Optimizing the Complex Urban: The Case of Sustainability and the Built Environment for the Eco-Cities in China

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***Abstract*—This study introduces and discusses approaches to optimizing the urban development by undertaking applicable modelling techniques and simulations that can guide and develop design as well as city planning criteria. This research paper will explore the available techniques and then suggest integrated methods to optimizing the urban. With focus on sustainability and the built environment, this study will analyze two practice-based case studies in the context of China and will suggest models for optimizing the urban. This paper will set a platform to argue and potentially use modelling techniques for such projects as a breakthrough towards future urban management and urban-scale construction projects. Through case study analysis in China, the paper suggests ways in which simulation and modelling techniques, particularly information modelling techniques, can inform better design. Furthermore, optimization of the built environment is the foremost argument of the paper, emphasising on environmental concerns and how we may find integrated solutions to overcome these. The current problem in urban planning is the lack of optimization and integration of multiple aspects of sustainability for the built environment. As a result, this study will explore this and contribute towards development of integrated solutions for better optimization of the built environment.**

***Index Terms*—sustainability, urban, built environment, optimization, modelling**

I. Introduction

Optimizing the urban environment requires holistic understanding of its complexity and multi-layered parameters and characteristics. The analysis of overlapping layers of the urban environment can benefit from simulation tools and modelling techniques that are available to optimize the urban environments. Successful examples include optimization of grid transit system [1], SUNtool as a modelling paradigm for simulating and optimizing urban sustainability [2], and urban modelling techniques using geographic information system environments [3] or integrated methods for urban design models [4]. Subsequently, this study aims to discuss such modelling techniques. It will also use case studies in the context of China to discuss integrated modelling methods and then encourage methods of achieving city information modelling. The outcomes of the study will contribute towards suggestive methods of achieving sustainability in the built environment and large-scaled construction sites in the urban context. The ultimate goal will be to discuss modelling techniques as better alternatives for sustainable management and development of the complex urban environments.

A. Sustainability and the Built Environment in China

Through the process of rapid urbanization and urban development in China, optimizing the built environment has become a major national strategic need. The increasing pollution, traffic and energy consumption in the urban areas is becoming alerting matters in China. Majority of the primary cities are now experiencing severe traffic and pollution. For instance, in summer 2013, City of Ningbo (in Zhejiang Province, East China) and the surrounding areas experienced the hottest temperature that was unprecedented in the past few decades. The effects are the increasing Urban Heat Island Effect (UHIE) in the central areas of the cities resulting in developing heavy pollution, health hazards and decline in urban living quality (Fig. 1). These are increasingly consequences from the current rapid urbanization that is occurring in China.

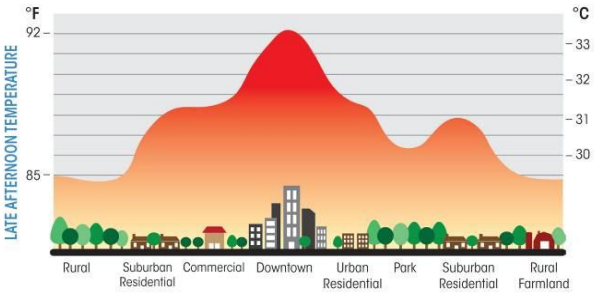

Figure 1. The illustration of urban heat island effect and city development (Source: CleanAir Partnership Website).

As part of China's 12th 5-year plan [5], implemented in March 2011, sustainability is considered as a priority to achieving better living environments (Fig. 2). The focus being on urban development and environments determines the importance of urban environmental quality and achieving technological methods that are

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scientifically viable for optimizing the built environment. In respect to the national long-term technology development programme, it is important to note technological methods that are applicable to optimizing the complex urban.

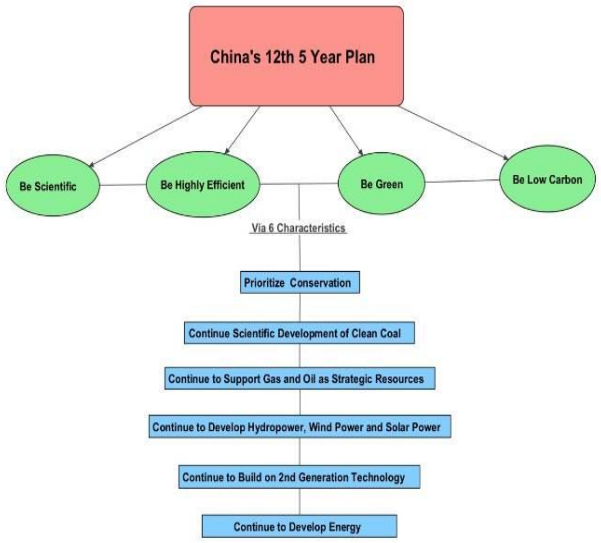

Figure 2. The 12th five year plan-energy characteristics and aspects (Source: US-China Cleantech website; based on Chai Songuye's four characteristics, October 2012).

With the growing global warming and China's agenda on sustainability for the environment, it seems very essential for this rapidly urbanizing country to take actions in developing as a role model for other developing countries worldwide. As a result, sustainability and built environment would remain as a major focus for the coming decades, enabling China to develop methods and models that can be utilized or transferred to other contexts. One of the examples is the growing interest in developing eco-cities and eco-developments [6] that are developing almost all over the dense parts of the country. With over 26 eco-projects in 2011, China appears in the frontline of reshaping and redeveloping the urban environments [6], emphasising on issues related to energy supply and consumption, carbon emissions and better management and design. China's new initiatives for future development and sustainability will be on the basis of developing 1- low-carbon developments; 2- city scaled eco-developments or so called eco-cities; and 3- sustainable and low-carbon retrofits for the existing contexts. Therefore, developing and applying methods to optimize these three will be essential to the future development and construction sector in China.

B. Understanding and Evaluating the Complex Urban

As a result of current urban pressures, the Chinese government is calling for improvements in city management and infrastructure to address problems in planning and urban growth. This is a major strategic importance at a national level as well as in a global scale, dealing with matters of climate change, urban resilience and urban growth. China's rapid urbanization is unprecedented and brought about new challenges of growth, management and development that are significantly correlated with land-use and demographic changes. The management and development of the built environment have become significantly vital while the need to use data and information from the context is increasing for optimizing the built environment.

With the current advancement of technologies and modelling techniques, it is now more applicable to evaluate the complex urban systems. In recent years, major emphasis has been on information modelling techniques, using data (often big data) to make decisions on design and construction solutions. This approach has significantly enhanced efficiency and quality of developments. Through the information model platform, understanding various components or elements of the complex urban systems has become more tangible in planning or optimizing the design. On the other hand, the use of geographic information systems (GIS) into urban planning has become an effective approach for evaluating the changes in the urban environments and offering a detailed analysis of the processes of development. In China, successful studies on the analysis of land-use changes through the use of satellite remote sensing, GIS and stochastic modelling [7] and the analysis of urban expansion and the impact on land-use changes with similar methods [8] are becoming more common in how urban environments are managed or even developed.

Overall, the authors argue that both understanding and evaluating the complex urban are complementary to each other. This means that we use the current modelling or simulation techniques to evaluate the context, helping to better understand the context for any future development, preservation or etc. Similarly we do analysis or research on the complex urban systems to gather data and knowledge and find methods of evaluating the urban context. More or less, this is a mutual relationship kept between the two and is becoming vital in the current smart development era, where big data is fundamental for development. Furthermore, analysis of the complex urban helps us to offer various management and development scenarios so that the best can be selected for better optimization of the built environments.

II. Enabling Tools and Case Study Analysis

For this study, two particular methods are considered as computational tools for optimizing the complex urban context or/and system. Both tools are considered as multi-layered techniques for optimizing either the performance or the design of the built environment.

A. The Use of Computational Tools in Optimising the Complex Urban

The first method is the use of computational fluid dynamics (CFD) in urban design and how this modelling technique (Fig. 3 and Fig. 4) is adapted to optimize the final design. This is a tool adapted from mechanical engineering into environmental design and then later into developing an integrated urban design model [4].

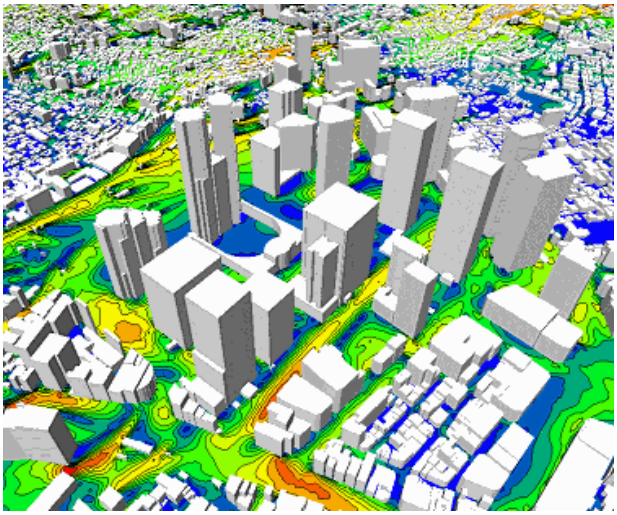

Figure 3. CFD model of the urban context–guidelines for practical applications of CFD to pedestrian wind environment around buildings (source: Architectural Institute of Japan)

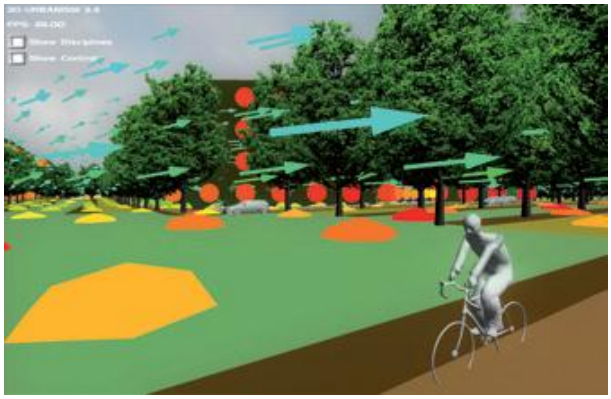

Figure 4. Screenshots of a proposed carbon city showing false colour representation of sound (spheres), lighting (false colour maps), prevailing wind (arrows), as well as people and vehicle movement (Source: Arup document on BEM Future tools, May 2011).

The other method is a more advanced tool, called 'Built Environment Modelling (BEM)' as a design process considering and representing all aspects of the built environment within a shared and virtual 3D model [9]. This experiential model allows designers and planners to think, test and develop optimized models according to particular parameters of sustainable design (including, physical, social, environmental, economic and geometrical parameters). This optimization tool is considered as a process model, helping to enhance inclusiveness and effectiveness of design, making construction fast and cost-effective [9]. Both the performance efficiency of design process and development are considered as key aspects of using the BEM approach.

B. Case Study af Urban Optimisation and Development for Eco-Cities in China

In 2009, the application of CFD in developing an integrated design model was tested on the Cao Fei Dian Eco-City design, Hebei Province, China [4]. This was a model developed to overcome issues of pollution, environmental performance and sustainability. Alongside a team of multi disciplines, the first author of this paper was involved in this study and developed a model based on computational simulation analysis. The aim was to optimize the urban, through the use of environmental information. Such use of technology for urban design models was innovative and developed a platform for further research and application of the method in optimizing the urban physics, spatial configuration and layout (including forms and layout of both buildings and open spaces). The initial aim was to optimize the built environment by introducing better integration and use of urban corridors, linkages in between the urban blocks and vegetation/green landscape for cooling the air (Fig. 5). The later was to reduce the impact of pollution and UHIE in the central business districts of the proposed eco-city.

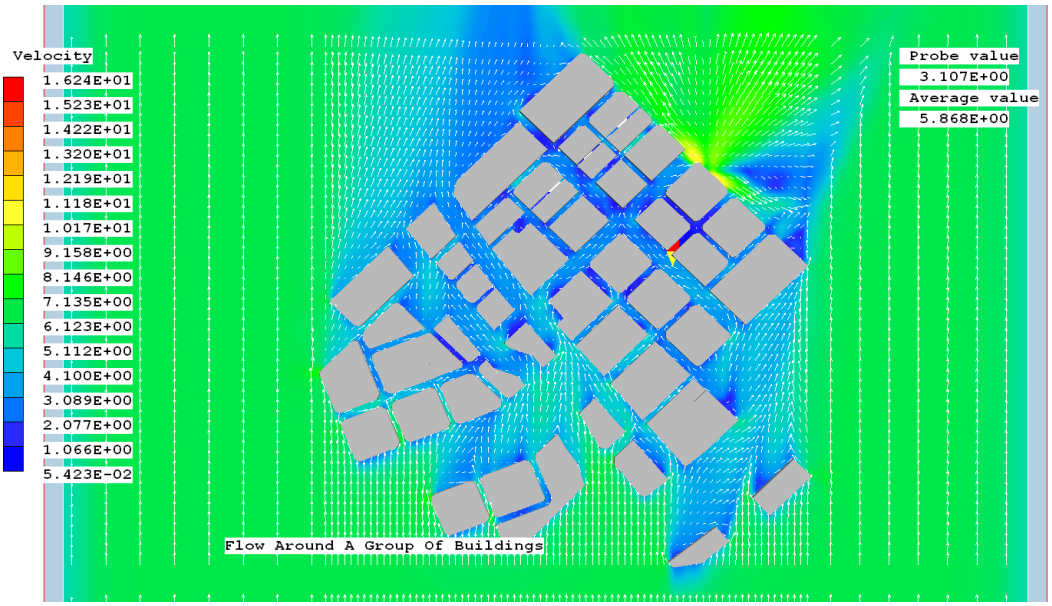

Figure 5. Example of the wind environment analysis for the Cao Feidian integrated urban design proposal (Source: Cheshmehzangi et al., 2010).

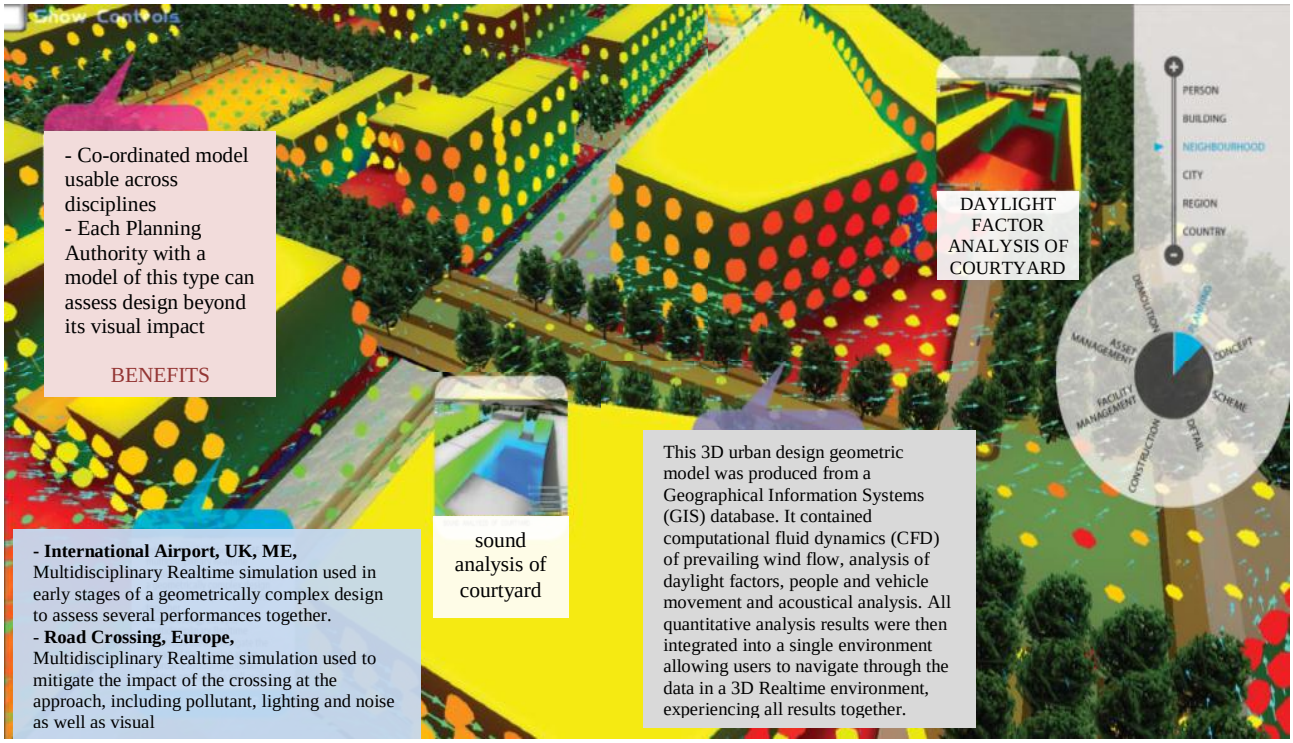

Figure 6. masterplanning a new city realtime modelling can visualiz e multidisciplinary factors, such as daylight analysis and vehicular movement, in a single, navigable environment (Source: Arup)

Previously, the application of CFD in the urban environment was to analyze the environmental conditions around the buildings [10]-[12]. In these previous studies, the application of such method in optimizing the urban was barely discussed. Now after further development of the model in practice, the use of CFD for optimizing the urban context allows practitioners in design and planning firms to develop different design or planning scenarios, demonstrating possibilities of how a variety of options for design can enhance efficiency, performance and sustainability of projects.

The second example is the application of BEM in practice. Similarly, this tool demonstrates the importance of evaluating the urban environments to achieve more sustainable and efficient design (Fig. 6). Similar to the use of CFD, the tool uses multi data but also show a virtual built environment through all stages of its lifecycle [13]. This method helps to enhance the construction and implementation of projects by suggesting solutions that are informative for designers.

This method was applied in practice for the research on a zero carbon city in China (2004-2007), led by Arup. This was to create a 3D urbanism platform, considering multidisciplinary Realtime qualitative simulation to achieve radical design innovation at masterplanning level [9]. Although this model is fairly complicated, it allows users to understand and evaluate multi layers of the built environment. This informative platform demonstrates an integrated approach to optimizing the built environment, considering cost, effectiveness and efficiency of design, construction development and management [13].

III. Discussions and Conclusions

As discussed and demonstrated through two different examples, we can witness a growing demand for application of integrated modelling methods for sustainability and optimizing the built environment. Although still at building scale level, methods such as Computational Design Optimization (CDO) signify the growing demand in computational simulation, physics and mathematical modelling for better design performance goals. Therefore, it is vital to consider the use of multi-layered data helping to optimize design, process of design, construction and implementation design. It is anticipated that such models would develop even further into optimizing bigger scale projects (i.e. neighborhood, urban and masterplan scales). Furthermore, the integrated models enable designers and planners to develop and promote holistic solutions for design thinking and implementation [4].

A. Advancement towards City Information Modelling

One may argue the current approach to optimizing the urban environments is in fact advancement towards City Information Modelling (CIM). In 2013, Gil *et al.* [14] urged for the increasing necessity for '*knowledge-based and performance oriented approaches to urban design*'. Therefore, there is this advancement from building-scale modelling methods to city-scale modelling tool that are emerging as new and practical methods of optimizing the urban context (Fig. 7).

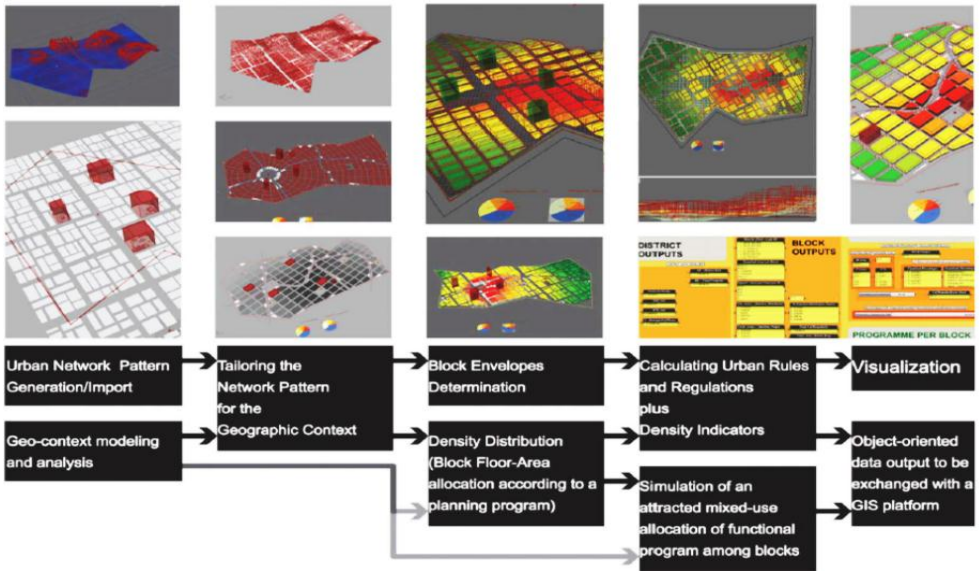

Figure 7. CIM prototype for design (Source: CityMaker, Jose Beirao)

The use of technology to develop generative design is enabling urban designers to consider both the interactive integration of analysis and the combination of dynamism of design workflow [14]. A better understanding of the urban environment comes from holistic evaluation, simulation and modelling of the context. The Realtime modelling approach and other tools of visualisation (such as GIS) can give a new direction to how cities and urban environments may develop. The performative age of design enables us to consider various aspects of design, integrating data management (for design) and information management (for the process of design).

B. Conclusions

The new practice for integrated urban design proposals should undertake multi-layered evaluation and computational tools that may support optimizing the complex urban. Both the complexity and multi-layered characteristics of the urban should not be compromised in practice. The influx of research in developing toolkits and modelling tools will certainly continue as our benchmarks for sustainability continue to rise. As a result, discussions derived from the study develop a platform for researchers and practitioners to discuss demands and requirements of future toolkits and question why integrated models require targeting optimization of the complex urban. To conclude, this study aims to advocate designers and researchers to seek methods that can enable us to think and optimize design at multiple-layers.

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