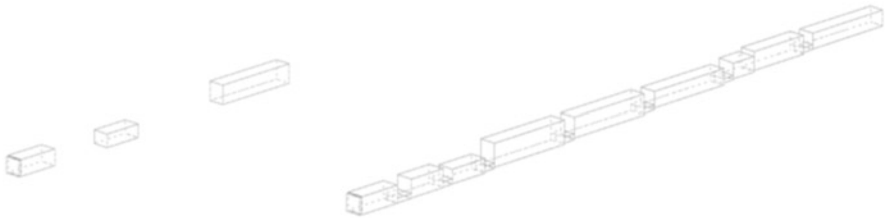


Fig. 5 From convex-voids to solid-void

substituting physical contiguity of space for mere visibility. See also “connectivity” in Sect. 3.2.4 for a related concept in solid-voids.

3 Solid-Voids: Aggregating Convex-Voids

While convex-voids can be thought of as the “atomic particles” of space—the basic units—solid-voids are more complex agglomerations of space, analogous in some sense to molecules (Fig. 5). Within the agglomerations the convex-voids belong together because of their tendency for affinity in perceptual and formal way.

Convex-voids are aggregated into solid-voids according to rules concerning the convex-voids’ tendency for affinity to each other in a basically perceptual, but reasonably objective[3] way. For example, convex-voids sharing an edge with no (large, and/or sharp) change in elevation normally would be considered contiguous, and so aggregated, as described in the rules below. Somewhat less obviously though still seemingly common-sensically, two spaces partially sharing an edge (qualified as before) where the shared length is sufficiently large (i.e. not too small, in relation to the partially shared edge’s full length) are also joined, subject to the further proviso that the spaces’ axes’ angular deviation is also within some reasonable limit.

In our method as currently implemented, convex-voids are thus aggregated into solid-voids according to three basic types of rules concerning the convex-voids’ interrelations:

Continuity of visual field between convex-voids and thus small angular deviation between them

Sufficiently large overlapped edges producing a gradual transition between spaces and thus a continuous spatial experience with no sudden breaks in spatial continuity.

Sufficiently small changes in elevation/slope, both with respect to sharp changes in ground height (and/or slope) and with respect to heights of the surrounding,

[3]Strictly objectively speaking, of course, all contiguous spaces are one, and the mere opening or closing of a portal potentially reconfigures a vast space/network of potential movement.

mainly vertical surfaces (i.e. mostly building façades, but also retaining walls, stairways and other features.)

Our method provides a basis for aggregation of convex-voids into larger complexes of solid-voids—that might correspond to known spaces as "Street" or "Boulevard". Strictly speaking, solid-voids are any agglomerated collection of convex-voids that can be recognisable as "individual" continuous spaces. Solid-voids construction is not a deterministic process that ends up only in a finite number of previously known categories. It is rather a representational method for the visualisation of open space that by its formal rigorous approach may produce some unexpected results that open new perspectives in understanding urban open space, its behaviour and qualities.

Solid-voids can be used in various ways. One of these ways is their analysis via their relatively simple properties and characteristics, as discussed in the following section. Another way is for characterisation of urban districts and other city sub-units according to the typologies of solid-voids found within them and around them, as described in Sect. 5.2. For instance, solid-void types in a regular grid and in an organic grid present distinct sets of characteristics and properties. Yet a third way of using solid-voids is as the basis for network analyses such as those of the sort found in *space syntax*. In the latter case, the network can be seen as an interwoven net of solid-voids.

In his article Christopher Alexander [5] compared two abstract collections of subsets: semi-lattice and tree arguing that inner structure of old cities is more similar to semi-lattice. He defined semi-lattice as: "a collection of sets forms lattice if and only if, when two overlapping sets belong to the collection, then the set of elements common to both also belong to the collection". The way that solid-voids are being constructed out of convex-voids would conceptually belong to the semi-lattice type of collection, meaning that one convex-void can belong to several solid-voids (Fig. 6).

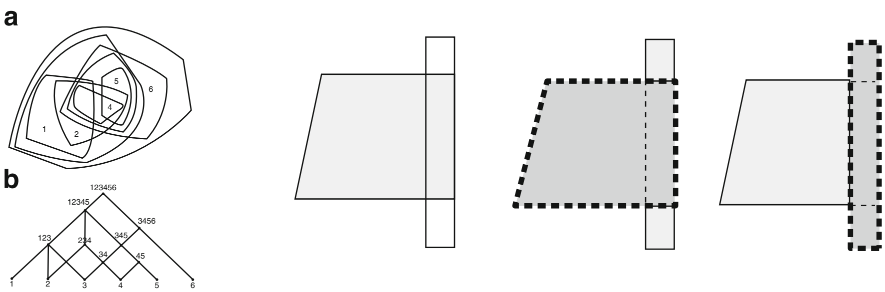


Fig. 6 Convex-voids as semi-lattice collections

3.1 Rules for Constructing Solid-Voids

We note that the construction of solid-voids is based on continuity of visual field that occurs when we pass from one to the other convex-void and because of that the linear elements for confirmation of angular deviation were generated (Table 2, 1). These elements by linking the middle points of space favour street central lines instead of *axial lines* of *space syntax* as suggested by several studies [8, 9]. Preference for usage of streets' and other spaces' central lines instead of axial lines is based on four principal advantages:

1. Possibility to compute the process of lines' derivation and link it with GIS.
2. Necessity to account for angular changes in urban space as important factor that influences spatial movements.
3. Importance of various morphological categories that could be neglected by usage of axial lines, such as separated streets that could be represented by only one axial line if they are part of the same visual field.
4. Possibility to account for navigation decision that happens on crossroads which are not represented by axial lines.

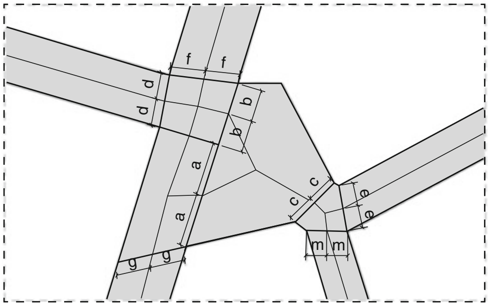
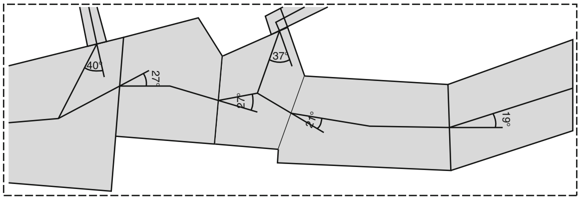
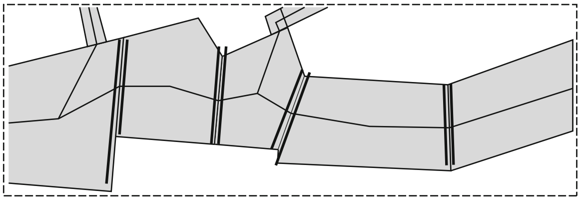
After having the basic linear network we proceeded with testing angular deviation. Within the presented case study the proposed maximum allowed angle is smaller than 30° (Table 2, 2) that was tested to produce visual continuity within the system. We define angular deviation as the difference in co-linearity of axes connecting two adjacent convex-voids. This property is employed in determining whether two adjacent spaces with connecting axes are candidates for joining into a "solid-void"—also subject to further conditions. When spaces have multiple axes, the choice of candidate spaces is also conditioned by the sequence—and thus direction—of search for joinable convex-voids hence allowing the formation of multiple solid-voids. Also, spaces joining at acute angles may therefore result in branching solid-voids, depending on the sequence/direction of search (Table 2, 1).

After defining the chain of spaces using central lines' angular deviation it was necessary to check if the overlapped edge between spaces is sufficient in a way that guarantees the continuity of spatial experience (Table 2, 2). For the study here presented we defined that the change in width should not be bigger than 1/3 of the wider space's edge length (Table 2, 3).

The implemented rules for constructing solid-voids' model are elaborated and visualised here in Table 2:

The value for angular deviation given here was found through simple empirical tuning of the model. However, it is a concern to keep in mind that such value should perhaps be validated either by applying statistical methods or by testing from a larger set of examples. The former would produce a specific value for maximum allowed angular deviation which can also be seen as a particular property of a grid sample, distinguishing regular from crooked grids. The latter could provide a universal value and hence allow the comparison of results between different grid samples. The same logic applies to rule 3.

Table 2 Proposed procedure for construction of solid-voids

<table>
<tr><td>1. Trace central lines within the convex-voids connecting the centroid of space with the middle points of its permeable edges</td><td>
</td></tr>
<tr><td>2. Check angular deviation between the central lines of the adjacent convex-voids in both, the plan and section view. Aggregation possibly can occur when angular deviation is less than 30°</td><td>
</td></tr>
<tr><td>3. Check the width difference between the aggregated spaces. Additionally, aggregation can only occur when the length difference between connecting segments of adjoining spaces is smaller than 1/3 of the wider space's edge</td><td></td></tr>
</table>

We also note that a simplified version of the aggregation rules would allow formation of space complexes on the basis of only 2D data but this would be inconsistent with the aims of our work in terms of addressing the critiques of space syntax noted in the Introduction. Discontinuities in plan elevation would also tend to be missed in a 2D-only rule-set, except where the boundary happens to correspond with some feature large enough to be captured. However, considering that the whole model is generated in a 3D environment, angular deviation can also be calculated in terms of the changes in elevation and at least certainly able to introduce slope angle in the model. As such, a fourth rule may constrain the formation of solid-voids within a specific allowed slope. However, as the case of Lisbon involves streets formed by large urban staircases this property will need further investigation in order to be able to capture these peculiar street types.

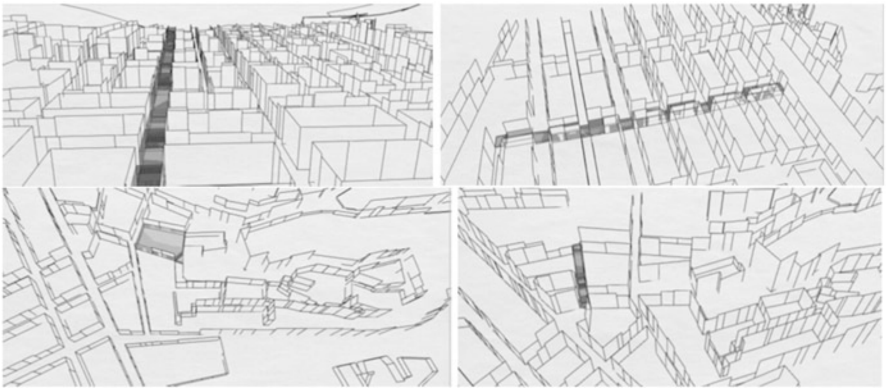


Fig. 7 Different convex-voids regarding number of particles

3.2 Characteristics and Properties Taken from Solid-Voids

3.2.1 Size Based Analyses

Number of Convex-Void Particles: ${}_{\mathrm{sv}}N$

First important characteristic of solid-voids is the number of convex-voids forming it. The case study of central Lisbon showed a great diversity regarding numbers of convex-void particles. From extremely small solid-voids, made out of two or three convex-voids, to the long ones constructed from 15 to 18 particles (Fig. 7). This characteristic of solid-voids reveals us how "knotted" a network is—the less crooked the network is the longer solid-voids tend to be. Importance of this characteristic in analysis of perception of urban space becomes apparent when we compare solid-voids from regular Baixa district and irregular Alfama. Since Baixa's network is regular with small or almost none angular deviations solid-voids' are significantly longer than Alfama's ones.

However, the chosen case study does not contain situations like long crooked streets typically found in organic grids[4] that can also be found in a larger sample of Lisbon's urban tissue. Considering the obtained results until now, it is our conviction that this method will be able to aggregate these streets in long but crooked solid-voids. N is therefore an expression of solid-void length measured by the amount of street segments.

[4]Portuguese medieval towns usually contain a long winding street crossing the grid called "rua direita" (ironically meaning straight street). Lisbon centre is accessed by very old streets with similar characteristics which can still be seen entirely or partially within its complex superposition of old and new grids. "Rua das Portas de St Antão" and "Rua dos Anjos" are two examples of such streets and many others can be identified.

Length of Solid-Void: ${}_{sv}L$

It is the sum of the lengths of all street segments forming the solid-void and gives the metrical value of ${}_{sv}N$ or the physical length of the solid-void.

3.2.2 Number of Façades Within a Solid-Void: ${}_{sv}N_f$

This characteristic of solid-voids is the basis for the calculation of the property of granulation and informs about the diversity of buildings facing the solid-void.

3.2.3 Granulation of Built Structure of Solid-Void: ${}_{sv}G = (N_f/L) \times 100$

Granulation of built structure is the ratio between number of façades and the length of a solid-void with the unit reduced to hundred metre sections. It gives the number of façades per hundred metres.

Within urban network it is often a case that solid-voids with the same length have significantly different number of buildings in it. This information reveals us the granularity of built structure which is important for understanding of spatial experience but as well for usage of space. When façades are narrower their number is higher and thus we have more buildings that give access to the same open space. The number of buildings entrances and their position can help us in better understanding of place activities and its liveliness (Beirão and Koltsova, forthcoming).

3.2.4 Connectivity: ${}_{sv}\mathrm{CON}$

Number of physically permeable routes leading from one solid-void toward other spaces. Connectivity here follows exactly the same definition as in Marshall's [7] route structure analysis.

3.2.5 Perceived Connectivity: ${}_{sv}\mathrm{CON}_p$

Number of all routes, physically permeable and not permeable, opening from one solid-void towards other spaces. This property includes visually accessible spaces without physical accessibility, for instance, a belvedere abruptly opened in the middle of a street or a view through a fence.

3.2.6 Void Connectivity: ${}_{sv}\mathrm{VCON}_p$

Number of other solid-voids connecting (or crossing) a solid-void. This measure gives a local value of the connectivity of solid-voids in the network. The concept is

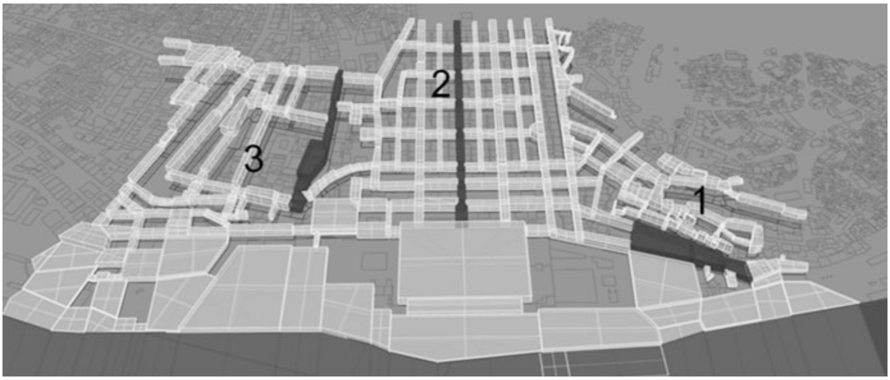


Fig. 8 Solid-voids from three different Lisbon's areas

Table 3 Characteristics and properties of solid-voids

Solid-void	$_{sv}N$	$_{sv}L$	$_{sv}N_f$	$_{sv}G$	$_{sv}$CON	$_{sv}$CON$_p$	$_{sv}$VCON$_p$
SV1	3	195 m	18	9.2	6	6	6
SV2	16	530 m	60	11.32	15	15	8
SV3	10	320 m	41	12.81	6	6	5

close to the concept of connectivity in *space syntax* and therefore we can also expect to find properties of the grid based on this one. However such properties still need further research (see Fig. 8 and Table 3).

4 The Generation of Tridimensional Representations of Public Space

4.1 Generic Codes for Calculating Properties of Urban Space

The use of generic codes or design patterns is not just used for the generation of analytical models but also to calculate the properties that we want to extract from those models. The primary properties are mainly calculated by the pattern that generates the model. For instance, average height of all the façades surrounding a convex space, is needed to generate the analytical model and therefore previously calculated to generate the convex-void model.

Using the four analytical models generated by the patterns we can extract a larger set of open space properties. The calculated properties can then be collected and organised in tables and classified by analytical models.

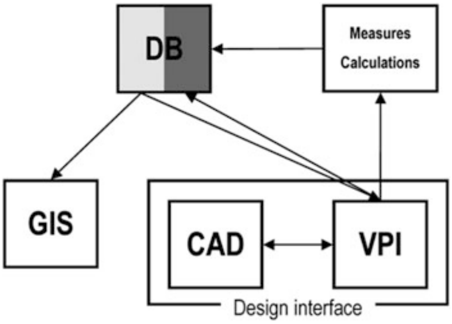


Fig. 9 CIM structure: a database DB is accessed by a GIS platform and a design interface composed of a CAD environment and a visual programming interface (VPI) including a set of calculations module that produces new information and stores it back in the DB

4.2 From GIS to the Analytical Model: The CIM Environment

The analytical models were all developed on a parametric city information modeling platform (CIM). A CIM platform involves access to geographic information in a CAD environment and the possibility of manipulating the existing data in a parametric visual programming interface (VPI). Generically a CIM environment works as shown in Fig. 9 [10, 11]. In our case, we used Rhinoceros as the CAD platform and Grasshopper as the VPI. The preliminary representations are captured from the geographic data and "cleaned" or "reinterpreted" in order to obtain the initial model representation according to the principles described in Sect. 2. Basically, the initial representations are composed of two basic layers: (1) a layer of convex spaces and (2) a layer of façade planes. An additional set of convex spaces is considered as a separate layer for the case of the open space defined by the river—see the Lisbon case study. In layer (1) the convex spaces are first drawn following Hillier and Hanson's instructions, then further subdivided according to the principles explained in Table 1, and finally elevated to their specific z coordinate using the GIS data on elevation. In layer (2), the façade planes are drawn using the GIS data (building polygons + façade heights) where the façade heights are given in the GIS database by the difference between entrance elevation and rooftop elevation.

The CAD + VPI platform, although able to replicate some GIS analytical procedures, is still useful for displaying and treating large amounts of data or faster for some basic analytical routines. However, when approaching design, in other words, when intervening and changing the territory, the CAD + VPI platform reveals its advantages through the incorporation of calculation tools that evaluate simultaneously existing and proposed or designed parts.

4.3 Generic Codes for Generating Models

Once having produced the two layers containing the basic representations, we used a set of predefined codes for generating the 3D models from which we could extract a set of measurements representing particular properties of the public open space (details in the preceding Sects. 2 and 3). We used basically two codes: (1) one code to generate the convex-voids' height model and (2) another to generate the corrected convex-voids' height model. These codes can in principle be used to generate similar models in any other urban context and are therefore considered to be reusable design patterns generically suitable for the purpose of generating convex-void models. A third code (3) is used to generate a graph linking the centre points of convex spaces which regulates the evaluation of angular deviation while linking convex-voids into solid-voids. The fourth code (4) is the solid-void modeler that converts convex-voids into solid-voids by evaluating the several possible aggregations forming streets and other types of "unitary" open spaces. The reusable codes or design patterns were all programmed in Grasshopper and were closed into "clustered" codes to allow easy reuse and simplify the overall code structure. It is our plan to improve these codes by extending their application in several other case studies before sharing them with the research community.

5 Public Space Classification by Means of Properties Correlation

5.1 Classification and Correlation Concepts, Motivations and Methods

In this chapter so far we have been describing properties and characteristics found in models representing public open space. Size, shape and orientation are common-sense notions employed in everyday language, which are in the main intuitively graspable though requiring some subtleties of definition and interpretation when looked into more closely. Similarly, the characteristics spaciousness/containment, enclosure/openness, and so on describe aspects of spaces which we commonly experience through observation and use of space, though recognising that these aspects are perhaps less basic, less obvious. We distinguish therefore between the typically measurable "characteristics" of space(s) and typically calculated "properties" of space(s) in order to draw attention to the difference between the more elemental factors (size, shape etc.) and the more complex, synthetic ones (such as containment) This taxonomy is useful in aiding thought about (1) which factors are directly or nearly directly measurable, versus being calculated, and (2) how the progression from characteristics to properties, or vice versa, might be extended.

Furthermore, we can begin from these observations about characteristics and properties to reason about how correlations among them may form patterns which could be the basis of a taxonomy of space. The taxonomic stage is found in many areas of science where extensive and increasingly methodical observation and description of phenomena builds up to a body of knowledge (or simply information) which can either generate or corroborate theory. Thus, the observation of patterns in morphological and other characteristics/properties of public space can lead us to further insights regarding, for example:

1. The historical/temporal transformative processes by which spaces change, gradually or abruptly.
2. The system (if any) of space types which characterises particular periods in and/or types of urban development.
3. The relations between space types and space uses.
4. The rules/guides which might direct intervention (via design, via policy etc.) in spaces of particular types in response to particular needs for change.

These four domains may contribute with new insights to the fields of urban morphology: (1) typology and classification, (2) urban ontology, (3) planning codes and (4) enhancing knowledge in these fields and improving the predictive capabilities of planners and authorities. The last of these four points is of special interest where public opinion and municipal means favour and allow only "surgical" interventions, in contrast with large-scale transformations of existing urban fabric. On the other hand, planning and design of new cities (such as in response to the various contemporary pressures toward urbanisation) can be guided by all of these types of insights, when seeking for models able to simulate the future "performance" of the projected urban fabric and systems.

Applicable methods of correlation and classification include clustering and User-Guided Feature Recognition (UGFR), as described in, Gil et al. [12], Sokmenoglu et al. [13], Chaszar [14, 15] and Chaszar and Beirao [16]. While even very simple methods of classification can suffice for some purposes—for example ranking, grouping and searching by size expressed as horizontal surface area, for purposes of identifying spaces suitable for particular activities or uses (or giving particular sensations, associations, potentials and so on—usually more complex identification/classification methods utilising compounded criteria are of greater interest). At the opposing end of the spectrum, the task becomes especially interesting when the number and exact choice of criteria are not known in advance, i.e. in an exploratory situation where even the possibility of discovering hitherto unidentified space types is not excluded.

The basic operations of course consist of: (a) choosing one or more (metric[5]) criteria, (b) sorting/ranking all spaces along the dimension(s) chosen and (c) defining "arbitrary", "natural" (or some hybrid of these) limits within the ranked/sorted data to delimit "bins", "buckets", "classes", "clusters", "types" etc. The terminology varies among domains, and "types" is the one most frequently encountered in studies of urban form as well as other design-related fields.

[5]Note that non-metric criteria can also be used, but in such cases only sorting, not ranking, is possible on that/those dimension(s).

5.2 *Example Classifications: Central Lisbon Case*

We can illustrate the above described principles and operations with more concrete examples drawn from existing urban fabric (though noting that work on projected, future urban fabric can also be so approached, and in many cases is actually easier to deal with). Here we find that differentiation or affiliation along four dimensions is sufficient to capture commonly used notions of public space typology, while for exploratory "discovery" of "new" types more dimensions are more suitable. Our example case—working with spaces in Central Lisbon and described below in Sect. 5.2 and at greater length in [17]—shows how classification based on convex-void properties and characteristics can reproduce categories of open urban space found in everyday language. More specifically: Area, Aspect Ratio, (perceived) Containment, and (perceived) Enclosure suffice to differentiate "praças" from "largos" and also from "rossios". Even simple size and shape analysis can also be enlightening as illustrated below.

Even though convex-voids are the simplest spatial "particles" that will be further used in more complex urban observations, their first degree analysis gave us important insight into several properties of three districts of Lisbon's central area that were part of our case study: (1) Alfama, (2) Baixa Chiado, (3) Colina de São Francisco (Fig. 10).

The properties of convex-voids here presented are: minimum, maximum and average area, volume and height (Table 4). These showed that even very different in area these three districts have quite similar height of convex-voids which is to say

Fig. 10 Case study of Lisbon central area

Table 4 Size based analysis of Lisbon central area

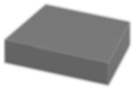
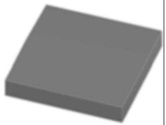
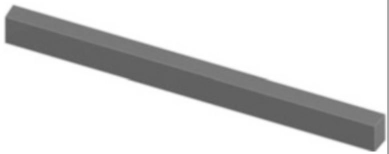
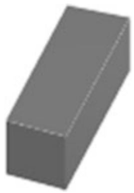
District	CV area domain (m^2)	CV area average (m^2)	CV volume domain (m^3)	CV volume average (m^3)	CV height domain (m)	CV height average (m)
Lisbon central area District 1	1.60–1,253.60	164.88	2.83–12,746.98	1,761.72	1.41–18.95	9.50
Lisbon central area District 2	23.68–31,379.36	697.78	199.78–5,19,192.51	8,968.08	2.34–23.58	11.90
Lisbon central area District 3	4.47–18,962.34	808.32	51.42–2,10,817.66	7,906.85	0.19–23.58	10.26

that average height of built/unbuilt surrounding even within different scales, from the traditional Alfama (average area of 165 m^2) to the Colina de São Francisco (average area of 808 m^2), is similar.

Similarly to size analysis, the initial observation of convex-voids' shapes allowed us to distinguish three main subgroups: regular, partially regular and irregular convex-voids (Table 5, a), related to degrees of symmetry and/or other patterns of repetition and variation. When we observe the distribution of these within the three districts from our case study, the first one, Alfama, consists of mostly partially irregular and irregular convex-voids, the second one, Baixa Chiado, of mostly regular ones and the third, Colina de São Francisco, generally of partially irregular ones. Thus, districts or sub-districts having some degree of structural consistency distinguishable from adjoining (sub-)districts can be identified and characterised. Combining observations of size and shape can of course still further refine the analysis, as noted in Chaszar and Beirao [16].

Observing aspect ratios, we developed several distinct metaphorical descriptions of public spaces that account not only for the proportions of shapes, but also for their scales with respect to the human body and its hitherto known impressions from the built environment (Table 5, b). In this way we recognised: (1) Canyon-like spaces (long and very tight ones), (2) Valley-like spaces (big and low ones) and (3) Stream-like spaces (long and middle height). Within the district of Alfama convex-voids have the smallest scale, very proximate to common indoor living surroundings, and thus we obtained for the descriptions from that language: (4) Room-like spaces (small to medium in size and height) and (5) Corridor-like (prolonged ones). We note that the choice of names for these types is not inherent to the method. Instead, they have been selected as mnemonics and as metaphors with potentially suggestive qualities to be tested through use; other analysts may prefer other terms and distinctions, according to their circumstances and purposes, in accordance with the exploratory capacities of the classification method [14–16].

Table 5 Shape types and aspect ratio

(a) Shape	Regular	Partially irregular	Irregular		
Example					
(b) Aspect ratio	Canyon like	Valley LIKE	Stream like	Room like	Corridor like
Example					

6 Discussion on Public Space Properties and Quality

Here we discuss some points regarding implications of the work described above beyond just description of open public space, especially with regard to urban analyses' potential for qualitative evaluations and for prediction of "optimal" or at least desirable urban fabric qualities.

Some of the questions naturally arising from a process of urban open public space representation and characterisation such as this concern how these relate to the quality of public space. That is, it is tempting to ask whether such an approach can help us identify "good" versus "bad" public space and even achieve "higher quality" where it seems "too low". A common denominator among urban planners and urban designers is the wish to understand how the form and other characteristics of urban space influence the sense of quality of such spaces, even though it is generally accepted that quality is essentially a highly ambiguous issue dependent on cultural environment, social context and even on the personalities of the people who experience such spaces. However, it is a goal of our research to understand how certain objective (measurable) properties and characteristics of public spaces relate to qualitative aspects, while keeping in mind that the definition of quality is controversial and full of nuances—the main questions being: what is "good" or "bad" urban space?, and furthermore is a particular definition of "good" or "bad" accepted by a small or large group of people, dependent on culture, climate, social or economical environment?

While we believe that our proposed method can help in such efforts, we must advise caution due to the significant complexity of the issue. Three main points are relevant here: firstly, any meaningful assessment of space quality must be highly multi-dimensional; secondly, any such assessment standard is likely to be provisional and situation-specific to some (possibly large) extent; and thirdly, even after composing an acceptable, agreed-upon assessment standard, the correlations between measurable properties and derivable characteristics of space on the one hand, and specific dimensions of quality on the other hand, are likely to be difficult to establish. In any case, establishing causal links between space descriptors and qualities would require extensive empirical studies conducted in actual urban environments, as theory is unlikely to be of much use in drawing valid conclusions on this issue.

We can envision a relatively effective comparative approach nevertheless, recognising that although public space quality may never be absolute, it may be assessed from a set of well identified properties that can be measured and compared against other values taken from examples selected by their recognised "goodness" or "positive quality". Cultural issues clearly indicate that quality is very much a function of cultural environment. Recognition of "goodness" is also an ambiguous factor as such recognition will probably be differently identified by stakeholders, planning authorities, urban planners and citizens. However, there are democratic and participatory ways of choosing among alternatives—if not actually reaching consensus—in that regard.

Three of the methods which could be used to assess quality in urban environments are as follows. First, we can add to the set of measurable properties and calculated characteristics a set of also measurable performative indicators which could correlate with objective (or at least widely enough agreed) expressions of "goodness", considering that we will probably follow some explicitly stated assumptions regarding what "goodness" is. For instance, does a particular space attract people? How many? This property could be measured by observation counting how many people per square metre use a space during the day. The assumption is that a space is better because it has more use (it is sought by more people), though recognising that some spaces are intended to remain less intensively used. Another expression of "goodness" we can objectively measure is land price. The assumption here is that higher prices correspond to desirable spaces and henceforth to spaces more valued by the general public (although remaining aware of market distortions due to speculative behaviour). The number of abandoned buildings, which could on the one hand tell that places are unwanted, can on the other hand simply express residues of economic maladjustments of planning codes and speculation without necessarily meaning that the urban form is wrong.

In any case, measuring performative indicators and correlating those with patterns in morphological arrangements seems at least to be a reasonably objective approach towards building a correlation between urban morphology and urban quality, even if not proving causality.

A second approach (perhaps less generic) would be to start by selecting examples of urban fabrics perceived by a set of stakeholders as exemplary achievements in terms of urban quality, measuring their properties and characteristics and using those as benchmarks to compare when developing new plans or implementation strategies. This method has the advantage of being adaptive to contexts and cultures if used consciously and consistently, but does not provide any explicitly stated and agreed standards for urban quality (only implicit or otherwise hidden ones). However, a consistent and continuous use of the method might lead to the finding of recurrent features or patterns in the assessment of quality that may in the future provide a reasonable list of good practices to follow. With such an approach, areas of study such as urban morphology and comparative urbanism can be operationalised rather than remaining purely descriptive and speculative.

A third approach relates to benchmarking as above, but proceeds from the accumulated professional knowledge of urban planners, designers, architects and engineers on the one hand, and "embedded" vernacular knowledge on the other. Both abstract, imagined urban fabric scenarios (for example as produced conventionally, or as generated via a CIM process) and existing examples of built urban fabric (including both well-known and obscure but highly regarded specimens) would be subjected to study. This approach then compares the properties, characteristics, emergent features and resulting qualities of these scenarios and specimens to see where there are significant concurrences and divergences.

The physical and visual qualities that we were describing so far belong to a formal realm that cannot be comprehensively understood without its functional or semiotic aspects. Nevertheless, the importance of what we perceive around us, and the affective responses we have to it should not be disregarded. Qualities such as spaciousness or containment might strongly affect our emotional state, for example evoking the emotion of freedom to someone and representing a threat to someone else (Arnheim 1977). Such public open space characteristics and their combinations can also influence the sense of formality and even the concept of "publicness" itself [18]. Factors such as these ultimately contribute to the quality of urban life and to the ways that people experience, act upon and inhabit the city, for even in social physics we and they are still agents with complex goals, fears and aspirations, not just particles responding mechanistically to abstract forces.

7 Conclusion and Future Work

To summarise very briefly, we have introduced a set of methods for incorporating 3D geometric data into analysis, classification (and when appropriate, generation) of open public urban space representations. This has been motivated partly by previously published critiques of existing urban space representation/analysis methods (such as *space syntax*) and partly by our own observations regarding shortcomings of existing representations' analytical and predictive capabilities. Our methods are developed from a combination of perception-based and "objective" encodings of urban space properties, and these properties are processed via algorithmic rule-sets to derive compounded characteristics of urban spaces. Spaces are addressed at various scales—from the more basic "convex-voids" to the larger aggregations of these into "solid-voids".

The methods thus developed are applicable both to studies of existing urban fabric and also to projection of proposed alterations or entirely new cities/districts/spaces, for instance through the operations of a generative CIM (City Information Model) which we have also briefly reviewed. Analyses of existing or new urban fabric can—via searches for and identification of patterns of similarity and difference—give insights to both the structure of the city/district/space and also the ways in which these may be perceived. The methods we have introduced support pattern identification of commonly recognised spatial types as well as of others which are uncommon or are quite common but usually not named (thus, strictly speaking, not classified).

Our planned future work on further development of the convex- and solid-voids method(s) includes refinement of the algorithms for generation of convex- and solid-voids from GIS and other relevant data, and also extension of the current set of urban space characteristics and properties from which they are derived. We also foresee the possibility of linking characterisation and analysis of indoor and outdoor spaces via these methods and characteristics. Furthermore, we wish to explore correlations between (1) the urban space characteristics calculated and patterns discovered using these methods and (2) the observed patterns of space use and behaviour of persons associated with types of spaces, which we hypothesise to depend both on positional/relational (network) factors as well as on more local factors of "individual" spaces or small, local aggregations of space. Such explorations would of course require accounting also for factors additional to the topological, 2D and 3D geometric data describing urban space, such as material properties and economic and social data.

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Appendix: Summary of Measures Extracted from Convex- and Solid-Voids' Model

Convex-voids' generation			
Convex-voids' height	${}_{cv}H$	${}_{cv}H = (\Sigma A_f)/P_s$	Convex-voids' height is derived from the average height of surrounding buildings
Corrected convex-voids' height	${}_{cv}H_c$	${}_{cv}H_c = {}_{cv}H + {}_{cv}H_{adj}$	Corrected convex-voids' height is sum of convex-void height with the height adjustment value (${}_{cv}H_{adj}$) which can be positive or negative depending on the characteristics of the surrounding spaces
Convex-voids' characteristics			
Area	${}_{cv}A$		
Volume	${}_{cv}V$		
Shape			
Aspect ratio			
Convex-voids properties			

Spaciousness/ containment	${}_{cv}S\ {}_{cv}C$	${}_{cv}S = A_g/A_{fv}$ ${}_{cv}C = A_{fv}/A_g$	Spaciousness/containment represents the relation between the area of the convex-void façades and its floor area
Enclosure/ openness to vision	${}_{cv}\mathrm{EV}$ ${}_{cv}\mathrm{OV}$	${}_{cv}\mathrm{EV} = P_e/P_{scv}$ $\mathrm{OV} = 1 - {}_{cv}\mathrm{EV}$ $(P_{ev} + P_{ov} = P_s)$	Enclosure/openness encodes the proportion of open or closed vs total perimeter
Perceived enclo-sure/openness to vision	${}_{cv}\mathrm{EV}$ ${}_{pcv}\mathrm{OV}_p$	${}_{cv}\mathrm{OV}_p = \left(\Sigma A_{fv} - \Sigma A_{fvadj}\right)/\Sigma A_{fv}$	Perceived enclosure/openness is a percentage of a convex-void's faces that is overlapped by surrounding ones
Enclosure/ openness to movement	${}_{cv}\mathrm{EM}$ ${}_{cv}\mathrm{OM}$	${}_{cv}\mathrm{EM} = P_{em}/P_s$ ${}_{cv}\mathrm{OM} = 1 - {}_{cv}\mathrm{EM} = (P_{em} - P_s)/P_s$	Enclosure/openness to movement takes into account obstacles to movement
Solid-voids properties			
Number of convex-void particles	${}_{sv}N$		Number of convex-voids that are forming the solid-void
Length of solid-void	${}_{sv}L$		Sum of the lengths of all street segments forming the solid-void
Number of façades within a solid-void	${}_{sv}N_f$		
Granulation of built structure of solid-void	${}_{sv}G$		Number of façades per hundred metres

Connectivity	${}_{sv}$CON		Number of physically permeable routes leading from one solid-void toward other spaces
Perceived connectivity	${}_{sv}$CON$_p$		Number of all routes, physically permeable and not permeable, opening from one solid-void toward other spaces
Void connectivity	${}_{sv}$VCON$_p$		Number of other solid-voids connecting (or crossing) a solid-void

A_g: Ground area of space
A_f: Areas of buildings' façades
A_{fv}: Area of vertical faces of convex-voids
A_{fn}: Areas of neighbourhoods' façades
A_{fvadj}: Area of vertical faces of adjoining convex-voids
${}_{cv}H_{adj}$: Height adjustment ($= {}_G H \times (3/\text{Sqrt}(9 + A_g))$)
${}_G H$: Gross height correction value ($(A_f - A_{fn})/P_s$)
L_f: Length (on ground) of façades (excl. "0-height")
P_s: Total perimeter of space
P_{ev}: Length of perimeter closed to vision ($= \Sigma L_f$)
P_{ov}: Length of perimeter opened to vision
P_{em}: Length of perimeter closed to movement

References

1. Ratti, C.: Urban texture and space syntax: Some inconsistencies. Environ. Plan. B Plan. Des. **31**(4), 487–499 (2004)
2. Hillier, B., Penn, A.: Rejoinder to Carlo Ratti. Environ. Plan. B Plan. Des. **31**(4), 501–511 (2004)
3. Habraken, N.J.: The Structure of the Ordinary, p. 40. MIT Press, Cambridge (2000)
4. Nan, L., Sharf, A., Xie, K., Wong, T.-T., Deussen, O., Cohen-Or, D., Chen, B.: Conjoining gestalt rules for abstraction of architectural drawings. ACM Trans. Graph. **30**(6), 185:1–185:10 (2011)
5. Alexander, C.: A city is not a tree. Ekistics **139**, 344–348 (1968)
6. Hillier, B., Hanson, J.: The Social Logic of Space. Cambridge University Press, Cambridge (1984)
7. Marshall, S.: Streets & Patterns. Routledge, London (2005)

8. Dhanani, A., Vaughan, L., Ellul, C., Griffiths, S.: From the axial line to the walked line: Evaluating the utility of commercial and user-generated street network datasets' in space syntax analysis. In: Proceedings of the 8th International Space Syntax Symposium (2012).
9. Jiang, B., Claramunt, C.: Integration of space syntax into GIS: New perspectives for urban morphology. Trans. GIS **6**(3), 295–309 (2002)
10. Beirão, J.: CItyMaker: Designing Grammars for Urban Design. CreateSpace Independent Publishing Platform, Charleston (2012)
11. Beirão, J., Arrobas, P., Duarte, J.P.: Parametric urban design: Joining morphology and urban indicators in a single interactive model. In: Achten H., Pavlicek J., Hulin J., Matejdan D. (eds.) Digital Physicality - Proceedings of the 30th eCAADe Conference - Volume 1/ISBN 978-9-4912070-2-0, pp.167–175, Czech Technical University in Prague, Faculty of Architecture (Czech Republic), 12–14 September 2012.
12. Gil, J., Beirão, J.N., Montenegro, N., Duarte, J.P.: On the discovery of urban typologies: Data mining the multi-dimensional morphology of urban areas. Urban Morphol. **16**(1), 27–40 (2012)
13. Sokmenoglu, A., Gulen, C., Sevil, S.: A multi-dimensional exploration of urban attributes by data mining. In: Computer Aided Architectural Design Futures 2011 [Proceedings of the 14th International Conference on Computer Aided Architectural Design Futures/ISBN 9782874561429], pp. 333–350, Liege (Belgium) 4–8 July 2011.
14. Chaszar, A.: Navigating complex models in collaborative work for integrated and sustainable design. In: Proceedings, CAADFutures, Liege (2011a).
15. Chaszar, A.: Spatial query and object recognition to support 3D digital building model use. EG-ICE workshop, Twente (2011b).
16. Chaszar, A., Beirão, J.N.: Feature recognition and clustering for urban modelling. In Proceedings, CAADRIA, Singapore (2013)
17. Beirão, J.N., Chaszar, A., Cavic, L.: Convex- and solid-void models for analysis and classification of public space. In: Proceedings, CAADRIA, Kyoto (2014).
18. Beng-Huat, C.: Decoding the political in civic spaces: An interpretive essay. In: Chua, B.H., Edwards, N. (eds.) Public Space: Design, Use, and Management, pp. 55–68. Singapore University Press, Singapore (1992)