Understanding technological interoperability through observations of data leakage in Building Information Modelling (BIM) based transactions

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The use of Building Information Modelling (BIM) and collaborative techniques have been identified as solutions to the problem of managing construction project information and data. However the implementation and success of BIM may stagnate due to issues associated with unsatisfactory technological interoperability, which can impede the flow of information through a project lifecycle. To gain further understanding of technological interoperability within a BIM-enabled project environment, a review of relevant literature was undertaken to assimilate key information and provide a framework for future research. An observational method of reviewing a series of data transactions between multiple BIM packages was then devised in order to assess interoperability issues, and inform future research design. Interim findings from the preliminary stage of this research project have been reported in this paper.

Keywords: *BIM, information technology, interoperability, technology transfer, data leakage*

INTRODUCTION

Poorly communicated and fragmented information is considered to be a contributing factor of construction project failure (Demian & Walters, 2013; Austin, Baldwin, & Newton, 1994), with several researchers identifying inefficiencies resulting in deficient decision-making (Ding et al, 2012; Kam, 2005), lifecycle management (Lucas, Bulbul & Thabet, 2013; Wong & Fan, 2013; Garba & Hassanain, 2004) and productivity (Eastman et al, 2011). All too often, information used within projects is assumption based, generated in isolation then homogenised resulting in potentially avoidable errors. Adherence to these traditional practices of information generation and management does not allow for information of potentially higher value to be captured during the complex and heterogeneous process of asset creation. As numerous disparate stakeholders are needed to reciprocate and recycle large quantities of information in order to make a series of interrelated decisions during the design, construction, maintenance and operational phases of a project lifecycle, a more holistic and collaborative approach to information management is required.

Building Information Modelling (BIM) and collaborative management techniques have been identified as potential solutions to managing construction project information, but the implementation and success of BIM may stagnate due to issues associated with unsatisfactory interoperability, with technological factors impeding the flow of information through the project lifecycle (Grillo & Jardim-Goncalves, 2010; Aranda-Mena et al, 2009). No single software is able to satisfy participants involved in the entire project lifecycle, leaving stakeholders to utilise a myriad of software packages to undertake functions necessary for project delivery and inabilities to exchange information accurately and seamlessly, generate further costly inefficiencies. Interoperability is defined by the IEEE as *"the ability to which systems and organizations work together exchanging information and resources"*. The aim of this paper is to enable further understanding of interoperability within a BIM-enabled project environment. To achieve this, a review of the salient literature is first necessary in order to assimilate key information about interoperability from technological and process orientated perspectives and to provide a framework for future research, then findings from an in-progress research project will be reported. A large body of literature is available relating to interoperability and BIM, that has had particular focus on the interoperability of data (Venugopal et al, 2012; Hetherington et al, 2011; Sacks et al, 2010a; Steel, Drogemuller and Toth, 2010), business (Grillo and Jardim-Goncalves, 2010; Shen et al, 2010; Aranda-Mena et al, 2009; Aranda-Mean and Wakefield, 2007), and software and web-based interoperability (Redmond et al, 2012; Toth et al, 2012; Chen et al, 2005). The literature has also considered the generation of frameworks to assess the value of interoperability at business level (Becerik-Gerber & Rice, 2010).

BIM AND INTEROPERABILITY

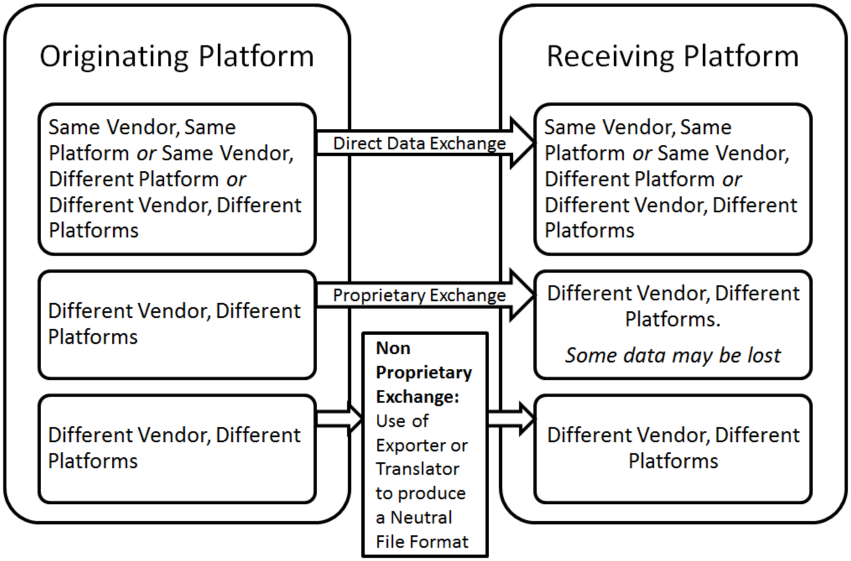
During the last decade, a paradigm shift has occurred in the way information is viewed, shared and organised within projects because of the proliferated use of Building Information Modelling. Multiple definitions of BIM refer to its application as a tool, a process, and a holistic information management methodology. *"consisting of a set of policies, processes and technologies"* (Succar, 2009, p.357). Despite the various definitions of BIM, there is consensus in relation to its implementation and usage occurring at strategic, organisational and project levels (Porwal & Hewage, 2013; Eastman et al, 2011; Kam, 2005) and benefits to be gained from an integrated approach combining people, processes and technology. As a consequence, it has been associated with collaborative methods of working such as Integrated Project Delivery (Wong & Fan, 2013), leading researchers to suggest this as the end goal of BIM maturity and other value-focused approaches such as Concurrent Engineering (CE) or Lean (Demian & Walters, 2013; Sacks et al, 2010b).

Similar to its implementation, the output/deliverable of BIM is also consistent throughout literature which a semantically linked, data-rich, object orientated, intelligent and parametric building information model (Eastman et al, 2011). The benefits and impact of BIM vary according to its context, definition and usage, where benefits can relate to the coordination and optimization of design, construction, maintenance and operational phases of a project lifecycle (Bryde, Broquetas & Volm, 2013; Wong & Fan, 2013; Ding et al, 2012). However, the implementation and large-scale BIM benefits remain generally unrealized due to issues of interoperability. Poor interoperability has been identified consistently as a major barrier for BIM implementation and usage and many researchers believe the benefits of BIM can only be realised if the associated interoperability issues are resolved (Demian & Walters, 2013; Porwal & Hewage, 2013; Azhar, 2011). Bryde, Broquetas & Volm (2013) suggest that poor software interoperability actually counteracts any benefits associated with BIM and collaborative working, most notably the inability to handle large quantities of data and exchange of data.

TECHNOLOGICAL INTEROPERABILITY

Literature relating to technological interoperability largely views interoperability from a software or data perspective, in which BIM is predominantly defined

Figure 1
Some common data exchange methods



as a tool (Toth et al, 2012). Shen et al (2010) and Venugopal et al (2012) argue that interoperable data alone is insufficient as it focuses purely on the interchange of data, and while the data may be exchanged freely, it does not account for quality or appropriateness for purpose. Therefore there is a need to view technological interoperability not only from a data perspective but also from a process perspective.

Data Interoperability

Data interoperability, within a BIM enabled project environment, focuses on the ability in which building information models are interpreted, shared and used between software applications (Grillo & Jardim-Goncalves, 2010; Shen et al, 2010). Eastman et al (2011) identifies four common methods of exchanging data that are depicted in Figure 1: Direct exchange of data using proprietary links within software, i.e. same vendor data exchange; Use of proprietary file exchange formats, i.e. simplified data formats which carry limited data between different vendors; Use of non-proprietary data model exchange formats, i.e. a neutral file format which can be used to exchange data between any software application that has a non-proprietary import and export function, and XML-based exchange formats (which will not be considered in this study).

The use of non-proprietary data models have been identified as the most favourable solution to interoperability, allowing successfully mapping between an applications' internal data structure and a universal data structure without the need for rework integrating data models (Grillo & Jardim-Goncalves, 2010). The other data exchange methods are restricted in terms of flexibility and inability to deliver 'smart' object data and limited data transfer (Eastman et al, 2011).

Direct Data Exchanges. The exchange of data through direct methods is hampered by its inability to integrate fully with software from other vendors. A possible solution could be the use of a master suite of software, however Ashcraft (2009) and Ibrahim, Krawczyk & Schipporeit (2004) argue that this method could limit innovation and would not account for every aspect of the building lifecycle. Using such methodology would raise additional issues such as hardware and resources required to utilise and maintain such an extensive approach.

Proprietary Data Exchanges. In relation to the use of proprietary file exchange formats, there is limited operability of such data exchanges as they are only able to transfer geometric data, and do not support the transfer of semantically linked descriptive objects (Eastman et al, 2011).

Non-Proprietary Data Exchanges. The most common non-proprietary data format utilised in the construction industry is Industry Foundation Classes (IFC). The IFC is a neutral data schema, conceived by buildingSMART (formerly the IAI) in 1995, with the intention of defining a common language for data sharing in the construction industry throughout a project lifecycle (Aranda-Mena & Wakefield, 2007). The IFC schema uses the ISO Express language (STEP-11) as its primary descriptor language (Grillo & Jardim-Goncalves, 2010), and is registered as an official international standard, ISO 16739:2013 This schema is a neutral data structure, which defines data relating to objects, attributes and relationships contained within a Building Information Model [1], consisting of multiple views which are used to define data set requirements depending on its intended purpose.

Process Interoperability

As well as data interoperability, frameworks associated with processes, information exchanges and requirements also need to be designed for interoperability if functionality between interoperable data models is to be ensured (Shen et al, 2010). Numerous methods of improving process interoperability within a BIM-enabled project environment defined by buildingSMART exist, including the Information Delivery Manual (IDM), Model View Definitions (MVD) and buildingSMART Data Dictionary (bSDD). These standards have been developed with the intention of improving IFC functionality, but the use of IDM's and the bSDD can be used for any exchange format.

Information Delivery Manual's and Model View Definition's. IDM's are registered as an official international standard, ISO 29481-1:2010 and are used as a method of improving process interoperability and functionality of data schemas, by describing subsets of project information at any step in the project workflow in order to fulfil the stakeholder's information requirements (Sacks et al, 2010a). However, there are limitations with the use of IDM's as they only define the tangibles where intangibles such as culture, value and management of contractual issues currently remain outside the scope of its coverage (Grillo & Jardim-Goncalves, 2010). Within an IFC schema, IDM's alone are insufficient to provide complete interoperability, as the IFC structure itself is highly redundant due to the varied options available to define the objects, relations and attributes, leaving data exchanges at risk of unreliability secondary to poor cohesiveness of data import and export (Venugopal et al, 2012; Steel, Drogemuller & Toth, 2010). In order to challenge this, MVD's are used to define how the information is structured within the IFC schema, a method supported by the National Building Information Modelling Standard (NBIMS). Model views are subsets of the entire schema which contain all the requirements used to satisfy specific information exchanges throughout the project lifecycle.

BuildingSMART Data Dictionary. In order to ascertain true coherency throughout the process there is a need to have a common language which defines processes and information within the IDM and the MVD [2,3]. The bSDD achieves this by defining a common vocabulary for objects within the IFC schema, bringing together disparate data sets and generating a coherent view of the information within the IFC schema [4]. The bSDD is based on the official international standard ISO 12006-3:2007.

This section established that technological interoperability does not only encompass the data interoperability but also discusses the need for considering technological interoperability from a process perspective, where the use of non-proprietary schema's were found to be the most suitable method for improving interoperability within a BIM-enabled project. In terms of how process interoperability is usually considered, several researchers have considered the more human aspects of process interoperability, particularly the impact that collaborative working has upon process dynamics (Rekola, Kojima, & Mäkeläinen, 2010; Tizani, 2007). Whilst it would be interesting to pursue how aspects of data filtering and comprehension are achieved throughout the common work of several diverse specialists, because of a need to limit scope, these aspects will not be considered in this work.

CURRENT STATUS OF TECHNOLOGICAL INTEROPERABILITY

The use of an IFC schema alongside an IDM, using MVD's and sBDD appears to be the most feasible solution to improving technological interoperability, however, noted usage throughout literature remains largely restricted to pilot projects and research conducted by industry or academia (Ma, Wei & Zhang, 2013; Redmond et al, 2012; Toth et al, 2012; Venugopal et al, 2012; Hetherington et al, 2011; Sacks et al, 2010a; Steel, Drogemuller and Toth, 2010; Chen et al, 2005). There currently appears to be an overreliance on direct software links to exchange information, though as discussed, the use of direct software links are rigid and often unable to deliver data throughout the entire project lifecycle. Current attempts to achieve technological interoperability involve the use of the Construction Operations Building information exchange (COBie).

Construction Operations Building information exchange (COBie)

COBie developed by the United States Army Corps of Engineers acts as a progressive record of information during a project lifecycle and has been integrated into the 2016 United Kingdom (U.K.) government target for collaborative 3D BIM on all public sector AEC projects - also known as Level 2 BIM Maturity - in attempts to improve information flow between capital phase and operational phases of a project lifecycle. Information within the capital phase of a project is captured through a series of data-drops at pre-defined stages of a project lifecycle (Lucas, Bulbul & Thabet, 2013). Instances of these data-capture points can be found at UK national level in the 2013 RIBA Plan of Works. The rigidity of this format produces little positive impact within the early stages of the project lifecycle, the information generated being evolutionary and iterative, as it only provides a one way information flow, resulting in inefficiencies associated to re-entry of the information if/when alterations are made. It could be argued that this was not its original purpose, though acts as a stepping stone to an integrated approach.

Associations and governments, realize that this method of technological interoperability is insufficient for an integrated approach, and view IFC as the solution to advancing technological interoperability, where the U.K. has identified the IFC schema in Level 3 of BIM maturity. Shen et al (2010) states that the widespread use of IFC has been limited due to the lack of resources for rapid development and promotion, where it could be considered that poor progress is limited due to software vendors focusing on their own proprietary functionality. Others (Aranda-Mena & Wakefield, 2007; Amour & Faraj, 2001) suggest that it may be due to socio-technological barriers such as skills, trust, training, interpretation. Grillo & Jardim-Goncalves (2010) believe that the reason for poor interoperability is poor understanding of the value associated with interoperability, and concludes that such technological interoperability is actually feasible. This view is contradicted by researchers who believe that the IFC schema in its current state is insufficient due to issues relating to information transfer and limited coverage of the schema (Delfosse et al, 2012; Hetherington et al, 2011).

IFC Limitations

Porwal & Hewage (2013) experienced that when implementing a potential BIM framework, IFC related issues relating to file generation, transference and data degradation meant that the information using IFC as the main source of file transfer was restricted to exchange between Architect's and Building Service Engineer's, which resulted in the team reverting back to using direct links between software. This is due to IFC's limited coverage, where objects not stated within the data schema are imported as mesh elements known as IFC 'proxy' elements (Venugopal et al, 2012; Steel, Drogemuller & Toth, 2010). Ashcraft (2009) argues that such issues lie not only with the IFC schema itself, but also the IFC translator embedded within the proprietary software.

Due to the various approaches to viewing the IFC schema, translators are often disparate to suit their primary function (Ashcraft, 2009), where some only provide one-way communication flow, as witnessed within Sacks et al (2010a) where the researchers used a version of IFC, IFC 2x2, which would not allow for two-way flow with the type of translator used, increasing the risk of potential information inconsistencies each time data was re-entered. Although rectified in the latest release of IFC 2x4, potential errors when exchanging information using IFC remain highlighted. As well as rework associated with IFC and its translators, IFC doesn't support the entire object information library of proprietary software, resulting in data loss through each import and export, degradation of information, and in some instances loss of semantic, descriptive and parametric functionality (Venugopal et al, 2012; Hetherington et al, 2011; Amour & Faraj, 2001). Ashcraft (2009) highlights that the inability to exchange data seamlessly and consistently could potentially result in litigious practices should errors related to re-entry or data-loss remain undetected. This highlights the flaw with viewing technological interoperability purely from a data perspective, as the implementation of process interoperability methods highlighted earlier could eliminate the risk of such issues, providing they are executed properly.

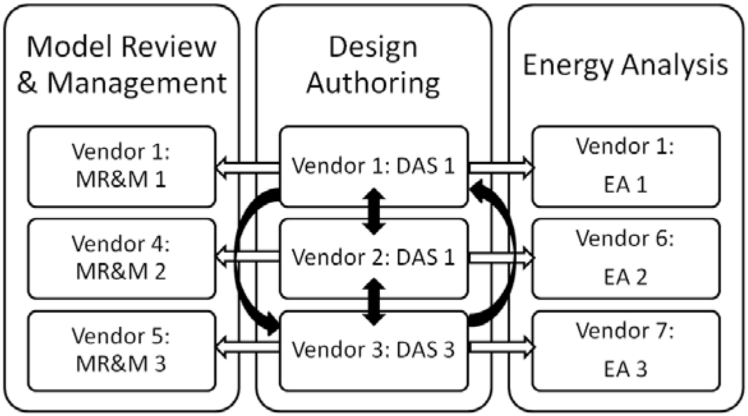
This lack of coverage also extends to building performance analysis, where in its current format; IFC inhibits the transfer of model details between BIM and Building Performance Software (Hetherington et al, 2011). Amour & Faraj (2001) argue that the limited coverage of IFC is actually due to its misinterpretations, where initial focus was intended for micro level aspects as opposed to macro, ensuring in its current state, the idea of an integrated repository using IFC remains undelivered with further development required to improve technological interoperability sufficiently to encapsulate the complex and evolutionary nature of the construction project.

METHOD

This section reports the interim findings from the preliminary stage of a research project. The purpose of this initial phase was to begin to develop a method of assessing technological interoperability by recording observations of data loss or leakage. Following the literature review, a series of data exchanges between multiple BIM platforms was planned, and an appraisal of 22 BIM enabled products commercially available in the UK was undertaken to determine the broad categories of BIM software types. Whilst descriptions of comparable products can vary widely between different vendors because of vendor marketing strategies there can also be instances where products offer combined functionality, for example 4D visualisation and clash detection functions can exist either in separate discrete BIM tools or can also be provided as a crossover product in model review and management software. Although the appraisal was not exhaustive, it was representative of the broad functional types of BIM software packages currently available which have been categorised as follows: Design authoring software (5 products); Energy analysis software (10 products); Model review and management software (5 products), Quantity take-off and measurement software (2).

A simple two storey model of a basic domestic dwelling was produced in each of the three BIM design authoring software packages, making use of objects available from a publicly available BIM object repositories. The originating model was then exported using various methods of exchanging data

Figure 2
Model of planned data exchanges. Arrows denoting several transactions between Design Authoring Software to Model Review & Management, packages and Design Authoring Software to Energy Analysis packages are omitted for clarity.



as detailed in the literature review to all other BIM design authoring software packages (bi-directional exchanges); three other model review and management software packages (one way data exchanges only). At the time of writing, there are several transactions yet to be undertaken from the design authoring platforms to the three selected energy analysis software platforms (one way data transactions).

By the time the research will have been completed, regardless of the actual higher number of data exchange transactions that will have occurred (unknown at present because of any multiples involved in any non proprietary exchanges), a minimum of 23 classifications of data exchange will have occurred, (Figure 2 illustrates these exchanges). 6 exchanges would occur from each design authoring platform to each receiving Energy analysis or Model review and management software packages (18 exchanges), and two way interoperability would be assessed between the three design authoring software packages (6 exchanges). No model manipulation would occur in the receiving platform upon completion of the transaction, other than a visual interrogation of the model and review of the data in the receiving application in order to assess model fitness for any subsequent tasks. Note that the top row of Figure 2 denotes same-vendor exchanges allowing for proprietary exchanges in addition to other types of exchanges detailed. The vendors own in-built Import/-Export functions were used rather than 3rd party applications in order to assess the quality of their functionality.

Whilst performing these exchanges, a 'soft' method of analysis was undertaken where the research team recorded observations where any obvious 'data leakage' had occurred. These were recorded using a simple checklist produced followed a review of appropriate academic and technical literature (including documentation from Pennsylvania State University, UK BIM AEC Protocols, AIA and BS 1192/BAS 1192.2). Upon completion of these preliminary tests, the checklist will be refined as the research team aims to make use of a more quantitative method of assessing technological interoperability.

INTERIM RESULTS

At this stage in the research two of the three rounds of classifications of data exchange have been completed: In Round 1, the bidirectional transactions between Design Authoring Software to Design Authoring Software (13 transactions) and in Round 2, the one way transactions from the Design Authoring Software packages to the Model Review & Management Software (21 transactions) occurred. Transactions between the Design Authoring Software to the Energy Analysis Software have yet to be undertaken. At this stage only broad observations have been reported.

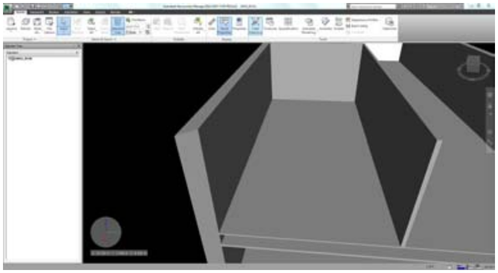


Figure 3
Transaction from design authoring software to model review and management software using a general translator for IFC 2 x 3

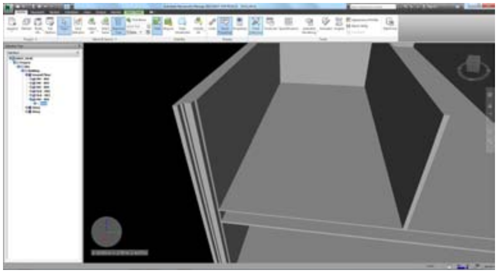


Figure 4
Separate transaction from same design authoring software to same model review and management software using different translator. Note difference in wall junction.

Round 1: Design Authoring Software to Design Authoring Software

There were several notable instances of poor interoperability in this round of transactions including some instances of wall & floor hatching not being transferred correctly and inconsistencies in the detailing of wall joints, with separately detailed wall joints not being transferred accurately. For example, detailed *Mitre joints* were consistently transferred from one platform to another, where in contrast any detailed *Butt joints* were not been correctly transferred. There was one transaction where the roof thickness was different in the receiving platform, and several instances where the naming of floor plans had not transferred across correctly. Component families often did not transfer across - several examples of this including different roof and floor types whilst suspended ceiling types did not transfer across; There were also some examples of components moving to incorrect locations, including internal walls relocating from level 1 to roof level, and the level 1 ceiling being imported at roof level.

Round 2: Design Authoring Software packages to the Model Review & Management Software

Although these transactions provided fewer instances of data leakage than in the previous round, there were also several notable observations, including substantial variances on the quality of the detail of wall joints in different transactions (see figures 3 and 4), and in minor instances wall objects being represented in different colour than originally designed. Construction detailing was not always apparent in the wall jointing, and dimensions would be displayed but the unit of measurement would not always be provided (i.e. m2, mm2, inches, etc). In some instances material assemblies were not shown, but more usually, material textures were not transferred across although the research team assumed that this is because of the different material libraries used by the separate vendors. Although this may be perceived to be a minor issue, this is something that the research team consider would create confusion in a site team, particularly in terms of confidence when relying upon a BIM. Finally, in some instances the research team could not always locate object GUID properties and cannot be sure that these items transferred across correctly.

DISCUSSION

This research project is at an early stage and only the interim results have been reported, it would appear that data leakage is more common when exchanging data between different design authoring software platforms than when transferring data to a platform specifically created for model review. The team has yet to complete the transactions and subsequent analysis of exchanges from Design Authoring

Software to the Energy Analysis Software packages is needed in order to verify this proposition, then following the final round of 'soft' analysis of data leakage, the team will need to review the processes, results and conclusions drawn from this preliminary stage of research before attempting to formulate a more robust method of measuring aspects of technological interoperability.

CONCLUSION

This immediate research highlights the need to consider technological interoperability within a BIM-enabled project environment from a process as well as a technology perspective to explore useful and seamless information exchanges. Whilst the research team are currently focused on the technology and process aspects of interoperability, they are aware of the limitations of failing to consider socio-technological aspects such as working cultures, values and management practices, raising the need for future research to address technological interoperability from a process-technology-socio perspective, an aspect omitted from this paper, due to the need to limit the initial scope. There are limitations associated with the research method selected and the partial progress of the data collection aspects of the project, however, this paper aimed only to provide an introduction to understanding technological interoperability by recording observations of data leakage that occurred from a series of transactions. Despite these instances, the most likely consequence of this work is confirmation that the use of the IFC schema appears to be the most feasible presently available solution; however improvements will be required in terms of semantic nature, functionality and comprehensiveness if the IFC format is to be used widely as the primary method for information exchanges.

This does raise questions - If a construction project is a constantly evolving process how can a single data schema cover the entire functionality of the building process, where certain objects are bespoke? A potential solution could be to simplify the schema to allow for easy customization by all project team members; however this could potentially lead to issues relating to integrity of the data schema. Another solution could be to educate the industry on how to correctly build upon the schema. The research raised another question in relation to the future development of the IFC schema. If the progress of the IFC development is slow due to the software vendors developing their own proprietary schemas, does the push for non-proprietary data schemas have enough commitment? BuildingSMART is a voluntary organisation and does not have the resources of the software vendors. Perhaps an integrated approach from all software vendors and buildingSMART focusing purely on the development of non-proprietary data schemas is needed.

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