AN INTERACTIVE GRAPHICAL SYSTEM FOR COLLABORATIVE ARCHITECTURAL DESIGN IN 3D VIRTUAL ENVIRONMENTS

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Abstract. This paper presents the development of an interactive graphical system applicable to collaborative architectural design in 3D virtual environments and its preliminary application for a building design project. This interactive graphical system integrates the spatial system and the stylistic system and specialises in styles representation and exploration in architectural design.

1. Introduction

A style is a manner of doing something, which is chosen from a wide range of ways to achieve similar result. Architectural styles classify architecture in terms of forms, techniques, materials, time periods, and regions. The spatial arrangement of a building combining with different elements and link-relationships of forms, different techniques, or different materials may form different architectural types and styles.

The increasing globalisation requires architecture and design firms to collaborate across different time zones and geographical locations. It requires additional time and financial inputs in relocating human and design resources. 3D virtual environments have the potential to make a major impact on global design teams by supporting distant design collaboration.

Most digital representations for architectural design address the final design documentation stage, CAD for example. Similarly, design representations in traditional 3D virtual environments mainly focus on the representations of 3D geometric forms for simulations. Specific information and numerical data are required in applying these representations to architectural design. There is a need to develop a representation system applicable in the conceptual architectural design stage that is flexible for representing design alternatives without the requirement of exact numerical data. The system can also be applied to types and styles developments of architectural design. Designers across different geographical locations and time zones can apply this representation system for collaborative design in 3D virtual environments.

This paper presents the theoretical framework of an interactive graphical system for representing architectural design in collaborative 3D virtual environments. The effectiveness of this graphical system is demonstrated in two design cases: building extension and architectural style transformation. The generation of architectural types and styles in this study is influenced by both a spatial subsystem and a stylistic subsystem.

2. Background

Collaborative design in 3D virtual environments and graphical representations for architectural design provide the foundation to develop this interactive graphical system for collaborative architectural design.

Collaborative Design in 3D Virtual Environments: Collaborative designing is a process of dynamically communicating and working together in order to collectively establish design goals, search through design problem spaces, determine design constraints, and construct a design solution (Hennessy and Murphy 1999; Lahti et al. 2004).

3D virtual environments are networked environments designed using the place metaphor. One of the main characteristics that distinguish 3D virtual environments from conventional virtual reality is that virtual environments allows multiple users to be immersed in the same environment supporting a shared sense of place and presence (Singhal and Zyda 1999). Multi-user 3D virtual environments have grown very rapidly, with examples such as Second Life (www.secondlife.com) soon reaching a million residents and boasting a booming in-world economy.

Driven by today's global economy, architects and designers often collaborate with distant counterparts. With the supports of collaborative 3D virtual environments, designers can remotely collaborate on projects without concerning the barriers of location and time differences. Distant design collaboration can significantly reduce the relocation costs and help to increase the efficiency in global design firms. Designers can also have dynamic communications for real-time information sharing and modifications of large data sets such as digital architectural models and building information. Current development of such systems, for example, DesignWorld (Maher et al. 2006) supports remote communication, collaborative modelling and multidisciplinary building information sharing.

Graphical Representations for Architecture: A graph is a set of dots, called vertices or nodes, connected by lines, that is, edges or arcs. Graphs in architectural design have been used to represent a variety of spatial structures and the adjacencies between rooms in a plan, Figure 1 (Steadman 1983). Bond graphs introduced by Paynter (Thoma 1975; Karnopp et al. 2000) is a kind of modelling tool that provides a unified approach to the modelling and analysis of dynamic systems, especially for hybrid multi-domain system including mechanical, electrical and hydraulic systems (Borutzky et al. 1995). Tsai and Gero (2006a; 2006b) extend bond graphs to architectural domain to develop Qualitative Archi Bond Graphs (QABGs) which are a qualitative energy-based unified representation for buildings. QABGs combine graphical representations and mathematical equations. They can be applied to building analysis of building subsystems, such as space-people systems and building energy systems, as well as of interactions between different building subsystems.

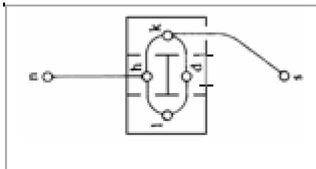

Figure 1. The graph of a plan, in which vertices represent rooms or exterior regions, and edges signify the existence of doors or other direct means of access between these rooms or regions (Steadman 1983)

The concepts of collaborative design, 3D virtual environments and graphical representations will be adopted to develop an interactive graphical system for collaborative architectural design in 3D virtual environment. Elements of QABGs will be extended so they are applicable to represent and explore architectural style in designing. QABG elements include terminals (T) and junctions (J), Table1. A terminal is a 1-port element which can be linked to a 0-junction or a 1-junction. A junction is a multi-port element which can be linked with one or more terminals. The mechanism developed in QABGs representing interactive behaviours will also be adopted in representing dynamic interactions.

TABLE 1. QABG elements (Tsai 2007)

1-port element: Terminal (T)			Multi-port element: Junction (J)
Energy source → T_S	Energy operator → T_O		
Active 1-port	Passive 1-port	Additive 1-port	
Source, S	Inductor, I Capacitor, C Resistor, R	Controller, CR Meter, M Building component, B	Transformer, TF Transducer, TD 0-junction 1-junction Energy controller, EC

3. Interactive Graphical System for Architectural Collaborative Design

An interactive graphical system for collaborative architectural design specialised in architectural style representation and exploration includes two subsystems: a spatial system and a stylistic system. Spatial arrangements of a building can be converted into a graphical representation, same as stylistic-component arrangements of a building. Graphical representations of each subsystem are generated by elements and element-link-relationships, that is, nodes and arcs of a graph. In designing, the spatial system represents the spatial arrangement of a building and the stylistic system represents architectural style of a building. Interactive mechanisms represent the interactive relationships within and between the two subsystems. The development of this graphical system for collaborative architectural design consists of the following three steps:

- Defining and developing elements and element-link-relationships of the graphical system, i.e. nodes and arcs. Designers can use these elements and follow element-link-relationships to generate both the spatial subsystem and the stylistic subsystem.
- Defining and developing linking and transforming mechanisms for interactions between the spatial subsystem and the stylistic subsystem. Designers can use this graphical system for collaborative design in individual and team design activities.
- Augmenting and modifying this graphical system to be applicable in 3D virtual environments. This graphical system provides designers with alternative representations and richer design language for supporting collaborative design in 3D virtual environments.

Spatial System: In the spatial system, graphical representations represent spatial topologies of spatial arrangements. Extending elements in QABGs, elements of graphical representations of the spatial system are as follows:

- **Terminals, 1-port elements**: include C, C_c, C_o, CR, I and S, Eq (1).
  C: is a container which represents rooms and spaces in a building, including C_c and C_o.
  C_c: represents enclosed spaces, such as rooms.
  C_o: represents opening spaces.
  CR: is a controller which represents doors.
  I is an inductor which represents passages, including corridors and steps.
  S: is the source from where people move into a building. It represents the outside environment.

$$T = \{C, C_C, C_O, CR, I, S\} \quad (1)$$

- **Junctions, multi-port elements**: include 0-junction and 1-junction, Eq (2), which are space-junctions.
  0-junction implies that people may progress to spaces different from the space where they came from. 1-junction implies that people are not able to progress to other spaces expect returning to the space they came from.

$$J_{\mathit{spatial}} = \{0, 1\} \quad (2)$$

Initial element-link relationships for graphical representations in the spatial system include a terminal linked to a junction, T-J, or a junction linked with a terminal, J-T. It includes the following forms: a source (S) links to a 0-junction, a source (S) links to a 1-junction, a 1-junction is linked with an I-element, a 1-junction is linked with a C_C-element, a 0-junction is linked with a C_C-element, a 0-junction is linked with a C_O-element, and a 1-junction is linked with a CR-element, Figure 3.

U	1	I	C_C	C_C	C_O	CR
|	|	|	|	|	|	|
S	S	1	1	0	0	1

Figure 3. Initial element-link-relationships between a terminal and a junction (T-J) for the graphical representations in the spatial system

Stylistic System: In the stylistic system, graphical representations represent topologies of stylistic-component arrangements. Elements of the graphical system in the stylistic subsystem are defined in a general form. Therefore, they can be applied in a wide range of different architectural styles. With the specifically defined stylistic elements, the graphical representations of the stylistic system can be applied to the specific architectural style.

- **Terminals**, 1-port elements: include two types, solid and void elements. They are represented by E_S for solid elements and E_V for void elements.
- **Junctions**, multi-port elements: include H-junction and V-junction, Eq (3). H-junction, horizontal junction, is applied to horizontal assemblies of stylistic components; and V-junction, vertical junction, is applied to vertical assemblies of stylistic components.

$$J_{stylistic} = \{H, V\} \qquad (3)$$

Interactions between Spatial and Stylistic Systems: Similar to QABGs, in an interactive graphical system, a bond will link two junctions, one in the spatial system and another in the stylistic system, when there is an interaction between two systems. Figure 4 shows an example of an architectural design project. Figure 4(a) is a 3D model, Figure 4(b) the spatial system represented by a plan drawing, and Figure 4(c) the stylistic system represented by 3D stylistic components.

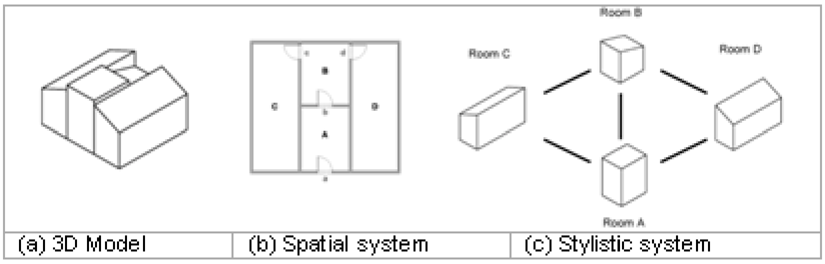

Figure 4. Architectural-design-project A
(a) 3D model, (b) the spatial system, and (c) the stylistic system

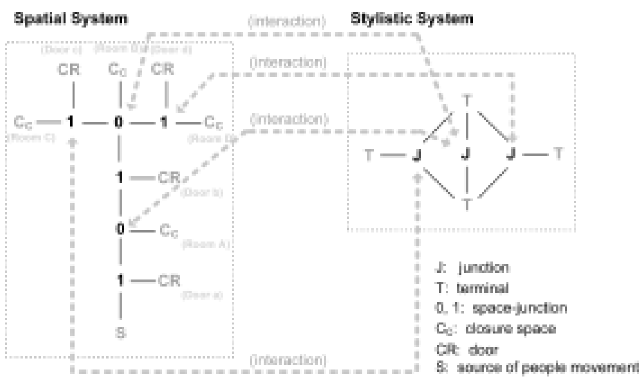

Figure 5. Interactions between the spatial system and the stylistic system

In the spatial system, the plan drawing of the spatial arrangement is converted into a graphical representation represented by specific elements, i.e. C_C, CR, I, S, 0 and 1. In the stylistic system, a graphical representation with general elements, i.e. terminals and junctions, represents the topology of the 3D stylistic-component arrangements. There are four interactive relationships between these two systems. When a spatial element or a spatial element-link-relationship in the spatial system has been changed, the corresponding element(s) and element-link-relationship(s) in the stylistic system will be changed simultaneously, vice versa.

Implementations in 3D Virtual Environments: The interactive graphical system is currently being implemented in a 3D virtual world platform: Second Life, for collaborative architectural design. Designers can immerse in the 3D virtual environment and remotely collaborate through the interactive graphical system. At the initial design stage, by using elements and element-link-relationships, designers can focus only on the concept-development of the spatial and stylistic properties of the design project as well as interactions between spatial arrangements and architectural styles. After the concepts of spatial arrangements and architectural styles are developed, designers can apply specific data to elements and element-link-relationships of the spatial arrangements and architectural styles for the design project in the 3D environment. Therefore, designers can also achieve more precise spatial arrangements and architectural styles of the design, and document and simulate them in the 3D virtual environment.

4. Demonstration

This section demonstrates interactive graphical systems to be applied to a building extension case and an architectural style transformation case. Case I demonstrates the usability in the spatial subsystem. Graphical representations can represent different spatial arrangements of a building project. It is similar in the stylistic subsystem. Case II, demonstrates the interactions between the two subsystems for supporting style transformation.

Design Case I - Building Extension: Figure 6 shows an example of a building design project: Figures 6(a) and 6(b), and its extension, Figures 6(c) and 6(d).

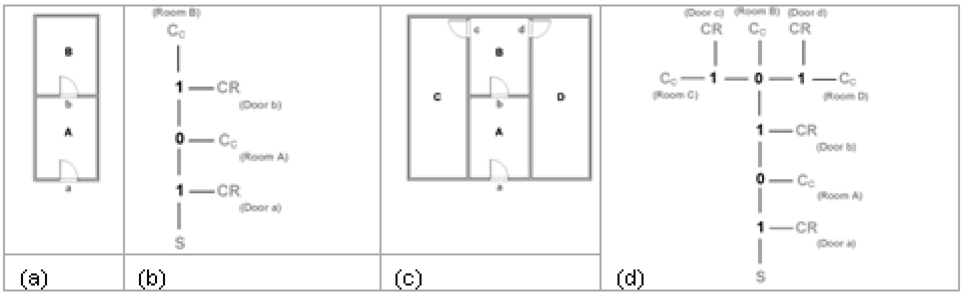

Figure 6. A building design project (a) the plan drawing and (b) the graphical representation and its extension (c) the plan drawing and (d) the graphical representation

Figure 6(a) is a plan drawing with two rooms, Room A and Room B, and two doors, Door a and Door b. Figure 6(b) is its graphical representation. This design is extended to consist of two more rooms, Room C and Room D, and two more doors, Door c and Door d. Room C is on the left-hand-side of the existing plan and Room D is on the right-hand-side, Figure 6(c). Figure 6(d) shows the graphical representation of the extended design. People can move from the outside (S) through Door a into the building to Room A and through Door b into Room B. From Room B, they can either move through Door c to Room C or through Door d to Room D.

Design Case II - Style Transformations: Designs A and B in Figures 4 and 7 are used to show the interactive graphical system being applied to architectural style transformations. The spatial arrangements of these two designs are the same. We use different 3D stylistic components to replace general terminal (T) and specify horizontal H-junction in the stylistic subsystem, which can result different outcomes.

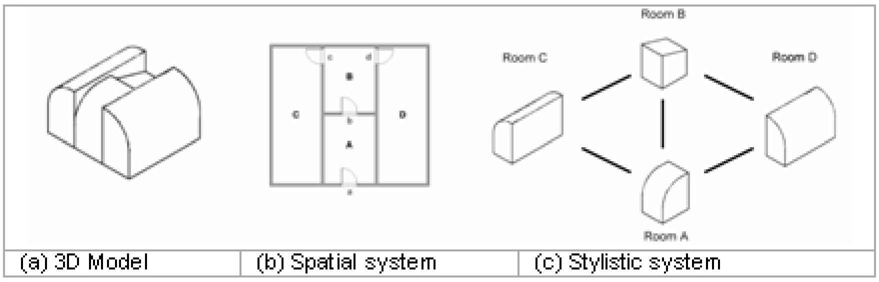

Figure 7. Architectural-design-project B

(a) 3D model, (b) the spatial system, and (c) the stylistic system

Figure 8 shows interactive relationships between the spatial subsystem and the stylistic subsystem for both architectural-design-projects A and B. The graphical representation of the spatial subsystem for both projects is the same and is placed in the middle of Figure 8. It interacts differently with the stylistic subsystem in projects A and B. The interactive relationships occurred at the same junctions linked by dotted lines. In project A, the stylistic components with straight horizontal or steep shape are applied for the forms of roofs for Rooms A, B and C. The forms of roofs for Rooms A, B and C, in project B, are transformed to shapes with curves and are represented with different stylistic components in the stylistic subsystem.

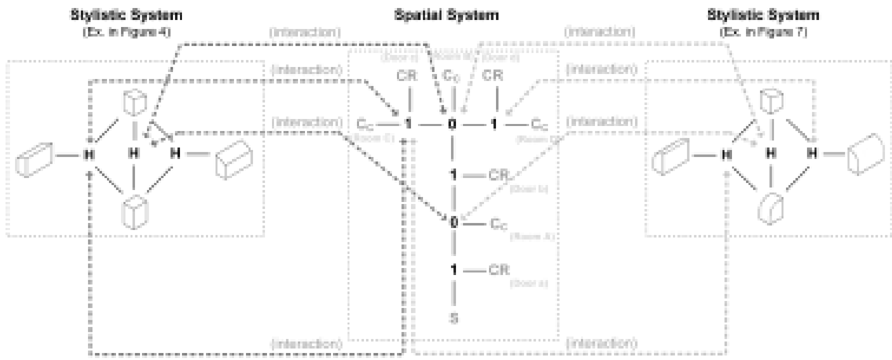

Figure 8. Interactions between the spatial system and the stylistic systems of Architectural-design-projects A and B

The spatial subsystem and the stylistic subsystem can also be modified at the same time. A link will be placed between two junctions (J), one in the spatial system and another in the stylistic system, if there is an interactive relationship between these two subsystems. When there are changes in the element(s) or element-link-relationship(s) within one system, the other system will automatically respond to the variation(s) of element(s) and element-link-relationship(s) and adjust accordingly.

5. Conclusion and Future Work

This paper presents the theoretical framework of an interactive graphical system for collaborative architectural design. It combines the spatial subsystem and the stylistic subsystem and specialises in stylistic representations and explorations in collaborative 3D virtual environments. Designers can flexibly apply this graphical system with only elements and element-link-relationships in the conceptual design stage. Then, assigning specific data, such as exact shapes and dimensions of architectural components, this graphical representation can also be applied to the final design documentation stage. In addition, this interactive graphical system is dynamic and automated.

This graphical system provides designers with alternative representations and richer design languages for supporting collaborative design in 3D virtual environments, from the initial conceptual design stages to the final design documentation stage. Our current development focuses on the technical implementation of the system in Second Life. Empirical data will also be gathered to further validate the framework, upon the completion of the implementation.

Acknowledgements

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