Dynamic Architectural Visualization Based on User-Centered Semantic Interoperability

Yungil Lee¹, Jinwon Choi*² and Jumphon Lertlakkhanakul³

¹ Professor, Hoseo University, Korea
² Professor, Department of Housing and Interior Design, Yonsei University, Korea
³ Post-doctoral Researcher, Millennium Environmental Design and Research, Yonsei University, Korea

Abstract

Technically-oriented architectural spaces today are becoming complicated because buildings contain a number of electronic facilities and complex structures. Furthermore, the advent of the ubiquitous environment enables buildings to provide various services to users and has accelerated the importance of architectural visualization as a problem-solving and communicating tool. It is recommended that architectural visualization be more intuitive and effective in order to support design decisions and collaboration. In this manner, this paper intends to define the role of current architectural visualization with considerations of previous research and related works in the practical field and proposes the appropriate method of architectural visualization. Also, in order to evaluate their idea, the authors recommend a prototype system based on dynamic and semantic representation using the avatar. This is a kind of simulator for the design of ubiquitous smart spaces and can deliver to users a better comprehension of how technological oriented space can be constructed and utilized.

Keywords: architectural visualization; semantic information; dynamic visualization; ubiquitous computing environment

1. Introduction

Traditionally, visualization to form a mental model or mental image of something has been a crucial assistance to the understanding and controlling of complex processes (Koutamanis 2000). The process of information visualization is graphically used to view encoded data in order to form a mental model of data. The principal task of information visualization is to allow the information to be derived from given data. Whatever the nature of the data is, the underlying philosophy of information visualization is to represent a problem so as to make the solution transparent (Simon 1996). Ware (2004) recommends several advantages of visualization as follows: the ability to comprehend huge amounts of data, the perception of properties that are otherwise not anticipated, the extraction of problems with data itself, i.e., detecting outliers or anomalies, the understanding of both large-scale as well as small-scale features of data, and the creation of various hypotheses related to the data.

Computational support has become one of the important research issues in the field of information visualization. In this regard, in his book on information visualization, Spence (2007) has pointed out the three principal reasons why the computer has affected massive advances in the field of information visualization. First, increasingly inexpensive and rapid access memory makes it possible to store truly vast amounts of data. Second, dramatically powerful and fast computation allows the rapid interactive selection of subsets of that data for flexible exploration. Third, the availability of high-resolution graphic displays ensures that the presentation of data matches the power of the human visual and cognitive systems. Koutamanis (2000) proposed that the wide availability of affordable computing power has been a significant factor for the application of information technology to the design and management of the built environment, and the democratization of computer technologies is changing architectural visualization in two significant ways. The first is that the availability of digital media promotes wider and intensive application of computer visualization. The second concerns the extension of architectural design to visualization in information systems. Lopes (1996) mentioned that pictures are re-emerging as vehicles for the storage, manipulation and communication of information, especially in relation to the visual environment.

The above listed qualities of visualization have long been recognized by architects, who have been enjoying using visual representation tools such as sketch,
diagram, image, mock-up model and so on. These visual representation tools have been used not only to solve problems but also to communicate with others. In general, visualization of real and imaginary space has been a traditional strong point of architectural education and practice (Evans 1989).

The gravity of visualization for architecture should also be disclosed in the situation of wider technocultural changes. Technically-oriented architectural spaces today are becoming complicated because buildings contain a number of electronic facilities and complex structures in order to provide a lot of advanced services to users based on a ubiquitous computing environment and to realize the non-Euclidean shape of buildings. It is recommended that architectural visualization as a problem solving and communicating tool is more intuitive and intelligent in order to increasingly support design decisions and collaboration.

In this manner, this paper intends to illustrate the role of current architectural visualization while considering previous research and the phenomenon of related works in the practical field and propose an appropriate method for it. At the end of this paper, the authors propose a prototype system by applying their opinion regarding the evaluation.

2. Data for Architectural Visualization

One of the most broadly accepted taxonomies for classification of data scales is the one defined by Stevens (1946). According to his taxonomy, there are four categories for measuring data scales: nominal, ordinal, interval and ratio. Shneiderman (1996) has defined taxonomy of seven data types in the context of information visualization as shown in Table 1. Conventionally, his definition seems to address almost all data types discussed that the authors can imagine. However, in order to make the role of information visualization in the field of architecture clear, we need to further discuss the previous stated data types from the perspective of architectural data modeling. The authors suggest four types of architectural data for visualization of current architectural space; geometrical, topological, semantic, and social. Fig.1. shows the difference among four data types.

1) Geometrical and Topological Data

In the research concerning data modeling for the development of Computer Aided Architectural Design (CAAD) systems, building data is generally classified into two categories: geometrical and topological data. Choi (1997) proposed the concept of a "structured floor plan" the structure of which is hierarchical and object-oriented, and plays an important role in containing design information for each design project during the design process. The data structure of Structured Floor Plan is a composition of objects that represent the important architectural elements as a conventional metaphor such as wall, window, column, slab, and so on, which link each other spatially. Also each space composed of architectural objects is linked with other spaces syntactically. In other words, each architectural object is composed of much geometry linked with other geometries (Choi et al. 2007). As the authors surmised in the previous statement, the architectural data is composed of geometrical data and their topological network representing the architectural metaphor.

2) Semantic Data

We can find an example of the semantic characteristics of current architectural data in the Building Information Model (BIM). BIM has become one of the important research issues recently. It is a set of information generated and maintained throughout the life cycle of a building and also the process of generating and managing a building information model (Lee et al. 2006). BIM covers geometry, spatial relationships, geographic information, quantities and properties of building components. It can be used to demonstrate the entire building life cycle including the processes of construction and facility operation. Quantities and shared properties of materials can easily be extracted. Scopes of work can be isolated and defined. Systems, assemblies, and sequences can be shown in a relative scale with the entire facility or group of facilities. According to Eastman et al. (2008), modern BIM design tools are smart and capable of defining objects parametrically. That is, the objects are defined as parameters and relations to other objects, so that if an object changes, all related ones will also. Parametric objects automatically re-build themselves according to the rules embedded. The rules may be simple, requiring a window to be wholly within a wall, or complex defining size ranges, and detailing. Yang and Zhang (2006) defined these characteristics of BIM as semantic characteristics. To them, this semantic interoperability is a crucial element in making building information models understandable and model data sharable across multiple design disciplines and heterogeneous computer systems.

<table>
<thead>
<tr>
<th>Data Type</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-dimensional or univariate data</td>
<td>Text, list of strings, source codes …</td>
</tr>
<tr>
<td>2-dimensional or planar/map/bivariate data</td>
<td>Geographic maps, plans …</td>
</tr>
<tr>
<td>3-dimensional or trivariate data</td>
<td>Real world objects …</td>
</tr>
<tr>
<td>Temporal data</td>
<td>Time line …</td>
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<tr>
<td>Multi-dimensional or multi-variate data</td>
<td>Relational and statistical data</td>
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<tr>
<td>Tree data hierarchies or tree structures</td>
<td>Tree data</td>
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<tr>
<td>Network or graph data</td>
<td>Graph data</td>
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For the sake of proposing the importance of semantic interoperability in building design, they suggest that the data model in building design and management systems should contain the data of selected CAD behaviors, relationships, constraints, and reference links as a termed object behavior semantically. In their suggested idea, semantic data is divided differently from topological data so that semantic data resembles a sort of topological data.

Dourish and Chalmers (1994) enlighten the meaning of semantics in their research related to information navigation. They give an example of a bookstore to illustrate semantic navigation easily. If we pick up a book because it is sitting on the shelf next to one we have just been examining, then we are navigating spatially. On the other hand, if we pick up another book because it was referred to in a citation in the first book, then we are navigating semantically. The semantic characteristics of current architectural space could be inferred from the hypertext system of a website. A hypertext system, for example, provides a 'link' between semantically-related items and offers a means to move from one item to another according to these semantic relationships.

3) Social Data
The previously stated Dourish and Chalmers' study related to information navigation tells that 4th data for architectural visualization exists because navigation must be one of the important aspects of information visualization: that is to say, social data (Dourish and Chalmers 1994). They presented the term 'social navigation' that was created to illustrate a unique phenomenon, in which a user's navigation through an information space was primarily guided and structured by the activities of others within that space. 'Social' navigation is opposite to 'spatial' and 'semantic' navigation. Spatial navigation depends on the structure of the space itself and 'semantic' navigation, in contrast, relies on the semantic structure of the space. We can refer to the example of bookstore again. If we pick up another book because it was recommended to us by someone whose opinion we trust, we are navigating socially (Dourish 2003). He proposed two characteristics of social navigation. First, social navigation will be considered as an aspect of collaborative work, in which information can be shared within a group to help each group member work effectively, exploiting overlap in concerns and activities for mutual coordination. Second, it will be presented as a way of moving through an information space and exploring activities and orientations of others in that space as a way of managing one’s own spatial activity.

In general, architectural space does not mean just physically-defined solid and void. Formerly, Kalay and Marx (2001) proclaimed the difference between 'Space' and 'Place'. According to them, "place is a space activated by social interactions, and invested with culturally-based understandings of behavioral appropriateness". Consequently, 'place-making' is the conscious process of arranging or appropriating objects and spaces to create an environment that supports desired activities, while conveying the social and cultural conceptions of the actors and their wider communities. Furthermore, the current technology-oriented architectural space based on the interaction between 'space and user' or 'user and user' is trying to provide various services that guide user's activities more than before, and finally the activities of users can intensify the social characteristics of place.

We can find an example of the social characteristics of current architectural data in the project of ubiquitous smart space. The College of Computing at Georgia Tech introduced ubiquitous smart space as the next revolutionary advance in smart space research (Abowd et al. 1998). According to their research, users of ubiquitous smart spaces will not have to delay, to interrupt, or to restructure their activities to take advantage of a central smart room facility if every space is smart. The visionary application that motivates and drives a coordinated effort by the research community is to create ubiquitous smart spaces as demonstrations of smart spaces that encompass entire working communities, and cover all aspects of each participant's life. They propose that their ubiquitous smart space provides several specific types of assistance for users including capturing everyday experiences, access to information, communication and collaboration support, natural interfaces, environmental awareness, automatic receptionist and tour guide, and training.

3. Methods to Visualize Architectural Data
1) Spatial Integration
The main idea of visualization is helping people to
think by a frame of reference and a temporary area to store cognition externally in the process of discovery, decision making, and explanation (Carsten et al. 2006). In architectural visualization, the frame of cognition can be inspired by physical space because most architectural data for visualization is associated with a physical three-dimensional space. Commercial CAD applications such as ArchiCAD and REVIT have been attempting to create spatially integrated BIM systems. In these software, when a user draws a building simply using traditional 2D metaphors, the systems automatically generate not only a 3D building model but also the relationship among objects. The user can input other related data into his drawing and the spatially mapped data is managed in specific rules. The 3D building model as a kind of graphic user interface enables users to search, browse, and analyze information linked with buildings and building components intuitively.

2) Multiple Views
In order to visualize different sorts of data simultaneously, the multiple view technique is often used in visualization environments (Carsten et al. 2006). In a research related to digital architectural visualization, Kountamanis (2000) proposed three visualization methods: projecting appearances, scientific visualization, and dynamic visualization. His idea of visualization based on advanced computational power means that architectural data should visualize not only building appearances but also the information behind, such as building behavior and performance. Compared with other subfields of computer graphics, information visualization has a serious restriction: the available screen space (Carsten et al. 2006). Especially, semantically rich building information is not easy to visualize at once in a limited screen space. Multiple views means both the visualization of different types of data simultaneously and the visualization of complex systems containing several information sources. Further, it means visualizations where several views provide a different abstract perspective on the same information. Multiple view systems provide dynamically visualizations where each view can be used separately without any loss of information. This is useful because the architect today should consider many different sorts of information semantically to create an appropriate result.

3) Representation of Social Data
According to Dourish's study, semantic and social navigation do not name types of systems; rather, they name phenomena of interaction. The conceptual segregation among "spatial" that is composed of geometry and topology, "semantic" and "social" styles of information navigation was intended to provide terms in which these different forms of data could be visualized. Social data should be based not simply on the data of others, but data about the activity of others (Dourish and Chalmers 1994). In the current architectural space like the ubiquitous smart space, we cannot visualize the social data just using traditional visualization techniques such as diagram, graph, 3D model, and so on. Even 3D animation cannot visualize the social data because it displays according to what the director orders and expects. Architectural design is not for the sake of a building itself but for dwellers. Therefore, architects should consider the dwellers' activities that correspond with the physical environment in order to make a proper alternative. Especially, the ubiquitous smart space provides a lot of services for dwellers according to their behavior and intension. It is not a one-to-one correspondence but a social phenomenon between users and environment or among users. In this manner, architectural visualization must represent the unpredictable social phenomenon and the authors cope with this by proposing a game-based visualization technique to visualize the social data in the new smart architectural space. Game-based visualization means a kind of simulation using avatars based on the 3D space model linked to diverse semantic data. After an architect creates a 3D space model that represents his or her idea, avatars that represent the dwellers can be placed in the virtual space. One can control his or her avatars to move from one space to another. When the avatar enters a space or meets other avatars, the virtual environment provides specific services based on several intelligent rules and then allows architects to decide the social phenomenon.

4. Implementation of V-PlaceLab
The authors suggest a prototype system namely 'V-PlaceLab' to evaluate their idea of visualizing the new architectural data. It is developed as a simulator for the ubiquitous smart space. This smart space refers to human centered and technologically-integrated space based on situation-aware, autonomic, and self-growing (http://www.cuslab.com). V-PlaceLab represents planned ubiquitous services
in the early stage of building design using virtual buildings, objects, and avatars. Semantic information defined in XML (Extended Markup Language) file format contains sequences of services mapping virtual buildings, objects, and virtual avatars. This system visualizes dynamically not only spatial but also semantic and social information according to an avatar's behavior and environmental situation (as shown in Fig.2.).

1) Virtual Building Data Model
Humans do not perceive architectural space as an image, but as a hierarchical composition of various elements (Lee et al. 2004). Therefore, our virtual building data model contains spatial information to explain the configuration and hierarchy of spatial components based on the idea of Structured Floor Plan (Arbanowski et al. 2001). Spatial information is not only a foundation of spatially-integrated visualization but also spatial reasoning that semantically enables virtual users to perceive and recognize the space using hierarchical relationships and spatial connectivity among building component classes.

2) Virtual Object Data Model
Objects in space are an important guidance for human behavior as well as the trigger of ubiquitous service. Thus, smart objects also contain their own functions and status to interact with users and other objects. Objects may contain specific events to be performed by a virtual user through an avatar in the same manner as occurs in the real world. This ability is enabled by means of sensors installed in smart objects. An object must belong to at least one space enabling it to communicate with other entities.

3) Spatial Context Data Model
The modeling of spatial context handles additional semantic information attached to a space. It describes typical characteristics and spatial configurations for the built environment. 'Domain' stores spatial information regarding building type in the same manner as 'Space Type' does for Space. Generally, the Domain and Space Type for each space are unique. They require disparate spaces, activities, and areas used by different types of user. The authors' spatial data model performs as a typical spatial knowledge base of any agent based system.

4) Virtual User Data Model
In order to provide proper services to each user in a ubiquitous smart space, the system must be capable of storing and retrieving a user's personal information accurately. The personal preferences and needs, persons to interact with, and sets of devices to control by each individual, define one's personal communication space (Arbanowski et al. 2001). Such personal information is stored in the Virtual User Data Model at 'User' and 'Activity' classes.

5) Interaction Data Model
Interaction in the virtual environment could take place by means of an Interaction Data Model. It functions as an interface between the Virtual User Data Model and the others. In other words, it enhances
the concept of human-centered service by applying context-aware ability. It serves as the key transaction and the initial status for any possible interactions by connecting all the components such as space, user, object, activity and event. Once a specific event motivated by a user is detected, all related activities will be retrieved as the user's potential goals. Each activity contains a set of commands for operating all related objects and services.

5. Architectural Visualization in V-PlaceLab

Fig. 4. shows an example of semantic data used in V-PlaceLab. This information is linked to a data model semantically as visualized in Fig. 7. The authors also developed a parser to read and represent these data in V-PlaceLab. Fig. 5. shows a class diagram of UCCS Package which is a group of classes that parses community data and creates instances defined in an XML file (as shown in Fig. 4.). Each class corresponds with the element of community and each manager class integrated to cmWorkspace manages each class instance. Originally, community data is created by u-Service Manager that manages sensors and actuators in the ubiquitous computing environment in order to provide an appropriate service to users according to the change of situation. However, V-PlaceLab contains u-Service Manager to unify design and simulation. u-Service Manager observes the avatar's behavior and intentions and generates an instance of community data that is delivered to the UCCS Package for visualization. The process to utilize V-PlaceLab and its functionality are explained in this section.

1) Building modeling

In order to demonstrate the system's functionalities, a scenario of a smart home was applied to V-PlaceLab. The goal of this demonstration was to make invisible processes visible and seamless based on the user's daily activity. The building modeling in this scenario results from an imitation of an actual smart home test-bed constructed at CUS Lab, Ajou University. The virtual test-bed was created with identical spaces, functions and furniture arrangement to the real spaces. The building model was created on the basis of the data model described in Fig. 3. The virtual smart home is composed of living space, bedroom and toilet. They are unique in shape, location, furniture, semantic and social information as well as smart home services. The living space is the area for watching TV and reading books at the sofa. It also serves as the hall connecting the other spaces. The bedroom has one bed. Examples of smart home services for each space are; lighting control, air temperature control, and appliance control.
user's intention and autonomously closes the curtain then adjusts the lighting and the temperature to be suitable for the activity. After watching a movie, the user uses the toilet and then goes to sleep in the bedroom. In the mean time, the system detects changes in the user's activity and adjusts all home services to meet the requirement of sleeping mode. Note that, input data for the scenario was generated by capturing real human action in the physical test-bed. Time series data of the user's action were then converted into XML format and transmitted to V-PlaceLab using TCP/IP protocol as shown in Fig.6. However, due to the problem of data synchronization, the visual simulation could not be carried out spontaneously to the real action. All action data were then parsed and visualized as automated animation through avatars as shown in Fig.7.

3) Functionality of V-placeLab

**Spatial integration:** Simulation based on the smart home scenario has shown spatial integration among geometry, semantic and social information. All spatial objects are displayed in three-dimension. The topology of spaces was created based on the semantic relationship between space and door classes. Likewise, other building components, furniture and appliances are semantically bound to spaces in the same manner. Social interaction in space is defined based on furniture layout. The sofa functions as an action point for watching TV and reading activities while the bed is a location for sleeping. All information are merged and united into one virtual building.

**Multiple views:** Data visualization in the V-PlaceLab can obviously be considered as multiple views. Different kinds of information can be visualized according to the purpose. Not only visible objects, but invisible information such as smart home computing groups and services in the scenario can be visualized using various methods. Fig.8. illustrates four different modes to visualize the community services. To avoid complexity of spatial integration, ‘Balloon’ and ‘Shadow’ metaphors were chosen to display invisible information above and below spatial objects respectively. Large balloons and shadows refer to a community of smart services working together for the same goals, whereas small balloons and shadows represent each service as a community member. There are two modes for color display represented by entity or by community. As information of community and service are instantly changed according to a user's action, V-PlaceLab serves as a virtual platform to view multiple information adapted over time.

**Game-based visualization:** Similar to physical settings, the virtual building model created in V-PlaceLab embodies the notion of ‘place’. Actors can perform actions in virtual spaces. Human-space interaction is enabled by the interaction the data model described previously. Avatars are exploited to represent user identity. Each activity is associated with an avatar motion which allows each avatar to move and to act with realistic poses. This results in the fourth dimension of space.

6. Conclusion and Discussion

This paper intends to illustrate the role of current architectural visualization and proposes an appropriate method for it. First, the type of data to be visualized is studied based on the previous research and practical field. The authors emphasized semantic and social data in the current architectural data visualization because they have become important in the era of a ubiquitous computing environment. In the method of visualization, they proposed three concepts of visualization for the semantic and social data composed of spatial integration, multiple views, and game-based visualization. At the end of the paper, the authors described a prototype system developed to evaluate their idea. V-PlaceLab, based on dynamic and semantic representation with avatars, is a kind of simulator for the design of ubiquitous smart spaces and can provide users a better comprehension of how technological oriented space can be constructed and utilized. Furthermore, this system as a framework for spatial information monitoring can be used to facilitate management service. Semantic data that contain services, events, building performance, records and so on is bonded to a 3D building model composed of conventional architectural metaphors as well as being represented simultaneously. V-PlaceLab can visualize the semantic data as various shapes in 1st person and 3rd person perspectives in the real-time manner (See Fig.8.). Especially, simulation using a virtual avatar can evaluate both the social phenomenon of this space and the performance of ubiquitous services.

In order to realize a more intelligent environment for social representation, we need to seriously consider the potential behavior of humans as they relate to objects and space. J. J. Gibson called this 'Affordance' which means latent action possibilities in the environment. [22]. If we apply this idea to V-PlaceLab, it will be able to yield more precise and various results of human behavior because 'Affordance' is related not only to the properties of an object but also to human abilities. In addition, 'Affordance' is a kind of situated information as potential action perceived. The authors’ future work is to elaborate on this aspect to provide a new opportunity to simulate the performance of a multi-functional built environment.

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