Multi-Perspective Urban Optioneering

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This paper investigates the state-of-the-art with respect to simulation-based planning support systems in order to draw a set of requirements and best practices for an urban planning and design framework that enables multiple stakeholders with differing perspectives to systematically explore design options, leveraging the latest analysis and simulation techniques. From these requirements and best practices, the foundations and structure of such an urban planning and design framework are developed. A number of technological and methodological challenges are identified for future investigation.

Keywords: *Urban planning and design, optioneering, simulation-based planning support systems*

INTRODUCTION

With the increasingly complex nature of future master plans, there is a need for comprehensive urban planning and design frameworks that leverage the latest analysis and simulation techniques in order to enable planning and design options to be systematically developed, evaluated, and analysed. In order to be effective in supporting collaborative decision-making, such frameworks must concurrently address the varying spatial and temporal scales of urban planning and the varying requirements and interests of different stakeholders. Currently, no such frameworks exists and, as a result, collaborative decision makers are unable to effectively reconcile their different viewpoints and objectives and only a very limited number of suboptimal planning options are explored using mainly ad-hoc manual approaches that are time-consuming and error-prone.

Such frameworks fall under what are referred to as Planning Support Systems, which are systems fully dedicated to support and improve the performance of those involved in undertaking specific planning tasks (Batty 1995; Klosterman 1997). They usually consist of a combination of planning-related theory, data, information, knowledge, methods and instruments that take the form of an integrated framework with a shared graphical user interface. They are typically used to provide projections forward to some point in the future or may involve some estimation of the impacts that result from some form of development (Geertman and Stillwell 2003; 2009).

This research focuses on planning support systems that enable stakeholders to apply complex types of simulation at varying spatial and temporal scales. Below, existing simulation-based planning support systems are reviewed and an approach referred to as 'Urban Optioneering' is described. A framework for simulation-based planning support systems is then proposed, consisting of a method and a platform. Finally, the discussion section highlights a number of technological and methodological challenges that have to be addressed in order to achieve and implement the proposed framework.

SIMULATION-BASED PLANNING SUPPORT SYSTEMS

Current urban planning and design practices typically use off-the-shelf impact-analysis software, mainly based on point scoring systems that use checklists and other methods that do not provide adequate feedback for planning sustainable environments. For example, AECOM's Sustainable Systems Integration Model (SSIM; Brown and Kellenberg 2009) is a method and tool for analysing urban plans using a set of key sustainability indicators. The method requires a small number of alternative plans to be developed, and then allows users to make selections for a variety of predefined systems and options, and to interactively see a cost-benefit analysis based on these indicators. However, the indicators rely on relatively simplistic calculations performed in MS Excel. For non-spatial indicators (such as energy use, water use, carbon emissions, and development costs), the calculations make extrapolations based on representative data defined by experts. For spatial indicators (such as connectivity, access to local services, and access to transit), the analysis consists mainly of various types of network analysis that do not take into account the complex dynamics of urban environments.

Even when adopting planning support systems that have the ability to run more advanced types of simulations, the feedback they provide focuses on isolated impacts of land-use planning; the interdependencies between different aspects as well as holistic overall considerations have to be done 'by hand' by the planning teams. For example, one of the more accessible systems is the CommunityVIZ planning and analysis platform (Walker and Daniels 2011), available as an extension to ArcGIS. CommunityVIZ has a comprehensive modelling framework that includes a set of built-in models for the dynamic simulation of complex urban phenomena, and also supports the ability to plug-in custom models defined by end users. However, the core of the modelling framework is proprietary and as a result the interactions between the various models cannot be controlled by end-users. Modelling complex phenomena by creating networks of linked models is therefore not possible.

The need for more comprehensive methods that integrate simulation-based planning support systems is increasingly recognised and accepted by practitioners. The complexity of planning urban development arises by the interaction of its components, and the fact that these interactions can lead to unexpected, counterintuitive results. Unfortunately, most of the existing solutions oversimplify such interaction.

This insight has led to numerous recent efforts in the development of systems that integrate a number of domain specific models (e.g., land-use, transportation and energy-supply). However, these monolithic systems hard-code these domain specific models in ways that are not easily modified by end-users, thereby essentially limiting the use of these systems to a very narrow range of planning questions. SynCity system (Keirstead et al. 2009) imposes an energy perspective; CitySim system (Robinson et al. 2009) imposes a resource-flow perspective; and UrbanSim system (Waddell 2002) imposes a transport and land-use perspective.

In addition, these types of systems can typically only be applied within a narrow range of scales, thereby hindering a truly multi-scale approach to urban design. Such monolithic models reach the limits of feasibility and practical usability due to huge data demand, limited life span and costs of maintenance (Conway and McClain 2003; Davis and Anderson 2004). Most of the academic approaches lack the continuity and support to achieve a level of maturity and industrialization that can make it usable for practitioners.

Multi-Perspective Optioneering

Optioneering is a collaborative decision making methodology that systematically explores a wide spectrum of options early on in the design process by iteratively developing, evaluating, and analysing alternatives (Holzer and Downing 2010, Gerber at al.

2012). Urban optioneering applies this methodology at an urban scale, allowing urban planning and design options to be developed in a more rigorous manner.

In the design of complex engineering systems, optioneering has become an important tool to guide the interaction between different experts, to test the consistency of proposed technical solutions and to evaluate their impacts. Variants of the optioneering approach, such as virtual prototyping, have been applied in many fields of design and engineering, from the design of airplanes and cars to the design of complex building constructions (El Khaldi et al. 2010). Leading architectural offices and development companies are using optioneering in their collaborative design processes, enabling highly specialized experts from all over the world to contribute to the design solutions. In this context optioneering has been proven as a model that supports complex decision making.

For the application of optioneering at the urban level, methods and systems have to be developed that are capable of engaging with the high levels of complexity inherent in urban planning and design. Urban planning and design processes have to integrate economic, environmental and social issues, have to cover different scales in space and time, and have to address multi-actor environments.

These processes therefore require various perspectives (e.g., financial, environmental, social, operational) to serve the different actors involved. Furthermore, due to the fact that urban plans are typically related to long-term decisions, they also have to face changing conditions and demands, with unforeseen and unexpected phenomena being the norm. From that point of view, current modelling and simulation approaches are lacking in open system thinking and "the capability of covering multiple system perspectives at once and in different levels of details to provide better understanding of the systems" (Tekinay et al. 2010).

In the scientific debate about modelling of complex systems many authors emphasize the limitations of single-perspective models (Lane 2006; Morin 2005; Mikulecky 2001). Single-perspective models are reducing the complexity to certain aspects and in this way are losing relations outside the partitioned frame, which cannot be brought back to life, even when different models are applied in parallel to each other. According to Seck and Honig (2012) a major reason for these limitations is caused by the fact that simplified hierarchical structures of technical systems are imposed on non-technical systems and thus inherit "a strong reductionist world view".

To overcome the principal limitations of single-perspective models, the development of multi-perspective models is widely discussed (Seck and Honig 2012; Kingston 2007; Frank 2002). Although the discussion until now did not result in concrete applications, various proposals have been made at a conceptual level.

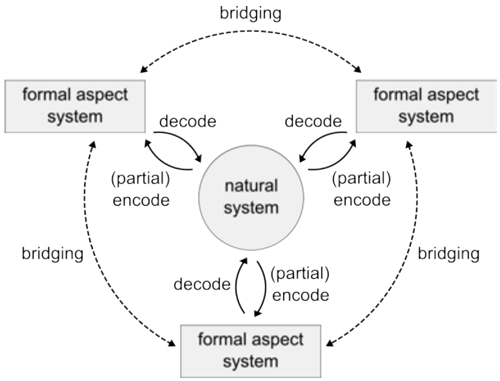

Figure 1
Modelling complex phenomena through multiple perspectives (After Seck and Honig, 2012).

Seck and Honig (2012) propose a complex system (the natural system) as an expansible collection of perspectives, where each perspective, although associated with its own formal aspect system, is related to "multiple non-isomorphic decompositions that may influence each other" (see Figure 1). In this way, the fixed hierarchy is replaced by flexible modularity; different formal aspect systems are connected by bridges, involving different steps of decoding and encoding. Such multi-perspective modelling is intended to "capture the tangledness of the systems that result when we observe the world from different perspectives" (Seck and Honig 2012).

The challenge is to elaborate the theoretical concept of multi-perspective urban optioneering into a practical framework for urban planning and design that reflects the multi-actor environment of the urban system.

PROPOSED FRAMEWORK

One of the fundamental characteristic of multi-perspective optioneering is that it is impossible to predict in advance the perspectives that will be most relevant to the stakeholders involved. This unpredictability results from the fact that urban planning and design is fundamentally an unstructured or 'wicked' process characterised by (1) multiple actors with differing, legitimate values and opinions; (2) high uncertainty; (3) aspects of irreversibility; (4) no clear solutions; (5) being fraught with contradictions; (6) being persistent and unsolvable (Rutledge et al. 2008). Any optioneering framework that is a closed system, based on the assumed relevance of a predefined set of perspectives, is therefore bound to fail.

In order to support multi-perspective optioneering, a radically different type of framework is proposed that is inherently open (Axelos 2006). The openness of the framework hinges on enabling stakeholders to define their own customized models that reflect the perspectives that are most relevant to them, and to the scenario and context being explored. These customized models are defined as networks of loosely coupled components, including a variety of domain specific simulation engines and data sets (Altintas 2011; Deelman at al. 2008; Curcin and Ghanem 2008).

The proposed framework consists of two parts: an Urban Optioneering Method and an Urban Optioneering Platform. The method and the platform are shown in Figure 2, and will be described in more detail in due course.

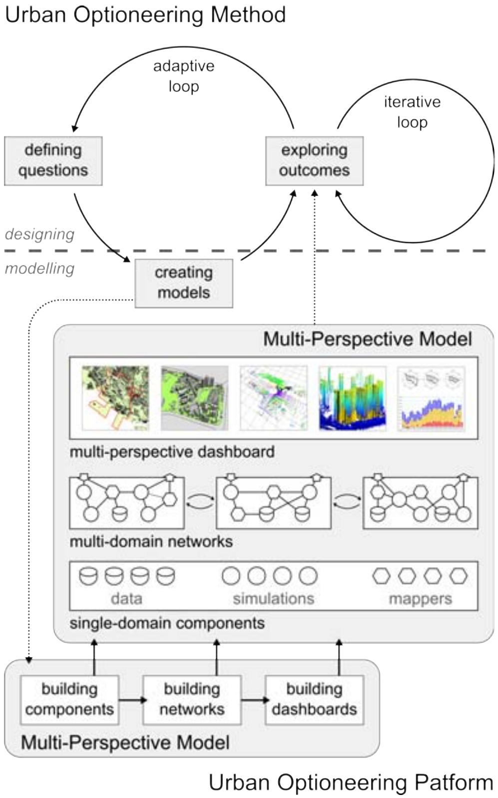

Figure 2
The proposed Urban Optioneering Framework consisting of an optioneering method and an optioneering platform.

Urban Optioneering Method

An Urban Optioneering Method is proposed that enables questions relating to specific urban planning and design scenarios to be explored using multi-perspective models. The perspectives can be related to the tasks of different planning agencies, to specific interests of different stakeholders or to different political, social, economic or environmental priorities.

For each question to be explored, customized models reflecting the differing perspectives need to be created, and the outcomes of those models need to be explored. The method consists of an adaptive-iterative process consisting of two nested loops: the adaptive loop and the iterative loop (see Figure 2). The adaptive loop comprises three key activities: defining questions, creating models, and exploring outcomes.

- Urban questions are defined, possibly by different stakeholders in the planning process, with differing and possibly conflicting concerns.

- Urban models are created as executable models, consisting of coupled legacy single-domain urban models and data sets.

- Urban outcomes are explored by iteratively executing models and analysing results, in particular, including cross-perspective analysis of data and result inconsistencies.

The iterative loop is part of the process of exploring model outcomes. For any given multi-perspective model, many variants can be explored based on differing assumptions and using differing data sets. These outcomes may involve the estimation of impacts on the present and projected into the future based on differing assumptions and data sets. Furthermore, the results from running model variants can be investigated using a variety of data analytics techniques. This process of iterative exploration will result in the accumulation of evidence and will culminate in actionable feedback, which may then trigger new or modified questions to be posed.

The proposed method enables stakeholders to ask complex questions. For example, the question may be posed: to what extent would the electrification of road transport reduce air conditioning use in residential flats? Since electric cars are quieter and cleaner, they will produce less noise and air pollution, thereby resulting in more people opting for natural ventilation over air conditioning. The model would have to include a complex set of domain specific tools and data sets. First, the behaviour of residents within flats may be predicted using a behaviour model, with input requirements that include localised environmental conditions (including temperature, humidity, and ventilation) and localised pollutant levels (including noise and air pollution). In order to predict the environmental conditions, environmental simulations would be required, using weather data and detailed urban models. These simulations may also include micro-climate simulations, such as heat island simulations. In order to predict the pollution levels, noise mapping and pollutant transport simulations would be required. Both the environmental simulations and the pollutant simulations may in turn require data from other simulations, such as traffic simulations and wind simulations. This original question therefore results in a complex cascading network of simulation engines and data sets.

Urban Optioneering Platform

An Urban Optioneering Platform is proposed that will enable stakeholders to fluidly build and explore computable multi-perspective models, consisting of loosely coupled legacy simulation engines and data sets. This process of exploration includes the ability to analyze and compare various partial models at varying temporal and spatial scales, thereby allowing conflicts and inconsistencies to be discovered.

Models are divided into three layers: components, networks, and dashboards.

- Model components are the basic elements from which models are built and may include legacy simulation engines, data sets, and data mappers. Such components are central to the modularity feature of the platform, as they allow additional components to be added to the platform as they become available and relevant.

- Model networks are executable networks that reflect sets of values and beliefs specific to the perspectives being applied. Such models are created by coupling together selected sets of model components, including legacy simulation engines.

- Model dashboards are customised graphical user interfaces and data-mashups associated with one or more models, where each model may reflect a different perspective. Such dashboards will allow input and output data from multiple perspectives to be analysed in an integrated environment. At its simplest, this may consist of some sliders for defining input data and some graphs and charts for displaying output data. However, it may also include complex spatiotemporal data manipulation and data analytics.

The Urban Optioneering Platform consists of two applications: one application for building models and another application for exploring models. They are defined as distinct applications since they represent fundamentally different modes of working, requiring different skill sets.

The Model Builder application provides tools building all three layers of a model. For building model components, a set of tools is required to help users to wrap existing computational objects such as legacy simulation engines, data sets, and data mappers. The resulting components will be archived as libraries of components to be embedded within larger models. For building model networks, a set of tools is required to help users to create multi-domain model networks from selected sets of components. These tools will allow models to be visually constructed as a network of components interconnected by wires. Features such as advanced type checking and debugging will need to be provided to help users build valid models. For building model dashboards, a set of tools is required to help users build customized dashboards from predefined user interface building blocks using visual drag-and-drop techniques.

Once a multi-perspective model has been built, the outcomes of the model then need to be explored. The Model Explorer application is conceived as a cloud-based application for deploying, executing, and managing multi-domain, multi-perspective models. On the front end, the application provides a graphical user interface for deploying models. On the back end, the application provides automated scheduling and data management procedures for robust fault-tolerant parallel execution of models and data analytics tasks.

The Urban Optioneering Platform aims to radically improve the way with which stakeholders are able to leverage the latest computational tools and techniques to explore critical questions that impact decisions in urban planning and design. The system enables diverse stakeholders to gather the evidence required to take positions, which can then be used as a basis for further discussions and negotiations.

DISCUSSION

In order to implement the proposed Urban Optionnering Framework, a number of technological and methodological challenges need to be tackled. Below, three fundamental challenges are discussed: building models; linking components; and making decisions.

Challenge 1: Building models

The challenge of model building focuses on developing a system that enables stakeholders to build complex models from a set of re-usable modular components

An approach needs to be developed that does not require advanced technical skills, as stakeholders, such as urban planners and designers, cannot be expected to have such skills. Previously, a distinction was made between two modes of working: building a model and exploring a model. As a result, it might be suggested that the stakeholders should refrain from getting involved in the model building process, which might be better left to people with more advanced technical skills. However, the process of building models cannot be subcontracted, for two reasons: the people building models need to understand the urban planning and design issues; second, the people exploring models need to understand the technological issues, such as the limits and constraints of the models being explored. It is therefore important to try and minimize the gap between building models and exploring them.

One approach to achieving this is to create a set of tools that allow stakeholders to be directly involved in the building of models from predefined components. With this approach, a distinction is made between building model components and building model networks. Model components, including various legacy domain-specific analysis and simulation programs and data sets, are built and tested by researchers who have the technical skills and are specialists in their corresponding field of science. Model networks are then built by stakeholders by assembling predefined components using graphical interfaces that do not require any programming or other advanced technical skills.

With regards to building model networks, two approaches can be identified, referred to as tightly coupled component models versus loosely coupled component models. Tightly coupled component models are developed in a standard programming language using a set of modular programming libraries for different single-domain models and the resulting program is then compiled into a single executable. (For example: Leavesley et al. 1996; Dahmann 1997; Watson et al. 1998; Rizzoli et al. 1998; Reed et al. 1999; Krahl 2000; David et al. 2002; Voinov et al. 2004; Rahman et al. 2004; Kolbe at al. 2005; Ahuja et al. 2005; Müller 2009). Loosely coupled component models are developed by coupling various analysis and simulation programs at the data level. These components are typically legacy programs developed as stand-alone executables that are wrapped in order to enable data exchange via input and output files (For example: Sydelko et al. 2001; Babendreier and Castleton 2005; Bernholdt et al. 2006; Fortube et al. 2008; Tan et al. 2012). The problem with the tightly coupled approach is that it still requires a significant amount of software engineering and programming knowledge. The loosely coupled approach is therefore seen as being preferable.

Challenge 2: Linking components

The challenge of linking components focuses on how to link together domain-specific analysis and simulation programs.

An approach needs to be developed that allows components to be interactively linked in complex ways. One promising approach is scientific workflow systems (Deelman et al. 2008, Altintas 2011; Toth et al. 2012). Such systems exhibit a common reference architecture that consists of a graphical user interface (GUI) for authoring workflows, along with a workflow engine that handles invocation of the applications required to run the solution (Yu and Buyya 2005, Curcin and Ghanem 2008). Nearly all workflow systems are visual programming tools in that they allow processes to be described graphically as networks of nodes and wires that can be configured and reconfigured by users as required (McPhillips 2009). Nodes may represent analysis or simulation programs, while wires represent the flow of data, linking an output of one node to an input of another node.

With regards to the dataflow between such nodes, a more difficult problem is the interoperability issues that invariably exist between various analysis and simulation programs (Janssen et al. In press). Such programs typically require independent domain-specific data models that are efficient within the domain, but are difficult to share across domains. Existing interoperability efforts such as IFC, CityGML, and gbXML attempt to bridge domains, and there are also efforts to extend or amalgamate such schemas to improve generality. However the challenge is non-trivial given the large set of domains that may be relevant.

In the domain of urban planning and design, such interoperability issues include in particular the ability to step up and down between different spatial and temporal scales of the data (also known as multi-resolution modelling). In general, it is feasible to overcome such incompatibilities using a range of data aggregation and compensation techniques (Reynolds et al. 1997). For example, data aggregation may involve combining sets of data at the precinct level in order to characterize the neighbourhood, while data disaggregation may do the reverse by taking data at the neighbourhood level and apportioning it to precincts based on various heuristics. Data compensation comes into play when certain data sets are missing or deficient. For example, when aggregating data from the precinct level to the neighbourhood level, missing data may need to be synthetically generated based on typical patterns and distributions.

Finally, an important element of the proposed framework is the development of bridges that connect distinct model networks, for example by using the outputs of two or more perspectives as inputs for other perspectives, in this way replacing the fixed hierarchical order of a single perspective model by flexible modularity.

Challenge 3: Making decisions

The challenge of making decisions focuses on how models can be used to support decision making in urban planning and design.

An approach needs to be developed that creates models that have the potential to generate actionable feedback. At a building scale, this can be achieved by analyzing complete design options. Due to the fact that design constraints and performance targets are often relatively well defined, actionable feedback can be generated by various techniques for optimizing and ranking alternative options, such as Evolutionary Multi-objective Optimization (EMO), Multiple-Criteria Decision Analysis (MCDA), and Multi-disciplinary Design Optimization (MDO). However, at an urban scale this may not be feasible due to the fact the complexity of urban problems means that reductive techniques for optimizing and ranking are not applicable, which in turn leads to feedback that is often ambiguous and contradictory.

In order to be able to manage the complexity, urban optioneering methods may need to focus on questions that are more narrowly defined, but that have a direct impact on how design options are developed and that are still relevant to a range of differing perspectives. It is proposed that through a more complex process of modelling and counter-modelling (Greenberger at al. 1976) using a variety of different types of models reflecting distinct perspectives, stakeholders will gradually gather the evidence required to take positions on questions that directly impact decision making in urban planning and design. An important part of this evidence is an analysis of the inevitable conflicts and inconsistencies that will arise between the different models.

CONCLUSION

The state-of-the-art in planning support systems was presented in order to draw requirements and best practices for the design and development of a framework that supports the complexity of the urban planning and design process. The foundations and structure of such an urban planning and design framework were drawn. Finally, the major challenges that have to be addressed in order to achieve and implement this framework were identified as an agenda for future research.

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