INVESTIGATING THE APPLICABILITY OF IFC IN GEOSPATIAL ENVIRONMENT IN ORDER TO FACILITATE THE FIRE RESPONSE MANAGEMENT PROCESS

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ABSTRACT: Some urban management tasks such as disaster management, delivery of goods and services, and cityscape visualisation are managed by using a GIS as the current state-of-art, as the tasks in these processes require high level and volume of integrated geospatial information. Several of these tasks such as fire response management also require detailed geometrical and semantic information about buildings in the form of geospatial information. This paper presents research focused on investigating whether the process of fire response management can be facilitated through the implementation of an IFC model in the geospatial environment. In the first phase of the research, a use case scenario is developed in order to investigate the possible use of IFC models in a fire response management process. In the next phase, software components are developed to transfer the required level of form and semantic information from the IFC model to the geospatial environment. The developed software components are then verified through unit and component testing and validated through system testing and semi-structured interviews. The paper first summarises the background on Building Information Modelling and the role of GIS in fire response management. The development of the use case scenario and the software components are then explained before finally summarising the validation and verification efforts.

KEYWORDS: IFC, fire response, BIM, GIS, geospatial.

1 INTRODUCTION

Building Information Models (BIMs) and Model Based Engineering have become an active research area in Computer Integrated Construction over the last 10-20 years. From an industrial perspective, the rise of the trend towards BIMs and model based engineering is due to the inadequate interoperability in the industry. Gallaher *et al.* (2004) indicated that US$15.8B is lost annually in the U.S Capital Facilities Industry due to the lack of interoperability. Today, BIMs are seen as the main facilitators of integration, interoperability, collaboration and process automation. A BIM is a digital representation of physical and functional characteristics of a building which serves as a shared knowledge resource for information about a building, forming a reliable basis for decisions during its whole lifecycle, i.e. from inception onwards (NBIMS, 2006). Over the last decade the Industry Foundation Classes (IFC), developed by International Alliance of Interoperability/buildingSMART, has matured as a standard BIM in supporting and facilitating interoperability across the various phases of the construction life cycle.

On the other hand, geospatial information and Geographic Information Systems (GISs) are used in various fields related to urban built environment, ranging from three dimensional cityscape visualisations to emergency response management. Today, fire response management process is commonly managed through the use of a GIS, while a high volume of geometrical and semantic information about buildings needs to be transferred and represented in the geospatial environment in order to successfully manage the overall process.

Until recently the transfer of semantic information and spatial relationships from building models into the geospatial environment could not be accomplished. This was mainly due to two reasons:

1. The inability of standard CAD models to store semantic information and spatial relationships due to their lack of object oriented data structures.
2. Geospatial information models handled and treated the data in a different manner than BIMs along with being insufficient in representing the detailed 3D geometry of building elements and 3D spatial relationships.

Both these factors made it difficult to transfer information from building models to a geospatial environment and to represent buildings within geospatial information models. This in turn prevented a complete automation of the fire response management process, where detailed geometric and semantic information about buildings is required to be held in the geospatial environment for the management of indoor navigation operation.

Today, BIMs (i.e. IFC as a maturing standard) are capable of containing geometrical and semantic information about the building elements in an object oriented data structure, where semantic information and spatial relationships can be derived. Furthermore, geospatial information models are developing in a way that they can support 3D geometrical representation of building elements and representation of 3D spatial relationships between them.

In light of such new technological developments in both domains, the overall research investigated ways and methods for overcoming the technical barriers that have prevented a complete automation of the fire response management process.

2 BACKGROUND

2.1 *Information modelling in the construction industry*

The traditional fragmented nature of the construction (AEC) industry causes diversity of the software in use, which in turn prevents effective information exchange between all parties. BIMs emerged in order to facilitate the effective management of construction information through the project lifecycle, by overcoming the barriers that prevent effective exchange and sharing of information.

Information models in the construction industry are usually developed by adopting ISO 10303 (Standard for Exchange of Product Data - STEP) technologies, e.g. EXPRESS, etc. Important efforts in this area include COMBINE, STEP Part 225, BCCM RATAS, EDM, SME and CIMSteel /CIS2 and IFC (Eastman, 1999; Zamanian and Pittman, 1999).

In 1994, 12 U.S. based companies joined together to examine the potential for interoperability in the AEC area. This first effort was based on the ARX development system for AutoCAD Release 13. Following this first effort, the organisations realised that there was economic benefit to be gained from such interoperability of software. As a result the participants decided to develop a vendor neutral standard for software interoperability. In October 1995, they established the Industry Alliance for Interoperability (IAI). The first version of the IAI's vendor neutral standard (IFC) was released in 1997. In 2005, IFC became an ISO Publicly Available Specification (16739).

The Industry Foundation Classes (IFC) is a collection of entities that together form a BIM. The IFC entities are defined by using ISO 10303 EXPRESS conceptual modelling language. The IFC objects allow AEC/FM professionals to share a project model and allow each profession to define its own view of the objects contained in that model. The BIMs (and IFC) aim to improve the efficiency in design, construction, and facilities management processes. Recent works on implementing and using BIMs and IFC include Spearpoint (2003), Maher *et al.* (2003), Kähkönen and Leinonen (2003), Yabuki and Shitani (2003), Lee *et al*. (2003), Underwood and Watson (2003), Kiviniemi *et al.* (2005), Grilo *et al.* (2005), Nour and Beucke (2005), Petrinja *et al.* (2005), Karavan *et al.* (2005), Caldas *et al*. (2005), Chen *et al.* (2005), Maher *et al.* (2005), Tanyer and Aouad (2005).

2.2 *The role of geospatial information in fire response management process*

Geospatial information is being used in many domains. Various elements of the urban fabric are already being represented within geospatial models. Furthermore, GISs are common systems that are used in urban planning and management activities. As Zeiler (1999) indicated, GIS and geospatial information are used in cadastre and land use planning, urban growth planning, planning and management of utility systems (electric, gas, water), demolition planning, emergency response planning and management, navigation and routing, delivery of goods and services, conservation and renovation projects, and in pollution management.

Local governments and fire departments use geospatial information and GISs to prevent fire and to manage emergency response operations in rural and urban areas. The literature in the area is extensive and some examples from the literature include Duburguet and Brenner (1997), Wang *et al.* (2005), Keating (2003), Schroeder (2000), Kwan and Lee (2005) who explained the use of geospatial information (and GIS) in Fire Response Management. On the other hand several studies (Beilin, 2000 and Brenner *et al.* 2001) demonstrated the use of geospatial information for assessing fire risk and for emergency response planning. Zlatanova (2007) provided a list of her publications related to the use of 3D geospatial information in emergency response management.

2.3 *Research methodology*

The aim of the study presented was to assess the applicability of an implementation of an industry standard BIM (IFC) in geospatial context, in order to investigate if the fire response management process can benefit from such an implementation. In order to build up the background theory, the first two phases of the research included literature reviews on Building Information Modelling and on the role of geospatial information in the fire response management process. The next phase included a technology review in order to gain further understanding of Building Information Modelling and the technologies related to storage and exchange of geospatial information. In the next phases of the research, a prototype system that transfers information from IFCs to geospatial environment was proposed, implemented and validated in three stages:

1. A use case scenario on fire response management was developed through semi-structured interviews in order to determine the level and amount of information to be transferred from the IFC model to the geospatial environment.
2. A prototype which would transfer the information from IFC to the geospatial environment was proposed and implemented as a set of software components.
3. The prototype software was verified and validated according to ISO 9126 through system testing and semi-structured interviews.

The following sections will explain the development of the use case scenario, the design and implementation of the software components, and verification/validation efforts.

3 DEVELOPMENT OF THE USE CASE SCENARIO

3.1 *Introduction*

A use case scenario describes the system's behaviour under various conditions as the system responds to a request from its stakeholders. The use case scenarios are usually defined in the form of casual and fully dressed versions, as explained in Cockburn (2001). The casual version of the scenario explains the process in an informal story-like style. The fully dressed versions of the scenarios are defined as a part of the functional analysis by the refinement of the casual versions. The fully dressed version of the scenario explains the process through a step by step approach in a formal way. The data needs and the structure of the proposed system are determined by the help of use case scenarios.

Following a literature and technology review in the field, a group interview was organised in the Greater Municipality of Istanbul in order to develop a use case scenario and establish a framework for the proposed solution. The group were composed of assistant directors from the Department of Surveying and Cadastre (of Greater Municipality of Istanbul), civil and surveying engineers from the Greater Municipality of Istanbul, experts from NETCAD (a commonly known Turkish GIS developer) and academics from Istanbul Technical University Centre for Disaster Rescue (which works jointly with Istanbul Fire Brigade and Istanbul Hospitals, for emergency response management research and training). The following sections will present the use case scenario development process and the scenario itself.

3.2 *Use case scenario development process*

The process was initiated with a group interview. In the beginning of the interview the participants from Istanbul Technical University (ITU) Centre for Disaster Rescue explained the data requirements for a successful fire response management operation. These general requirements can be summarised as the following:

1. The first type of information required for the operation is regarding roads in order to manage the routing of fire brigade vehicles and ambulances during the operation.
2. Other information required about roads includes the type of roads (i.e. asphalt or gravel), slope of the roads, and the seasonal condition of the roads (e.g. a road can be muddy after a heavy rain).
3. In the operation, the location of fire brigade stations and hospitals are also required to be known.
4. The types and capabilities of fire brigade vehicles (i.e. the maximum height of stairs in the vehicles) in a fire brigade station need to be known in order to select an appropriate fire station and fire brigade vehicle for the operation.
5. The demographic and traffic information about an area where the operation will be carried out need to be known, i.e. traffic may prevent the fire brigade vehicles reaching the site in the estimated time if the area is highly populated.
6. The information about surrounding buildings also need to be known in order to manage the access to the building from surrounding buildings (if needed) and to prevent the spreading of fire to them.
7. The usage type of the building (e.g. hospital, school) also needs to be known.
8. The location of fire sensors and fire alarms inside the building need to be known.
9. If any electronic control system is installed in the building (e.g. a system to close some doors when a fire occurs) then the information about such a system should be in the database of the disaster rescue centre.
10. The location of emergency exits in the building need to be known.
11. The electrical installations and pipelines surrounding the building also need to be known.
12. The location of the fire hydrants nearby the building need to be known.
13. The material of building elements (i.e. walls, doors, windows, etc.) need to be known.
14. The opening directions of doors and windows need to be known to assist the fire brigade staff.

During the interview the participants mentioned that these data requirements are only a small portion of the real life data needs, and a real life situation would require more data from other different resources. In the meeting, the participants were informed about the data richness of BIMs in that they contain information about materials of elements, and functions of elements such as the opening direction of doors and windows. Based on this the participants then pointed out that the data rich structure of the BIMs would provide specific advantages in facilitating the fire response management process. The BIM to be used was selected as the IFC as it is the mainstream standard for building information modelling.

A use case scenario was developed with the research group in the next stage of the study. As a first step in order to keep the scenario simple, a subset of data needs was selected from the above mentioned data needs. The participants agreed that the data requirements for the scenario would be in regard to the:

- Location of the fire brigade stations
- Road network between the building and the fire brigade stations
- 3D geometrical model of the building
- Opening directions of doors and windows
- Material of building elements

In the next stage, the scenario for fire response management operation was developed. The causal version of the scenario is presented in the next section. The fully-dressed version, which is not presented in this paper as it does not comply with the level of detail presented here, is presented in Isikdag (2006).

3.3 *Use case scenario for the fire response operation*

The Centre for Disaster Rescue of Greater Municipality of Istanbul is responsible for managing fire response operations in the city. According to the scenario, a fire occurs at the Institute of Science and Technology building of Istanbul Technical University. A witness informs the Centre for Disaster Rescue about the fire. An operation team is formed immediately in the centre. A member of the team determines an appropriate fire brigade station (which has suitable vehicles), calls the station and informs the station about the fire. At the same time the response team begin to use their GIS based fire response management system. In the first stage of the operation, a shortest route analysis is carried out to find the shortest route from the appropriate station to the Institute (where the fire occurs). In the next stage, the operation team uses the information about the shortest route to direct the fire brigade vehicles to the building. At a later stage when the fire brigades arrive at the building, the operation centre directs the fire brigade personnel inside the building by informing them about the opening directions of the doors and the materials of building elements. According to the scenario, the Centre for Disaster Rescue has access to the BIM of the building (in form of an IFC model).

In technical terms, according to the scenario:

1. The operation team, in the first stage, uses a system (of software components) to extract the required information (3D model of the building that contains opening directions of doors and windows, and material of walls) from the IFC model and transfer it into the geospatial environment.
2. The operation team then uses their readily available GIS based response management system to merge the background data (i.e. locations of fire brigade stations, road network) with the geospatial representation of the BIM, to manage the operation without loosing both time and the necessary information as a result of switching between various applications and data models.

Three use cases are derived from the use case scenario in the next stage. Figure 1 outlines these use cases.

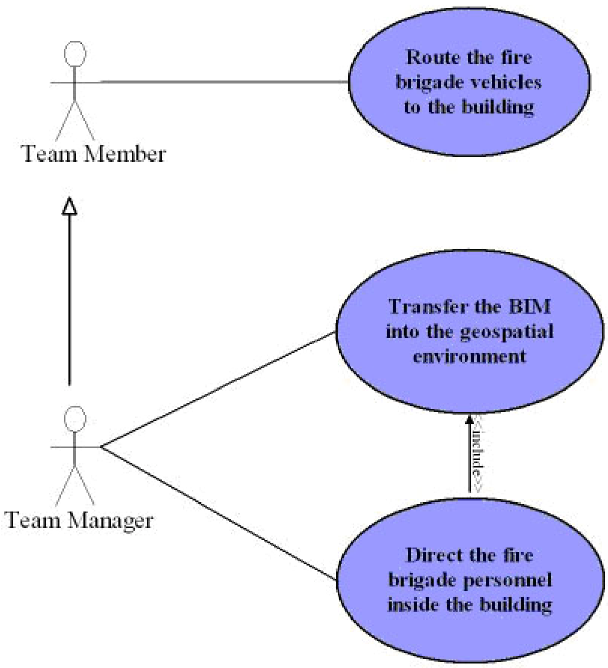

Figure 1. Use Cases Diagram for the fire response operation.

4 THE DESIGN OF THE PROTOTYPE SOFTWARE

The prototype software for transferring the information from the BIM (IFC) into the geospatial environment is developed in light of the use case scenario explained in the previous section. As mentioned in the use case scenario, the software components are developed in order to extract a 3D model of a building from the IFC model and to transfer it into the geospatial environment. The resulting 3D geospatial model would contain opening directions of doors and windows and material of walls along with their 3D geometrical representation. The prototype software components are developed in three layers, namely human-computer interaction (HCI Layer), problem domain (PD Layer) and data layer (Figure 2).

The data layer of the system consisted of a model server database (namely EDM) where IFC models were stored and a spatial database (ESRI GeoDatabase) where the resulting geospatial data model was stored. The problem domain layer of the system consisted of two internal and two external software components. The external software components were APIs, i.e. the model server API, which was used to query the IFC model in the model server and retrieve the required information from the IFC model and the Spatial Database API, which was used to create the geospatial model.

The internal software components were the input processing and the output creation packages. These packages were developed as COM+ components. The input processing package was used to convert different geometrical representations of building elements (CSG/Sweeping) to Boundary Representation (BRep), which is a common geometrical representation form for geospatial models. The input processing package was also used to derive spatial relationships and semantic information from the IFC model. The information obtained from the IFC model was held transiently in the objects of the input processing package. In the next stage, the output creation package used this transient information to create persistent geospatial objects inside a spatial database. The persistent geospatial objects were created with the help of the ESRI GeoDatabase API - an API developed to interact with the ESRI Spatial Database. The geospatial objects are stored within a data model based on ESRI Multipatch object model. Figure 2 depicts the physical design of the prototype software.

As shown in Figure 2, the system is designed in form of separate components in order to provide flexibility for further extensions. For example, when a need to create the output in another geospatial model arises (i.e. in form of CityGML) the development of a new output creation package will be sufficient rather than having to redevelop the whole system. The HCI layer of the system is consisted of a single windows user form. The form had command groups that are used to query the IFC model and get information about the building elements, before transferring them to the geospatial environment. It also contained several other commands which are used to transfer the transient information from the input processing packages' objects to geospatial objects and persist them in the spatial database.

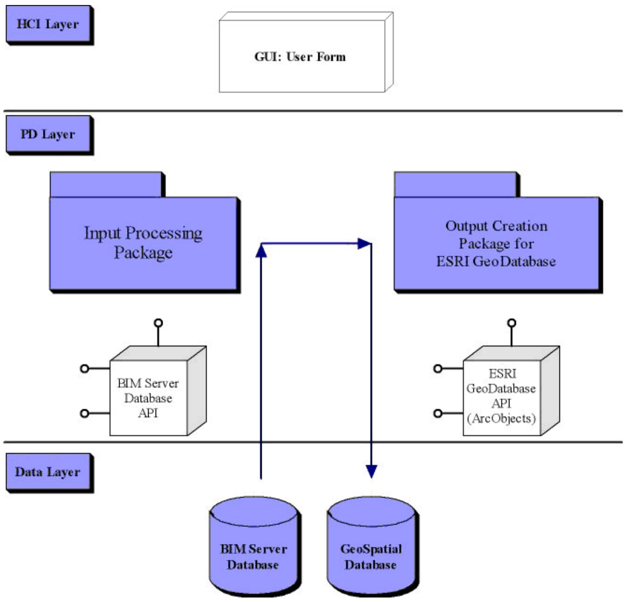

Figure 2. Physical Design of the prototype software.

5 VALIDATION AND VERIFICATION OF THE PROTOTYPE SOFTWARE

Following the development of the prototype software components, they were verified through unit, component and system tests. Unit tests were conducted to test the individual classes of the input processing and output creation packages, while the component tests were used to test the components as a whole. System tests were used to test the components and the interactions between them.

Figure 3 and Figure 4 present a result from the system testing phase of transferring a 3D building model from the IFC model into the geospatial environment. In the first figure, an IFC model of a 3 storey building is seen in a CAD application then in the next figure the transferred model is seen inside a GIS.

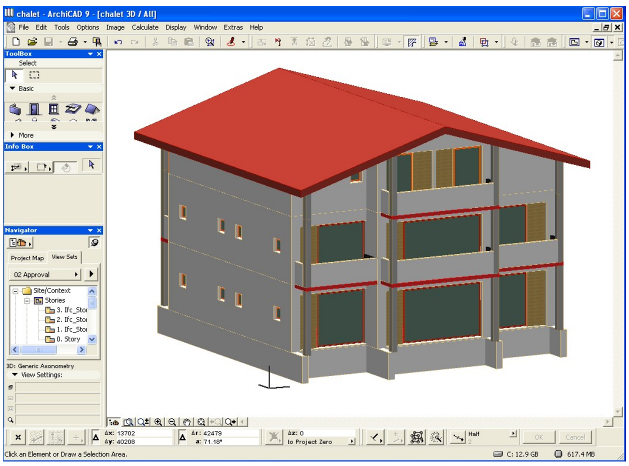

Figure 3. IFC model of a three storey building shown in a CAD application.

In the next phase the system was validated by using scenario-based testing (with test cases) and later evaluated in light of ISO 9126-1 (first part of the standard for Software Engineering Product Quality) by semi-structured interviews.

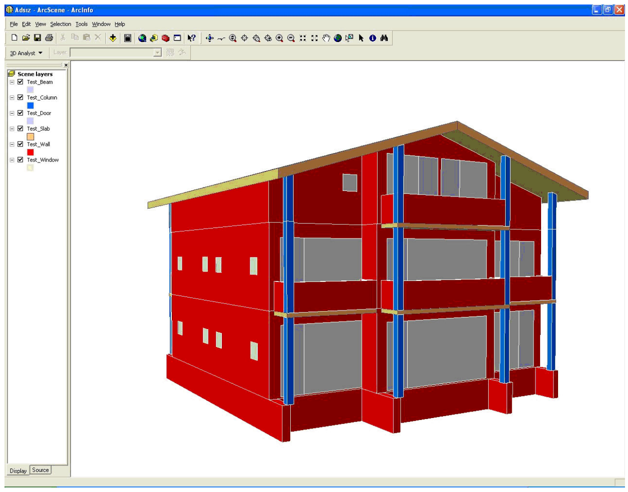

Figure 4. A three storey building transferred from an IFC model, shown inside a GIS.

The test cases were based on the use cases defined earlier (Figure1). It should be noted that the test cases are different from use cases as they explain a process in a higher level of detail and focus on interactions more closely. The test cases mimic the real flow of events with real users and real data, and the results of interactions are measurable in terms of success/failure. Kaner (2003) provided extensive information on scenario based system testing by using test cases. The test cases were completed by participants from NETCAD, Greater Municipality of Istanbul and academics from Istanbul Technical University Centre for Disaster Rescue. All test cases were completed successfully. The test model was the BIM of an Institute of Science and Technology building of ITU which was in IFC format. Table 1 provides the details of the test-cases completed during the scenario-based testing process.

Table 1. Test-cases completed during scenario based testing.

Test Case ID	Event Description	Process	Result
A	**Route the fire brigade vehicles to the building**		
A-1	Import the road data to the emergency response management system	Import the road data (showing the roads around Maslak, Levent, Sariyer) to ArcGIS environment	Success
A-2	Import the fire station locations to the emergency response management system	Import the fire brigade station locations to ArcGIS environment (showing the fire brigade station locations around Maslak, Levent, Sariyer)	Success
A-3	Locate the appropriate station in the system	Query the fire stations by their ID and find the location of appropriate fire station in the system by its given ID	Success
A-4	Find the shortest route form the appropriate fire brigade station to the Institute	Find the shortest route between these two locations by using the network editing tools in ArcGIS	Success
B	**Transfer the BIM into the geospatial environment**		
B-1	Run the system and make the database related operations	Run the prototype system Import IFC and Aspect Model* schemas Import the physical file into EDM database Populate the Aspect Model entities by mapping from IFC model classes to Aspect Model classes	Success
B-2	Populate the Input Processing Unit Object Model	Populate Input Processing Unit Object Model classes from Aspect Model* *: The Aspect Model is a middle-tier information model stored in the BIM database	Success
B-3	Create the 3D building elements as persistent geospatial objects	Create the 3D building elements with required attributes in form of an ESRI GeoDatabase	Success
C	**Direct the fire brigade personnel inside the building**		
C-1	Import the building plan from the database	Import the building model into the ArcGIS based system from an ESRI GeoDatabase. Opening directions of doors and windows and material of building elements are represented as attributes of related features	Success
C-2	Direct the fire brigade personnel inside the building	By giving them directions of the fire and by indicating the opening direction of doors and windows and the materials of walls, when required	Success

The system evaluation by semi-structured interviews was undertaken after the scenario-based testing process. Participants from NETCAD, Greater Municipality of Istanbul and academics from Istanbul Technical University Centre for Disaster Rescue joined the semi-structured interviews. The questions in the interviews were regarding the system quality in order to evaluate the functionality, usability, efficiency and portability of the system. During the interviews every participant was given a chance to inspect the source code of the system as some questions were related to the coding itself. All participants were interviewed on a one-to-one basis in light of a set of questions. During the interviews the participants mentioned that the developed components can successfully create 3D representations of columns, beams, slabs, windows, doors and walls in the form of 2D and 3D geospatial objects. Object attributes (e.g. material of elements) and spatial relationships were also present in the geospatial object model.

Several problems that affected the system quality were identified during the component and systems tests as:

- Time behaviour of the output creation package was poor.
- The 3D building elements were not located in actual orientation of the building.
- The spatial relationships in the IFC model were not represented in form of topological relationships in the geospatial model.
- The objects represented with BRep method in the IFC model were not processed and transferred into geospatial objects.

The evaluation results showed that the time behaviour of the output creation package is not satisfactory. The results of the performance tests (carried out during the system tests) mainly indicated that this is due to time spent on creating the geospatial objects. The reason behind it was the complex structure of the ESRI Multipatch object type which was used in the implementation.

Another result from the evaluation indicated that the resultant building elements were not located within the actual orientation of the building. Geo-locating the output with the right orientation is an important aspect of the implementation. Further research could accomplish this in several ways:

- *By using the information (attributes) obtained from the IFC model:* The transformation can be achieved by obtaining the latitude and longitude of the building from IfcSite object and getting the rotation as True North from IfcGeometricRepresentationContext object.
- *By using a geospatial object as a template:* In this method, the coordinates of three points of the template geospatial object need to be known for the transformation operation.

The evaluation results indicated that the spatial relationships of the IFC model were not represented in the form of topological relationships in the geospatial model. This was mainly caused from the limitations of the geospatial model used in the implementation. Although 3D topological models exist to a certain extent, they are only implemented in specific databases for research purposes and are still not integrated into state of art GISs. Further research and developments on 3D topological modelling and their implementation in GISs will contribute to the efforts towards better representation of building elements in geospatial environment.

Another criticism about the prototype was that the IFC objects whose geometry is defined by the BRep method were not processed and transferred into geospatial objects. This appeared mainly because of the design decision that was taken in order to solve the problems in the transformation from CSG and Sweeping Representations to Boundary Representation (BRep). The transformation of the IFC objects whose geometry is defined by the BRep method to the BRep models of geospatial environment might cause such problems as:

- The resultant geospatial model would require a high amount of storage space in order to store building elements that have detailed geometries. In such situation the resultant model needs to be compressed or simplified using the geometric model simplification techniques.
- On the other hand, the system's performance would become worse during this transformation process as it would have to process more complex geometries.

6 SUMMARY AND CONCLUSION

Fire response operations are commonly managed by using a GIS as the current state-of-art, and require high level and volume of integrated geospatial information together with detailed geometric and semantic information about buildings. However, building information has not been transferred into and represented in geospatial environment due to the lack of semantic information in early building models and due to incompatibilities between the data models in the two different domains. This situation mainly prevented the management of indoor navigation process in a fire response management operation.

In contrast, when the building information is made available in the geospatial environment, the emergency response management team will have the ability to use their readily available GIS based response system to manage the outdoor and indoor operation seamlessly, without loosing time and necessary information through switching between various applications and data models. In order to realise this, the study investigated the applicability of BIMs (IFC in particular) in the geospatial environment.

Following a literature and technology review on Building Information Modelling and geospatial information, a use case scenario was developed in order to determine details of the process. The scenario also acted as a framework for the implementation. In the next stage, a prototype to transfer information from IFC to the geospatial environment was proposed and implemented as a set of software components. Finally, the prototype was verified by unit and component tests and was validated according to ISO 9126-by system testing and semi-structured interviews.

Two types of mismatches occur between IFC models and geospatial environment as form and semantic mismatches. In order to prevent these mismatches, the transfer of information from IFC to geospatial environment should address two specific issues, i) the transfer of geometric information and ii) the transfer of semantic information.

The geometric information is about the geometry of the building elements and spatial relationships. The geometry in IFC models is represented with CSG, Sweeping and BRep methods. On the other hand, in (vector) geospatial models the geometry is usually represented by BRep method, thus in most cases the transformation from CSG and Sweeping representations to BRep appears as a need to represent the building geometry correctly in the geospatial environment.

The spatial relationships in the IFC model can either be transformed to topological relationships of a 3D topological geospatial model or these relationships can be preserved within database tables using a custom geospatial model based on 2 and 2.5D geospatial objects.

The semantic information is about the object types and their functions and functional constraints. Semantic information in IFC can be represented by creating similar object types in the geospatial object model (i.e. CityGML model is a good example on that) and the functions of the BIM objects (i.e. building elements) will be represented in object attributes of the geospatial model. On the other hand, the functional constraints can be represented by object attributes or by topological rules (if a topological model is used in geospatial representation).

In the next stage of this research, the focus will be on investigating if the proposed implementation will facilitate the process of fire response management.

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