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SIGNIFICANCE OF A SOFTWARE INTEROPERABILITY MATRIX FOR ARCHITECTURAL ENGINEERING AND CONSTRUCTION INDUSTRY

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SUMMARY: *Traditional project management applications are appeared working separately of their participating project teams and isolating the input of each team to both geometry and non-geometry of the project. With the introduction of Building Information Modelling (BIM), Architectural, Engineering and Construction (AEC) industry expected it would be a panacea as a tool to effectively collaborate project teams and to efficiently share geometry and non-geometry data relevant to not only design and construction but also covering the whole life-cycle of the project. All these BIM functions are relied on its automation capability; in other words, BIM vision totally discourages manual processing of data. As a result, good interoperability practice needs to pass data automatically between applications of different project teams. Many international associations are working in search of full interoperability among BIM players of the project; however, the goal is yet to succeed. The current study identifies the impact due to poor interoperability between applications and takes considerable effort to minimise or eliminate if possible. Software Interoperability Matrix (SIM) is the proposed solution delivering the outcome. Action research is the methodology adopted to develop SIM, in which researchers and professionals actively participated. Major industry contribution of SIM is to realise interoperability issues between BIM players prior to the project and upon identification, precautionary measures can be taken introducing new plug-ins or completely switching to new compatible application if it is the only solution.*

KEYWORDS: *BIM, AEC, Collaborate project teams, geometry and non-geometry data, Automation, Full interoperability, BIM players, SIM, Action research*

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1. INTRODUCTION

BIM applies object-based parametric modelling which enables automation with the changes of given parametric rules. These parametric rules combine different objects by sharing a large set of data among them. Therefore, BIM does not represent objects with fixed geometry and properties like traditional 3D Models or their 2D counterparts do. As a collaborator, BIM has the capability to coordinate and integrate all participating stakeholders all through the facility's life cycle in a construction environment. The stakeholders can be either internal or external upon the collaboration and main team players are from the client and the organisations of architectural, engineering, construction, fabrication, and facility management. The importance of BIM using for object-based parametric modelling and as a collaborator has clearly expressed in (NIBS 2007) for the vision of National Building Information Modelling Standard. Accordingly, standardised machine-readable BIM facilitates an improved planning, design, construction, operation, and maintenance process for each facility, new or old, which contains all appropriate information created or gathered about that facility in a format which can be used by all throughout its life cycle. In other words, the nature of BIM technology allows different stakeholders to use the BIM in multiple ways depending on the specific needs they may have (New York City Department of Design and Construction 2012).

This is theoretically well established; however, and practically, multiple BIM applications are required throughout the life cycle with required overlapping data for different design and construction intents.

In general, interoperability is the ability to exchange data between applications which is one of the biggest challenges on the way to fully integrated and collaborative project teams (McGrow Hill Construction 2014; Wegner 1996). A study conducted by McGrow Hill Construction (2014) states that 8 in 10 users of BIM software tools in the United States consider lack of interoperability between software applications to be a limiting factor in achieving the full potential of BIM. Without exception, international guidelines and standards have widely acclaimed this is one essential criterion to be noted and taken prior actions for successful BIM adoption; otherwise, badly impact on the project is unavoidable. Poor interoperability issues may not exchange data completely or partially from one application to another. In some instances, complete geometry exchange is possible; however, property and metadata can be lost; this is also regarded as poor interoperability. Without being aware of these at the project initiation, particularly in the planning phase, poor interoperability causes longer time delays to find solutions at the project implementation. This also incurs additional costs paid to vendors and as a result causes impact on project cost. It can be extremely worse in some situations when heavy conflicts occur between two BIM players of the project team which can perhaps be extended to even legal problems.

The current study attempts to track the interoperability issues in the form of a matrix; hence, the aim of this study is to develop a Software Interoperability Matrix (SIM) targeting the BIM models used in commercial and construction projects. SIM identifies impact due to poor interoperability between applications and takes considerable effort to minimise or eliminate if possible. As the first step, SIM provides a comprehensive list of software applicable to most BIM models. Working formats and capable export formats are also included under those software applications which allow two software applications at a time to compare and evaluate possible exporting formats. This not only assesses export efficiency with the ranks of none, partial and complete but also provides sufficient information and advice about the exchange problems. The benefits include that project team members can identify their software applications and check the export efficiency prior to project implementation. It will be particularly useful for BIM managers when creating tenders and extract information from design consultants, subcontractors/fabricators, and in-house construction managers. Based on SIM data, the viability of the sharing of two software applications can be checked and solutions to exchange issues can be introduced with new plug-ins or links having discussed with vendors. If the issues further persist, the option of change of familiar software to compatible software is also available. If the client has specific software demands due to exceptional modelling requirements of the project, then team members can easily adapt and find successful exchange solutions required using SIM.

2. LITERATURE REVIEW

BIM is not a single product or service but a result of a collective effort of design and construction teams and supported multiple software applications. Traditional 2D drawings and 3D model's objective was limited to supporting only geometry and layout verification; however, BIM vision is further extended for many other aspects where non-geometry is also required, such as: structural analyses, energy analyses, schedule generation,

fabrication support and specialised detailing. Manual processing of data is discouraged by BIM vision and good interoperability practice needs to pass data automatically between applications, and for multiple applications to jointly contribute to the work at hand (Eastman et al. 2011). Furthermore, considerable academic research validates the above fact stressing full interoperability between these applications (Kim et al. 2015; Laakso & Kiviniemi 2012; Ozturk 2020; Pauwels, De Meyer & Van Campenhout 2010; Pauwels et al. 2011; Pauwels, Zhang & Lee 2017). Hence, interoperability is a problem for successful BIM adoption in a construction project which is shared by many all around the world. Many international associations are working on the problem and their efforts are under way to establish standards, protocols, guidelines and best practices across the entire construction industry. The subsequent section is their voice.

In the US, several associations have confronted interoperability issues and developed guides for future BIM adopted construction projects. The Associated General Contractors of America emphasises that interoperability is one criterion you should look for in a BIM tool – the tools you use should work well with other software, as being able to interchange document formats or convert documents helps (Associated General Contractors of America 2006). They have provided a matrix of 'example BIM tools' which provides some extent details about various BIM tools, may be helpful selecting a BIM tool upon intended BIM use; however, this matrix does not converse interoperability between different BIM tools. US National Building Information Modelling Standard (NIBMS) identifies the role of interoperability to provide seamless data exchange at the software level among diverse applications, each of which may have its own internal data structure (NIBS 2007). It mainly relies on achieving interoperability by mapping parts of each participating application's internal data structure to a universal data model and vice versa. Its recommended open universal data model has the ability to make any application participate in the mapping process and thus become interoperable with any other application that also participated in the mapping. It strongly believes that interoperability eliminates the costly practice of integrating every application (and version) with every other application (and version).

Software compatibility and data flow test has been recommended to be included in BIM Management Plan (BMP) by the US Department of Veterans Affairs (VA 2010). It is strongly reliant on Industry Foundation Class (IFC) enabled software models that the models not IFC compliant are only permitted with the permission of VA. Versioning of software shall be managed by the BIM teams throughout the project lifecycle. BIM guidelines developed by the New York City Department of Design and Construction (2012) encourages the use of software applications that foster collaboration throughout the design and construction process. The level of interoperability and collaboration may be increased by software applications produced by the same developer but specific to each discipline. The protocol developed by (OFCC 2012) has not requested specific BIM authoring software applications; however, all members of the design team shall provide models and data in the format necessary to support the model level of detail required for the project. Specific deliverable file formats upon requirements of specific projects will be described in the request for professional services and bidding documents for those projects. Open architecture embedded software applications (software based on or using open standards) are recommended for greatest interoperability between consultants, contracting authority, and owner facility maintenance and management systems. IFC compliance with the latest version of IFC is recommended for those applications.

ERDC (2012) has taken continual efforts to advocate for technology interoperability in the market in order to maintain the broadest options for software selection based on cost effectiveness and end user satisfaction. It has also implemented COBie and other open data standards, which will promote further coordination along similar lines for operations-related deliverables. Computer Integrated Construction Research Program (2013) reports that software needs to be selected to support the BIM uses. They have seen the list of software packages that support BIM implementation is constantly shifting and growing. Another important guide of theirs to select software is that the organisation knows what they need the software to support and keeps in mind that one software package may support multiple BIM uses. For greater interoperability, most BIM guides and standards recommend adopting IFC enabled BIM models. This is no exception to the MIT Department of Facilities (2012) and GSFIC (2013). However, GSFIC is aware of issues related to converting BIM files to IFC format from the native file format and therefore acknowledges that the IFC format is not completely robust at this time. Therefore, architects/ engineers' responsibility is to document any known issues with IFC BIM at the time of upload. The list of issues should be submitted as a word document to accompany the BIM file.

General Services Administration (GSA) BIM Guide Series has also recommended and encouraged the open standard for information exchange (GSA 2007). GSA is still using proprietary data formats for many 3D-4D BIM

applications due to the absence of such a current standard widely supported by software applications. Their recommended IFC defines a structure for BIM data that is independent of individual applications. This is a useful feature for interoperability and can be used to exchange BIM data among different applications and participants in a building project. Hence, vendor-neutral IFC schema for BIM is the backbone of a process and technology that enables software vendors and end user organisations to achieve interoperability between a wide array of application types for the building industry (GSA 2007). Georgia Tech (GT) is another organisation that adopted open architecture for interoperability in their BIM requirements and guidelines. They are aware that the project team may use any BIM software capable of delivering the necessary requirements during the design and construction process but they encourage them to use products based on or using open architecture for the greatest interoperability between consultants and GT (GIT 2011). Their pre-approved information exchange formats include Construction Operation Building information exchange (COBie), IFC and OmniClass.

British Standard Code of Practice- Collaborative production of architectural, engineering and construction information-BS 1192: 2007 guides that projects should follow a common set of generic processes at the highest level, which are fine-tuned on a project-by-project basis. Co-ordination of the project model files as they develop are to be applied to project design production (BSI 2007). In asset management perspective, the method of information exchange shall be compatible with the systems and processes operated by the organization in order to ensure that the material can be checked, validated and then be made use of in the day to day operations (BSI 2014). AEC-UK (2012) has given paramount importance to interoperability between software products for successful BIM working. The same protocol has stated that requirements and limitations of the target software/hardware system shall be understood in order that BIM data can be prepared appropriately for exchange prior to data transfer between different software platforms. Similarly, data exchange protocol between different software/hardware systems shall be verified through sample testing to ensure data integrity is maintained. In 2015, the UK turned to BIM mandatory for public construction projects; hence, necessary precautions are required for interoperability issues.

Norwegian Home Builders Association (2012) has expressed the importance of finding sensible interchange formats that handle the most possible information, and which most people can benefit from. Such could be IFC, gbxml or other open model formats, model files in proprietary format, smc files, Excel spreadsheets, text documents, dwg or other. According to NATSPEC National BIM Guide in Australia, testing of software compatibility is one of the main parts of the construction BIM manager's role (NATSPEC 2011). It also believes that greater interoperability can be gained with Information supporting common industry deliverables provided in existing open standards, where available, and that way, lifecycle use of building information is guaranteed. In situations where open standard formats have not yet been finalised for those contract deliverables, mutual agreed formats can be used allowing the re-use of building information outside the context of the proprietary BIM software. IFC and COBie are prominent standards accounted for open standards. In Hong Kong, the Hong Kong Institute of Building Information Modelling recommends BIM models being created using suitable authoring software applications which are IFC compliant to allow BIM model interoperability (Hong Kong Institute of Building Information Modelling 2011). In Singapore, the Building and Construction Authority- Singapore says that interoperability is very important and provides the essence of the agreement between collaboration parties and is a significant part of the BIM exchange protocol (proprietary or open standard) in the BIM Execution Plan (Building and Construction Authority- Singapore 2013).

The organisation buildingSMART is an international association that develops standards, tools and training to ensure that the industry knows what open BIM is and how to use it effectively to achieve greener, leaner and more efficient buildings and infrastructure (buidlingSMART 2015). BuildingSMART was formerly known as the International Alliance for Interoperability (IAI) and founded as worldwide interest in product modelling for the construction sector expanded. In 1995 it became an open, not-for-profit industry-led organisation promoting the Industry Foundation Class (IFC) as a neutral product model supporting the building lifecycle. They help new BIM users to gain familiarity. The buildingSMART alliance is made up of Chapters and Members: Chapters are local membership organisations in specific countries principally concerned with the implementation of open BIM within that country. These chapters are led by and members of the parent body buildingSMART International, Membership of buildingSMART International is also open to corporate entities worldwide. Currently there are 16 Chapters representing: Australia, Benelux, Canada, China, French, German, Hong Kong, Italia, Japan, Korea, Middle East, Nordic (Finland and Sweden), Norway, Singapore, United Kingdom and USA.

BuildingSMART Finland chapter, in their common BIM requirements report, recommends minimum of IFC 2×3 certification for software modelling of BIM adopted public projects (buildingSMART Finland 2012). However, the report further mentioned that this requirement can be overridden with project requirements. Moreover, designers need to specify all the BIM software and their versions, and what version of IFC they include in the tender documents. It is also important having a mutual agreement between project participants on all version or software changes during the project. Carrying out of a testing phase is strongly required before the final decision of adaption to new versions. The use of non-IFC-certified file formats at the official decision points of the project must be accepted by the project management. Simultaneously all mutually agreed data exchange methods and formats may be used in the daily work as stressed by buildingSMART Finland (2012) shown below:

> *In some cases, the Client can specify the software used in the project. For example, construction companies are developing their own BIM processes around specific design software solutions and they may require the use of these design tools. Moreover, the Client may have specific software demands if the project has exceptional modelling requirements or there is for example process development in parallel to the project- Guideline.*
>
> *(buildingSMART Finland 2012)*

All these BIM standards and guidelines reviewed have identified information exchange and interoperability between different applications is a major aspect in BIM execution and included among common contents of their reports (FIATECH 2013). However, for all this discussion and debate about the importance, there are very few tools that actually help people on the ground in terms of understanding the level of interoperability between software programs. Even available tools may be developed in-house and customised to their needs or focusing only on specific projects or still experiencing difficulties in data sharing or inefficiencies of data integration (Ozturk 2020). Hence, they can be approached and used by only those participating organisations and public access is restricted. In some cases, vendors may provide the level of interoperability for their suite of software and with other vendors' software, it is often hidden. Given that seamless integration of a suite of commercial applications based on open standards is improving but has not yet been fully demonstrated, a necessity arises now for a mean to understand the level of interoperability of proprietary data formats until those open standards are fully grown. Currently several exchange practices have been tested; as a result, direct data exchange between proprietary tools using other approaches to IFC based such as Application Programming Interfaces (APIs) and Extensible Mark-up Language (XML) formats has been a common practice to some extent as well. The proposed software interoperability matrix tool will explore a comprehensive list of BIM software and their information exchange arrays and, will provide a perfect solution to understand the level of interoperability. This has been developed targeting generic practice of BIM in commercial building projects, health building projects and infrastructure projects; hence, BIM users have the opportunity to utilise SIM for their specific projects.

3. RESEARCH METHODLOGY- DEVELOPMENT OF SOFTWARE INTEROPERABILITY MATRIX TOOL

Action research is a flexible enquiry process carried out by individuals, professionals and/or educators within a professional practice to continually understand, evaluate, and change to improve practice (Frost 2002; GTCW 2002(a); Koshy 2009). Hence, action research approach of the research methodology is applied to develop SIM. It involves implementing actions which change existing programs and practices, and the subsequent analysis of what happens (Rossman & Rallis 2011). As per the action research, the first author got involved in professional practice with the industry partner. Action research was implemented in five iterative phases as shown in FIG 1.

A prototype for this study is defined as an aid that would provide information to the staff member in the organisation and assist in their decision-making processes when adopting Building Information Modelling. A prototype is a form of instruction and could include various formats; a guideline, tool, checklist, flowchart or matrix. For this study, a matrix was identified suitable for recording interoperability of different software. Accordingly, an iterative process undergoing five major phases applied to the development of Software Interoperability Matrix (SIM). As earlier mentioned, that the first author got involved with the industry partner, he is accountable for data collection from professional BIM users in view of modifying preliminary prototypes to industrial endorsed prototypes. As the first activity, first round data collection was conducted during this phase. Four main respondents (we call them key informants) were targeted in the data collection from the industry partner either with a great awareness of or fluent hand on experience on BIM. Once the data collected, the next step is to

analyse data for developing the prototype. Verifying or pilot testing of the prototype is essential prior to check its validity on field. Phase three was dedicated for the task in which the first activity was to pilot test the prototype by the key informants. Then, fine tuning of the prototype was carried out based on their feedback. After this activity, prototype is ready for testing it on field which was done in phase four. The case provided by the industry partner was supposed to be used for validity of the prototype in phase five. Due to the time constraint of the project, phase five could only carry out through a hypothetical case.

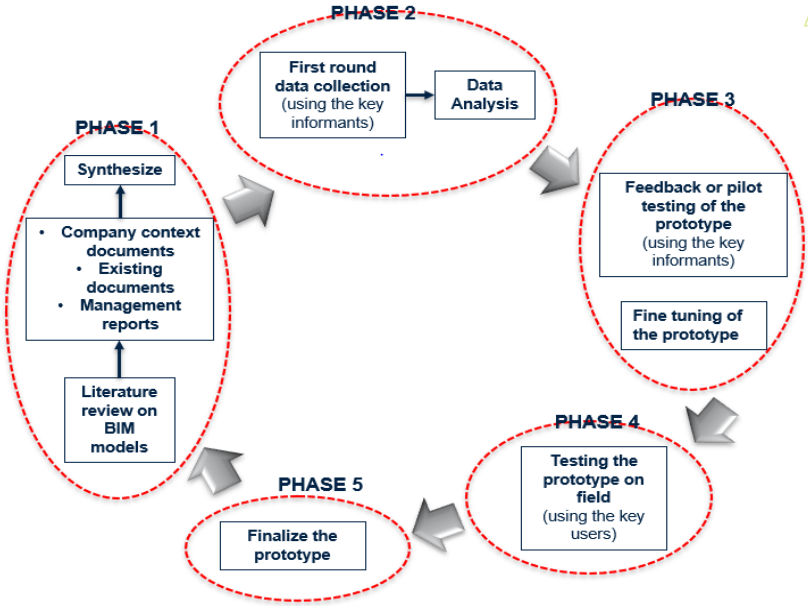

FIG 1: Action research plan for developing SIM prototype

A summarised description of phases is given in Table 1:

Table 1: Major phases applied in developing SIM

Phase	Description
Phase 1: Literature and context	Materials obtained from extensive literature review along with the review of company context documents are synthesized to develop the preliminary SIM prototype
Phase 2: Creation of prototype of SIM	Creation of SIM prototype involves data collection from professionals, who are responsible for BIM implementation service support within the organisation and hence referred to as key informants of the organisation, to allow the creation of SIM. Once the data is collected, the next step is to analyse data for developing SIM.
Phase 3: Initial pilot testing of the prototype	Verifying or pilot testing of the prototype (SIM) is essential prior to checking its validity on field. Phase 3 is for initial pilot testing of the prototype; hence, the SIM will be pilot tested by the key informants. Fine-tuning of the SIM is carried out based on their feedback.
Phase 4: Field testing of the prototype	SIM tools are ready for testing them on field which will be done in Phase 4. Accordingly, respondents from key stakeholders, that actively participate in BIM implementation, are selected for testing the pilot tested SIM on field. The final SIM is developed on the basis of their feedback.
Phase 5: Project testing of the prototype	Consequently, the SIM is finalised for BIM implementation ready for testing on a live case study construction project, which will be done in Phase 5 (Hypothetical case study was used due to the time constraint of one year of the project).

4. RESULTS AND DISCUSSION

A comprehensive knowledge of the available commercial BIM applications and capabilities is a driving force to understand interoperability. Between them, importing and exporting capabilities from their native file formats and other available formats will be greatly useful for the above aspect. The nature of BIM technology allows different stakeholders to use the BIM in multiple ways depending on the specific needs they may have (New York City Department of Design and Construction 2012). In real BIM practice, the software can be identified in two distinctive groups depending on the purpose it is used for: Authoring and Collaboration. Design authoring is a process in which 3D software is used to develop a BIM based on criteria that are important to the development of the building's design (New York City Department of Design and Construction 2012). Hence authoring software can be regarded as design tools to create models for different disciplines in the project team. Disciplines that use authoring software can be mainly listed to the following disciplines:

- Architecture & Landscape
- Structural
- Mechanical (HVAC)
- Electrical, Communications & Security
- Fire Services
- Hydraulic Services
- Civil

At a more detailed level, there may be intra-disciplines for each of the broad disciplines; for example, base building and landscape model will be created by the main architectural firm and tenants fit outs will be created by another architectural firm/s. Collaboration software applications foster, as the name suggests, collaboration throughout the design and construction. These may mainly cover following discipline areas:

- Model Visualisation
- Spatial Coordination
- Schedule Planning- 4D Modelling
- Cost Estimation- 5D Modelling
- Facility Management- 6D Modelling

Once the software is figured out, the format is the next important concern in terms of interoperability. In practice, Most BIM software comes with a working format which is the main format the software would be created and exporting formats which enables the model in convertible formats and export to another software applications. The first tool in the process of developing SIM is to collate potential industrial BIM software applications and their formats, both working and export, with the intended discipline use. The tool forms a four main column table where the columns are Discipline, Intra-discipline, Software and Data Format respectively. The fourth and last column has been again divided into sub-columns to show the working format and export formats of the software. The list of software is developed in consultation with key informants and following the review of several literature and company context documents. The result is the inclusion of most common software that the industry would use for future BIM adopted projects. SIM Tool 1 provides an aggregated list of software to be used in different disciplines in a BIM integrated project, applicable to the construction of commercial buildings and infrastructure, and also their working and export formats (see ***Error! Reference source not found.*** and ***Error! Reference source not found.***). For a particular project which is gearing for BIM integration and at the initial stage, this will provide the project team a comprehensive knowledge of software each discipline would use to create and share their models. This particular information will be carried out to SIM tool 2 to check the export efficiency between authoring and collaboration software, in other terms their interoperability. Tool 1 has built-in automation to pass this particular information to Tool 2.

Table 2: SIM tool 1- for construction of commercial buildings

Discipline	Intra-Discipline	Software	Data Format	
			Working Format	Export Formats
Architecture & Landscape*	● Base Building and Landscape ● Tenant Fit-outs	Revit	rvt	rvt,dwg, dxf, dgn, nwc, fbx, ifc, sat
		Archicad	pln	pln,dwg, dxf, dgn, nwc, smc, fbx, ifc
		Bentley Architecture	dgn	dgn,dwg,dxf, ifc
Structural*	● Base Building and Landscape ● Tenant Fit-outs	Revit	rvt	rvt, dwg, dxf, dgn, nwc, fbx, ifc, sat
		Bentley Structures	dgn	dgn,dwg,dxf, ifc
		Tekla Structures	ifc	ifc
		Advance Steel	dwg	dwg, sat, dwf, ifc
		ProSteel	cis/2	cis/2, sdnf, pxf
Mechanical (HVAC)*	● Base Building-Design ● Base Building-Workshop ● Tenant Fit-outs-Design ● Tenant Fit-outs-Workshop	Revit	rvt	rvt, dwg, dxf, dgn, nwc, fbx, ifc, sat
		CADmep	dwg	dwg, nwc, ifc
		DDS-CAD	dwg	dwg, dxf, dwf, ifc
Electrical, Communications & Security*	● Base Building-Design ● Base Building-Workshop ● Tenant Fit-outs-Design ● Tenant Fit-outs-Workshop	Revit	rvt	rvt, dwg, dxf, dgn, nwc, fbx, ifc, sat
		CADmep	dwg	dwg, nwc
		DDS-CAD	dwg	dwg, dxf, dwf, ifc
Fire Services*	● Base Building-Design ● Base Building-Workshop ● Tenant Fit-outs-Design ● Tenant Fit-outs-Workshop	Revit	rvt	rvt, dwg, dxf, dgn, nwc, fbx, ifc, sat
		AutoSprink	dwg	dwg
Hydraulic Services*	● Base Building-Design ● Base Building-Workshop ● Tenant Fit-outs-Design ● Tenant Fit-outs-Workshop	Revit	rvt	rvt, dwg, dxf, dgn, nwc, fbx, ifc, sat
		CADmep	dwg	dwg, nwc
		DDS-CAD	dwg	dwg, dxf, dwf, ifc
Civil*	● Base Building and Landscape ● Tenant Fit-outs	Civil 3D	dwg	dwg, nwc
		12D	12da	12da, ifc
		Mircostation	dgn	dgn
		Terramodel	tml	tml, dtm, dxf
Model Visualization**	●Base Building and Landscape ● Tenant Fit-outs	3ds Max Design	3ds Max (*.max)	
		Showcase	Autodesk 3D Scene File (*.a3s)	
		SketchUp Pro	SketchUp Models (*.skp)	
Spatial Coordination**	● Base Building and Landscape ● Tenant Fit-outs	Navisworks	nwf	
		Solibri	smc	
		Bentley Navigator	ifc	
Schedule Planning- 4D Modelling**	● Base Building and Landscape ● Tenant Fit-outs	Navisworks	nwf	
		Synchro	Synchro Projects (*.sp)	
		RIB iTWO	RIBiTWO	
		Innovaya	inv	
		Vico Control	ifc	
Cost Estimation- 5D Modelling**	● Base Building and Landscape ● Tenant Fit-outs	Cost-X	dwfx, ifc	
		Navisworks	nwf	
		RIB iTWO	RIBiTWO	

Discipline	Intra-Discipline	Software	Data Format	
			Working Format	Export Formats
		DProfiler	bak,sim	
		Innovaya	inv	
		Vico Cost Estimator	ifc	
Facility Management- 6D Modelling**	● Base Building and Landscape ● Tenant Fit-outs	WebFM	ifc model (ifcxml)	
		Zuuse	ifc model (ifcxml)	
		VEO	ifc model (ifcxml)	
		EcoDomus FM	ifc model (ifcxml)	
		Zutec	ifc model (ifcxml)	
		Bentley Facilities	ifc model (ifcxml)	

Table 3: SIM tool 1- for construction of infrastructure

Discipline	Software	Data Format	
		Working Format	Export Formats
Architecture & Landscape*	Revit	rvt	rvt,dwg, dxf, dgn, nwc, fbx, ifc, sat
	Archicad	pln	pln,dwg, dxf, dgn, nwc, smc, fbx, ifc
	Bentley Architecture	dgn	dgn,dwg,dxf, ifc
Structural*	Revit	rvt	rvt,dwg, dxf, dgn, nwc, fbx, ifc, sat
	Bentley Structures	dgn	dgn,dwg,dxf, ifc
	Tekla Structures	ifc	ifc
	Advance Steel	dwg	dwg, sat, dwf, ifc
	ProSteel	cis/2	cis/2, sdnf, pxf
Roads*	Bentley MX Road	dtm	dgn, dwg, LandXML
	AutoCAD Civil 3D (Road Module) (Infraworks)	dwg	dwg, nwc
Bridges*	Bentley Bridge Information Modelling (BRIM)	dtm	dgn, dwg, LandXML
	AutoCAD Civil 3D (Bridge Module) (Infraworks)	dwg	dwg, nwc
Rail*	Bentley MX Rail	dtm	dgn, dwg, LandXML
	Autodesk Rail Layout Module	dwg	dwg, nwc
Tunnels*	AutoCAD Civil 3D	dwg	dwg, nwc
	Bentley Inroads	dtm	dgn, dwg, LandXML
Power*	Autodesk Utility Design	dwg	dwg, nwc
	Bentley Utilities Designer	dgn	xfm, rdbms
	Bentley power generation solution	Adaptive information model data format based on ISO 15926	dgn, dwg
Geotechnical*	Bentley's gINT & GeoStructural Analysis	dtm	dgn, dwg, LandXML
	Autodesk Geotechnical module	csv	dwg, dgn
Mechanical (HVAC)*	Revit	rvt	rvt,dwg, dxf, dgn, nwc, fbx, ifc, sat
	CADmep	dwg	dwg, nwc
	DDS-CAD	dwg	dwg, dxf, dwf, ifc
	Revit	rvt	rvt,dwg, dxf, dgn, nwc, fbx, ifc, sat
	CADmep	dwg	dwg, nwc

Discipline	Software	Data Format	
		Working Format	Export Formats
Electrical, Communications & Security*	DDS-CAD	dwg	dwg, dxf, dwf, ifc
Fire Services*	Revit	rvt	rvt,dwg, dxf, dgn, nwc, fbx, ifc, sat
	AutoSprink	dwg	dwg
Hydraulic Services*	Revit	rvt	rvt,dwg, dxf, dgn, nwc, fbx, ifc, sat
	CADmep	dwg	dwg, nwc
	DDS-CAD	dwg	dwg, dxf, dwf, ifc
	Bentley Water and Wastewater	dtm	dgn, dwg, LandXML
	Autodesk Storm and Sanitary analysis	dwg	dwg, nwc
Civil*	AutoCAD Civil 3D	dwg	dwg, nwc
	12D	12da	12da, ifc
	Microstation	dgn	dgn
	Terramodel	tml	tml, dtm, dxf
Model Visualization**	3ds Max Design	3ds Max (*.max)	
	Showcase	Autodesk 3D Scene File (*.a3s)	
	SketchUp Pro	SketchUp Models (*.skp)	
	Infraworks 360	3ds, dae, dxf, FBX, obj	
Spatial Coordination**	Navisworks Simulate / Manage	nwf	
	Bentley Navigator	ifc	
	Solibri (Rule Checking)	smc	
Schedule Planning- 4D Modelling**	Navisworks Simulate / Manage	nwf	
	Primavera P6	xer	
	Synchro	Synchro Projects (*.sp)	
	RIB iTWO	RIBiTWO	
	Innovaya	inv	
	Infraworks 360 (static staging only)	3ds, dae, dxf, FBX, obj	
	Vico Control	ifc	
Cost Estimation- 5D Modelling**	Cost-X	dwfx, ifc	
	Navisworks Simulate / Manage	nwf	
	RIB iTWO	RIBiTWO	
	DProfiler	bak,sim	
	Innovaya	inv	
	Vico Cost Estimator	ifc	
Operation & Maintenance / Asset Management*	AssetWise	ifc model (ifcxml)	
Facility Management (Buildings) - 6D Modelling**	WebFM	ifc model (ifcxml)	
	Zuuse	ifc model (ifcxml)	
	VEO	ifc model (ifcxml)	
	EcoDomus FM	ifc model (ifcxml)	
	Zutec	ifc model (ifcxml)	
	Bentley Facilities	ifc model (ifcxml)	

The purpose of SIM Tool 2 is now to check the export efficiency between the authoring and collaboration software, which is very important for the project team collaboration and models integration. Export is referred here authoring file format is sent to collaborative software platform and check how the required work of collaborative software is compatible with. If total functions work as required; then, it is called 'Complete Export Efficiency' whereas only some functions can be worked; then, it is called 'Partial Export Efficiency'. If no functions can be worked; then, it is called 'None Export Efficiency'. Similar to Tool 1, Tool 2 is also expressed in a table format. The table includes six columns, and they are namely 'Authoring Software', 'Collaborating Software', 'Export Format', 'Export Efficiency', 'Remarks (Problems/Solutions)' and 'Contacts (Experts/Organisations)'. Export efficiency will be categorised as either None, Partial and Complete. In a partial export situation, there may be a possibility to lose data in terms of Geometry, Relations, Properties and Meta data. 'Complete' is regarded as exchange of data with no data loss and identical to the original data source whereas 'None' has no ability to transfer even single correct information of authoring software to collaboration software. **Geometry Data** is data connected with geometry such as solids, extrusions, shapes and **Relations** link one object with another(e.g. windows, doors link to a wall). Similarly, **Properties** are used together to define material, a particular type of performance and contextual properties(e.g., common roof, beam reinforcements). **Metadata** is only related to the information used and managed over time(e.g., information ownership, tracking of changes, controls and approvals).

In the presence of high technical content nature, an example will be supported for the explanation of Tool 2. For the example, ArchiCAD will be taken as the authoring software and Navisworks will be the collaboration software. According to the captured details from Tool 1, the working format of ArchiCAD is pln and, dwg, dxf, dgn, nwc, smc, fbx and ifc are other available export formats. Collaboration software applications are only applicable to working format; hence, nwf (nwc is its cache file) is the corresponding working format of Navisworks. The export is referred here from ArchiCAD to Navisworks; therefore, the export of each listed formats of ArchiCAD will be compared with Navisworks. Accordingly, eight combinations can be created for the model export from ArchiCAD to Navisworks and they are shown in ***Error! Reference source not found.***. The results show that a model developed in ArchiCAD can be completely exported to Navisworks with the use of its nwc export format. In contrast, export efficiency using two of its export formats in fbx and smc is 'None' and, five other formats including the working format pln have the potential to partial data exchange if only used NWC File Export Utility. All situations, it supports the transfer of object geometry and associated meta data, which means the possible data loss of relations and properties. Autodesk and Graphisoft are the contacting organisations for these exporting combinations. Captured through various collection methods such as key informants' experience of models transfer, referring of context documents/ websites/ blogs, there has been 895 combinations embedded into the SIM Tool 2.

Table 4: Example for SIM tool 2- exporting combinations of ArchiCAD and Navisworks

Authoring Software	**Collaborating Software**	**Export Format**	**Export Efficiency**	**Remarks (Problems/ Solutions)**	**Contacts (Experts/ Organizations)**
ArchiCAD	Navisworks	pln	Partial	Has to use NWC File Export Utility. Supports transfer of object geometry and associated meta data	Autodesk/ Graphisoft
ArchiCAD	Navisworks	nwc	Complete	Complete	Autodesk/ Graphisoft
ArchiCAD	Navisworks	dwg	Partial	Has to use NWC File Export Utility. Supports transfer of object geometry and associated meta data	Autodesk/ Graphisoft
ArchiCAD	Navisworks	dxf	Partial	Has to use NWC File Export Utility. Supports transfer of object geometry and associated meta data	Autodesk/ Graphisoft
ArchiCAD	Navisworks	dgn	Partial	Has to use NWC File Export Utility. Supports transfer of object geometry and associated meta data	Autodesk/ Graphisoft
ArchiCAD	Navisworks	fbx	None	None	Autodesk/ Graphisoft
ArchiCAD	Navisworks	ifc	Partial	Has to use NWC File Export Utility. Supports transfer of object geometry and associated meta data	Autodesk/ Graphisoft
ArchiCAD	Navisworks	smc	None	None	Autodesk/ Graphisoft

Some may argue knowing of interoperability details between authoring software and collaboration software is sufficient for BIM collaboration; however, collaboration even happens between authoring software of which data sharing is somewhat required for models development. This objective is achieved from the last tool of SIM, called Tool 3, which is to facilitate the need of interoperability details between authoring software. Due to the technical nature applicable with the tool, similar tactic with an example demonstration in Tool 2 will be applied for Tool 3 to explain about it. Tool 03 will help checking interoperability between software applied between different disciplines (inter- disciplines e.g., Revit for Architectural model and Bentley Structures for Structural model) as well as within the same discipline (intra-disciplines e.g., Revit for Architectural base building model and ArchiCAD for tenant fit out model). Except the changes to first two columns as authoring software 1 and authoring software 2, table format for Tool 3 is very identical to the table with six columns and descriptions used in Tool 2. For the example, Revit and ArchiCAD have been selected for two authoring software. The export of available formats between software has been considered occurring in both directions i.e., from Revit to ArchiCAD and vice versa. This has created 16 exporting combinations between two software, and they are shown in ***Error! Reference source not found.***.

Table 5: Example for SIM tool 3- exporting combinations of Revit and ArchiCAD

Authoring software 1	**Authoring Software 2**	**Export Format**	**Export Efficiency**	**Remarks (Problems/ Solutions)**	**Contacts (Experts/ Organizations)**
Revit	ArchiCAD	rvt	None	None	Autodesk/ Graphisoft
Revit	ArchiCAD	nwc	None	None	Autodesk/ Graphisoft
Revit	ArchiCAD	dwg	None	None	Autodesk/ Graphisoft
Revit	ArchiCAD	dxf	None	None	Autodesk/ Graphisoft
Revit	ArchiCAD	dgn	None	None	Autodesk/ Graphisoft
Revit	ArchiCAD	fbx	None	None	Autodesk/ Graphisoft
Revit	ArchiCAD	ifc	Complete	with the help of GRAPHISOFT ArchiCAD Connection Add-In	Autodesk/ Graphisoft
Revit	ArchiCAD	sat	None	None	Autodesk/ Graphisoft
ArchiCAD	Revit	pln	None	None	Autodesk/ Graphisoft
ArchiCAD	Revit	nwc	None	None	Autodesk/ Graphisoft
ArchiCAD	Revit	dwg	None	None	Autodesk/ Graphisoft
ArchiCAD	Revit	dxf	None	None	Autodesk/ Graphisoft
ArchiCAD	Revit	dgn	None	None	Autodesk/ Graphisoft
ArchiCAD	Revit	fbx	None	None	Autodesk/ Graphisoft
ArchiCAD	Revit	ifc	Complete	with the help of GRAPHISOFT ArchiCAD Connection Add-In	Autodesk/ Graphisoft
ArchiCAD	Revit	smc	None	None	Autodesk/ Graphisoft

The results show only ifc format with the help of Graphisoft ArchiCAD connection add-in has the ability to completely transfer data between Revit and ArchiCAD both ways. All the other formats are not even in the position

to transfer single data between two software models. Autodesk and Graphisoft can be contacted for interoperability issues between these two.

The next step of the process is to imagine a new project scenario for each construction type (Commercial buildings and Health buildings) and, their interoperability issues will be checked using SIM. In the absence of a new project of industry partner which is easily adaptable to the developed SIM configuration, the project has changed the direction to use such a new hypothetical project scenario from real case studies. In this way, researchers are quite confident that the experience gained is quite useful in upcoming real projects' application. The report provides a scenario for a construction project of commercial buildings; however, similar procedure can be applied for a construction project of infrastructure.

5. SIM REAL APPLICATION CORRESPONDING TO A HYPOTHETICAL COMMERCIAL BUILDING PROJECT

The project proposed here has first decided to use the following software applications to develop BIM models for different disciplines as shown in ***Error! Reference source not found.***.

Table 6: SIM Tool 1 for the proposed project

Discipline	**Authoring Software**	**Collaboration Software**
Architecture & Landscape	Archicad	
Structural	Tekla Structures	
Mechanical (HVAC)	DDS-CAD	
Electrical, Communications & Security	Revit	
Fire Services	Revit	
Hydraulic Services	CADmep	
Civil	Civil 3D	
Model Visualization		3ds Max Design
Spatial Coordination		Navisworks
Schedule Planning- 4D Modelling		Synchro
Cost Estimation- 5D Modelling		Vico Cost Estimator
Facility Management- 6D Modelling		Bentley Facilities

The selection of software is then automatically fed to SIM Tool 2 and particular software is filtered from the columns of Authoring Software and Collaborating Software. This will generate the whole details of interoperability between different formats of authoring and collaborating software. These results are given in ***Error! Reference source not found.***.

The results showcase that some authoring software applications cannot be completely transferred to some collaboration software. This will help the project team members to proactively find solutions to these issues either using useful remarks of SIM Tool 2 or discussing with software vendors. If viable solutions cannot be found either way, then the project team can negotiate with other software applications which have good interoperability. Good interoperability software applications can be checked with SIM Tool 2. Simultaneously, interoperability between authoring software can be checked with SIM Tool 3. ***Error! Reference source not found.*** shows the produced results of interoperability for the selected authoring software. Similarly, in Tool 2, the results of Tool 3 can be used for the project team members to proactively find solutions to interoperability issues either using useful remarks of SIM Tool 3 or discussing with software vendors. In situations where viable solutions do not exist from the previous ways, project team is recommended to go with negotiated software applications which can interoperable well with others. For this purpose, SIM tool 3 provides valuable sources.

Table 7: SIM Tool 2 for the proposed project (only part of the full generated table)

Authoring Software	Collaborating Software	Export Format	Export Efficiency	Remarks (Problems/ Solutions)	Contacts (Experts/ Organizations)
Revit	Navisworks	rvt	Partial	Some Revit families will lose some of its details, e.g. a pipe shows as a line, regardless of the detail level setting in Revit.	Autodesk
Revit	Navisworks	nwc	Complete	No loss of information	Autodesk
Revit	Navisworks	dwg	Partial	loss of data	Autodesk
Revit	Navisworks	dxf	Partial	loss of data	Autodesk
Revit	Navisworks	dgn	Partial	loss of data	Autodesk
Revit	Navisworks	fbx	Partial	loss of data	Autodesk
Revit	Navisworks	ifc	Partial	No loss of geometry with proper IFC data. However, the file structure (as in the selection tree in Navisworks) is different to a NWC export from the same Revit project.	Autodesk
Revit	Navisworks	sat	Partial	loss of data	Autodesk
ArchiCAD	Navisworks	pln	Partial	Has to use NWC File Export Utility. Supports transfer of object geometry and associated meta data	Autodesk/Graphisoft
ArchiCAD	Navisworks	nwc	Complete	Complete	Autodesk/Graphisoft
ArchiCAD	Navisworks	dwg	Partial	Has to use NWC File Export Utility. Supports transfer of object geometry and associated meta data	Autodesk/Graphisoft
ArchiCAD	Navisworks	dxf	Partial	Has to use NWC File Export Utility. Supports transfer of object geometry and associated meta data	Autodesk/Graphisoft
ArchiCAD	Navisworks	dgn	Partial	Has to use NWC File Export Utility. Supports transfer of object geometry and associated meta data	Autodesk/Graphisoft
ArchiCAD	Navisworks	fbx	None	None	Autodesk/Graphisoft
ArchiCAD	Navisworks	ifc	Partial	Has to use NWC File Export Utility. Supports transfer of object geometry and associated meta data	Autodesk/Graphisoft
ArchiCAD	Navisworks	smc	None	None	Autodesk/Graphisoft
Tekla Structures	Navisworks	ifc	Complete	Mostly on the problem that colours of both models are different	Autodesk/Tekla
CADmep	Navisworks	dwg	Partial	Need to install corresponding object enabler for complete exchange (before 2009 versions), otherwise straight away happens	Autodesk
CADmep	Navisworks	nwc	Complete	Version 2011 onwards	Autodesk
CADmep	Navisworks	ifc	Complete	Complete	Autodesk
DDS-CAD	Navisworks	dwg	Partial	Object properties are not supported	Autodesk/Nemetschek/DDS
DDS-CAD	Navisworks	dxf	Partial	Object properties are not supported	Autodesk/Nemetschek/DDS
DDS-CAD	Navisworks	dwf	Partial	Object properties are not supported	Autodesk/Nemetschek/DDS
DDS-CAD	Navisworks	ifc	Partial	Object properties are not supported	Autodesk/Nemetschek/DDS
Civil 3D	Navisworks	dwg	Partial	loss of data	Autodesk
Civil 3D	Navisworks	nwc	Partial	loss of data	Autodesk
Revit	3ds Max Design	rvt	Complete	Complete	Autodesk
Revit	3ds Max Design	nwc	None	doesn't support, nwc only for navisworks	Autodesk
Revit	3ds Max Design	dwg	Partial	Geometry may be perfect but data loss in properties	Autodesk
Revit	3ds Max Design	dxf	None	None	Autodesk
Revit	3ds Max Design	dgn	Partial	Geometry may be perfect but data loss in properties	Autodesk
Revit	3ds Max Design	fbx	complete	No geometry loss. Data are gone but they are irrelevant in 3DS max.	Autodesk
Revit	3ds Max Design	ifc	None	None	Autodesk
Revit	3ds Max Design	sat	Partial	Only Body objects are compatible	Autodesk
ArchiCAD	3ds Max Design	pln	Complete	Can set up the scale and type of exporting. Type can be Archicad object (native output) or element types-materials or layers-materials or materials only. This will be done with the 3ds supporting add-on	Autodesk/Graphisoft
ArchiCAD	3ds Max Design	nwc	None	Does not support	Autodesk/Graphisoft

Authoring Software	Collaborating Software	Export Format	Export Efficiency	Remarks (Problems/ Solutions)	Contacts (Experts/ Organizations)
ArchiCAD	3ds Max Design	dwg	Complete	the content of the file depends on the conversion system of the original modelling software. This decides for example, that the 3D surface in the original file appears in the dwg as block, polyline, 3d primitive, region etc.	Autodesk/Graphisoft
ArchiCAD	3ds Max Design	dxf	Partial	Geometry data passes fine but other data may loss	Autodesk/Graphisoft
ArchiCAD	3ds Max Design	dgn	Partial	Geometry data passes fine but other data may loss	Autodesk/Graphisoft
ArchiCAD	3ds Max Design	fbx	Partial	Geometry data passes fine but other data may loss	Autodesk/Graphisoft
ArchiCAD	3ds Max Design	ifc	None	None	Autodesk/Graphisoft
ArchiCAD	3ds Max Design	smc	None	None	Autodesk/Graphisoft

Table 8: SIM Tool 3 for the proposed project (only part of the full generated table)

Authoring Software	Authoring Software	Export Format	Export Efficiency	Remarks (Problems/ Solutions)	Contacts (Experts/ Organizations)
Revit	ArchiCAD	rvt	None	None	Autodesk/Graphisoft
Revit	ArchiCAD	nwc	None	None	Autodesk/Graphisoft
Revit	ArchiCAD	dwg	None	None	Autodesk/Graphisoft
Revit	ArchiCAD	dxf	None	None	Autodesk/Graphisoft
Revit	ArchiCAD	dgn	None	None	Autodesk/Graphisoft
Revit	ArchiCAD	fbx	None	None	Autodesk/Graphisoft
Revit	ArchiCAD	ifc	Complete	with the help of GRAPHISOFT ArchiCAD Connection Add-In	Autodesk/Graphisoft
Revit	ArchiCAD	sat	None	None	Autodesk/Graphisoft
ArchiCAD	Revit	pln	None	None	Autodesk/Graphisoft
ArchiCAD	Revit	nwc	None	None	Autodesk/Graphisoft
ArchiCAD	Revit	dwg	None	None	Autodesk/Graphisoft
ArchiCAD	Revit	dxf	None	None	Autodesk/Graphisoft
ArchiCAD	Revit	dgn	None	None	Autodesk/Graphisoft
ArchiCAD	Revit	fbx	None	None	Autodesk/Graphisoft
ArchiCAD	Revit	ifc	Complete	with the help of GRAPHISOFT ArchiCAD Connection Add-In	Autodesk/Graphisoft
ArchiCAD	Revit	smc	None	None	Autodesk/Graphisoft
Revit	Tekla Structures	rvt	None	possible If conversions available	Autodesk/Tekla
Revit	Tekla Structures	nwc	None	possible If conversions available	Autodesk/Tekla
Revit	Tekla Structures	dwg	Complete	Complete	Autodesk/Tekla
Revit	Tekla Structures	dxf	Complete	Complete	Autodesk/Tekla
Revit	Tekla Structures	dgn	Complete	Complete	Autodesk/Tekla
Revit	Tekla Structures	fbx	None	None	Autodesk/Tekla
Revit	Tekla Structures	ifc	Complete	However, Revit 2012 has very poor ifc export ability	Autodesk/Tekla
Revit	Tekla Structures	sat	None	None	Autodesk/Tekla
Tekla Structures	Revit	ifc	Complete	using the Revit ifc import feature	Autodesk/Tekla
Revit	CADmep	rvt	Complete	with the help of Revit addin to CADmep	Autodesk
Revit	CADmep	nwc	Complete	Object enabler should be the same version	Autodesk
Revit	CADmep	dwg	Complete	Complete	Autodesk
Revit	CADmep	dxf	Complete	Complete	Autodesk
Revit	CADmep	dgn	Complete	Complete	Autodesk
Revit	CADmep	fbx	Complete	Complete	Autodesk

Authoring Software	Authoring Software	Export Format	Export Efficiency	Remarks (Problems/ Solutions)	Contacts (Experts/ Organizations)
Revit	CADmep	ifc	None	None	Autodesk
Revit	CADmep	sat	Complete	Complete	Autodesk
CADmep	Revit	dwg	Complete	Complete	Autodesk
CADmep	Revit	nwc	Complete	Complete	Autodesk
Revit	DDS-CAD	rvt	None	None	Autodesk/Nemestec/DDS
Revit	DDS-CAD	nwc	None	None	Autodesk/Nemestec/DDS
Revit	DDS-CAD	dwg	Complete	Complete	Autodesk/Nemestec/DDS
Revit	DDS-CAD	dxf	Complete	Complete	Autodesk/Nemestec/DDS
Revit	DDS-CAD	dgn	None	None	Autodesk/Nemestec/DDS
Revit	DDS-CAD	fbx	None	None	Autodesk/Nemestec/DDS
Revit	DDS-CAD	ifc	Complete	Complete	Autodesk/Nemestec/DDS

6. CONCLUSION AND FUTURE RECOMMENDATIONS

Interoperability plays a major role in improving data exchange between applications of a collaborative project team environment specially BIM integrated AEC projects. Past studies, survey statistics and different international BIM guides firmly indicate that lack of interoperability leads to limit the full potential of BIM application in AEC projects. Current research adopted an action research plan to identify and tackle interoperability issues. It came up with a prototype solution in the form of 'Software Interoperability Matrix (SIM). Three SIM tools (Tool 1, Tool 2 and Tool 3) have been supported to develop SIM. Among three tools, Tool 1 provides a comprehensive list of software applicable to most BIM models along with their working formats and export formats. Consequently, Tool 2 will check the export efficiency between authoring and collaboration software. As Tool 2 is only limited to between authoring and collaborative software, Tool 3 helps checking interoperability between authoring software. All tools are presented in tables in which complete table has been given for tool 1 within the paper covering construction of both commercial buildings and infrastructure. Due to many combinations are attached to tool 2 and 3, those tools have been presented as examples only covering part of the combinations. For improved clarity, paper has also explained the actual application of SIM tools in AEC industrial projects hypothetically corresponding to a commercial building project.

This digital interactive tool (SIM) will provide Project Directors and Managers information that will enable more informed decision-making during the tender preparation and documentation period. With this tool, project team members can identify their software and check the export efficiency with various other disciplines early in the process. It will be useful for Project Directors and BIM Managers but also when creating tenders and extracting information from Design Consultants, Subcontractors, and in-house Construction Managers. Eventually, with the application of SIM, this can reduce time and cost impact due to the awareness of exchange issues from the design stage. To the best of our knowledge there is no other tool available like this in marketplace. All in all, whole project team (Owner/ Client, Architects, Engineers and other designers, General contractor, Sub-contractors, Fabricators) will be benefited by SIM tools to identify interoperability issues in advance and act accordingly. This will heavily reduce cost and time of future projects due to interoperability issues. The current research has validated phase 5 of the action research plan adopted for this study only using a hypothetical case study due to time constraint (Initial plan was to extend the project but it did not happen due to new reform of the industrial partner); however, validation of SIM through future real case studies will give a clear picture of SIM and its real usage to AEC industrial projects. The findings will further accumulate flaws and challenges which will direct future research to improve the functionality of SIM.

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