Interactive graphical representation applied to collaborative virtual world for architectural style study

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ABSTRACT: The interactive graphical representation supports multiple design representations and their interactions. It consists of representations for the spatial subsystem and the stylistic subsystem of a building to facilitate design collaboration in 3D virtual worlds, for designers or computational design agents alike. This paper presents the application of the interactive graphical representation applied to collaborative virtual world for architectural style study of the pavilions designed by J. B. Fischer von Erlach.

Keywords: Collaborative Virtual Worlds, Graphical Representation, Architectural Style.

INTRODUCTION

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 worlds distinguish themselves from other networked technologies by having place characteristics. It is not just another communication tool but the ultimate destination where we shop, are entertained and get educated (Kalay and Marx 2001). In the AEC (architecture, engineering and construction) domain, the ever increasing globalisation results in large projects that require global design teams to collaborate across different geographical locations and time zones, which often demands additional time and financial inputs in coordinating and relocating human and design resources. 3D virtual worlds have the potential to make a major impact on global design teams by providing an online place that support distant collaborative design activities without designers being physically present. However, the majority of design representations in traditional 3D virtual worlds mainly focus on the representations of 3D geometric forms for simulations. Specific information and numerical data are often required in applying these representations to design. Therefore, there is a need to develop a representation system applicable in the conceptual design stage that is flexible for representing more complex design concepts and alternatives.

A style is a manner of doing something, which is chosen from a wide range of ways to achieve similar result. Style perception involves the interaction between the preconscious perceptual recognition of style elements and relationships at different scales and levels of abstraction, conscious reasoning about similarities and categories, and explanatory inference to a coherent understanding of the artefact (Stacey 2006). 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.

Qualitative Archi Bond Graphs (QABGs) (Tsai and Gero 2006a, 2006b, 2008) are energy-based unified representations for buildings. Combining graphical representations and qualitative equations as well as using unified variables, elements and constitutive relationships, QABGs can be applied to multiple architectural domains to represent and simulate dynamic behaviours in buildings. Gu and Tsai (2008) extended QABGs to develop the interactive graphical representation that supports multiple and interactive design representations through a spatial subsystem and a stylistic subsystem. In designing, designers can flexibly apply different subsystems to accommodate different design needs and representation preferences.

This paper proposes an application of the interactive graphical representation using QABGs to collaborative virtual worlds for architectural style study focusing on architectural form making in a simplified geometrical way. It commencement from an introduction of a refined interactive graphical representation framework, including elements and element-link-relationships in the spatial subsystem and the stylistic subsystem. The paper then demonstrates the application of the interactive graphical representation for a architectural style study in a 3D virtual world, Second Life (www.secondlife.com), with three case studies of pavilion designs by an Austrian architect of the Baroque period, J. B. Fischer von Erlach. The interactive graphical representation provides designers with multiple representations and richer design languages in 3D collaborative virtual worlds.
1. INTERACTIVE GRAPHICAL REPRESENTATION

A graph is a set of dots, called vertices or nodes, connected by lines, that is, edges or arcs. Extended from QABGs (Tsai and Gero 2006a, 2006b), the interactive graphical representation consists of graphical representations for a spatial subsystem and a stylistic subsystem of a building, Figure 1. Each subsystem is generated by elements and element-link-relationships. Applying the interactive graphical representation to a building design, the spatial subsystem represents the spatial arrangement of the building. Elements of the spatial subsystem represent different rooms, spaces and the spatial junctions of these rooms and spaces. When two rooms or spaces are linked, there is a bond placed in between these two rooms or spaces. In contrast, the stylistic subsystem maps the spatial subsystem. Elements of the stylistic subsystem represent the forms and shapes of rooms and spaces as well as their junctions. Bonds represent where two elements link with each other. The combination of these elements and element-link-relationships for different forms and shapes of rooms and space composes the architectural style of the building. Applying the interactive graphical representation to a building design, since the spatial subsystem and the stylistic subsystem are mapping to each other, in designing, when one element or on element-link-relationship in one subsystem is changed, the corresponding ones in other subsystem will also be changed.

Figure 1: The interactive graphical representation comprises of a spatial subsystem and a stylistic subsystem.

1.1. Spatial subsystem

In the spatial subsystem, graphical representations symbolize topologies of spatial arrangements. Extending the existing elements in QABGs, graphical representation elements in the spatial subsystem are as follows including terminals (T) and junctions (J).

- **Terminals (T), 1-port elements**, include C, CC, CO, CR, I and S. They are shown in Eq (1).
  - C: is a container which represents rooms and spaces in a building, including CC and CO.
  - CC: represents enclosed spaces, such as rooms.
  - CO: represents open spaces, such as a courtyard.
  - CR: is a controller which represents doors.
  - I: is an inductor which represents passages, such as corridors and steps.
  - S: is the source from where people move into a building. It represents the external environment.

\[
T = \{ C, CC, CO, CR, I, S\} \tag{1}
\]

- **Junctions (J), multi-port elements**, are space-junctions including 0-junction and 1-junction, Eq (2).
  - 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.

\[
J_{\text{spatial}} = \{0, 1\} \tag{2}
\]

Initial element-link relationships for a graphical representation of the spatial subsystem include a terminal (T) linked to a junction (J), T-J, or a junction (J) linked with a terminal (T), 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 CC-element, a 0-junction is linked with a CC-element, a 0-junction is linked with a CO-element, and a 1-junction is linked with a CR-element. These element-link relationships are illustrated in Figure 2.

Figure 2: Initial element-link relationships between a terminal and a junction (J-T) for a graphical representation of the spatial subsystem.

1.2. Stylistic subsystem

In the stylistic subsystem, graphical representations symbolize topologies of stylistic components and their relations. Two forms of the stylistic subsystem include a general form and a specific form. Elements for the stylistic subsystem defined in a general form can be applied to a wide range of different design projects for different architectural styles. With the
specifically defined stylistic elements, the graphical representation of the stylistic subsystem can be applied to a specific architectural style. Elements for the stylistic subsystem in a general form include terminals (T) and junctions (J).

- **Terminals (T), 1-port elements**, include solid and void elements. They are represented by T for solid elements and T' for void elements. Solid elements and void elements represent enclosed spaces and open spaces respectively. They are simplified to imitate human's initial space experiences, which involves mass volumes without any decoration or small supplementary components.

- **Junctions (J), multi-port elements**, are assembling-junctions including H-junction and V-junction, Eq (3). H-junctions, horizontal junctions, are applied to horizontal assemblies of stylistic components. In contrast, V-junctions, vertical junctions, are applied to vertical assemblies of stylistic components.

\[
J_{\text{stylistic}} = \{H, V\} \tag{3}
\]

Terminals in a general form for the stylistic subsystem can be extended and formed to be applicable to specific design projects for specific architectural projects. However, junctions for the stylistic subsystem in both general form and specific form are the same, H-junctions and V-junctions.

1.3. Interactions between the two subsystems

In an interactive graphical representation, a bond will link two junctions, one in the spatial subsystem and another in the stylistic subsystem, when there is an interaction relationship occurred between the two subsystems.

Figure 3 shows different representations of an architectural design example. Figure 3(a) visualizes the design as a 3D model, Figure 3(b) shows the spatial arrangements of the design in the form of a plan drawing, and Figure 3(c) extracts and illustrates the stylistic components, in this case the style of the roof, and their relations in the design.

![Figure 3](image)

**Figure 3:** An architectural design example represented as (a) a 3D model, (b) plan drawing representing the spatial arrangements, and (c) decomposed 3D stylistic components.

In the spatial subsystem of the interactive graphical representation, the plan drawing shown in Figure 3(b) can be converted into a graphical representation to highlight the spatial arrangements of the design with specific elements, i.e. CC, CR, I, S, 0 and 1, shown on the left-hand side of Figure 4. In the stylistic subsystem of the interactive graphical representation, a graphical representation with general elements, i.e. terminals (T) and junctions (J), can graphically outline the topology of the stylistic components and their relations, shown on the right-hand-side of Figure 4. There are four interactive relationships between the two subsystems, the spatial subsystem and the stylistic subsystem, Figure 4. These interactions are occurred in each room, Rooms A to D. When an element or an element-link-relationship in the spatial subsystem has been created or modified, the corresponding element(s) and element-link-relationship(s) in the stylistic subsystem will respond and update simultaneously, and vice versa.
2. INTERACTIVE GRAPHICAL REPRESENTATION APPLIED TO COLLABORATIVE VIRTUAL WORLDS

Interactive graphical representations have been applied to architectural design for building extension design project and architectural style transformation design project. The former demonstrates the usability of the interactive graphical representation in the spatial subsystem. A graphical representation is extendable and flexible. It can represent different spatial arrangements of a building project. It is similar in the interactive graphical representation in the stylistic subsystem. The latter demonstrates the interactions between the two subsystems for supporting style transformation in designing (Gu and Tsai 2008).

Applying the interactive graphical representation to collaborative design in a 3D virtual world in Second Life, designers remotely collaborate using interactive graphical representations through a real-time 3D modelling window powered by Second Life, augmented with a web window. Designers immerse in the 3D virtual world to collaboratively design and model. They develop and explore the spatial arrangement of the design in the web window. They design and apply stylistic components using Second Life. The interactions between the two interfaces are automated. The system architecture is illustrated in Figure 5. Figure 6 is an example of the interactive graphical representation applied to Second Life for collaborative design.

At the initial design stage, by using elements and element-link-relationships, designers can focus specifically on the conceptual development of the spatial and stylistic properties of the design. The interactions between the spatial arrangement and the stylistic development are automated. After the initial design concepts are developed, designers can apply specific data to elements and element-link-relationships of the spatial arrangement and stylistic components for detailed design. Therefore, similar to traditional 3D virtual worlds, designers can still use this system for design documentation and simulation in the later design stages.

3. INTERACTIVE GRAPHICAL REPRESENTATION FOR ARCHITECTURAL STYLE STUDY
In the following, interactive graphical representations are applied to collaborative virtual worlds for architectural style study, for interactions between the spatial arrangements and stylistic developments. Three pavilions, Cases I to III, designed by the Baroque architect J. B. Fischer von Erlach will be used as examples, Figure 7.

![Figure 7: Pavilion designs by J. B. Fischer von Erlach (Knight 1994)](image)

3.1. Architectural style of the pavilion designs

In 2D plan drawings for the spatial arrangements, in Case I, the bottom of Figure 7(a), the plan is composed of spaces with oval and square shapes. In Case II, the plan drawing at the bottom of Figure 7(b), square shapes are replaced by irregular hexagons. In Case III, the plan drawing at the bottom of Figure 7(c), compared with Case II, is conceived by replacing oval shapes with regular hexagon shapes, and also replacing irregular hexagon shapes with oval shapes.

The 3D models as shown at the top of Figure 7 can be viewed as the combinations of different 3D forms and shapes of spaces which compose the architectural style of the pavilions. The 3D model of the pavilion in Case I, at the top of Figure 7(a), consists of cubes, 3D rectangular components and 3D oval components, Figure 8(a). In Case II, the 3D model of the pavilion, at the top of Figure 7(b), consists of 3D oval components, 3D irregular hexagon components and 3D trapeziums, Figure 8(b). Two 3D trapezium components can form a 3D regular hexagon component. In Case III, the 3D model of the pavilion, at the top of Figure 7(c), consists of 3D oval components and 3D regular hexagon component, Figure 8(c). To sum up, the 3D components for composing three pavilions by J. B. Fischer von Erlach includes:

- Cube
- 3D rectangular components
- 3D oval components
- 3D irregular hexagon components
- 3D regular hexagon components
- 3D trapezium components

These components are specific components and can be composed as a 3D component library in Second life to build up J. B. Fischer von Erlach’s style pavilion. Further, with the 3D component library, designers can apply to the design projects for representing J. B. Fischer von Erlach Pavilion Style.

![Figure 8: 3D components of the three pavilions by J. B. Fischer von Erlach](image)
3.2. Interactive graphic representations applied to the pavilion designs

Interactive graphical representations applied to collaborative virtual worlds for the three pavilion cases designed by J. B. Fischer von Erlach are shown in Figures 9 to 11 respectively. In Figures 9 to 11, on the left-hand-side of each figure is the graphical representation for the spatial subsystem which also implies the circulation of people movement in this spatial subsystem. The graphical representation of the stylistic subsystem in a general form of each pavilion represented by terminals (T) and junctions (J) is shown in the middle in Figures 9 to 11 respectively. Bonds in between the spatial subsystem and the stylistic subsystem in each interactive graphical representation show the interactive relationships between the two subsystems of each pavilion. Then applying the specific 3D components to replace the general components in each graphical representation of the stylistic subsystem, the graphical representation of the stylistic system for each specific pavilion is formed, shown on the right-hand-side in Figures 9 to 11 respectively. Figure 12 shows 3D models of Cases I to III pavilions composed in the virtual world in Second Life.

CASE 1

Spatial Subsystem
(Spatial - Circulation system)

Stylistic Subsystem (Stylistic component system)
(Represented by Terminals and Junctions, T-J)

Stylistic Subsystem (Stylistic component system)
(Represented by 3D stylistic components)

Figure 9: Interactive graphical representation of Case I pavilion by J. B. Fischer von Erlach

CASE 2

Spatial Subsystem
(Spatial - Circulation system)

Stylistic Subsystem (Stylistic component subsystem)
(Represented by Terminals and Junctions, T-J)

Stylistic Subsystem (Stylistic component subsystem)
(Represented by 3D stylistic components)

Figure 10: Interactive graphical representation of Case II pavilion by J. B. Fischer von Erlach
The analyses of the interactive graphical representations for these three pavilions, Cases I and II have very similar structures of the graphical representations of both the spatial subsystem and the stylistic subsystems. The spatial arrangements in both Cases I and II are linear. The differences between them are in the spatial subsystem. Case I is composed of a rectangular space, Room F. However, Case II is composed of two trapezium spaces, Rooms E and G. Therefore, Case II has a more complex spatial arrangement. The difference can be viewed as the change of the spatial subsystem between Cases I and II. There are also changes of interaction relationships and changes in the stylistic subsystem between Cases I and II. In the stylistic subsystem, although the specific components of Case I, square shapes components, are replaced by irregular hexagons components and become different form as Case II. However, the structures of the general form of the stylistic subsystem remains the same between Cases I and II. There is no change in the spatial subsystems in both Cases I and II. Compared Case III with Cases I and II, the situations are more complicated. Both the spatial subsystem and the stylistic subsystem, including the general form and specific form, of Case III are changed compared with Case I and II. The interactive graphical representation clearly and truthfully represents these changes.

CONCLUSION

This paper presents the interactive graphical representation applied to collaborative virtual worlds for architectural style study. The application of interactive graphical representations for collaborative 3D virtual worlds provides designers with alternative representations and richer design languages for supporting collaborative design.

An interactive graphical representation combines graphical representations for the spatial subsystem and the stylistic subsystem of a building. Designers can flexibly apply this interactive graphical representation with only elements and element-link-relationships in the conceptual design stage as well as in a later stage by assigning specific data, such as exact shapes and dimensions of architectural components. Interactive graphical representations are flexible and
extendable. In addition, they are dynamic and autonomous. When an element or an element-link-relationship in one subsystem has been created or modified, the corresponding element(s) and element-link-relationship(s) in other subsystem will respond and update simultaneously, and vice versa.

Interactive graphical representations have been applied to architectural design for building extension design project and architectural style transformation design project. In this paper, interactive graphical representations are demonstrated by applying to specific architectural style study of pavilions designed by J. B. Fischer von Erlach. A library of the specific components for these pavilions is also developed after analysing. With the 3D component library, designers can apply to different design projects for different architectural styles, if these design projects or architectural styles share the same 3D components. The 3D component library can also be changed and extended for different design projects and for different architectural styles, based on the specific 3D components being applied in the projects.

Interactive graphical representations will further be applied to case studies for other architectural style and to collaborative architectural design in virtual worlds for hybrid architectural style design. These results obtained will enhance the prototype system implemented in Second Life.

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REFERENCES


