Research on a comprehensive and transferable ritual semantic model to auto building design in historical games

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Abstract

Feudal historical buildings with ritual elements constitute fundamental scenes in numerous excellent games. However, research on design methodologies for factual historical buildings in games remains inadequate regarding both precision and migration capability. To address this issue, this paper presents an in-depth investigation into the semantic or ontological modeling of ritual elements and their integration with game engines and PCG. Firstly, we comprehensively propose a ritual semantic model for the automatic generation of ancient buildings within game historical scenes. Secondly, we design the ritual semantic model to enable loose coupling with the game environment and building system based on ontology design patterns. Thirdly, through analysis of the ritual semantic system of Style Lei, we conduct experimental verification of the ritual semantic model and demonstrate its migration capability via comparative analysis. The models and experiments proposed in this paper, along with the analysis of ritual elements in the Chinese Style Lei architectural system, can provide valuable references for both automatic game scene design and related research.

Full Text

Preamble

Research on a Comprehensive and Transferable Ritual Semantic Model for Automatic Building Design in Historical Games

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Feudal historical buildings with ritual elements constitute the fundamental scenes of many acclaimed games. However, research on design methods for factual historical buildings in games still falls short of demands for both precision and migration capability. Addressing this gap, this paper presents a deep reflection on the semantic and ontology modeling of ritual elements and their integration with game engines and procedural content generation (PCG). First, we comprehensively propose a ritual semantic model that enables automatic generation of ancient buildings in game historical scenes. Second, we design the ritual semantic model to provide loose coupling capability with the game environment and building system based on ontology design patterns. Third, through analysis of the ritual semantic system of Style Lei, we conduct experimental verification of the ritual semantic model and demonstrate its migration capability through comparative analysis. The models and experiments proposed in this paper, along with the analysis of ritual elements in the Chinese Style Lei building system, can provide useful references for both automatic game scene design and related research.

CCS CONCEPTS • Knowledge representation and reasoning • Ontology engineering

Additional Keywords and Phrases: Ritual Semantic Model, Auto Building Design, Historical Games, Comprehensive and Transferable

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1 Introduction

Feudal historical buildings with ritual elements are fundamental scenes in many excellent games, and establishing an automatic design method for ritual architecture construction is of great significance. AAA games increasingly take place in highly detailed virtual worlds, often featuring complex historical building scenes. Notable recent examples include the Assassin' s Creed, Elder Scrolls, and Romance of the Three Kingdoms series [Figure 1: see original paper], where players explore extensive ancient cities filled with detailed and visually appealing facades. From Indiana Jones and Lara Croft: Tomb Raider to medieval Florence, Paris, and London, from hot ancient Egyptian cities to cold Viking villages, or to humid Angkor Wat, game companies have produced tens of thousands of historical buildings with high fidelity that have been well praised by players. Academics in virtual heritage have also accepted games with factual reconstructions of history as viable ways of allowing more people to explore and relive historic events and heritages (Champion, 2009).

However, research on design methods for factual historical buildings in games still fails to meet demands for both precision and convenience.

1.1.1 The Ontology Researches of Historical Buildings Lack Ritual System Content

The organization, sharing, and digital processing of feudal historical building information in game scenes can be classified as the development of formal knowledge representation models (ontologies) for the cultural heritage (CH) domain. Based on RDF (Resource Description Framework) and OWL (Web Ontology Language), the standard data model and ontology language of the Semantic Web, relevant ancient building ontologies such as CIDOC-CRM (Doerr, 2009), the Europeana Data Model, and VRA (Visual Resource Association) offer enhanced representation capabilities while supporting inference, querying, and interlinking of the voluminous, diverse, and heterogeneous Cultural Heritage information primarily available in museums, art galleries, and other CH institutions. The purposes of organizing CH ontology data and enabling the development of enhanced data services are to improve the exhibition and conservation effects for physical collections and their digital counterparts. Semantic Web ontologies are the most widely used for CH, mainly because of their enhanced expressiveness, allowing complex semantic relationships among CH entities to be obtained and represented through the Web (Liu and Bikakis et al., 2017). Europeana (Valtysson, 2020), an EU-funded initiative, aims to collect semantic metadata about various national cultural heritage sets and publish their integrated version in a machine-understandable way compliant with Linked Data principles (Cacciotti and Valach et al., 2013). MIDAS (England), a British cultural heritage standard for monument inventories, and The Core Data Standard for Archaeological Sites and Monuments (Carlisle and Avramides et al., 2014) translate their documentation standards to CIDOC-CRM compatible ontology, providing a framework for documenting monuments. Etim (2019) discusses ritual ontology in Africa and proposes religious-related ritual hierarchy and ritual definitions. A more historical scene semantic generation-relevant research (Liu and Wu, 2016) presented a rapid rule-based modeling approach to building ancient Chinese architecture based on a module semantic rule system abstracted from an official manual of ancient building "the Yingzao Fashi." Sacco and Liapis et al. (2017) presented a Game Character Ontology (GCO), a lightweight vocabulary for describing character information in video games without any definition about game scenes. In general, few ontologies directly study ritual architecture or establish ritual ontology alone, especially in the game field.

Although previous ontologies offer a solid methodological and technical background from which CH information can be organized, their representation is nevertheless not rich enough for designing the multi-faceted ritual domain of feudal historic buildings, especially concerning the relevance of game scene autogeneration from the perspective of heritage realistic reproduction (Cacciotti and Valach et al., 2013).

1.1.2 High-Precision Modeling Methods for Historic Buildings Based on 3D Scanning and Manual Modeling Are Costly

Post-processing high-precision 3D scanner data in game environments by professional tech-artists is a reliable way to reproduce feudal historical buildings from reality with high precision. However, this approach for game scenes of high-precision historical buildings requires substantial financial investment and personnel time costs, and the related data and personnel skills are hardly reusable. Taking Ubisoft as an example, in the production of Assassin' s Creed, a large number of high-precision models are created through high-precision laser scanning and manual refinement, such as the Cathedral of Santa Maria del Fiore in Florence and Notre Dame de Paris. However, according to USA TODAY (Snider, 2019), scene designers spent two years restoring the original appearance of Notre Dame de Paris, with accuracy down to every stone. To improve efficiency, approaches for point-cloud segmentation and primitive shape detection should be employed. The most commonly used methods are Least Squares (Wolf and Ghilani, 1995), Least Median of Square (Massart and Kaufman et al., 1986), and RANdom SAmple Consensus (RANSAC) (Jin and Lee, 2019). Many researchers have exploited these methods in architecture reconstruction and 3D modeling. Liu and Wu (2016) provided an adaptive approach for primitive shape extraction from point clouds. Früh and Zakhor (2004) presented a system to map cities in 3D using two 2D laser scanners mounted on a truck. Gao and Shen et al. (2018) summarized rules to extract solid geometry components from point clouds of elements in traditional Chinese buildings. Huang and Brenner et al. (2011) presented a generative statistical approach to automatic 3D building roof reconstruction from airborne laser scanning point clouds. However, these high-precision manual or computer-assisted modeling methods obviously cannot be extended to all historical game scenes, let alone ritual-enhanced building reconstruction.

1.1.3 BIM-Based Historic Building Modeling Method Not Integrated with Games

Building Information Modelling (BIM) and semantic web technologies are two technologies often used for the documentation of the built environment and cultural heritage resources. Pauwels and Bod et al. (2013) combined the application of BIM software and semantic web technologies to a case study: the Book Tower in Ghent, Belgium, which showed that recorded semantic information can be essential to managing a recovery plan with cultural diversity and environmental sustainability. Bonsma and Bonsma et al. (2018) proposed a Heritage-BIM ontology to represent all the complexity of the related context in terms of ancient architectural techniques and components, important events related to the history of the building/site, and all the data that define the actual value of the monument in terms of historical heritage. According to Historic England (Thouki, 2019) and Arayici and Egbu et al. (2012), custom semantic content creation is a requirement for BIM projects, since usual construction object libraries are related to new-build rather than historic building components. However, the inclusion of BIM objects from very different sources (creators, skills, purpose, and context) is problematic for information consistency. Thus, to facilitate the international exchange of heritage information, ISO 128 (graphical representation of objects on technical drawings) (Nopnakorn, 2003), ISO 16739:2013 (IFC, Industry Foundation Classes for data sharing) (Markič and Donaubauer et al., 2018), ISO 1302:2002 (surface texturing in technical product documentation) (Qi and Jiang et al., 2013), ISO 21127:2014 (Beretta and Alamercery et al., 2019), and CityXml (Li and Tang et al., 2017) (reference ontology for the interchange of cultural heritage information) need to be considered. In the domain of design and construction of buildings, the interoperability issue is closely tied to the notion of interpretation (Li and Tang et al., 2017). Because of different purposes, the semantic interpretation stored by the BIM system(s) used to document the artifact and the interpretation by the end designer of the cultural heritage artifact in game scenes often make the ontology self-contradictory.

1.1.4 The Researches on Procedural Content Generation (PCG) of Buildings in Games Lack Transferable Ritual Elements

PCG refers to the creation of game content automatically (or semi-automaticly) through algorithmic means. Attempts at generating game content procedurally have a fairly long history, with PCG aspects appearing in games such as Rogue (Toy and Wichman et al., 1980), Diablo (Entertainment, 1996), and Elite (Braben and Bell, 1984). The first comprehensive declarative semantic model of a game world useful for PCG was proposed by Smelik (Smelik and Tutenel et al., 2011), who defined four levels of abstraction of modeled game objects: geometric objects level (including 3D geometric meshes, textures, etc.), semantic objects level (represented by a set of generated objects and their features), structure level (including feature extent and structural objects), and specification level (outline shape and semantic attributes). Bontchev (2017) presented a semantic consistency moderator to ensure the maintenance of consistency in the semantic model of the content. In the field of automated generation of building facades, L-systems were among the first techniques proposed (Coelho and Bessa et al., 2007). These rewriting systems create buildings by manipulating an initial arbitrary ground plan (a lot shape) with transformation and extrusion modules. To obtain more interesting building shapes, several approaches have been devised. Wonka and Wimmer et al. (2003) introduced the concept of split grammar, a formal context-free grammar designed to produce building models. The split grammar resembles an L-system where shapes are primitive elements rather than symbols. In recent years, a more specialized approach, the CGA shape grammar, has been applied to building facades (Silva and Müller et al., 2013). Shape grammars have been used and described before, especially in the architectural domain (Li, 2001; Tepavčević and Stojaković, 2012). Architects have described shape grammars as languages of design, supported by a vocabulary of shape rules. Shape rules are specified as spatial relations with context-sensitive rules that allow the possibility of modeling roofs and rotated shapes. They start with a union of several volumetric shapes (the building boundary) which is divided into floors. The resulting facades are further subdivided, through shape rules, into walls, windows, and doors. Epic Games also included shape grammars in their commercial game engine, Unreal Engine 3 (Dormans, 2010), a procedural artist-driven tool for constructing buildings used in the development of city-based games (Tutenel and Smelik et al., 2011). The procedural system uses rulesets, similar to shape grammar rules, to split facades into scopes and automatically place meshes on them (Dokter, 2014). However, the focus of all these building-relevant PCG techniques is not on the automatic generation of ancient buildings, especially in the absence of ritual elements, which cannot be described in shape grammar-like semantics.

1.2 Goals and Research Questions

Although much work appears related to the automatic generation of ritual buildings in games, there is still no direct research on transferable methods that can alleviate the enormous burden of ritual building creation and make it easier to tailor content to game designers, especially considering the international nature of ritual elements. Addressing this problem, this paper deeply reflects on the semantic and ontology modeling of ritual elements and their integration model with the game engine and PCG.

Based on existing research on the semantics of PCG buildings or BIM rules, we establish a transferable generative ritual semantic model for game historical buildings. This approach is suitable for modeling each type of ritual building in game scenes by assembling ritual elements [Figure 2: see original paper]. The fundamental difference between our approach and previous work is that we design an uncoupling ritual semantic system and apply it in the automatic generation of ancient ritual buildings in a game environment according to the

Chinese "Style LEI" ritual system as an example. Moreover, the Chinese "Style LEI" ritual semantics also apply to a Japanese ancient building as proof of its migration capabilities. The most important step of the approach is to abstract the ritual semantic elements and design an uncoupling layer to ensure compatibility with various buildings. To achieve this, we must analyze the ritual systems, especially the "Style LEI" system, and formalize them into semantic definitions.

[Figure 2: see original paper] The framework of this research

The article is organized as follows. Section 2 describes the ritual systems and characteristics of the ancient Chinese "Style LEI" ritual system. The compatible design according to ontology design patterns for ritual construction of ancient buildings is presented in detail in Section 3. Section 4 presents experimental results to demonstrate the efficiency and migration capability of the approach. We discuss our results and suggestions for future work in Section 5.

2.1 Universal Ritual System

T.O. Ranger (Ranger and Kimambo, 1972) sees ritual as constituted of four structures: 1) Symbolic structure—that ritual is an aggregate of symbols, a totality that aids adequate understanding of human society. 2) Value structure—that ritual is expressive of authoritative messages about crucial values and relationships between values. 3) Telic—that sees ritual as performed for the sake of an end, designed to have an effect on people and bearing concern for posterity and future generations. 4) Role structure—implies ritual as the product of interaction of different human actions representing different social categories/classes and not a product of individual ingenuity and initiative. Thus, it transcends individual/subjective interests of participants but tends to embrace the common good (Etim, 2019).

The fundamental purpose of a ritual system is to make legal explanations and arrangements for the rationality and authority of feudal hierarchy, and its essence comes from the symbolic distribution of rights. Most countries in the world have experienced a long feudal era (Topolski, 1981). From 475 BC to 221 BC, China entered a feudal society that lasted for nearly 2,000 years. The imperial administration made detailed regulations on architectural styles for different feudal grades, known as ritual buildings. After the collapse of the Western Roman Empire in 476 AD to the French Revolution in 1789, feudal lords and the Holy See in various countries also marked feudal levels through building materials, arch spans, building heights, etc. The Middle East, in places such as Saudi Arabia since the Arab Empire in the 7th century AD (Etemad, 2017), has preserved feudal chieftain systems, with feudal hierarchy also expressed through dome height and indoor garden size. Similarly, countries such as India and Japan have their own ritual rules for architecture. In general, ritual systems in most feudal countries define important elements of buildings in common, whatever they may be.

[Figure 3: see original paper] Feudal hierarchies in China, Medieval Europe, and

Japan

Although there are many differences in the sources of feudal ritual systems between countries and cultures, such as "God and my right" (Britain, France) versus "Heaven and my right" (China, Japan), and the systems of feudal ritual levels also differ—for example, each country has different royal titles, official bureaucratic positions, and other ritual hierarchy (Harem, Vassals) systems—the characteristics of ritual permeating all elements of feudal social architecture were the same.

2.2 Characteristics of Ancient Chinese "Style LEI" Ritual Buildings

During the thousands of years of evolution of ancient Chinese architecture, the architecture of the Qing dynasty developed a comprehensive and rigorous methodology and hierarchy. Among all skilled craftsmen and architects, the LEI family was responsible for the design, construction, and maintenance of imperial architecture and gardens in the Qing dynasty (Jiaojiao, 2004), and the buildings they designed are therefore called "Style LEI" buildings [FIGURE:4, FIGURE:5]. The architectural manual "Qing Dynasty Architecture Method" (Example of Qing Gongcheng Zuofa Zeli' s Engineering Practice) written by the government's engineering department stipulated the building hierarchy in which buildings of different grades have different scales, structures, units, shapes, and materials. The manual served as guidance for the design and construction of royal buildings and gardens by the LEI family. Researchers analyze the LEI family and their architecture from a historical perspective based on documents, codices (Shengmei, 2008), models, and diaries (Dingkun, 1989).

[Figure 4: see original paper] "Style LEI" ritual buildings in urban area of Beijing
[Figure 5: see original paper] "Style LEI" ritual buildings and ritual system

Current research on "Style LEI" buildings mainly focuses on historical analysis, literature review, architectural design method research, and its ritual system (Dingkun, 1989; Jiaojiao, 2004; Shengmei, 2008). There are many ritual elements in Style LEI, but they can be classified into three types: 1) Ritual space structure. The ritual elements of spatial structure control the spatial layout and basic structure of the building. For example, the area of the building foundation, the spacing, and the number of pillars are all specified according to the feudal level. 2) Ritual components. Ritual components may or may not have architectural functions, but they must have distinct 3D structural characteristics. For example, the number of roof beasts is also specified according to the feudal level. 3) Ritual decorations. Ritual decorations are ritual elements that decorate other architectural functional components [Figure 6: see original paper] without any architectural functions themselves, and their three-dimensional structure is not very obvious either. For example, architectural color paintings have patterns also specified according to the feudal level.

[Figure 6: see original paper] The architectural functional components of Style

LEI building

2.3.1 Ritual Building Generation Process in Game Scenes

For simplicity, the question of semantic or ontology modeling of ritual elements and the integration model with the game engine and PCG will be expressed in four layers of a runtime environment [Figure 6: see original paper]. To begin with the semantic compatible design of ritual buildings, considering a building process (area colored in blue in [Figure 7: see original paper]) as described by the Building Topology Ontology (BOT) (Rasmussen and Lefrançois et al., 2021) and IFC ontology in BIM (Iadanza and Maietti et al., 2019), which is admittedly shared by a wide range of the community, it may be adequate to say that a ritual building is a particular kind of bot:Building, an upper class of the OWL Description Logics (DL). The following questions can be considered: 1) What are ritual buildings? A small set of historical buildings. That notion of ritual building is captured by the class dot:RitualBuilding, which is defined as: "Any inheritance of a dot:building (but not a part of it), which cannot exist without the ritual system and the specific ritual grade, and are temporally and spatially located in a specific feudal dynasty." In the context of the former "Style LEI" survey, features of ritual buildings are also elements in the domain of buildings. 2) What is the PCG driver? A content generator, which is a particular producer of dot:Building. 3) How is the Ritual Building made? Following a procedure in PCG, which can be considered an individual of IFC:Process that can instantiate IFC:RitualBuildingConstraints, a particular sequence of class bot:RitualElement according to the ritual system. 4) Where is the IFC:RitualBuildingConstraint made? In a ritual system, represented by several elements in a domain that can be used as inheritance types of the class IFC:RitualConstraint, defined as an exclusive value for a specific ritual grade. For example, Roof beasts Constraint, pillars Constraint, and Paintings Constraint are all subclasses of IFC:RitualConstraints from "Style LEI." 5) When is the bot:RitualElement made? In the PCG driver' s execution, instantiated by an individual of bot:Element and IFC:RitualBuildingConstraint. 6) Which is the result of the building generation? An encoding of a value represented by an individual of dot:RitualBuilding. This encoding can be achieved by asserting all the IFC:RitualBuildingConstraints to the PCG driver using the instantiated bot:Element (such as bot:Pillar, a simple definition of structured geometry data including diameter and height as required variables, which may be directly assigned by a specified IFC:RitualBuildingConstraint).

[Figure 7: see original paper] Scope of the Ritual Semantic Model (in blue color)

2.3.2 Decoupling Design Based on Ontology Design Pattern

To describe, manage, and auto-generate ritual buildings appropriately with migration capability, it is necessary to understand stable and abstract parts of the ritual system so that information on ritual buildings can eventually be organized "correctly" everywhere. In this initial decoupling design, ontology design patterns go through all relevant information sources to construct a general understanding or abstract model of the ritual building. For instance, through a critical and comparative literature review, we can investigate whatever elements and constraints (geometrical, structural, colorful, material, spatial, and so forth (Arayici and Egbu et al., 2012)) may be used for a ritual system.

Particular aspects of the building elements and constraints of "Style LEI" at hand raise the first question of decoupling design: how can this information be organized and made compatible with other ritual systems or building systems? In the case of the ritual survey in "Style LEI" documents, our decoupling design consisted of the thoughts enumerated below. 1) Does a ritual constraint necessarily apply to a building? No, only if the building has a building element that matches this constraint. 2) What kinds of building elements do ritual constraints affect? All of them. According to the development of archaeology and literature research, in theory, all building elements can be constrained by rituals because rituals are artificially defined and do not bind to any building entities. 3) Is there an upper limit to the ritual constraints applied to a building? No, for the same reason as the previous point. 4) Should the generation process of ritual buildings be defined by ritual semantics itself? No need. In historical games, PCG already contains spatial and temporal rules; if in the BIM field, IFC also defines the construction semantics of the building. 5) Whether ritual semantics need to consider the difference of game engines—for example, some engines express building modules as boundary-surface models while others use volume models? No need. In the game field, PCG' s design has already taken these game engine differences into consideration; we only need to coordinate ritual semantics with PCG' s definition. 6) Will ritual semantics be static in a game scene? No. With the continuous expansion of the game scene and changes in gameplay, it is possible to have multiple feudal dynasties or even multiple countries in one game, necessitating flexible specification of the ritual building system corresponding to the game design. 7) Does a feudal dynasty have only one ritual system? No. From Style LEI' s research, it can be found that China' s Qing Dynasty ritual architecture system underwent many changes.

From the above considerations, it can be concluded that although the purpose of this research is to automate the generation of ritual buildings in game scenes, the ritual semantics part cannot be bound to the game engine and building entities, neither to the PCG driver, nor can it necessarily exist statically in one game. Thus, according to the six families of Ontology Design Patterns (OPs) (Gangemi and Presutti, 2009), we choose ontology design patterns (as numbered dash boxes in [Figure 8: see original paper]) three times to uncouple the ritual semantics from the specific game environment: 1) Correspondence OPs to match ritual and building elements. 2) Correspondence OPs to represent ritual building rules through PCG Rules. 3) Reasoning OPs to filter or derive the currently required ritual system.

Under such a ritual semantic design as shown in [Figure 8: see original paper], the ritual elements of historical buildings in game scenes not only have the execution efficiency and quality of PCG but also become dynamic and reusable.

[Figure 8: see original paper] Ritual semantic model based on ontology design pattern

According to the design of the ritual semantic model, the process applied in the game is as follows: 1) According to the design of the ancient scene of the game, find the corresponding feudal dynasty. 2) Select the ritual grade and find the corresponding ritual system in the feudal dynasty. 3) Obtain the building constraints defined by the ritual system. 4) Configure the basic building elements and their properties in PCG. 5) Match the building elements of ritual constraints with the building elements defined in PCG. 6) Instantiate the ritual building elements through PCG. 7) Position and assemble the combination of ritual building elements through PCG.

3 Experiments

Based on the semantic design of the ritual system above, we selected ritual system elements from Style LEI, taking the main hall and the square pavilion as examples, and conducted experimental tests. The experimental environment is Unreal 4.26, the PCG driver is implemented using the blueprint system inside Unreal, and the instantiation of building elements is realized through the asset management module inside Unreal.

[Figure 9: see original paper] The procedure of the Experiment

The first experimental building object is the main hall, the largest part of the ancient Chinese-style residential suite. The ritual elements of the main hall include four items: the area of the foundation; the number and spacing of the pillars; the number of roof beasts; and the architectural paintings. First, according to the preset two ritual grades of Qingwang (ritual grade 3) and Baylor (ritual grade 5), the corresponding ritual elements are automatically generated. Second, they are matched with geometry and textures through the building element definition in the PCG driver. Third, the overall model of the building is automatically generated through the building combination rules of the PCG driver, which is similar to previous rule-based ancient building production.

[Figure 10: see original paper] The main halls of Qingwang (ritual grade 3 on the left) and Baylor (ritual grade 5 on the right)
[Figure 11: see original paper] The ritual elements on main halls of Qingwang (grade 3 on the left) and Baylor (grade 5 on the right)

To test the reusability and migration capability of the ritual semantic model, we added two ritual model migration experiments. The first one changes the building type from the main hall to the square pavilion, a common leisure building in Chinese classical gardens. It can be seen that the ritual model constraints and ritual elements are still correctly matched to their corresponding building elements.

[Figure 12: see original paper] The square pavilion with ritual elements of grade 5 (Baylor)

The second ritual model migration experiment tests the migration capability of the ritual semantic model more widely. We adopt the Japanese ancient-style main hall (Paine and Soper, 1981) as the base building. Through the automatic matching of the ontology design pattern described in Section 3, the PCG driver enhanced by the ritual system identifies building elements of the same type that can match with the ritual constraints and applies three ritual elements: the foundation area, the roof beast, and the colored painting from the Chinese Style Lei ritual system. The attributes of the foundation and pillars mismatch with the Chinese Lei ritual system, and the other ritual elements are not expressed in the generation.

[Figure 13: see original paper] The migration of "Style LEI" ritual elements to a Japanese main hall

Based on the above experiments, the integrity of the basic design of the ritual model and the migration capability of the ritual system have been verified in this study.

4 Discussion

The research in this paper basically achieves the preset goals. Compared with previous research, the three contributions of this paper lie in:

First, we comprehensively provide a ritual semantic model that can be used for automatic generation of ancient buildings in game historical scenes. This model has not been clearly defined in previous BIM research, cultural heritage ontology research, game ontology research, or ritual ontology research. It meets the application requirements of semantic models of the game world (Kessing and Tutenel et al., 2012): 1) Semantics should further support procedural generation, allowing designers to combine and integrate multiple existing technologies to generate a coherent whole. 2) Designers should be able to define physically sound game worlds, making it possible to mathematically represent dependencies between object features.

Second, we designed the ritual semantic model to provide loose coupling capability with the game environment and building system based on ontology design patterns, making it easy to expand and migrate. We analyzed the PCG semantic system and building semantic system in detail, defined a suitable ritual semantic model, and further abstracted cross-cultural and cross-regional ritual semantic features. Through the ontology design pattern, we realized decoupling among the ritual semantic model, building semantics, PCG driver, and specific games.

Third, through the analysis of the ritual semantic system of Style Lei, we conducted experimental verification of the ritual semantic model and proved its migration capability through comparison. Ritual elements have abstract consistency and concrete complexity. We analyzed in detail the ritual semantic system of Chinese Style Lei buildings and established four types of ritual constraints and building element operation interfaces, which can be migrated to building elements in other countries or cultures. For example, a Japanese main hall was ritualized in the experiment by Chinese Style Lei ritual elements.

Considerations for future work include the following:

First, a lightweight semantic model for in-game rituals can be further studied. We suppose that heavy, complex OWL models of ritual ontology must not be used to accomplish game design tasks. In the experiment, we found that the ritual semantic model (stored in XML format) defined based on Industry Foundation Classes (IFC) (Pauwels and De Meyer et al., 2011) or BOT (Rasmussen and Lefrançois et al., 2021) is not convenient to load. On one hand, there is a lot of redundant markup data, which takes up substantial storage space. On the other hand, such semi-structured text is quite inefficient for real-time lookup and matching in Unreal' s blueprint system while being more suitable for web semantic models (Sinclair and Lewis et al., 2006). In fact, it is entirely possible to alternate to a lightweight semi-structured data format such as JSON, but this format is very poorly suited for human reading or web crawler traversal. This aspect can be further researched.

Second, the ritual semantic model can be further extended to other countries and eras. Style Lei is a typical official architectural system in China with an obvious ritual system and clear feudal hierarchy. In the literature survey, we found that expressions of ritual systems in architecture vary greatly among countries worldwide (Paine and Soper, 1981; Etemad, 2017). The coordination and comparison of specific ritual building systems in other countries were not conducted in this study. We also noticed that many countries have mixed rituals. For example, some regions in Central Asia (Katz, 2005; Chan, 2020) historically had a mix of both Islamic ritual systems and Chinese ritual systems. How to express the diversity of ritual elements still needs further exploration.

Third, research on ritual building communities is needed. The ritual semantic model and its application in this paper are based on single buildings, but in fact, for example, ritual building communities or ancient cities in China and Japan also have a ritual topographical layout as a whole covering flat areas of tens of square kilometers. How to automate the generation of ritual building communities on a larger scale is an unfinished part of this study.

Fourth, artificial intelligence methods for ritual semantic model auto-extraction should be investigated. The disadvantage of this study is that the analysis of the ritual semantic model requires extensive literature review work by professionals, and it remains a high-cost and time-consuming task to refine a shareable ritual semantic model at present. In the future, combined with the latest NLP artificial intelligence model progress, we should conduct research on the automatic extraction of ritual semantics from large numbers of historical documents to provide ritual semantic models conveniently, accurately, and comprehensively.

5 Conclusion

The automatic generation of ritual buildings is very important to the design of historical games, and this paper presents research on the whole chain from bottom to end addressing this problem. Based on in-depth analysis of the ritual system, a ritual semantic model with high mobility and compatibility is realized with the help of ontology design patterns, which is also a field application case of interoperability in frontier ontology research. The models and experiments proposed in this paper, and even the analysis of ritual elements in the Chinese Style Lei building system, can provide useful references for related research.

Finally, the connotation of the ritual system actually extends far beyond the building field. Its application in games involves educators, art directors, game designers, screenwriters, software developers, graphics, and sound designers. The research presented in this paper is only a small step in this general direction. We also believe that the automated design of historical games under ritual systems will inspire a great deal of interdisciplinary research.

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Note: Figure translations are in progress. See original paper for figures.