SEMIOTIC APPROACH TO BUILDING INFORMATION MODELLING BASED SERVICE MODEL

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Building Information Modelling (BIM) seeks to integrate information and business processes throughout the entire building life cycle. This technology is able to generate 3D models that semantically represent facility information dynamically over the life cycle of a building, but is limited when it comes to meeting the needs arising from the operation and management of facility services. There is little research which shows that the BIM model links to Facility Management (FM) systems. This paper presents a BIM based service model, which adds both a pragmatic and social aspect beyond semantic level to assist facility management services from a semiotic perspective. The pragmatics of BIM provide context for services of building operation. The social aspect is related to norms that govern service delivery. Service contextual information is to extend building classes represented by the UML class diagram. Norms are specified by a norm analysis method of a semiotic approach. The extended BIM will be able to provide service context information required by facility management systems to operate a building.

Keywords: BIM, facility services, semiotics, service orientation, norms.

INTRODUCTION

Buildings have been regarded as special and complex products that provide functional space enabling people to live, work and achieve. Built spaces not only provide users with infrastructure, but also a context within which services are required, e.g. HVAC (heating, ventilation and air conditioning) or specialist services. Administration of these services is within roles of facility management (FM). The maintenance and operation of buildings is often the longest and most expensive stage in the project lifecycle, and it accounts for approximately three times the construction cost. Furthermore, FM involves the management of all the facility services that support the core business of an organisation. An overview from the top level of enterprise services shows that facility services belong to the category of support services (Asgari *et al.*, 2009). Organisational studies show that organisational effectiveness can be improved by creating a total quality environment that underpins core business activities. Therefore, effective and efficient FM is vital to the building lifecycle management. Operating buildings by approaches of intelligent buildings (IB) (Clements-Croome, 2004) and intelligent pervasive space (Liu, 2010) makes a contribution to FM for optimising user comfort and energy consumption. New technologies and concepts developed in IB allow various service systems managed and controlled in an integrated manner based on sensor networks. Accordingly, the approach of IB has affected the way FM personnel operate and manage a building (Wong, 2005).

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Presently, FM is facing challenges in information management. FM is developed into an integrated service delivery process by adopting computer-aided and service-oriented paradigm across various FM services' systems. In such building environments, daily operations generate vast and heterogeneous information, and this management process is an intensive consuming resource. Services are operated and delivered according to personal preference and organisational policies in the form of rules, or norms relating to the allowed and desired behaviour of service systems (Noy *et al*., 2007). Those features not only require integration of building information, technical engineering knowledge and understanding of the service process, but also align the semantic and knowledge-based building information model with service processes.

The use of Building Information Modelling (BIM) offers an effective approach to representing building semantics for design and construction by defining building objects and their relationships. Furthermore, the BIM system is a shared data repository and knowledge resource for facility information forming a reliable basis for decisions making during the lifecycle of a building (NBIMS, 2007). BIM can partially overcome identified semantic and syntactic issues in FM (Vanlande *et al*., 2008). However, BIM does not support the consideration of building activities and the context of use, i.e. lacking pragmatic and social aspects from a semiotic perspective, which limits BIM as a through-life solution. Semiotics is a theory of signs, which provide an effective way to analyse complex sign systems. A building is a complex sign system, which allows stakeholders to utilise, interpret and interact with. FM services require different information to meet the needs arising from operations of services. This paper takes views from a semiotic perspective, specifically, from a semantic, pragmatic and social aspect, the upper three layers in an organisational semiotic framework to analyse information requirements for FM services. In this context, FM services take into account building space, buildings system and user requirements to achieve its objectives.

To improve and enhance the effectiveness of BIM for FM, this paper presents a semiotic approach to extend BIM. Accordingly, a thematic service model is developed. Such a specific domain model is not only able to provide essential service context information, but also links service norms to related virtual building objects in order to support the service delivery process in a collaborative and efficient way. The remainder of this paper is organised as follows. The next section introduces organisational semiotics (OS) used in the BIM extension, followed by a review of the state of the art in BIM for FM. The paper will then present domain requirements and norm analysis to capture norms in the service process, alongside with a case study of the BIM based service delivery to validate the approach. In the last section, a conclusion is drawn.

A SEMIOTIC PERSPECTIVE OF BUILT SPACE

A building is a complex sign system, which has its meanings. Different disciplines involved in the process of developing a building interpret this sign system from their viewpoints, which are reflected in the information models that they use. In operation and maintenance stage, built spaces such as offices provide affordances to support users' activities through FM services. Such enabling spaces can be treated with the notion of *"habitat"* (Anderson and Brynskov, 2007), which is delineated by the three physical dimensions plus the temporal aspect, with great emphasis on the utility and added value of the services to the user. FM service deliveries are organised information-rich activities involving interactions between building systems, facility systems and users activities within organisations. The requirements for developing a through-life information model are not only technical, but also rather social and organisational. Therefore, acquiring knowledge and capturing information requirements, management and utilisation of such a socio-technical environment is essential to develop BIM for FM.

Semiotics (Peirce, 1931-1958), as a well-established discipline of signs and information, offers a comprehensive theory to understand the nature and characteristics of sign and information system (Stamper, 1996). A sign is something which stands out to somebody in some respect or capacity (Liu, 2000). A broader notion stated by Eco is that *"semiotics is concerned with everything that can be taken as a sign which is anything that stands for something else"* (i.e. words, images or objects) (Eco, 1976). Organisational semiotics (OS) is a branch of semiotics applied to understand organisations based on the use of artifacts and communication. OS regards organisation as an information system that is able to process and manage information, and study organisations using semiotic methods.

Organisational semiotic framework is an approach that systematically concerns with the use of signs. A built space or habitat can be interpreted at six semiotic levels, which are employed to derive information requirements for developing BIM for FM. Peirce conceived of three original divisions of semiotics, known as syntactics, semantics and pragmatics to study the properties of signs. In addition to the traditional three layers, Stamper (1973) added another three - physics, empirics and social effect. All these branches of semiotics are organised into an OS framework, which has been widely used in the design of information systems and organisational analysis (Stamper, 2000). More than that, this approach has been used in designing buildings (Glover *et al*., 2004; Noy *et al*., 2007). In the context of building domain modelling, the OS framework is used to capture different aspects of a building and how it reflects to develop IFC (Industry Foundation classes) based virtual models (Tian and Liu, 2014) and in analysing BIM system (Hartmann, 2012).

The bottom three levels relate to the physical infrastructure of a habitat. Physical level represents a section of physical spaces and time in a built space, i.e. geography, geometry and properties such as materials. Facility service management often takes into account the spatial and temporal aspect (e.g. a seminar room is scheduled with different events that require different services). The empirical level represents building architectural and mechanical designation that need to not only meet design specifications, but also comply with regulations and codes (e.g. the capacity of disabled toilet needs to meet certain standards in dimensions and facilities to assist the disabled for use conveniences). The syntactic level represents the requirements of topology of space and building systems, i.e. the layout of space and logical relationships between building system elements.

The top three levels are associated with the service feature of a habitat. The semantic level concerns meanings of built spaces, which provides the context that services are constructed. A space needs to be socially and physically defined for its functions and purposes, which are supportive for business activities. Such service context concerns building use constrained by limitations in a physical space. Pragmatics concerns the purposes of built spaces that realised by various services. What services that a built space can afford can be decided as long as the semantics of a space is built up. Facility services are functional based on the building systems and facility systems constructed in built environment. The social aspect is related to social values created for building users through using services. To achieve service objectives realises on implementing norms to deliver services. In an organisation, norms (Stamper, 2000) govern people’s behaviour. In respect to FM services, norms are the business rules that set during the service process to meet users’ requirements. Norms can be rules or regulations that relate to service delivery.

BUILDING INFORMATION MODELLING FOR FACILITY MANAGEMENT

BIM is known as data rich, object-oriented, model-driven intelligent and parametric digital representation of facilities. There are various notions defined by different research groups. From FM’s point of view, we adopt a notion of BIM as a central knowledge repository, which is able to manage the whole building and project information for the entire life cycle of the facility. Realising the significance of the post construction stage of buildings from perspectives of sustainability and cost efficiency, has gained increasing interests in the research of leveraging BIM for building operation and maintenance.

There are a few researches taking place in exploring BIM’s role on supporting FM functions such as relocation, space management and building performance analysis, and so far it is still emerging (Eastman, 2011;Serginson, 2012). It is recognised that with providing life-cycle data inclusive of operational information, BIM has potential to support the FM service process (Azhar, 2011; Becerik-Gerber, 2011; Arayici, 2012). Building information for FM identified includes geometric, semantic and topological information (Schlueter, 2009), However, transferred data is limited to graphical and spatial information (e.g. room areas and attributes) and asset information, but not service context such as spatial and topological relationships (Akcamete, 2010). In addition, considering effective building operating and decision-making, it also requires a high-level integration of various types of information generated during the FM process.

The IFC (industry foundation classes) building data model is a neutral data format, aiming to describe and exchange information regarding building components in an objectified way, used in the AEC/FM industry (Buildingsmart, 2012). IFC's model supports domain information relating to building services, such as building controls domain. But the service systems defined in IFCs are not linked to facility services management. For instance, relations between service and systems, service requirements for spaces and service elements, which are concerned by FM operations at the operational level. In addition, considerable building services are yet to be included, which are required for the FM database from a management perspective. Furthermore, as the integration of building systems becomes a significant part of building design and FM, this niche area is worth being explored and addressed in the BIM model. Specifically, on the one hand, required service components property sets are insufficient; on the other hand, the knowledge of service engineering behind the data model is not represented, which is significant in understanding how the facility management workflow of building operations.

REPRESENTATION OF THE SERVICE MODEL

This research aims to develop BIM based service model, a domain model, which specifically supports facility operations with an IB concept. The service model is developed based on OS framework, alongside with IFC schema to represent domain knowledge. FM service related objects, information and their relationships in the service model are represented in a visual format by UML (unified modelling language) class diagram. The class diagram enables the service model not only to follow the data structure and semantics of BIM, but also to represent related context information for service processes.

Daily operations of IB featured building management system (BMS) is based on rules and context information such as location and schedule, as well as building user's preference, which need to be pre-configured during construction commissioning phase. The context information is classified into three categories, user context, physical context and service context. The upper three levels of OS framework mainly concern information requirements for user and service context, while the lower three levels cover physical context. User context information covers building occupancy, users' profile, related policies and their preferences. Service context information refers to service requirements and service co-ordination. Given more context of building utilisation, integrated facility systems are able to better support facility service management towards intelligent building automation and energy efficiency.

UML class diagram represents the service model, which extended FM service concept to BIM (Figure 1). Addition to IFC model's classes such as space and wall, two classes that *scenario* and *service* are added on, while other related classes have been extended in both attributes and their relationships. At the semantic level, the service model further defines room functions by detailing scenarios of building utilisation. Scenario is a concept depicts a context of utilisaiton linking between zone, users' activities and required services. A room may have multiple functions that differ different scenarios accordingly. Scenarios could be defined separately depending on how an organisation is to use space and what services will be involved. For example, a scenario of lecture and a scenario of fire require different services in a same seminar room. At pragmatic and social level, service class is added in the service model to specify user's service preferences and requirements associated with spatial and temporal information. Service class stores service related information requirements, preference such as preferred temperature and humidity. Required services will be assigned to a particular scenario based on users' requirements.

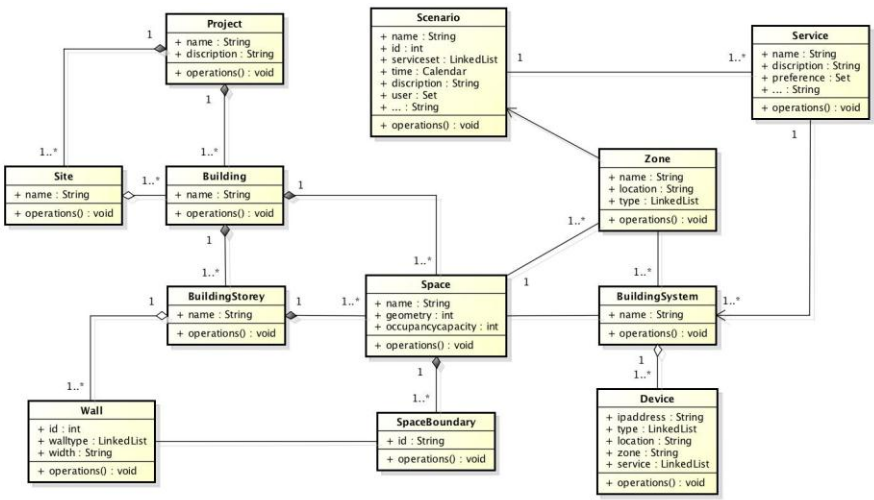


Figure 1: Class diagram of service model view

Added value of services can be achieved by the service model facilitating FM systems to deliver and co-ordinate services. For example, addition to building services, an event booked in a space may also need catering service or parking service. Relevant service related information can be retrieved and exchanged through the service model. Furthermore, a service may need co-ordination of a number of service systems such as a fire service. Required building system could be assigned to a specific service. Main service related classes and their descriptions in the service model including zone, space and building system are shown in Table 1.

Table 1: Demonstration of main classes in service modelling

Classes	Information required	Class descriptions
Service	Service type, service properties	A concept describes facility services, such as HVAC, lighting, fire, security etc.
Zone	Zone type, user assignment, user schedule assignment	A spatial concept links to building management of systems and administration.
Building system	Building system type, system mechanical topology, operational properties	A concept describes building system topology, device location, operational attributes and functions.
Space	Spatial capacity, zone assignment	A spatial concept describes physical aspect and spatial containment of a space.
Scenario	Service assignment, service schedule assignment	A concept describes a situation which happens in a zone with specific service requirements reflecting actual use of building facilities

APPLYING THE SERVICE MODEL FOR SERVICE MANAGEMENT IN EDUCATION ENVIRONMENT

To elaborate the service model approach we adopted, we set up a building service model to assist facility service management in the Information Research Centre (IRC) at the University of Reading. Service co-ordination for booking and using a seminar room is simulated in this section.

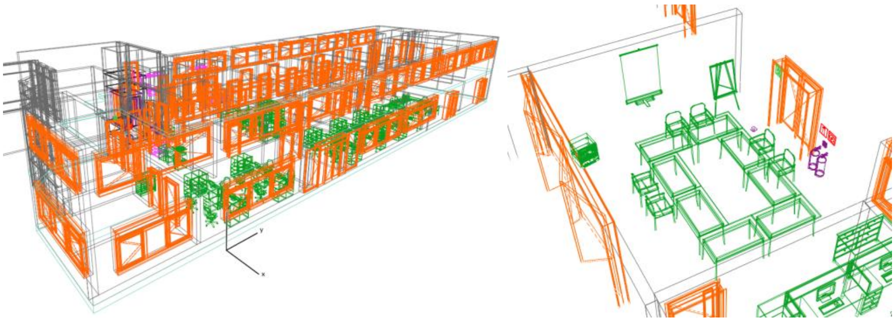
Building Service Model Establishment

The context we applied is the IRC department purpose-built for education, which contains offices, a seminar room and relevant auxiliary spaces (Figure 2). The seminar room in IRC is a multi-functional room, which can take roles of small group lecturing, seminars and meetings with supporting facilities and furnishings in place. We have set up a semantic building model to represent IRC containing information required to reflect the context of building use, including spatial information, service preference, service requirements, scenario specification, etc. An example of scenario in the seminar room is presented in figure 3. The lecture scenario in the seminar room requires a number of services, such as room booking, HVAC, lighting, and other systems co-ordinated on the application level. The services such as lighting, HVAC and fire protection service are assigned and modelled into the lecture scenario. In addition, other facility services such as catering, cleaning and car parking service can link to the scenario if there is a need of related information for a corresponding service system. For example, car parks location, or catering requirements or furnishing requirements for the room can be specified.

The Process of Booking and Implementing Services

There are listed rooms that could be centrally booked for users through university's booking system. The room booking process has been identified and shown in figure 4.

For consideration of energy efficiency, BMS has been linking to central room booking system to deliver lighting and HVAC services according to room schedules. The activity diagram (Figure 4) shows a workflow of the facility management system of booking and utilisation of the room. Room booking system checks if the IRC seminar room is available at the requested time slot. If the seminar room is available, then the system will proceed to reserve the room with the specific event clarified, and then update a new schedule of the room. To achieve this task, relevant information is required to provide from service model, such as room capacity, identification of required facility services, group preference of the indoor environment (lighting, temperature), lay out and furnishing requirements. An event of lecture in the seminar room is generated in the BMS, as long as the room is booked. Required services such as lighting and HVAC will be automatically invoked and achieve indoor comfort according to user's preference through system integration.



(a) IRC building model *(b) seminar room*

Figure 2: Semantic building models in a 3D view

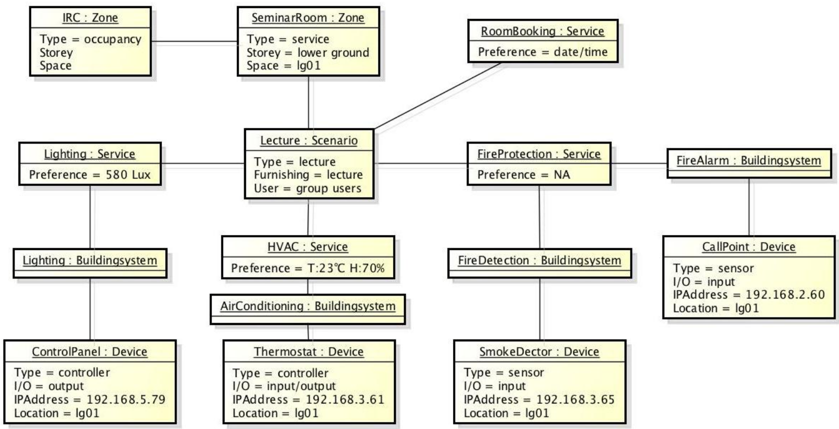


Figure 3: A scenario of lecture in the seminar room represented by UML object diagram

Fire protection service is compulsory under building's regulations. No matter whether a building is occupied or not, the fire related systems have to be functional all times. IB features in fire protection services are achieved through system integration in BMS. Fire systems, such as fire alarm and sprinkler systems, would be integrated with other building systems, such as access control and HVAC. The bottom diagram of figure 4 describes a process of a fire occurring that requires a number of activities from building operations. In the case of an event of a lecture, multiple sub-services are invoked and interactions are triggered. For example, the access control system is interfaced with the fire system to release the controlled exit in the room. The camera in the room of a CCTV system is interconnected to monitor the situation by displaying live videos. In addition, pre-selected cameras near the fire scene and on the evacuation route are able to be used to monitor the situation.

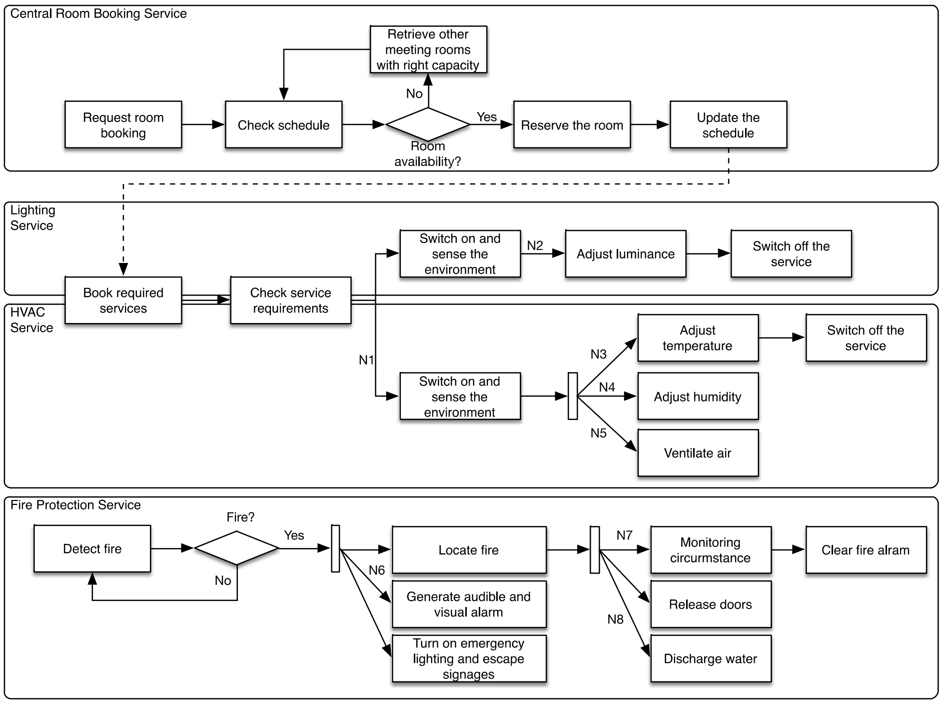


Figure 4: Facility services co-ordination process of booking and using a seminar room by activity diagram

Norm analysis method (NAM) (Liu, 2003) is used to elicit and represent knowledge about the organisations, and formalises the requirements. This approach allows capturing engineering and operational knowledge. Those are the important aspects we acknowledged in building utilisation that we defined as norms. In order to place BIM based facility services management, we need to associate operational data and building semantics with service process activities. As long as the context built up, the operational knowledge of facility service management is required to populate. There are operational rules to govern specific device systems in certain areas (a space or a zone) to deliver services. We adopt Liu's norm representation for knowledge as follows (Liu, 2000):

Whenever <condition> **if** <state> **then** <an agent> **is** <deontic operator> **to do** <action>.

Norms can be specified with using NAM as long as the workflow diagram is clarified, shown in table 2. The formal language version is for the BMS to execute. Lighting, HVAC and fire protection service implement according to specified norms. The agent represents each service system to perform certain actions. Virtual objects of devices (actuators or sensors) in systems relevant to the seminar room can be identified in the service model. Using the service model allows facility managers to define building utilisation and provide information for engineering and configuring service systems in BMS. By providing and linking context information related to utilization of the seminar room for lecture, FM can optimise service delivery according the schedule to save running cost. With integrating field-specific norms, the knowledge-based BIM system can enhance building operations in practice. A critical prerequisite to build such a knowledge-based system will be a full understanding of the service processes and activities and norms which are captured and represented in a BIM model.

Table 2: Norm specifications for the building operation activities in a process of service co-ordination

Norms	Service agent	Norm specifications
Norm N1	HVAC	***if*** <time arrives 15 minutes before the seminar begins> ***then*** <agent> ***is*** <obliged> ***to*** <turn on the HVAC system in the room>
Norm N2	Lighting	***if*** <Luminance level is lower than desired level> ***then*** <agent> ***is*** <obliged> ***to*** <switch on and dim up the lighting>
Norm N3	HVAC	***if*** <temperature is lower or higher than desired temperature> ***then*** <agent> ***is*** <obliged> ***to*** <increase or decrease the temperature>
Norm N4	HVAC	***if*** <humidity is lower or higher than desired humidity level> ***then*** <agent> ***is*** <obliged> ***to*** < increase or decrease the humidity >
Norm N5	HVAC	***if*** <CO_2 level is higher than desired level> ***then*** <agent> ***is*** <obliged> ***to*** <provide fresh air>
Norm N6	Fire alarm	***whenever*** <a fire event is generated > ***then*** <agent> ***is*** <obliged> ***to*** <generate fire alarm>
Norm N7	Surveillance CCTV	***whenever*** <the location of fire is identified> ***then*** <agent> ***is*** <obliged> ***to*** <display live video from the cameras in the fire zone>
Norm N8	Fire suppression	***whenever*** <the location of fire is identified> ***then*** <agent> ***is*** <obliged> ***to*** <discharge water in the fire zone >

CONCLUSIONS

Facility services are managed in a trend of integrated and co-ordinated manners from a service-oriented perspective. Building information modelling has been proved to be an effective technology based methodology to provide required information for design and construction. BIM is also able to integrate building operation data resource as a comprehensive building data repository and platform. This paper presented BIM-based service modelling, which supports efficient facility service management by providing context information required during the service operation processes. Organisational semiotic framework is used to analyse information requirements, and extend BIM with stressing semantic, pragmatic and social aspects of built spaces, which add service context and link norms in the service model. Furthermore, norm analysis method is deployed not only to derive service rules for operation, but also to align BIM's virtual objects into the service operation process. The case of room booking and implementing co-ordinated services simulated showed that BIM based service model cannot only provide prerequisite context information required for different service requirements, but also facilitate service co-ordination in an energy efficient way.

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