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Cloud-based Building Information Modelling

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Executive Summary

This report contains the deliverable summarizing findings from ESR12, ESR13, and ESR14 regarding existing technologies and assessment of market opportunities and barriers. The material is based on literature reviews done during the first year of the students. The three parts of this reports covers data level integration between BIM and GIS tools, technologies needed for realizing ideal Cloud-BIM as well as a case study proposal for CBIM use. The report ends with conclusions from the work package leader based on the material presented by the ESRs.

1 Introduction

1.1 Purpose and target group

The purpose of this public report is to present some aspects of the current state of the art in Cloud-BIM (CBIM) for the construction industry.

1.2 Contributions of partners

The following Table 1 depicts the main contributions from participant partners in the development of this deliverable.

Table 1: Contribution of partners

Participant short name	Contributions
Nyberg	Executive summary, introduction, and conclusions
Guyo	Content to section 2
Chen	Content to section 3
Ding	Content to section 4

1.3 Relation to other activities in the project

The following Table 2 depicts the main relationship of this deliverable to other activities (or deliverables) developed within the CBIM Project and that should be considered along with this document for further understanding of its contents.

Table 2: Relation to other activities in the project

Deliverable Number	Contributions
D21	Public Presence of CBIM (Website, Social Media)

2 Data level integration between BIM and GIS tools

Building information modeling (BIM) and geographic information systems (GIS) are two closely related domains. BIM tools are primarily focused on representing building data while GIS tools are geared towards analyzing and describing spatial information about a certain environment (Wang, Pan and Luo, 2019). And hence cooperation between the two domains will enable us to design and build infrastructures that are well integrated with their environment.

The benefit of BIM and GIS integration is well noted by the scientific community. Accordingly, research works in the topic have increased in the late 2010s (Wang, Pan and Luo, 2019). These research works have identified many benefits of BIM and GIS integrations such as energy efficient design of an urban environment, protecting and preserving historical and cultural heritages, and monitoring and supporting construction supply chain management (Wang, Pan and Luo, 2019) (Irizarry, Karan and Jalaei, 2013).

However, there are some crucial differences between BIM and GIS technologies that make seamless integration between the domains hard to attain. For instance, BIM tools were originally focused on designing new objects with high levels of detail while GIS tools were focused on analyzing objects that already exist in an environment (Karan, Irizarry and Haymaker, 2016). As a result, they evolved differently. Researchers working on integration of the two domains has also pointed out other differences between the domains such as difference in concept of level of development (LOD) (Wang, Pan and Luo, 2019), difference in the data structure they use to store and exchange data (Zhu *et al.*, 2018), difference in geometry, in scope and in the coordinate system they use (Herle *et al.*, 2020).

Regardless of the challenges, however, many methods, through the years, have been proposed by researchers to achieve integration between BIM and GIS. The methods have been classified in several ways by different authors. This report will use the classification provided by Amirebrahimi et al. (2015). The author used three categories. The first is *application level integration.* This level of integration involves reconfiguring and manipulating existing BIM and GIS tools. This would mean a BIM tool will be reconfigured to include GIS capabilities or a GIS tool will be reconfigured, and BIM tool capabilities will be incorporated into it.

The second category of integration method identified by Amirebrahimi et al. (2015) is *process level integration*. In this method, rather than modifying the BIM and GIS tools, as in the first category, the tools will be left separate and a system that will allow participation by the tools will be implemented. The third category identified by Amirebrahimi et al. (2015) is *data level integration* between BIM and GIS. This is integration between BIM and GIS through data transfer. The data transfer can happen through application programming Interface (API) or thorough open data standards.

Industry Foundation Classes (IFC) and City Geography Markup Language (CityGML) are open data standards that are frequently mentioned in discussion of data level integration between BIM and GIS (Wang, Pan and Luo, 2019). IFC is an open source file format developed for building data sharing and exchanging between BIM applications (Karan, Irizarry and Haymaker, 2016). It is developed and maintained by buildingSMART International and is the basis for ISO 16739-1:2018 (International Organization for Standardization (ISO), 2018). The developers are currently working on IFC extensions that will allow the data standard to support infrastructural data.

CityGML, on the other hand, is developed for representation and exchange of 3D city models (Vilgertshofer *et al.*, 2017). It is developed by Open Geospatial Consortium (OGC) and adopted as an OGC standard (Open Geospatial Consortium 2012). CityGML has a concept called application domain extension (ADE) that allows users to enrich the data model with new classes and attributes without altering the semantic structure of CityGML (Biljecki, Kumar and Nagel, 2018). This concept has been important in BIM and GIS integration discussion since it allows extension of CityGML to provide support for building data coming from BIM tools.

Even though they are not as widely implemented as IFC and CityGML, there are other open data standards that can contribute to data level integration between BIM and GIS. IndoorGML is an open data model that supports geometric and semantic information that is relevant for indoor navigation (OGC 2020). The data model can be connected with IFC and CityGML because it allows referencing of objects in the external dataset (OGC, 2020).

Another data standard (also from OGC) is LandInfra. LandInfra is a conceptual model for land and civil engineering infrastructures (OGC, 2016) even though it is yet to be implemented by any software tool. This standard can represent subsurface data, legal information of buildings and survey related information which are represented by neither IFC nor CityGML (Kumar *et al.*, 2019).

All the open data standards discussed in previous paragraphs can play an important role in BIM and GIS integration. However, none of them or, in fact, no data standard available today can fully support data from BIM and GIS tools. Hence, no single open data standard can provide, by itself, full data exchange between BIM and GIS tools. This led many researchers to attempt to overlap or map open data standards over each other with some success.

Most previous BIM-GIS data level integration studies were focused on unidirectional conversion of IFC to CityGML (Wang, Pan and Luo, 2019). Some examples include de Laat and van Berlo (2011) and Cheng et al. (2013) who proposed a unidirectional transformation from IFC to CityGML using CityGML ADE. Another example is Donkers et al. (2016) who presented a conversion algorithm to convert from IFC model to CityGML LOD3. There was also a proposal to extract indoor building information from IFC into indoorGML(Teo and Yu, 2017). Similar data conversion applications can be found in some commercial software such as Feature Manipulation Engine (FME) and ArcGIS.

Another method of data level integration of BIM and GIS proposed by researchers is aggregation of all data from BIM and GIS models (in IFC and CityGML format, respectively) into a single model or database (Wyszomirski and Gotlib, 2020) (El-Mekawy, Östman and Hijazi, 2012). Meanwhile others proposed linked data approaches, including semantic web technologies, to enable data exchange between BIM and GIS models (Vilgertshofer *et al.*, 2017) (Karan, Irizarry and Haymaker, 2016) (Herle *et al.*, 2020). These methods allow original data models (IFC and CityGML) to remain in their original form and links to be created between them (often using semantic web representations).

While the methods listed in the previous paragraph achieved some level of data level integration between BIM and GIS, they had some limitations. The unidirectional conversion from IFC to CityGML, ignored the need to transfer data from CityGML to IFC. Additionally, the conversions resulted in data loss and data inconsistency (Herle *et al.*, 2020). Integrating all data from IFC and CityGML into the database requires systems that can work with databases which are not available for BIM. And using semantic representation of data models for creating link is challenging because these representations are created by multidisciplinary professionals and thus may lead to inconsistency (Karan, Irizarry and Haymaker, 2016).

In conclusion, data level integration between BIM and GIS has been the topic of many studies in the past. Even though there have been advancements in the field, research in the topics Is ongoing because the challenges of integration remain. Currently, there is no data format that can represent all information from BIM and GIS. Therefore, there needs to be more research work to design and implement an effective method to overlap and map the available open standard overreach.

3 Technologies needed for realizing ideal Cloud-BIM

Numerous specialists have contended for presentation of a concurrent engineering in the Architecture, Engineering and Construction (AEC) industry. For instance, Love and Gunasekaran reasoned that plan and development cycle ought to be refined all the while; for example that members in the undertaking ought to be accumulated into an assembled advancement measure by being a multi-disciplinary gathering (Love, P.E. and Gunasekaran, A., 1997). Avnet and Weigel showed a use of the Design Structure Matrix (DSM) and Integrated Concurrent Engineering (ICE) to extract design of space frameworks (Avnet, M.S. and Weigel, A.L., 2010). They proposed to speed up workflow by getting together all applicable individuals in a similar space to do engaged, community-oriented plan studies for seven days.

Notwithstanding, the cutting-edge tools for construction - Building Information Modeling (BIM) and the related BIM cycles of making a calculable and shareable 3D dataset among different spaces inside a construction project – do not uphold concurrent engineering. Using BIM, designers can represent material and functional features of a building such as building geometry, topology, quantities and properties of building elements (Liu, H., Lu, M. and Al-Hussein, M., 2016). Applications of BIM for facility maintenance also encompass real-time data from environment stations, system maintenance, indoor sensors, occupancy status, etc. Thus, in supporting 3D, real-time, intelligent and dynamic modelling applications, BIM has evolved to support the traditional serial practice of the Architecture, Engineering and Construction and Facility Management sector (AEC/FM) (Wong, J., Wang, X., Li, H. and Chan, G., 2014), where the projects involve a great number of professional consultants (architects, engineers, builders) that must exchange information and share ideas to complete design tasks. Collaboration within BIM processes is based on transfer of models stored in discrete computer files. This is adequate for serial handover of information, but not for concurrent engineering.

File transfers are made in either the formats specified by the vendors or using a neutral format such as Industry Foundation Classes (IFC), giving rise to the possibility of information distortion or loss within the process of data transmission. Therefore, BIM, as a matter of fact, is used for visualisation, clash detection, building design and construction of as-built models rather than for collaboration concurrently among different team roles within the process of the design and construction period (Pauwels, P., De Meyer, R. and Van Campenhout, J., 2010).

The underlying driver of the issue is that the manners by which BIM data is caught and put away don't uphold continuous plan data sharing and management. Further entangling the issue is the way that diverse expert orders conceptualize structures in various psychological examples, and BIM instruments are along these lines likewise discipline explicit, with various item patterns. For concurrent design, all members ought to have the option to see and control the items that compose an architecture at the same time.

In an effort to devise BIM tools that do support collaboration, researchers have proposed object-based storage in the cloud (Afsari, K., Eastman, C.M. and Shelden, D.R., 2016). It is conceivable that cloud-based BIM could provide project participants of various domains with the abilities to manage and exchange design information and solutions concurrently (Redmond, A., Hore, A., Alshawi, M. and West, R., 2012). It is recognised that cloud computing performs may effectively address current barriers of BIM by providing real-time access to the information, on-demand access to computing resources and applications and potentially better interoperability (Mahamadu, A.M., Mahdjoubi, L. and Booth, C., 2013). The cloud BIM server systems also have the advantage that they can store status information for individual objects or systems as metadata (Afsari, K., Eastman, C. and Shelden, D., 2017). However, in and of themselves, they do not support real-time multi-user and multidisciplinary editing.

Semantic Web technology provides an alternative approach as it can gather extensive information into a single Semantic Web (Berners-Lee, T., Hendler, J. and Lassila, O., 2001). A Semantic Web approach could enable the representation of information in multiple different but linked graphs. For example, explicitly linking a building description in the IFC schema to representations of the identical architecture according to an alternative schema. Applications could depend on this web of information as a crucial data source to provide services as demanded for each of the participants in the design team.

It has been shown that the enhancement of decision making in the AEC industry benefits from the adoption of Semantic Web technology. The consistency-checking system proposed by Yruchyshyna and Zarli (Yurchyshyna, A. and Zarli, A., 2009), for example, shows how to check if an architecture conforms to legal regulations via semantic queries. Another instance is that an IFCOWL system was developed to convert an IFC schema to a Semantic Web graph, improving the way of segmenting information represented in IFC files (Beetz, J., Van Leeuwen, J. and De Vries, B., 2009). Pauwels et al. investigated the adaptability of Semantic Web technology, in particular, for architecture acoustics and for the sharing of 3D data within the AEC industry (Pauwels, P., Van Deursen, D., 2011.). In this work, they did not emphasize graph and ontology deployment to describe the information and enhance interoperability, but elaborated how rules work based on such graphs for performance checking and for the translation of 3D data.

The combined advantage of improving the representation of architecture and building information through the description of "graphics-based knowledge specifications" is the basis for a conceptual design platform called ConDes. While the proposed system is not based on Semantic Web technologies, it is a good illustration of how architecture and construction information is represented semantically, and how it can be reused in high-level reasoning to enhance the quality of design decision support (Pauwels, P., Van Deursen, D., De Roo, J., 2011).

In addition to Semantic Web and knowledge graph technologies, Virtual Reality technology provides a means to enhance collaboration among different domains as well. For example, Roupé et al. (Roupé, M., Johansson, M., Maftei, L., 2020.) came up with a novel platform for design collaboration called ViCoDE, which features synchronized integration of multiple immersive VR systems and a multitouch table that assists the collaboration and interaction of design work with prompt response. In this work, they achieved a high level of common understanding of the design, but they all use a single building model instance at the same time, on a single software platform, and on the same computer.

In outline, the issue is that current BIM stages do not support concurrent multidisciplinary and multi-user collaboration. There are advancements that could uphold improvement, for example, Semantic Web representations of building design data, semantic enrichment methods using AI to bridge the gap between disciplines, property and knowledge graph databases and cloud computing, but these have not been applied in research or in practice to solve the problems.

4 Case study for CBIM use

As discussed in the preceding text, existing technologies within the BIM ecosystem are diverse and, to a large degree, static and it is difficult to work across domains. This leads to outdated and often disparate BIM models being circulated within an organisation, causing effort duplications, version control issues and lack of trust in the model etc. A unified, up-to-date Cloud-based BIM model would allow all stakeholders to make more informed and confident choices.

Currently, most of the attention for BIM development is directed towards buildings and other “unique” infrastructure, such as bridges or highway interchanges. However, road networks are also highly relevant in this space and present an opportunity to advance the automatic generation and updating of BIM models. Roads, to a large degree, consists of repeated geometry and adhere to strict design rules. As they are a very “predictable” asset type, they are an excellent candidate for developing techniques to automatically generate 3D geometry, identifying assets, and storing asset information.

Beyond the wider contributing to CBIM technologies that automatic 3D geometry generation may bring, producing CBIM models with up to date in-situ data (i.e. a Road Digital Twin) is worthwhile in itself. The importance of a well-maintained and safe road network is very well known. Effective road asset information and asset condition information is a keystone to enable this. At present, these are overwhelmingly completed manually with no geometric data collected (that can be used for 3D modelling). The common factor in all of these is that they are carried out either by humans (subjective results) or by specialised equipment, such as laser scanners or Lidar systems (very expensive).

The current standards in industry vary greatly between the asset owner, commonly road authorities, and between different classes of roads, even if they are controlled by the same authority. The frequency of inspection is low in almost all cases. For instance, roads on the UK’s strategic road network are only inspected at most once every six months and sometimes only once every two years.

These techniques are not being utilised as often as needed due to high costs. The information collected is also fragmented and there is no simple way of visualising the data collected. In the majority of cases, data is collected, the problem areas identified, the data stored, logged and it is never touched again.

CBIM creates an opportunity to improve these processes and allows a more active way of curating and access essential road asset condition data. The opportunities within the AEC sector that the introduction of CBIM may create spans many assets and many use cases, as it makes the most important factor in large undertakings accessible and reliable: information and access to information.

While the development of BIM, and more recently CBIM, has been highly promising in the last few years, there are many barriers to development that must be addressed. Barriers specific to the technical feasibility of introducing CBIM for road networks include:

- The size of the asset.

Roads are very large assets, and the data required to store all of it is often too big and is abandoned after its purpose is used. Due to the size of the asset, manually creating a CBIM model is very labour intensive.

- The constantly changing nature of the asset.

Due to constant use, roads, and thus their digital counterparts, must be regularly updated to ensure reliability of the asset status. This will require techniques to automatically detect changes and update these changes to the model.

- The number of stakeholders that require access to data.

As with more generic BIM, information representation between different aspects of the road must be continuously updated to ensure that data does not clash.

It must be noted that not all barriers are technical. Structural barriers within organisations, budgeting prioritisations within road authorities, lack of training and standardisation within the organisation etc. all contribute to this.

The benefits towards road maintenance and asset control described are merely a small subset of these. Conversely, the barriers faced in CBIM implementation for roads merely represents a subset of the barriers to implementation.

5 Conclusions

The three different views to the problem complement each other. In the section about data level integration between BIM and GIS tools findings include that even though there are good open and industry standard formats for interoperability within BIM and GIS, there is still research needed for integrating BIM and GIS data. The section about technologies needed for realizing ideal Cloud-BIM explains current limitations in existing solutions, including the fact that concurrent engineering is not well supported. Object-based storage in the cloud is presented as potential solution to concurrent engineering, but the proposed systems do not support real-time multi-user and multidisciplinary editing. One potential solution to be researched is the use of Semantic Web and knowledge graph technologies. Finally, a potential case study for CBIM use in relation to road networks is presented, as road networks presents interesting challenges for a Cloud-BIM system. These challenges include the size of the asset, the constantly changing nature of the asset, and the number of stakeholders that require access to data. By solving these challenges, the results can be generalized for other use cases of CBIM.

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