Building Information Modeling – A Game Changer for Interoperability and a Chance for Digital Preservation of Architectural Data?

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ABSTRACT

Digital data associated with the architectural design-and-construction process is an essential resource alongside -and even past- the lifecycle of the construction object it describes. Despite this, digital architectural data remains to be largely neglected in digital preservation research – and vice versa, digital preservation is so far neglected in the design-and-construction process. In the last 5 years, Building Information Modeling (BIM) has seen a growing adoption in the architecture and construction domains, marking a large step towards much needed interoperability. The open standard IFC (Industry Foundation Classes) is one way in which data is exchanged in BIM processes. This paper presents a first digital preservation based look at BIM processes, highlighting the history and adoption of the methods as well as the open file format standard IFC (Industry Foundation Classes) as one way to store and preserve BIM data.

General Terms

Communities, preservation strategies and workflows, specialist content types

Keywords

Architectural 3D data, Building Information Modeling, 3D preservation, IFC

1. INTRODUCTION

Mankind's desire to construct buildings – and with that the history of architecture – can be traced back to the Neolithic period. Buildings do not only provide shelter, but serve many functions in our life. Cities may be easily identified through a characteristic building, such as the Eiffel Tower or the Sydney Opera House. Naturally, design and construction of buildings remains one of the largest sectors in the 21st century – in the US alone, the annual spending on construction in 2013 was at $898.4 billion [1].

The construction of "standard" objects, such as residential buildings or smaller to mid-size non-residential structures, are as much a part of the design-to-construction process as projects which focus on the combination of aesthetic expression, physical principles and innovation, such as in the case of the "3D print canal house", a research- and building site in Amsterdam where architects are for the first time testing the use of 3D printed building parts in design and construction.[1] Another area are large (total cost more than $10 million) and mega-projects (total cost over $1 billion), such as the new Istanbul airport with a planned capacity of 150 million passengers per year [2].

Architectural records may be archived for different purposes and reasons, three of which should be mentioned here: The first case is that of regulatory requirements, which require the deposit of design and construction records, especially in the case of publically funded buildings, to a regional or national body such as a national archive. The second case is that of the building owner or facility manger, who relies on the availability of the information for reconstruction or simple maintenance purposes. The last example is that of the architectural records being preserved by a library, archive or museum for the historic value or the significance of the construction object or the architect. Prominent examples of special collection libraries for architectural content include the Avery Architectural & Fine Arts Library at Columbia University[2] or the RIBA Library of the Royal Institute of British Architects[3].

This paper gives an insight into the various stages at which architectural data is produced and used along the building's lifecycle. The lifecycle view provides an understanding of the different actors which function as producers and consumers – and therefore also as the designated community for the digital data produced. Until recently, the domain has been dominated by a lack of interoperability which has lead to a decline of productivity. While the concept of Building Information Modelling (BIM) has existed for over 30 years, it has only been adopted recently. A brief history of the process and its adoption shall give a better understanding of the idea behind Building Information Modelling. Lastly, IFC (Industry Foundation Classes) is introduced as an open and standardized way to exchange Building Information Modelling. A description of the format against sustainability factors and a brief risk assessment puts the

[1] http://3dprintcanalhouse.com/

[2] http://library.columbia.edu/locations/avery.html

[3] http://www.architecture.com/LibraryDrawingsAndPhotographs/Home.aspx#.U0g9tqJcLQE

content type and format further into a digital preservation perspective.

2. RELATED WORK

Despite the economic value of digital architectural data and despite the significance that digital architectural records may hold in the cultural heritage context, very little research has been conducted regarding the digital preservation of the material. First efforts in this direction were made by MIT's Façade (Future-proofing Architectural Computer –Aided Design) project[4], which ran from 2006 – 2009. The project focused on proprietary CAD (computer aided design) files which were deposited in the institution's DSpace based preservation repository. The project pointed out the heterogeneous software landscape in architectural practice and the legal restrictions connected to the proprietary formats as two of the biggest problems in the preservation process. Façade reached the conclusion that the best preservation strategy would be to preserve 4 versions of the object: (1) the original submitted digital object, (2) an access copy, in particular 3D PDF (3) a full "preservable standard format", in particular STEP or IFC[5] (Industry Foundation Classes) (4) a "preservable standard format" containing just the geometry, in particular IGES [3].

While not dealing exclusively with architectural CAD data, the 2013 DPC (Digital Preservation Coalition) report "Preserving Computer-Aided Design" comes to a similar result, suggesting that archives should keep the original CAD file and migrate to at least one vendor-neutral format, where in particular STEP standard based formats are pointed out as being suitable [4].

Both points of reference – MIT Façade as well as the DPC report – focus on the CAD object as the preservation starting point, therefore following an object-centric as opposed to a process-centric approach. A process-centric approach helps us to understand different players involved in production or usage scenarios of the data. This will eventually lead to BIM – a practice that had not been as widely adopted during the running time of the MIT Façade project as it is today.

3. A LIFECYCLE VIEW

A lifecycle view of a typical building is a helpful tool to understand the various stages at which architectural data is created and used. The beginning of the lifecycle is marked by the conception of the structure to be built, while the demolition or the re-purposing mark the end or re-start of the cycle. The steps in between may be broken down into two high-level categories: construction and use. These high-level categories signify the temporal aspect of the lifecycle in regards to data production and data re-use – while the construction phase, which is simultaneously the part of the cycle where the most data about the building is produced, lasts on average about 2.5 years, the usage phase, where data from the construction phase is re-used, lasts about 60 or more years.

A more granular look at the two main stages sheds light upon the different actors involved in the construction and usage processes.

[4] http://facade.mit.edu

[5] The project did not look at STEP and IFC in the context of BIM data, as the process had only just begun to establish itself in the architectural practice [3].

The concept and the design phases are typically led by the architect who designs the building. Based on this initial design, further actors are involved in the pre-construction phase to define specific needs to various aspects of the building, such as structural engineers or HVAC (heating, ventilation, air conditioning) engineers. Furthermore, information regarding cost or projecting details such as time schedules are defined in preparation of the construction process. During the construction phase, part of the data produced so far is used by the site or construction manager to organize and monitor the physical construction phase itself. At this stage, the construction management as well as the construction companies produce further data, which documents the as-build state. Besides project management information and costs, this may include specific product information or further specifications of the original design. During the hand-over stage the produced data can serve as a verification measure of the construction vs. design process – moreover, it forms the necessary documentary basis for the operation of the building. For large objects such as, e.g., hospitals, hotels or large-scale office buildings, facility management companies rely on complete and exact data regarding various building parts to ensure economically efficient and safe operation and maintenance of the structure. During the use-phase new data may be created for various reasons, such as in the case of producing documentation for regulatory decrees, e.g., in form of required documentation for new fire safety regulations, or in the case of the documentation of minor modifications, such as the installation of a new parts within the heating system or the tearing down of a non-bearing wall to create a larger room.

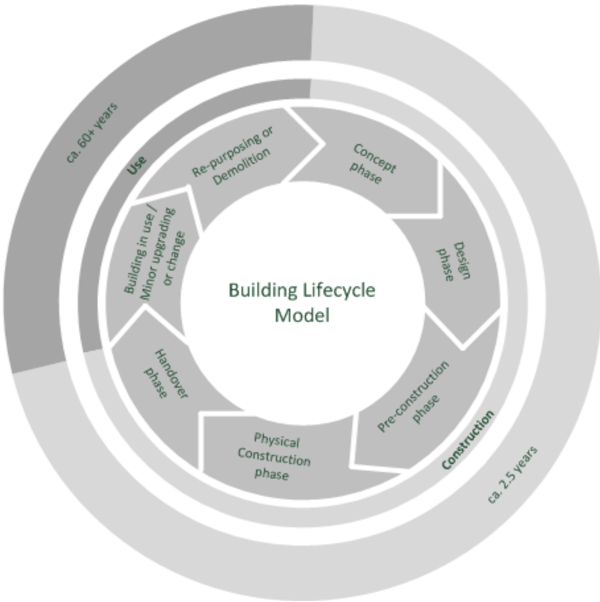

Figure 1. Building Lifecycle

As suggested above, the vast majority of data about a building is produced during the "construction" stages. Table 1 shows the amount of paper-based information that typically occurs for large-scale projects (construction cost exceeding $ 10 Million). In addition to showing the amount of documentation produced, the table displays the fragmented nature of the construction domain resulting in the comparatively high number of different companies involved in the process. Based on EU industry sector statistics, companies with fewer than ten employees accounted for 90% of the European construction industry workforce in 2005 [5].

Table 1. Typical numbers for large-scale projects with a cost of $10 Million [6]

Number of pages in documents	56,000
Number of individual participants involved	850
Number of companies involved (including suppliers and sub-sub-contractors)	420
Number of types of documents generated	50
Number of banker boxes to hold project documents	25

How can cooperation between and seamless integration of so many actors be realized in a business process as diverse as the design-to-process one? That the situation is not ideal has been displayed in various ways – one being a 2004 analysis conducted by Teicholz [7], where the 1964 to 2004 productivity index of the construction domain was compared against that of all other non-farm labor domains. While productivity for the non-farm labor domains had gone up steadily, that of the construction domain had actually decreased. In other words: construction projects of 2004 cost significantly more hours per dollar than they did in 1964. Teicholz sees one of the main reasons for the productivity decline in the nature of ICT stand-alone-system developments of the various actors involved in the design and construction process. While each sub-domain may use state-of-the-art systems in their own right, there is a lack of interoperability which in the worst case leads to information being exported from a digital system to paper documents and then manually re-imported from there [7]. A 2013 analysis of the UK's construction industry's supply chain suggests that the situation has not improved since Teicholz observations made in 2004. The 2013 analysis shows poor quality information and incompleteness of design as a major cost factor, in some reported cases being as high as 25% of the overall building cost [8].

The lack of cooperation in the digital age is a much reported issue in architectural and construction related research [7], [10], [11], [12]. Hitchcock and Wong, to give one example, point out that in the case of energy simulation building models, the lack of robust data exchange methods has lead to a practise, where data is collected from various sources and transformed based on professional expertise and a rules-of-thumb approach instead of a standardized one. This often leads to a range of different possible energy simulation building models for the same initial object [9].

The fragmented nature of the documentation of the architectural design-to-construction records naturally poses a challenge not only for the cross-sectional usability, but also for the preservation process of the digital information associated with an architectural design- and construction project. As described above, actors involved in the design-to-construction process may use their domain-specific and often proprietary monolithic software solutions to produce information.

4. BUILDING INFORMATION MODELLING (BIM)

A solution to the lack of interoperability, to incomplete data and to the low productivity associated with these problems is seen in a widespread adoption of Building Information Modeling (BIM) as a consequent model throughout a building's lifecycle [13].
While the acronym BIM is most frequently translated as "Building Information Modeling", it may be resolved in the following ways: [10]:

1. as Building Information Modeling, which describes the business process of generating and maintaining semantically rich digital objects which contain geometry and layout as well as information on material, cost estimation and scheduling.
2. as Building Information Models, the instantiation produced by the process described in (1)
3. as Building Information Management, which refers to the organization and control of the processes associated with processes in (1), the digital objects in (2) and their utilization along a building's lifecycle

A good definition of the term is given by Nederveen et al. [14]:
*"a **Building Information Model** is an information model of a building (or building project) that comprises complete and sufficient information to support all lifecycle processes, and which can be interpreted directly by computer applications. It comprises information about the building itself as well as its components, and comprises information about properties such as function, shape, material and processes for the building life cycle"*.

4.1 Brief History of BIM

The idea behind BIM dates back to the 1970s and 1980s. Early terminology used to describe the concept differed. Charles Eastman first proposed the idea behind what is today known as BIM in 1975, describing a prototype of a "Building Description System" which aimed to combine the advantages of manual drawings and physical models in a computer graphics based system. The "Building Description System" recognized a number of facts which formed the foundation of what is today known as BIM, such as the fact that every element of a building essentially consists of three types of descriptions – (1) shape (2) location and (3) a list of properties – and that every element may occur several times in a building, differing in only the location descriptor [16].

From there, research and development in the USA and Europe further developed the idea while assigning different terminology to the concept. While the term "Building Product Model" established itself in the USA, in Europe, the term "Product Information Model" was used. Robert Aish specified the concept further in 1986, including most of the cornerstones that today make up BIM and giving it the label of "Building Modelling" [13].

The full term "Building Information Modelling" was introduced in 1992 by G.A. van Nederveen and F. Tolman, who focused on the modelling of different views of a building in order to support various stakeholders' needs [17].

Despite the fact that the concepts of BIM had been represented in AEC software as early as 1987[6], the terminus coined by van Nederveen and Tolman remained dormant for 20 more years until a 2002 Autodesk Building Industry Solution White Paper entitled "Building Information Modeling". Autodesk described Building Information Modelling as it's "strategy for the application of information technology to the building industry" [18]. At the core of Autodesk's strategy was the inclusion of digital databases, which shall facilitate collaboration, better change management, as well as easier reuse of information.

In the context of digital preservation it is interesting to note that the white paper states two preservation cases:

1. The system shall "capture and preserve information for reuse by additional industry specific applications"

2. The system shall capture audit trail information about changes made by all team members and preserve it "for as long as this information is useful" [18]

The fact that the terminology BIM was then picked up by the two other large software companies on the AEC design market – namely Bentley Systems and Graphisoft – can be attributed to industry analyst Jerry Laiserin. Laiserin suggested a global adoption of the term "Building Information Modelling" reasoning that "CAD is no longer sufficiently descriptive of the breadth and depth of the design process" [19] and he gave the CEOs of the respective companies a forum to exchange opinions on the adoption of the term [20],[21],[22].

4.2 Moving beyond CAD – key features

As previously mentioned, building models describe a building as a structured set of intelligent components which in themselves are characterized on three levels: they are associated with a computable graphic / are spatial, they are described through data attributes and they may be modified through parametric rules. The data which describes the elements shall be consistent, non-redundant and include behavior, such as information needed for energy simulations [13].

As opposed to other industries' application of parametric based modeling, BIM software comes with a pre-defined set of building elements, which are broken down into smaller categories or "families" at which level they may be modified or extended by the user. These families are described in parametric relationships to each other, enabling the software to coordinate and manage the changes made to the building model. To give an example: a floor is attached to a wall – if the floor size is changed, the wall moves accordingly. These conditions are defined in rules – to again pick the example of a wall: rules include checking that doors and window locations lie completely within a wall and that the locations of doors and windows do not overlap each other.

Building Information Modeling allows the generation of different views – or representations – based on a single building model, e.g. in form of a 2D or a 3D representation or in form of a design view and a view of the HVAC (heating, ventilation, air conditioning) parts. Figure 2 shows an example of different views generated from the same model.

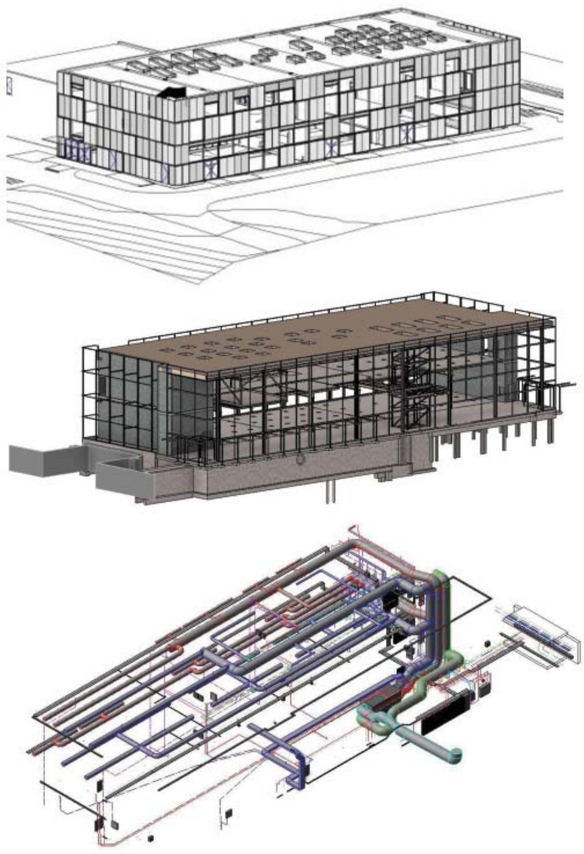

Figure 2. Different views of the same object – architect (top), construction engineer (middle), HVAC engineer (bottom)

The different views shall allow the different actors to remain an easy access to the file on a level that feels "familiar" to their domain. This interoperability enabler shall lead to accurate and complete data, thus supporting the design-to-construction process down to the handover phase. In the usage phase of the building's lifecycle, complete and detailed data shall greatly benefit facility management in efficient and sustainable operation of the building [13].

4.3 BIM Adoption

While Nederveen et al. specifically included a building's life-cycle-long support in their earlier quoted BIM definition, they also pointed out in 2010 that the definition may be considered as a future outlook which is currently far from common practice [15]. But what does the situation look like today?

While the popularity of the search term "Building Information Modeling" suggests a growing interest in the subject matter (see Figure 3), table 2 shows that BIM is seeing growing adoption and is as of today a required process for publically funded construction projects in a number of countries.

[6] In a 2003 issue of the LaiserinLetter, Graphisoft's then Vice President for Architecture Chris Barron described Graphicsoft's adoption of the concepts of BIM in ArchiCAD's "Virtual Building" approach, which dates back to 1987. [22]

Table 2: BIM and IFC adoption

Country	BIM Status	IFC Status	Driver
Australia	Not mandatory	Not mandatory	Association driven Driven by public organisations like the Australian Construction Industry Forum; successful BIM implementations for maintenance of some large objects like the Sydney Opera House.
Denmark	Mandatory (partially)	Mandatory (partially)	Government driven Regulations starting April 2013 were passed by the Danish Building and Property Agency[7] and are required for construction projects which are at least 50% state financed, exceed overall construction cost of 5 Million DKK or are results of architectural competitions. BIM and IFC are both mandatory for those objects. Triggered by the 2007 government initative "Det Digitale Byggeri" (Digital Construction) some Danish government / state level agencies had previously already been requiring BIM, and specifically IFC.
Finland	Mandatory	Mandatory	Government driven Both BIM and the delivery in the IFC file format are mandatory for government projects since 2007 as per Senate Properties[8] regulations.
Germany	Not mandatory	Not mandatory	Association driven A first government initiative was the recently published "BIM recommendations for Germany", intiated by the Federal Institute for Research on Buidling, Urban Affairs and Spatial Development[9].
Hong Kong	Mandatory	Not mandatory	Government driven BIM will be mandatory for all Hong Kong Housing Authority[10] projects from 2015 (for some, from 2014) on. While the inclusion of open standards is encouraged, no specific requirements in regards to IFC are made.
Netherlands	Mandatory (partially)	Mandatory (partially)	Government driven Rijksgebouwendienst (Rgd)[11] of the Dutch Ministry of the Interior has been requiring BIM for only some of the publically funded projects since 2012. For those projects where BIM is required, BIM extracts including the IFC model alongside CAD drawings and measurement data, calculations, etc. are expected per the Rgd BIM Standard of 2012.
Norway	Mandatory	Mandatory	Government driven The government organization "Statsbygg"[12] has been requiring BIM as well as IFC for all government construction projects since 2010.
Singapore	Mandatory (partially)	Mandatory (partially)	Government driven The Building and Construction Authority (BCA) has passed regulations requiring BIM for new building projects exceeding 5,000 sqm in size. The BCA developed e-submission system for BIM requirements "CORENET" implements the IFC model.[13]
United Kingdom	Mandatory	Mandatory	Government driven The Government initiative "Government Construction Strategy"[14] requires BIM for all government construction projects from 2016 on. Models will need to be available in the COBie UK 2012 schema[15], which may be derived from an IFC MVD.
USA	Mandatory	Mandatory	Government driven General Service Administration (GSA)[16] regulations have been requiring BIM for government construction projects since 2008. For those projects, the availability of the native CAD format and the IFC object are required. The Army Corps of Engineers is a second government body which made BIM mandatory for all projects

[7] http://www.bygst.dk

[8] http://www.senaatti.fi/en

[9] http://www.bbsr.bund.de/

[10] http://www.housingauthority.gov.hk/en/index.html?url=/en/

[11] http://www.rgd.nl/english/

[12] http://www.statsbygg.no/System/Topp-menyvalg/English/

[13] https://www.corenet.gov.sg/

[14] https://www.gov.uk/government/publications/government-construction-strategy

[15] http://www.bimtaskgroup.org/cobie-uk-2012/

[16] http://gsa.gov/bim

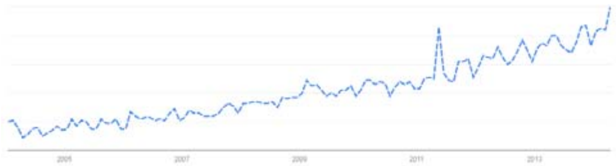

Figure 3: World-wide Google search term development for "Building Information Modeling" 2004-2014[17]

It has also been recognized, that the use of BIM technology and processes significantly changes the relationships, communication and collaboration ways of the actors being involved in the design-to-construction process [13]. This is closely tied to the third acronym interpretation of BIM given in the introduction to this chapter: Building Information Management.

On an organizational level, the role of the "BIM Manager" is being given more attention, with government based guidelines – such as Hong Kong's roadmap for a strategic implementation of BIM – specifically suggesting a BIM manager in every project "to develop integration mindset and whole lifecycle systems' mindset to project participants" [25].

On an ICT level, the integration and collaboration need is being met through model servers, which manage file exchange between the different actors as well as versioning and consistency. These model servers allow the import from and export to CAD & BIM desktop tools and may furthermore integrate product databases provided by vendors or large agglomerated databases like the nbs (National Building Specification) National BIM Library[18]. Most model servers will store the information on the models in databases, which are used to generate the views for the specific needs pertaining to the respective actor – such as a view for the structural engineer as opposed to the facility manager (see figure 3). The respective actors work with the models in their own sub-domain specific software and upload the results to the BIM Server, where the information on the construction object is then synchronized.

BIM integration in software can be divided into two approaches: One is a vendor based solution, where a vendor will support BIM integration through different software solutions within a suite. An example for this is Autodesk's BIM solutions, where models can easily be exchanged between different available software modules for architectural design, construction and facility management.[19] This vendor-based BIM process is sometimes referred to as "closed BIM". While it comes at the price of complete dependency on the software vendor, it allows tight integration and the full exploitation of features that single software systems of a suite entail. In Figure 4, the given examples for closed BIM data exchange include the native BIM formats DWG (AutoCAD Drawing), RVT (Autodesk Revit Project File), DGN (MicroStation DesiGN File) and GSM (Graphisoft ArchiCAD File).

The second approach facilities collaboration between the different involved actors through the use of publically available standards as exchange methods between different software platforms. This method is sometimes referred to as "open BIM". While this approach comes at the price of most likely not being able to maintain some of the functionality that the source software included for the original file format, it allows for a much higher degree of flexibility between the different actors without any software vendor dependency.

A few of the exchange formats shown in figure 4 are proprietary exchange formats, of which DXF (Data eXchange Format) is the most common one. DXF is a format defined by Autodesk which has become somewhat of the smallest common denominator in the exchange of vector data between CAD systems. The problem with the DXF format is that it typically changes with every new release of the AutoCAD family [23].

A second group of file formats shown in figure 4 can be classified as access formats, as they are stable and openly available formats which are supported by a number of readily available viewers while only exposing a fraction of the BIM information (e.g., JPEG, PDF, PDF 3D, OBJ).

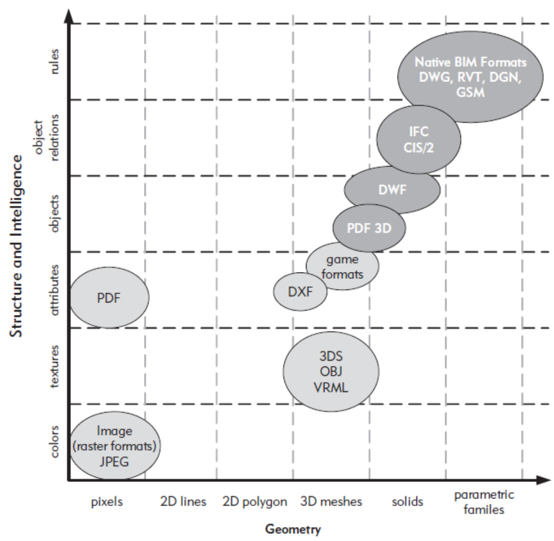

Figure 4. Level of geometry, structure and intelligence in potential data exchange formats [13]

Currently only two open exchange formats exist which fully support BIM: IFC (Industry Foundation Classes) and CIS/2 (CimSteel Integration Standard). Both standards are based on ISO-STEP technology (see chapter 5.1), are human and machine readable, are standardized, publically recognized and widely used. While CIS/2 supports structural steel design only, IFC is targeted at the entire BIM spectrum. A mapping between the two standards has been developed to allow for interoperability.[20] Widely used

[17] retrieved April 9th 2014

[18] http://www.nationalbimlibrary.com/

[19] http://www.autodesk.com/solutions/building-information-modeling/overview

[20] The mapping is available at website of the National Institute of Standards and Technology: http://www.nist.gov/manuscript-publication-search.cfm?pub_id=861673

“Open BIM” model servers, such as the “BIMserver”[21], use IFC as the data exchange format.

While XML (Extensible Markup Language) is a file format often used for interoperability reasons and data exchange, it currently only finds usage for smaller sections of the BIM process. An example for this is gbXML (Green Building XML) which is a schema supporting the data contained in BIMs to engineering analysis tools. Semantically, gbXML could be considered a subset of IFC, as it does not contain relevant information which cannot be modelled in IFC [24].

A general problem that pertains to any exchange format is the fact that it relies on stable import and export mechanisms into and out of often proprietary source systems. These mechanisms need to be checked consistently after updates of the source software as well as after updates to the exchange format.

5. INDUSTRY FOUNDATION CLASSES (IFC)

While the term “Building Information Modelling” was not widely adopted until 2002, as described in the previous chapter, the strife for interoperability in the AEC (architecture, engineering, construction) / FM (facility management) domains is much older. The need for easily exchangeable and reliable data has put forth the development of the Industry Foundation Classes (IFC) standard.

IFC can be described as a hierarchical object sub-typing structure, in which objects are nested in an entity tree and each entity is described with attributes. The attributes may describe an object’s material, behaviour (e.g., thermal characteristics) or contextual properties (e.g., weather data) as well as process related characteristics such as time, fire safety regulations, building use or projected cost [13].

The latest IFC version (IFC4) contains 766 entities, meaning that 766 different concepts or objects exist in the schema, each of which can be instantiated numerous times within a model, be described with attributes and be set in relation to other entity instances [26].

As of today, the IFC data model is the only comprehensive, public, non-proprietary and well-developed data model which supports the full design-to-construction process [13].

5.1 Brief History of IFC

The “standard behind the standard”, so to speak, is STEP, which is standardized as ISO10303. The idea behind the STEP standard itself dates back to 1984 when the decision to develop an open product modeling standard which could serve the needs of a wide variety of industrial and manufacturing industries was made by the ISO TC184/SC subcommittee. This was to be achieved by central core elements, which domain specific application protocols could be built upon, thus avoiding redundant standard development across several domains and paving the way for easier collaboration between different industrial manufacturing industries. At the heart of the common core of STEP was the idea of a robust data model describing concepts like relationships, attributes, constraints and inheritance [12].

The method to describe these concepts was realized in form of the EXPRESS information modeling language, which functions as the core of various other STEP data models, for example the aforementioned CIS/2 or for application protocols of other domains, for example LOTAR[22] for the aerospace and defense industries. File formats and schemas based on STEP need to be based on a machine readable modeling language instead of a binary file format. The language should include clear data declarations but also include rules and constraints to model procedural requirements. The standard requires the mapping to be applicable to different implementations, namely a text file format (“Part-21”), a SQL and object based database implementations as well as an XML schema (“Part-28”). Lastly, it should allow for the development and inclusion of sub-models to support the needs of specific domains [13].

While the initiation of STEP development dates back to 1984, the first STEP standard was not released until 1994. For the AEC/FM industry this was too slow-moving and unresponsive to the domains’ needs which lead them to undertake their own efforts in driving interoperability through format development and standardization. It may seem surprising that the development of IFC was at it's base a process driven by software companies. Under the lead of Autodesk, 12 U.S. based industry and software companies founded the IAI (Industry Alliance for Interoperability) in 1994 with the aim to drive tool and standard development supporting the data exchange amongst actors involved in planning, construction and maintenance of a building. In 2005 the IAI changed its name to buildingSMART[23] [12].

The years 1994-1999 can be considered the early days of IFC prototyping. Format version 1.0 focused solemnly on the architectural part of the building, while IFC version 1.5.1. was the actual first implementation in a BIM software. While the efforts so far had been mainly conducted in the U.S., IFC version 2.0 was the first true international prototype, incorporating work of newly established international IAI charters. IFC2.0 incorporated schemas for cost estimation, building services and construction planning and can be considered the last prototype of the IFC format development [12]. The file format versions 1.0 to 2.0 are now considered obsolete and are no longer supported [26].

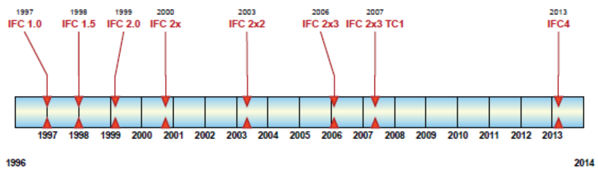

Figure 5. Timeline overview of IFC format releases [27]

The first stable “production” release was IFC2x, released in 2000. The next major release IFC2x2 in 2003 added new domain areas, while IFC2x3 in 2006 addressed mainly quality issues of the model. Even though STEP ISO10303 conformity is still fulfilled, IFC became its own ISO standard in 2013: ISO16739. The same

[21] http://www.bimserver.org/

[22] http://www.lotar-international.org/

[23] http://www.buildingsmart.org

year, the most recent version was released: IFC4. The IFC4 release enables new BIM workflows which have been developed within the domain since the 2x developments, including GIS interoperability and enhanced thermal simulations. Furthermore, ifcXML schema description, which was previously conducted in parallel to the text file format IFC-SPF, is now included in the general version specification. Simultaneously, the XML Version has been improved significantly, reducing the needed lines down to 14% of what it was at in IFC2x3 XML, making it 6 times more efficient [27].

5.2 IFC Adoption

As mentioned before, IFC is today a widely accepted standard [13], [12]. Seven out of the eight national regulatory bodies which require BIM and are documented in table 2, also require the documentation of the design-to-build process using the IFC file format standard. The only exception to this is Hong Kong, who is just now in the process of realizing BIM regulatory requirements and mentions the focus on open standards, however, without implicitly pointing towards IFC. It will remain to be seen, whether IFC will be picked up in the requirements there as well [25].

On a software level, a number of freely available IFC viewers are available, such as the Solibri Model Viewer[24] or the DDS IfcViewer[25]. Furthermore, the IFC core model is today supported by more than 150 software tools.[26] To make the stability of import and export routines into and out of CAD or other systems transparent, the buildngSMART foundation maintains a certification process for third party applications. Here, software developers may certify their application towards the support of an IFC version. Currently, certification is available towards the IFC2x3 standard and has been started or completed for 31 different applications.[27]

6. DISCUSSION

As demonstrated in Figure 4, the IFC file format preserves a high degree of the BIM object's intelligence and geometry. While some parametric information as well as rule functionality of the source systems may be lost, a growing adoption of the file format has built a community which addresses these questions in processes such as certification procedures for import and export routines out of monolithic domain-specific software. Furthermore, the file format is supported by a growing number of open source tools for file analysis, viewing and manipulation.[28]

BIM certainly simplifies the process of capturing a building's documentation by containing a lot of information which was previously only available in a spread-out manner across numerous pieces of documentary evidence. It furthermore fulfills a lot of the needs of the various designated communities aligned around the building's lifecycle. IFC seems to further support this process from a preservation view by doing so in an open, standardized and well adopted way.

Measuring the file format against well recognized sustainability factors will give further insight into digital preservation suitability of the file format [28].

6.1 File Format Sustainability

The sustainability factors described here are based on an analysis conducted as part of the DURAARK (Durable Architectural Knowledge) project [28]. It needs to be noted that three representation forms are available for the IFC file: in addition to the previously mentioned clear-text renditions IFC-SPF (IFC STEP Physical File, .ifc) an IFC XML (.ifcxml) and IFC-ZIP (.ifczip) version is available, which compresses either IFC-SPF or IFC-XML using PKzip 2.04g compression. The sustainability factors only describe IFC-SPF and IFC-XML, particularly in version IFC4, as the xml specification is included in the general IFC4 specification [28], [27].

Disclosure

As the IFC file format is openly available and standardized, all necessary information about the file formats' design and structure is available.[29] The standardization is clearly written and includes a change log comparing the current to the previous schema. While versions IFC1.0 to IFC2.0 were non-productive prototypes, the version family IFC2x, which was superseded by IFC4 in 2013, remains supported by current tools.

Internal technical characteristics

Following the STEP principles, both the XML and the text based SPF version of the format are human and machine readable, implementation independent and free from encryption. While the schema is certainly complex, this serves the purpose of the nature of BIM. The required different views in the BIM process are supported through the availability of Model View Definitions (MVD), which allow sub-domain views onto the model, e.g. for a structural engineer.

External technical characteristics

As a platform and implementation independent standard, the IFC file format does not depend on specific hardware or software. An IFC file may, however, depend on external information, as product catalogue entries may be referenced through URIs (uniform resource identifier) pointing towards, e.g., a vendor's dataset.

Format Acceptance

IFC is a well adopted standard which is recommended by several national regulatory bodies for the documentation of the design-to-build process for publically funded structures. It is well supported by a large number of tools.

Patent

The IFC standard is open and vendor-neutral; it is free from any patent restrictions.

[24] http://www.solibri.com/products/solibri-model-viewer/

[25] http://www.dds-cad.net/downloads/dds-cad-open-bim-viewer/

[26] http://www.buildingsmart-tech.org/implementation/implementations

[27] http://www.buildingsmart-tech.org/certification/ifc-certification-2.0/ifc2x3-cv-v2.0-certification/participants

[28] http://www.buildingsmart-tech.org/implementation/get-started/ifc-open-source/ifc-open-source-summary

[29] http://www.buildingsmart-tech.org/downloads/ifc

Logical Structure and Transparency

As a clear text format with a well-defined schema, IFC is human and machine readable and transparent to methods for validation of the schema and the file format itself. However, while the schema is rather large to support the entire BIM process, this also requires a certain degree of flexibility with a lot of attributes and entities being optional. This complicates schema validation. Nevertheless, well-formedness on the low-level syntax of the file format itself, which is the main requirement for renderablity and accessibility, is transparent to analysis.

6.2 File Format Risk Assessment

The sustainability analysis put forth two particular problems. The first problem relates to potential problems connected with the validation of the schema. This is closely tied to the flexibility, which is based on a large number of entities, attributes and rules to capture all aspects of the design-to-build process. While validation software for the schema at large exists[30], it checks against the entire schema, which makes it hard for the respective sub-domain actors to find the validation errors that pertain to their scenario. With the release of IFC4 a full integration of the model view definitions (MVD) into the XML structure was announced, which may pave the way for easier view-based validation procedures.

The second problem is that of the digital object's dependency on external resources. This is especially the case when the IFC model is enriched with information from vendor product catalogues or external BIM Libraries and entries are only referenced through a URI. A possible way to address this is to store the respective linked dataset alongside the IFC file. While this would preserve the object in its original state, it would not solve the question of easy traceability of changes in the product database, i.e. if a referenced part such as a door knob is no longer available. This problem is currently being addressed as part of the DURAARK project (Durable Architectural Knowledge), where a semantic digital observatory is proposed, which monitors the external resources regarding their stability and availability and mirror changes into a semantic digital archive [29].

A third problem, which is not a result of the sustainability factor analysis but lies in the nature of file formats which are primarily used as data exchange formats between monolithic systems, is that of the dependency on software vendors to produce accurate import and export routines. In the case of IFC problems have especially been reported in regards to data exchange between different proprietary software [30], [31]. Pazlar and Turk pointed out in 2008 that vendor-side IFC interfaces are not where they should be given the years of development and should not be blindly trusted [31]. Recent efforts in research and development have been targeting this gap through automated metrics for similarity and difference detection [32]. On the user side this means that client side import and export routines in systems have to be checked for every new version of the external software as well as for every new version of the IFC format. BuildingSMART's certification procedure for software vendors is here a good contribution to transparency. Nevertheless, consistent checking of the reliability of the import and export functionalities should be conducted to guarantee completeness of the data. This risk is therefore closely tied to the first risk mentioned – i.e., that of the schema validity as per the different stakeholders – as such validation rules may also assist in the checking of correct data after an export.

7. CONCLUSION

In the introduction, three different purposes for the archival of architectural design-to-construction records were mentioned:

1. Regulatory requirements where objects may be deposited to a regional or national body

2. The building owner or facility manager, who relies on the availability of the information for the maintenance of the object

3. Cultural heritage value of the record based on the structure it documents or on the creator of the object

The lifecycle view of the building itself seen in juxtaposition to the data that is produced and used along the lifecycle showed that in traditional architectural digital practice, where systems were monolithic and data exchange was often conducted in a manual "print-out" way, interoperability – and with that also curation and preservation of the data – posed to be a major problem.

While Building Information Modeling was largely developed and adopted to increase productivity within the design and construction domains, it can certainly be seen as a game changer for digital preservation as well. Table 2 shows a growing number of national bodies which have required BIM to be part of publically financed construction projects. These national bodies tend to stand in close connection to all three of the preservation scenarios mentioned above: as they are national agencies, the data they request will eventually be deposited to a national archive. In the case of the USA this might be The National Archive and Records Administration[31]. Meanwhile regulatory body – such as the General Service Administration - itself is responsible for the maintenance of the building, so the digital object will remain actively used there, most likely within a BIM server which enables the traceability of updates conducted to the building as part of maintenance or minor reconstruction over the course of years. In this context it is very well imaginable that there will be a growing need to implement preservation functionality on top of such BIM servers as the objects' capabilities will be further exploited more and more facility managers and building owners will realize the potential of BIM data availability. Lastly, BIM may ease the preservation of cultural heritage, as the information is available in a central object which significantly eases the maintenance.

While growing adoption of the file format may stand for longevity of the file format and while the standard itself presents strong sustainability factors, this paper has shown that a number of risks do exist. As a growing number of IFC files are already being produced today, the digital preservation and the AEC domains need to engage in joint efforts to identify, understand and manage these risks as early as possible.

[30] A validation tools is included in the buildingSMART certification platform: http://gtds.buildingsmart.com/

[31] http://www.archives.gov/publications/general-info-leaflets/26-cartographic.html#architect

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