Information Technology and Architectural Practice: Knowledge Modeling Approach and BIM

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Abstract
This paper presents recent developments in information technologies and their impact on architectural design. It presents a practical technique for knowledge-based information modeling extending the currently prevailing Building Information Modelling (BIM) to include information beyond the building elements, and to foster analysis during the design process. Interactive web-based application for information discovery and design analysis is discussed as a case study. The application integrates several aspects of the early schematic design, and is intended for demonstration of integrated design factors.

Introduction
Architectural design requires immense amount of information for inspiration, creation, and construction of buildings. The process from the initial conception to the finished product involves substantial knowledge and involvement of multidisciplinary agents, such as architects, engineers, and planners as well as their collaboration. As buildings become more complex due to the introduction of innovative technologies and increased awareness of social and communal needs, design process requires significant modifications of previous practices to respond to newly emerging requirements. Improved environmental sensitivity, energy efficiency, integrated building systems, life-safety and security measures, as well as high performance are the driving factors at present. These factors might not result in the development of new building types, but rather they change the nature of architectural discourse and practice and impact the design process. In particular, integrated practice, use of virtual building, simulations, modeling, and analysis of design decisions have become crucial.

Recent developments in information technology are providing means and methods for improvement of current practices to respond to these changes. Energy and thermal simulations, modeling of structural behavior, improved design representations, and enhanced collaboration using digital media are being utilized in the design process. Traditional CAD programs present data based on geometric entities, capturing the spatial relationships but not the domain-specific information. Building Information Model (BIM) provides a common database of information about a building including geometry and attributes. The goal of BIM is to provide a common structure for information sharing that can be used by all agents in the design process and construction, as well as for the facility management after a building is constructed and occupied. BIM allows designers to fully use the concepts developed during the schematic design phase, advance data transfer into
the design development phase, and integrate visualization efforts into project development.

Knowledge modelling approach is presented in this paper that aims to capture implicit design factors, computationally represent integrated relationships between them, and foster design analysis. Integrated design as an approach and recent developments in information technologies that support integration are discussed. Development of a web-based application is presented as a case study, aimed to foster extension of BIM to include contextual information and general design knowledge. The advantage of such system is that improved decision-making and analysis processes are actively supported by computational tools.

**Integrated Design Approach: Methodology**

Design process can be perceived as a successive concretion of the description of future characteristics of an artifact, and it leads from the incomplete to complete, abstract to concrete, and conceptual to precise descriptions (Grabowski et al., 1996). By nature, it is a non-linear process that requires analysis, evaluation, synthesis, and decision-making. In that sense, it requires constant information flow between the designer and environment. According to Kalay (2006), architectural design analyzes current stages of being and develops plans for improved new states, and it gathers and processes information from different sources, re-arranges and produces new information, and simulates the expected outcomes.

Integrated architectural design requires interdisciplinary approach and comprehensive methodology that considers multifaceted design requirements to produce buildings with improved performance. Buchanan (1995) states that the design cannot be reduced to one science, but rather it should be concerned with connecting and integrating knowledge from different disciplines. It is important to differentiate between integrated design as an approach and as a project delivery method, as portrayed in Figure 1. Integration as an approach requires comprehensive consideration of design factors, systems and requirements, and balances these to form a building. Integrated design as a delivery method requires collaboration between different agents from the earliest stages of the project.

According to Bachman, there exist three types of integration: physical, visual, and performance (2003). Physical integration relates to building elements, components and systems, and the common space that they share. The floor-ceiling section of many buildings, for example, is subdivided into separate zones for lighting, ducts, and structure to support the floor above. These segregated volumes prevent interference between systems by providing adequate space for each system. Connections between components and among systems in general constitute physical integration. Visual integration involves development of visual harmony among many parts of a building and their agreement with the intended visual effects of design. This may include exposed and formally expressive components of a building that combine to create its image. Performance integration relates to shared functions of elements and systems, such as unified functions in one building element. Whether integration is visual or physical, the various interdependent components must interact with one another to create a harmonious balance. The complex relationship between intentions, systems, environment, and requirements greatly affects integration in the design process.
Integration as an approach and as a delivery method, entails advanced design methodology, and improved means of communication. Technological advancements that impact information processing have the potential to affect the integral processes and artifacts of architectural design, and revolutionize the profession. Kalay states, “It can do so by transforming the access to the information form a sequential process into an interleaved one, where decisions are made in an a-synchronous yet coordinated manner”
Representations of architectural principles and knowledge are essential for the future implementations of information technologies and advanced applications.

**Information Technology and Design: Representation**

Technological revolutions affect processes and products of architecture. Assessing the impact of information technology on architecture is challenging, since “we are still in the midst, if not at the very beginning of the revolution” (Kalay, 2006). Information technology has the potential of transforming current design processes into a network of design, manufacturing, and management organizations where multiple professions are involved and geographic locations are insignificant. Understanding the future of architectural practice is even more challenging, since currently available computational tools are starting to change processes. When the architectural drawing was introduced, organization of work and image of practice changed, as well as products. Especially exigent are the tools that have the ability to represent what was formerly obtained through education and practice, and the implicit values of architectural knowledge. Figure 2 presents the difference between the past practices, where processes are distinct activities separated from the information that direct the final product, and the future where information-centric integrated processes are essential. It is important to note that the present is a transitional stage, where both approaches are present. Information-centric methodologies for design depend on computational representations of design processes, knowledge and elements.

![Figure 2: Role of information in design, production and management processes.](image)

Paradigm shift in architecture and construction industry has been originated by the BIM design and management methodology, where the primary causal elements are:

- Transfer in computer software techniques from procedural algorithmic programming languages to object-oriented; and
- Change in the building representation from drawings and written specifications to integrated models, taking building elements and spaces as the starting point (Bjork, 1995).

BIM acts as an integrated, comprehensive building model which stores information contained in traditional building documents, such as drawings, specification, and construction details, in a centralized or distributed database. Information management in

this form changes the design procedure and documentation, since all the relevant information is organized as a database, rather than sets of drawings, specifications, etc. Data that resembles traditional documentation are specific views of common information. It virtually simulates design and construction, and provides groundwork for collaborative design, since all the relevant information, such as spatial organization, building components, building systems (mechanical, electrical, plumbing, HVAC) is incorporated into building descriptions.

Visualization of design in three-dimensional space is one of the advantages of BIM; however, it is not the only capability and the integrative nature of contents must be emphasized. Beyond visualization, BIMs are used to review constructability issues where the construction team is able to analyze design decisions while in the early stages of the process and provide responses to the design team. Information about the site, such as existing conditions, infrastructure systems and utilities can be included in BIM and analyzed. Construction schedule can be integrated with the building model to visualize the sequencing of construction activities, which is also referred as “4D” modeling, since the time dimension is included. Cost estimation is another dimension, commonly referred as “5D”, since materials and components are analyzed and directly linked to cost databases to produce financial information and assist in analyzing design decisions as they relate to the economic factors.

Goal of using BIM is to provide a common structure for information sharing that can be used by all agents in the design process and construction, as well as for the facility management after a building is constructed and occupied, as seen in Figure 3. Information contained in BIM can be used internally for analysis and simulations, such as structural analysis or energy performance. Construction documentation is automatically generated and updated when the changes are made to the model. The information about the model can also be extracted for external applications. The major benefits of BIMs

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**Figure 3: BIM utilization during design and operation.**

were outlined in a recent study of the utilization in the architecture and construction industry as the ability to create views and schedules dynamically and automatically, instant reflection of changes in all drawings and schedules, and single integrated file for a project (Tse et al., 2005).

**Role of Information: Applications**

Current information technologies allow for improved planning, visualization and simulation of growth, land use, and infrastructure control. Geographic Information System (GIS) technology is effectively utilized for research, development, implementation, and monitoring of the planning efforts. Graphical interface to complex sets of data, mapping, and three-dimensional visualization offer simplified analysis of complex sets of factors (Brail and Klosterman, 2002). Virtual cities in conjunction with GIS offer navigable environment and effective digital simulation of real cities, which give planners and designers an opportunity to visualize un-built spaces and interaction with the existing infrastructure (Dodge et al., 1998).

Visualization and analysis of BIMs within virtual 3D city models are possible through integration of GIS and BIM data (Hagedorn and Dollner, 2007). Virtual 3D city models represent objects and components of urban areas at a lower level of information detail and rely on spatial data. An approach for integration is through distributed, heterogeneous web services and geo-visualization system, where BIM data is mapped on building representation in GIS.

Besides integration of BIM and GIS data, there are also other advantages for combining other information technologies to assist the design process. For example, information over the web could be accessible through applications that internally contain knowledge-bases and links to various data-sources. Manufacturers of architectural products provide online catalogs and details; however, these are currently not formatted to allow a method for accessing data internally.

BIM-based CAD and these new web-based technologies will change the information delivery and processing. Distributing information between BIM and external sources is a viable solution, where BIM stores some information and points to other systems rather than embeds within the model. Communication and information exchange between the systems becomes crucial in this case. In order to achieve this, representations of knowledge about building element, components, systems, etc. are necessary and the relationships with the design factors. Moreover, integration of contextual aspects requires representation of the surrounding features and their effects on the building design, thus comprehensive computational descriptions are needed to achieve further extension of information technologies in architectural design.

The emphasis should be placed on the content of information stored in the BIM, and how that information is accesses and utilized. Ibrahim et al. (2004) state:

Objects should have a specific structure of their related information that relates to the different stage of the building design lifecycle. Every bit of information is relevant in one stage or another in the design process. It is up to the designer to decide when to reveal each bit of information according to how much decision he is willing to make in the design phase he is working on. Starting in the preliminary design phase, objects would be generic and only describe the function and some of the general geometry specific to that object. It would only be used to define spaces, enclosures and openings while
developing architectural plans. In subsequent stages, more detailed specifications could be decided and specified.

The missing part is the information that guides the initial design. Although the use of BIM has been increasing in the architecture and construction industry, development of computer applications that integrally aid the overall design process, assist the designer in decision-making process and analysis, foster collaboration and exchange is still in the initial stages. Integration of BIM, knowledge-based semantic web, and GIS systems is the next objective of many research efforts (Benner et al., 2005).

Case Study: Web Knowledge-Based Analysis Application

Future trends in architectural design and practice rely on advanced implementation of information technologies (Aksamija and Grobler, 2007). Currently, various applications are utilized for design, research, collaboration and simulation; however, there is a lack of tools that fully support integration and collaboration. There are numerous existing tools and platforms that support communication and documentation, but few that address the design process itself, and actively aid the decision-making process. The future generation of computer applications and software for architectural design should incorporate these aspects. According to Al-Homoud (2001), future trends in computer-aided design and building modeling should involve:

- More accurate models with greater flexibility;
- User-friendly interfaces;
- Graphical representations;
- Comprehensive programs covering all needs; and
- Interfacing between different packages.

This research utilized ontology as the basis for the development of web knowledge-based application, aimed for early schematic design (Figure 4). An ontology is a knowledge-based model that represents a domain, and it is used to reason about the objects in that domain, as well as the relations between them. It is a knowledge representation about a subject, and it describes individuals as the basic objects, classes as collections or types of objects, properties and characteristics and the relations between them. The representation structure provides a set of terms and descriptions that express the facts within a domain, while the body of knowledge using this representation is a collection. The purpose of ontology, developed during this research, is to capture design factors influencing buildings design. The application that utilizes ontology is primarily used for indexing, aimed to present information to the user, and foster decision-making process in design.

The development of real-world ontology-based knowledge management software applications is in the early stages (Maedche, 2003). Majority of research and implementation efforts have been aimed at ontology representation, engineering and reasoning. Standardized features that are widely adopted in traditional database-driven information systems, such as scalability, reliability and transactions, are typically not available in ontology-based system.

The developed application integrates several actions necessary for schematic design:

- **Site analysis:** Analysis of context through satellite maps and demographic data;
- **Energy analysis**: Access to external web-based tools;
- **Material selection**: Access to material information and product catalogs;
- **Collaboration**: Communication through a forum and real-time discussion;
- **Precedents**: Analysis of precedents;
- **Ontology**: Analysis of design factors; and
- **Search**: Access to external information through general web search.

Ontology represents architectural design factors in a semantic model, as seen in Figure 5. It is also linked to the precedents, displaying information for existing buildings (Figure 6). The frames allow navigation of classes, individuals and properties, presenting the context and relationships.
The development and use of knowledge management tools in construction industry has overlapping phases, depending on aspirations and flexibility. The first step aims to improve traditional design by developing cooperation via internet portals for universal access to traditional design documentation (Agger, 2002). However, the design process is not affected by these implementations; rather the communication system between agents is improved. The second approach is the model-based design, which is currently gaining popularity. In this case, modeling is based on the parametric components, but the process uses traditional project documentation where the representations of building design are still achieved by geometrical orthogonal projections and floor plan. The next step is the overall model-based construction, which aims to integrated design in the whole sector, from the initial schematic design, through all design phases and construction, and numerous systems and components (Shaked and Warszawski, 1995). In order to achieve this goal, contextual information must be modelled, and the information structure must be presented in a machine-readable format.

Conclusion

Designers have always been investigating improved means of communicating design which follows the demand in industry. Today, two and three dimensional drawings are simply not sufficient to represent and capture knowledge necessary for building construction. Building practice is changing from traditional to integrated, where agents are starting to collaborate from the very beginning of the project. All these aspects require significant changes in the building representations. The challenge in representing design in a computable form lies in the fact that some of the driving forces are intricate and difficult to quantify. Designers use implicit knowledge, acquired through education, training, and practice, to produce final outcome. However, explicit knowledge, such as building codes, regulations, and material databases, are used in the process.

Virtual building and Building Information Modeling (BIM) are being increasingly used in architectural design practice. These methods consider building as a common database of information, allowing for comprehensive representation, analysis, and information processing. The focus of this research has been computational
representations of design factors, particularly capturing design knowledge to be used by software applications. Conducted research was aimed at extending BIM to include contextual information and design knowledge to aid designers in the decision-making process.

Web-based application, which utilizes the knowledge-based model for decision-making process in architectural design, was presented. The application integrates several functions necessary for schematic design: site analysis, energy analysis, material selection, collaboration, and exploration. The benefit of this approach is that this system assists designer in the process, and aids the decision-making process.

Bibliography


