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Steel Model Approval: Can BIM provide a drawing-free approval process?

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Abstract−Despite widespread use of Building Information Modelling (BIM) software used within their industry, the approval of steelwork contractor's design information is largely based on the approval of 2d-drawings. These workflows can be modernised to take advantage of current technology and provide productivity gains, but barriers to change exist. This research is an attempt to answer the research question of if a model-based approval process, which removes the need for drawings, is achievable. To answer this question, a mixed methodology was used. A literature review was performed to understand how the approval process works, what information is required and what BIM technologies and processes are available. An interoperability test was performed on a typical steelwork BIM model to evaluate if current neutral data exchange exports could capture the required approval information. Thirdly, a quantitative research study was performed, questioning structural engineers operating within the Irish construction industry on what their opinions where on this issue and to understand their concerns around using BIM. The findings were that structural engineers were sceptical on the issue and had strong concerns around BIM contractual issues and other BIM participants. The neutral exchange exports from the steel detailing software "Tekla Structures" were found to be generally good but lacking in key areas. The findings of the literature review, interoperability test and survey results were triangulated to derive a set of requirements to enable a BIM model-based approval process to be acceptable to a significant cohort of Irish AEC sector.

Keywords − Building Information Modelling, Steel Construction, Model Approvals, Data exchange, Interoperability

I INTRODUCTION

Due to their specialist knowledge and expertise, subcontractors have an increasing design responsibility for the technical design related to their works [1]. The process of design, construction and operation of building projects has developed in recent years with Building Information Modelling (BIM) improving the use and exchange of information across all project phases [2].

Steelwork contractors are often considered as one of the most proficient in BIM technologies of all specialist trade subcontractors [3]. Object-based parametric design software has been in use by steelwork contractors before even the earliest multi-discipline BIM platforms were available [4]. In the case of some sub-contractors, BIM modelling may not always provide benefits to how their work is executed [5]. For steelwork contractors however, BIM-modelling is business as usual. The use of BIM models as the information exchange for the approval of a steelwork contractors design information is still an emerging process only [6]. Design information approvals are still commonly based on 2d drawings. When BIM is not fully integrated across all parties, the result is an increased workload with information being exchanged and coordinated in both 2D and 3D [7]. Traditional workflows of drawings approval are wasteful and no longer appropriate [4]. As part of the overall preparation of design information, from modelling to detailing and then preparing drawings, drawing preparation can take up to 25% of the overall time [8].

Technical and legal challenges in the approval of a digital model or its individual model objects are barriers to a drawing-free information process. Construction drawings are used to act as contract documents in projects which complicates their removal from the project delivery process. [4]. Another consideration is that steelwork contractors as specialist subcontractors provide only a part of the building elements. The need for them to communicate their information with other project participants is essential to enable the understanding of how their building elements interact with those of others and to know how the entire building's systems work [4].

This paper is an attempt to answer the research question:

"Is a drawing-less, model-based approval of structural steel contractors design information achievable?"

a) Research Objectives & Methodology

To answer the research question, the following objectives were used:

1. to critically examine both how the approval process works and the information which would be contained on a set of approval drawings.
2. to critically examine BIM-based data exchanges and processes.
3. To evaluate the suitability of current model data exchanges from steel specific modelling software.
4. To devise a set of conditions which would be required for model-based approval to be acceptable to stakeholders

To achieve objectives 1 and 2, a review of the literature was performed. To provide context within the Irish market and to validate and enhance the literature review findings, quantitative research was used. Findings from the survey results were derived using the recommendations of Bock and Sergeant [9]. To achieve objective 3, an interoperability analysis based on De Gaetani et al. [10] was performed. Finally, the results of the literature review, interoperability test and survey were triangulated to propose the conditions which would be required for model-based approval to be possible.

II Traditional Approval Processes

The design phase of the structural steel supply chain can be categorized as for when the need for a steel structure is identified until when fabrication information is prepared [11].

Several parties make up the structural steel supply chain. Architects and clients specify the parameters for buildings. The structural engineer has overall responsibility for the structural soundness of the building design and specifies the dimensions and steel grades for the beams and columns which form the steel frame. The main contractor procures, organizes and coordinates the works of the various sub-contractors including the steelwork contractor [12]. The structural engineer should have sole responsibility for the overall design and stability of the structure. They should ensure that their design, and the design carried out by other engineers and designers are compatible [13, 14].

The steelwork contractor has design elements to consider before they can begin fabrication and erection. Areas of design responsibility for the steelwork contractor are steel connection design and temporary works design [14]. There are occasions where steel connections are designed by the steelwork contractor, which is common practice for buildings, and occasions where connections are designed by the structural engineer, which is common in complex structures such as bridges [14, 15]. In the National Structural Steelwork Specification by the British Constructional Steelwork Association (BCSA) [16], three design scenarios are listed for how design responsibilities can be shared across a steel construction. These range from the steelwork contractor being responsible to full member design and layout, to connection design only.

Where design is carried out by the steelwork contractor, the structural engineer must provide information which defines the parameters of this work [14]. The structural engineer maintains overall responsibility for structural stability and must review, comment upon and approve the connection details and designs [17]. To allow the Steelwork Contractor to design steel connections, the connection forces should be provided to the Steelwork Contractor in a clear and understandable format [18]. Where the steel elements interface with concrete elements, such as foundations, the allocation of design responsibility can be complicated and can be shared between the structural engineer and the steelwork contractor [19]. If the steelwork contractor has design responsibility for connection design, they are required to submit design calculations for approval. In this case, blow-up detail sketches or drawings showing the arrangement of the connections should be included as part of their deliverables.[16].

Steelwork contractors first develop a three-dimensional steelwork model which they then use to generate their detailed drawings. The drawings are then submitted to the design team for approval [20]. The BIM authoring tool *Tekla Structures* is widely used within industry for this purpose [21]. The steelwork model must be clash free and fully modelled to the correct level of detail prior to the fabrication drawings being produced [18]. The drawings prepared by specialist sub-contractors is commonly referred to as shop drawings [22]. Shop drawings are one of many types of construction submittals. Other contractor submittal types of note are product data and design data [23]. A formal process for submission of construction submittals can be used including submittal logs and numbering [24]. The American Institute of Steel Construction refers to the submittal process as the steelwork contractors responsibility to carry out the "transfer of information from the contract documents into accurate and complete approval documents" [25].

Information is not always submitted for approval in one submittal but can be spread across multiple information exchanges. This practice is common in larger projects which could be split up into phases [26].

Once the structural steel submittal has been submitted to the design team, the structural engineer will review and approve the information. The purpose of this review is to check that the information will meet both the client's requirements and the specified standards, and to ensure that designs are adequate [14]. This also increases the chance that errors and misinterpretations of design will be exposed [27]. Depending on the how the allocation of design responsibilities has been prior agreed, the structural engineer may be providing approval or merely be commenting on the steelwork contractor's drawings and design. During approval, issues can be resolved quickly and effectively with direct communication between the steelwork contractor and the structural engineer if contractual arrangements allow it, however a written record of outcomes are advised [17]. When reviewing the drawings or other information, the engineer can use different designations of acceptance. Table 1 displays the classifications that are commonly used.

Table 1: Approval Status types [16, 22]

Status	Description
A	Approved without comment.
B	Approved as noted, re-submission not required.
C	Revise as noted and re-submit.

If comments are provided by the structural engineer or other consultants, these are often provided as marked up drawings. Difficulties can arise when mark-ups from multiple parties contain conflicting comments [28]. The shop drawings will also need to be coordinated with other trade contractors which may also provide marked – up comments which will have to be addressed in any revisions to the drawings before they are re-submitted for final approval [29]. Once drawings have been approved, they become contract documents and fabrication can commence [15].

III Structural Steel Information Requirements

The drawings prepared by the steelwork contractor show plans and elevations as well as enlarged details to show the assembly of components [16].

The drawings need to convey the details of the materials used such as the profile shape [15], the steel grade and sub-grade [17]. Where members are pre-cambered to offset deflection over long spans, the drawings should detail the requirements, including location and geometry [15].

Connections designed by the steelwork contractor should be referenced on the drawings to a location on the structure [16, 17] Enlarged details of the connections, especially in cases of complex geometry, may also be required on the drawings [16].

On drawings, it is difficult to correctly convey welding information and intent [30]. Weld symbols are usually used to identify welds to convey the size and type of weld or whether the welds are to be shop applied or site applied, though Weld Procedure Specification (WPS) sheets can be used for more critical welds [15].

The surface treatment of steel members is information that will be required to be conveyed. Common descriptive information required include which surface coating is required for steel members, the surface preparation, the dry film thickness, and colour requirements if any. Information is also required on which members, or parts of members, are required to be left unpainted [25].

Fabricated assemblies should be identified with an ID mark [11]. It should be identified if the members are part of the permanent or temporary works [16]. In projects within the European Union, the execution class must be stated and correct to facilitate CE marking [17].

Spatial location must also be displayed. The structural grid must be indicated and the locations of the steel members in relation to the gridlines. Also top-of-steel levels and base levels must be indicated [26]. The steelwork contractor may need to convey any bracing offsets or member eccentricities which were introduced to facilitate buildability, as the engineer may need to consider their effects on an idealised centre-line analysis [17].

IV BIM-based Workflows in Steel

There has been some progress on the development of BIM-based approval processes within the steel industry. At a presentation for the 2019 NASCC Steel Conference, Gayer, Schwartz, & Cobb [6] detail processes used in previous efforts of using steelwork models for approval. The processes described involve the structural engineer using the same native modelling software for the approval review that was used by the steelwork contractor to develop the model. Two processes were outlined in the presentation, the first process was where a copy of the native model was sent to the structural engineer for review. The other was where a cloud solution was used that both the structural engineer and steelwork contractor could access live and in real time. Using native models for the approval process was also recommended by The American Institute of Steel construction (AISC) [31] and Moor [32], reasoning that the interoperability level is not sufficient enough with current neutral data exchange formats.

Some advantages of using native software for review were detailed by Gayer et al. [6]. Interoperability issues can be avoided as the approval model is as originally detailed. In-built view filters within the software can be set-up to colourise and group elements within the model. If more detail is required to be inspected, the part fabrication drawings are linked to the model elements within the native software and can be called up and viewed instantly.

Gayer et al. [6] highlight that to enable their processes to work, consultation with software vendors and pre-start meetings between project parties were used to set-out ground rules The agreed processes and data requirements were written into the engineer's specification; therefore, making them contractual requirements.

Negative elements resulting from using the processes were also encountered by Gayer et al. [6]. Buy-in by all parties is essential; where one party is not on board, bottlenecks can occur. The very large file transfers required for native models caused difficulty. The process was isolated, leaving the main contractor and other parties removed. There were large software costs involved as all parties were required to have licenses for the same software and required training to use.

Moor [32] sees three different levels of model-based approval. Firstly, an "assist" method where the steelwork model is used to assist the structural engineer in approving the steelwork contractors' drawings. Secondly, a "lite" approach where the model is used for approval but all the details of the approval such as comments and mark-ups are stored outside the model. Finally, the most complete method suggested by Moor is where all comments and approval information are kept within and remain with the native model, though Moor suggests that the software was not advanced enough for this at that time.

The developers of Tekla software made efforts in developing tools for an approval system for both 3D and 2D data from within their application [33]. The software add-in, *In Model Reviewer*, has been developed to allow model elements and 2d drawings to be grouped as submittals within Tekla. A tool is then available for a reviewer to add comments and stamp the submittal elements with their approval status. Approval status is then written to model elements as attributes which can then be queried within the model. Information exchanges within a native format is a closed exchange. All who need to be party to this information will require compatible software. The sharing of information in a native format can be described as a ClosedBIM workflow. Subcontractors only provide a part of a building's system. Their information must be communicated between their native platform and the platforms used by other trades, consultants and contractors [4]. An OpenBIM workflow involves the sharing of information in a neutral exchange format that can be accessed with a variety of different software platforms [34].

V Data Exchanges

Much work has been done to enable the exchange of structural steel information through neutral data exchange formats. One of the earliest efforts was the Steel Detailing Neutral File (SDNF). Originally developed by Intergraph as an interface between two CAD packages PDS/FrameWorks and StruCad, SDNF provides a neutral file format for point-to-point exchange of steel data objects [31, 35]. Another effort was by the Eureka Cimsteel project with the development of the Cimsteel Integration Standards (CIS). The second edition of the standard, CIS/2, was released in 2000 and was supported by the AISC, resulting in wide use in the North American structural steel engineering industry [4, 36]. CIS/2 is STEP-based data schema [31]. After the development of the exchange format Industry Foundation Class (IFC) by buildingSMART International, CIS/2 was eventually replaced by this schema as the exchange format norm for the structural steel industry [37].

IFC is a schema which could be described as a data structure or a specification. This schema can be expressed in various file formats. The most common of these formats is IFC-SPF, a text format which is compact in size and is the most widely used IFC format [34].

IFC is an object-orientated specification which describes object definitions. These definitions can refer to real-world objects such as walls or doors, or they can refer to more abstract objects such as processes, controls, or roles. As well as this, IFC also describes the relationships between objects. The root concept of IFC is therefore object, relationship and property definitions [34].

IFC is organised though a hierarchical structure. Starting at the site level, the definitions will also then be subdivided into buildings, then floors, and then zones and spaces within those floors and finally the objects within the zones and spaces [34].

Since its inception, IFC has gone through multiple development cycles. The most current release is version IFC4 which is still in the development of being certified by software companies. The previous version IFC2X3 is the most widely used version currently in Industry [34].

The reason for using IFC is to exchange information for a specific purpose [34]. Data schemas such IFC are developed with a broad scope to support as much uses as possible. For data exchange on projects however, only a small subset of the data schema is required. This subset model is known as a Model View Definition (MVD) [4]. Model View Definitions are developed using a methodology known as Information Delivery Manual (IDM) [34]. The IDM methodology is defined in the International Standard ISO 29481 [4]. The standard is intended for software developers and experts to develop MVDs and is not intended for use by standard users [34]. The buildingSMART International MVD database currently has six official MVDs along with another four in draft format, based on either IFC2X3 or IFC4 [38]. There are many other unofficial MVDs developed for specific exchanges by other parties other than buildingSMART [39].

Though IFC has been widely adopted for use by software companies, poor implementation has affected its take up in industry [4]. Users of IFC should not expect it to work off the shelf. Proficient use of the format requires testing of exchanges to ensure correct exchange of information [40].

To drive forward the use of IFC in the steelwork industry, AISC developed the BIMSteel initiative which centred on interoperability, data exchange standards and the supporting business processes. The initiative focused several information exchanges. These include information exchanges between steelwork contractors and contractors/consultants and exchanges with material suppliers and with fabrication machinery [41]. The initiative developed MVDs for each exchange in the steelwork design process from EM1 (concept model) up to EM11 (final steel detailing model) [42]. Only EM8/steelXML and EM11 (fabrication model) are supported now [43]. The BIMSteel initiative purely only addressed technical issues, not cultural or social aspects. Contractual boundaries involving risk, standard of care and contractual issues were beyond the scope of the IDM developed by the AISC [44].

VI BIM Processes

Where a project is being executed to defined BIM standards such as ISO 19650-2:2018 or the earlier standard PAS1192-2:2013, certain processes must be adhered to. The steelwork contractor would usually be appointed by the main contractor who would be considered their "appointing party", with the sub-contractor being the "appointed party". These are important terms which are referred throughout the ISO 19650 series [45]. As an appointing party, it is the main contractor's duty to establish the Exchange Information Requirements (EIR) at an appropriate level of information need for the appointment before appointing the subcontractor [46]. When tendering for a project, the main contractor will have to assess their subcontractor's capability to delivery information as a task team in accordance with their EIR, then establish a mobilization plan to sufficiently plan out their mobilization phase for information delivery and management post-tender award [47].

Post-tender award, the rules for how all parties to a project will produce, manage and exchange project information will be set out in a BIM Execution Plan (BEP) [47]. How the steelwork subcontractor will meet the information requirements in specific information exchanges will be reflected in their Task Information Delivery Plan (TIDP) which is then added to an overall Master Information Delivery Plan (MIDP) for the entire delivery team [46, 48].

The lead appointed party will have established a Common Data Environment (CDE) for which all parties can share information. The CDE has a specific workflow used to support collaborative production, management, sharing and exchange of project information [48]. The CDE is a process consisting of a gated workflow made up of four states, work in progress, shared, published and archive. The gates act as sign-off procedures, allowing information to pass between each of the four states [49]. CDE information should follow a specific file naming convention as specified in the national annex of ISO 19650-2:2018, along with specific revision and status codes to ensure users understand the suitability of the information. Task teams submit their information to the CDE shared state for appointing party (or someone acting on their behalf) review and acceptance. If the review is accepted, then the information moves to the published state [48]. This process is often managed with CDE solutions delivered via online software-as-a-service cloud-based platforms [40, 50].

As BIM processes grow in maturity and becomes increasingly a contractual requirement, the various obligations, liabilities and limitations must be navigated by those industry [51]. The steelwork contractor and engineers reviewing their information will have contractual and legal risks to consider. Almarri, Aljarman, & Boussabaine [52] investigated the key legal concerns and risks among different project team members of the use of BIM in projects.

Table 2: Top 10 ranking of BIM risks related to contractual issues identified by Almarri et al.[52]

Rank	BIM risks related to contractual issues
1	Lack of legal/contractual agreements
2	Trades on site may not be working from the model
3	Unclear if the model is a contract document
4	Unclear what dimensional accuracy is expected in documents
5	Risk of (as-built) information inaccuracy
6	Unclear how to deal with BIM documents' precedence
7	Unclear BIM deliverables
8	Misplaced assumptions that the design team, with a "push of a button", is able to produce a perfectly coordinated series of documents through BIM
9	Lack of BIM standard contracts
10	Unclear what documents will be contract documents

Table 3: Ranking of BIM risks related to BIM use identified by Almarri et al [52].

Rank	BIM risks related to BIM use
1	Modelling participant does not meet the standard of care required
2	Lack of control of the ownership over the BIM by the creator
3	Lack of knowledge of the missing data
4	Unclear procedures for dealing with contributions that must be kept secret
5	The user whose contribution to the design caused the software to alter model details is responsible for inaccurate changes
6	Unclear procedures for compensation accessibility that might result in misuse or re-use of a project participant's contribution
7	Risks affecting the software owner, resulting from inaccurate modifications being made to the design
8	Blurred responsibilities of the parties towards each other
9	Lacking contribution by stakeholders
10	Risks of separate responsibilities between contractors and design team in their responsibilities and liabilities

Almarri et al. derived a ranking of risks for each type of project participant. Identifying 17 risks in total, the ranking of concern (highest first) of top 10 legal risks related to contractual issues among engineers is shown in Table 2. Almarri et al. [52] also identified the ranking among engineers of legal risks in the uses of BIM in relation to dealing with data, intellectual property rights and participants and liability issues, the top 10 of which is shown in table 3.

VII Interoperability Test

In the development of the test model, a review of literature containing the development of test models was carried out to inform the approach taken. Ramaji and Memari [39] used a structural model of a two story office building which contained typical structural elements to validate a tool for interpretation of IFC models from one MVD to another. Quintana et al. [53] used sample models from a company participating in their research to evaluate model geometry degradation between native models and an exchange format. Sacks et al. [54] used a live project model to develop a workflow for generating shop drawings from a BIM model for submittals. Lee et al. [55] and De Gaetani et al. [10] used a bespoke simple model of a precast garage building to test an IFC checking tool. Nizam and Zhang [56] also used a bespoke simple model to test information exchange between two BIM authoring software. On review, it decided that a bespoke model containing typical structural elements would be the best approach for this research. A bespoke model was developed using Tekla Structures suitable for exporting an IFC file containing the elements to test an approval model.

a) Export Type

Although Tekla have begun implementing IFC4, IFC 2X3 is the only IFC version currently supported [57]. Tekla does not have a specific model-approval MVD so an alternative must be selected. Coordination View 2.0 is currently the most common MVD in use based on IFC2X3 [34, 39] and is the Tekla IFC export version certified by BuildingSMART [58]. For this reason, Coordination View 2.0 was selected as the IFC export type for this research.

b) Model Element Classification

Based on their functionality, Coordination View categorizes linear building elements as the object types, IfcColumn, IfcBeam or IfcMember, though the data structure of each category is identical. IfcColumn is used for vertical elements, IfcBeam for horizontal elements and IfcMember for inclined elements such as braces [39]. Tekla uses these classifications and additionally classifies plate members as IfcPlate or IfcDiscreteAccessory, welds as IfcFastener, bolts as IfcMechanicalFastener and surface treatments as IfcCovering.

c) Model Attributes

Tekla exports many of its model attributes as part of an IFC export as default. One limitation of this is that the object properties can be spread across different property trees and can be difficult to find. Park et al. [59] used user-defined IFC property sets to export relevant bridge data in the absence of a specific bridge MVD. Property sets are information containers which hold object properties within a property tree. These can then be assigned to different object types within IFC [60]. Tekla IFC exports contain built-in property sets for many object types by default. To capture in export the object properties not captured by default, an approval property set was created including each model element classification type. The property sets contained each of the relevant information requirements derived from the literature review which were not captured by default.

d) Model Checking

Zhang et al. [61] suggest two approaches to IFC model checking, a programming approach such as that used by the software package Solibri Model Checker, and a schema-based approach such as using the open-source tool jSDAI. Muller et al. [62] suggest using manual and visual checking methods, which was used in this research. A scale based on that used by Di Gaetani et al [10] was devised to assess the interoperability of the IFC export:

1. Good interoperability: the exported parameter is successfully transferred and correctly received by the BIM software importing it.
2. Medium interoperability: the exported parameter is transferred but not correctly received by the BIM software importing it; some details may have been lost; however, the imported information can still be used and is meaningful.
3. Poor interoperability: the exported parameter is transferred but not in the form it was in in the original BIM software; the parameter has changed and could be misleading.
4. No data found/exported: the exported parameter is not found in the BIM software importing it or there was no practical method for exporting the parameter within the export.

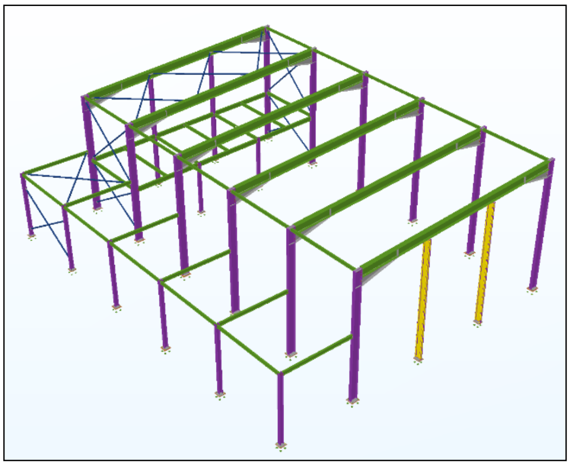

Figure 1: Test Model

e) Test Results

Tekla has a hierarchy option for exporting model elements at either assembly level, or part level. Assembly level export was not deemed suitable for this test as it does not allow for querying of the individual elements within the assemblies. In an assembly level export, property trees within the IFC only pertain to the overall assembly and not to individual parts. Therefore, a part level export was used.

For Linear elements such as beams, columns and braces, interoperability was generally good. Many required attributes were exported as default and other attributes could be added as user-defined attributes and exported within the bespoke property set. Beam camber was found to be difficult to convey correctly. Within the native model, Tekla has the option to include camber within the geometry of the model object. This prioritizes the manufacturing process over the design process as it displays the model object in its pre-installation state rather than its post-installation state, which would be required for design coordination and approval. A beam camber value can be included as an attribute, however the location along the member cannot be easily conveyed.

Table 4: Linear elements test results

√ = Good Interoperability

■ = Medium Interoperability

□ = Poor interoperability

✕ = No data found/exported

Linear elements

(IfcColumn/IfcBeam/IfcMember)

Attributes/Properties	**Interoperability**
Geometry	√
Identification	√
Profile shape	√
Steel grade	√
Product Standard	√
Execution class	√
Camber	□
Service openings	√
Level	√
Location (relation to grid)	√
Phase	√
Status (perm/temp)	√

Plate or fitting elements can export attributes as competently as linear elements however, difficulty arises where these elements are part of parametric components. Tekla manages connections between linear elements with parametric tools referred to as "components". System components are available for each connection type such as endplate, shear plate, haunch etc. Component parameters are entered via a dialogue box with a limited number of object attributes. Parameters ranked as medium interoperability in Table 7 are not exportable as part of system components. A possible work around for this would be to create custom components for each connection type but this would be time intensive or require a high skill level to allow the components to be parametric.

Table 5: Plate/Fittings test results

(Symbols as per table 4)

Plates/Fittings

(IfcPlate/ IfcDiscreteAccessory)

Attributes/Properties	**Interoperability**
Geometry	√
Identification	√
Profile shape	√
Steel grade	√
Product Standard	■
Execution class	■
Service openings	√
Level	√
Location (relation to grid)	√
Phase	■
Status (perm/temp)	■

Tekla models welds in two ways, as a triangular profile when displaying a fillet weld or with no profile when displaying a butt weld. Fillet welds are exported in IFC sufficiently. On drawings, weld information is captured via weld symbols as per ISO 2553. Most of the information that would be captured in a weld symbol can be conveyed as attribute in the IFC export.

Within the native Tekla software, the butt weld is still identifiable by the symbol however, the information for these weld types is lost completely in IFC export. For this interoperability test, butt welds were the only model objects not exported, as reported in Tekla's export log.

Table 6: Welds test results

(Symbols as per table 4)

Welds (ifcFastener)

Attributes/Properties	**Interoperability**
Weld type	□
Weld size	□
Site/Shop weld	□

As with plates, bolts information is captured well but user-defined attributes are limited within components.

Table 7: Bolts/Anchors test results

(Symbols as per table 4)

Bolts/Anchors (ifcMechanicalFastener)

Attributes/Properties	**Interoperability**
Geometry	√
Bolt type	√
Bolt grade	√
Bolt size	√
Bolt Length	√
Hole size	√
Bolt finish	■
Anchor bolts to walls/founds	■

Surface treatment information has good interoperability exported as IfcCovering however there could be usability issues on reviewing the IFC due to it obscuring the main element underneath. Surface treatments may be better served as user-defined attributes on the main linear elements or as a coded reference to an external surface treatment schedule document.

Table 8: Surface Treatment test results

(Symbols as per table 4)

Surface Treatment

(IfcCovering)

Attributes/Properties	**Interoperability**
Surface Preparation	√
Manufacturers Product ID	√
Colour Requirements	√
Coating thickness	√
Unpainted Areas	√
Fire resistance period	√

On drawings connection ID which are referenced to calculation sheets are identified by annotations. Annotations in IFC MVDs are in development for IFC4 but are not currently implemented yet [34].

Table 9: Connections test results

(Symbols as per table 4)

Connections	
Attributes/Properties	**Interoperability**
Reference ID	×
Location	×

VIII SURVEY

To provide context within the Irish market and to validate and enhance the literature review findings, an online survey questionnaire was issued to a select group of experienced consultant structural engineers ranging from large – mid size – niche consultant practices operating across the spectrum of Irish based construction projects. The respondents all had experience of the review and approval of structural steel subcontractor submittals. There were 10 completed responses, with almost all the respondents at a senior position within their respective organisations. Figure 1 displays the experience level of the survey respondents.

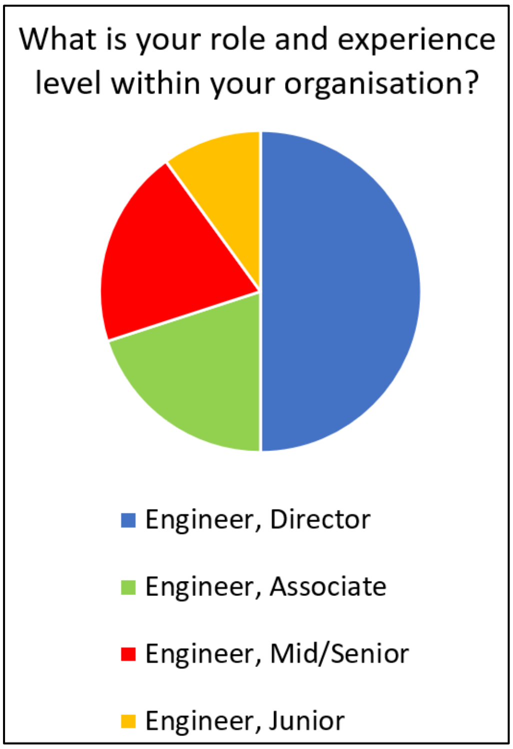

Figure 2: Survey Respondent Experience Level

The attitudes of the respondents were questioned with regards to the use of BIM models in the approval process, as shown in Figure 3. Only 1 of the respondents believed it was possible that a steel BIM model could be used entirely for approval without the need for drawings. Another 4 out of 10 respondents believed a BIM model could be used to some extent, however, half of all respondents believed that the steel BIM model was only useful for coordination between trades and that drawings alone should be used as part of the approval process of steelwork contractor design information. As seen in figure 4, all respondents believed that general arrangement drawings and detail drawings were critical to the approval process, with only 4 out of 10 considering an IFC model as a requirement. Gayer et al. [6] stated that a drawing-less model review was not viable and the survey respondents would seem to agree with this.

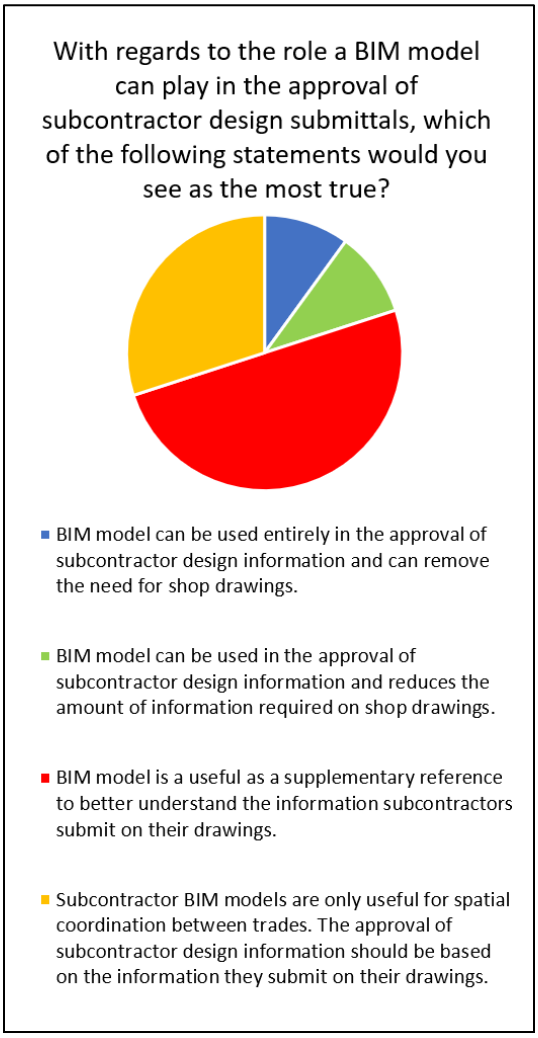

Figure 3: Respondents attitude to model-based approval

On software use within their organisation, figure 6 shows that almost all respondents used Autodesk Revit, but half of all respondents also used Tekla. Less than half of respondents used Autodesk Navisworks. The NBS [2] also found that Revit had a very large userbase, but it's use as a review tool would be limited. 7 out of 10 respondents used the BCSA's NSSS to develop their specification, with five of those using the latest 6th edition.

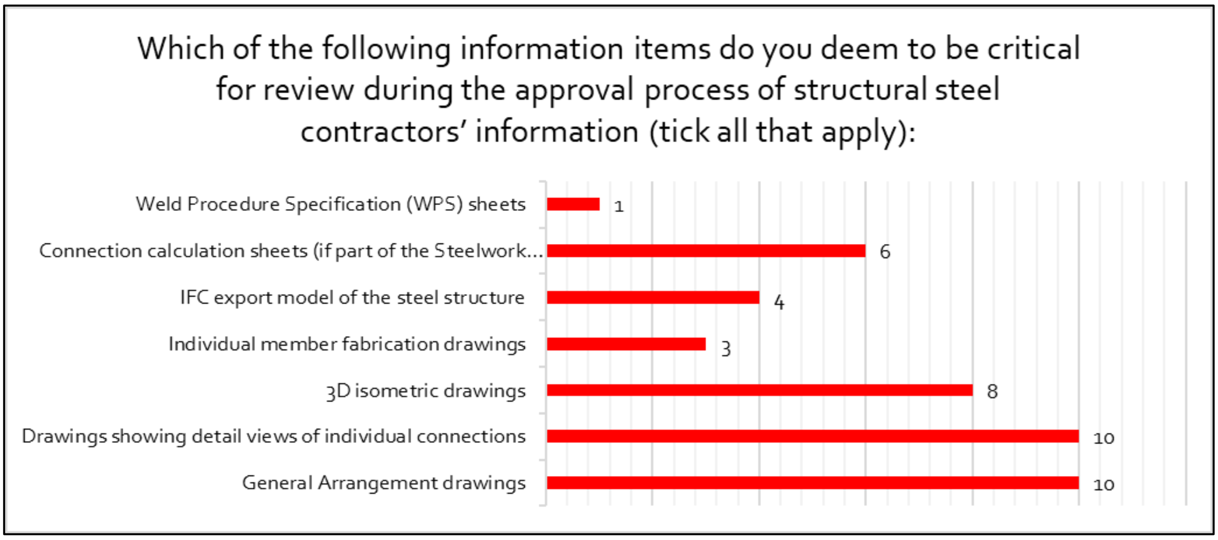

Figure 4: Respondents approval information requirements

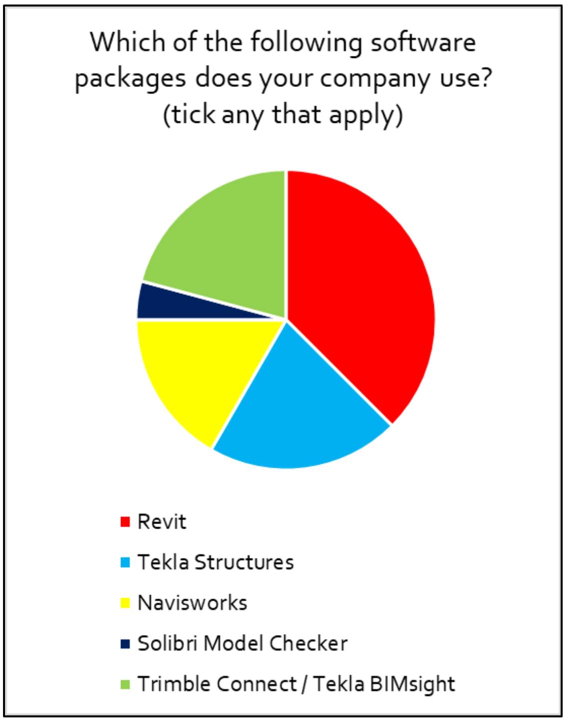

Figure 5: Respondents software use

The respondents were questioned on their attitudes to the BIM risks identified by Almarri et al. [52] to ascertain if the same concern were held among Irish structural engineers. Risks which were deemed not relevant to this research were omitted from the survey questions. The risks were placed on a 5-point Likert scale to identify the intensity of concern for each of the issues with most-concerned receiving the highest score [63].

With regards to working with BIM data, as shown in figure 6, the issue of highest concern was a "lack of knowledge of missing data". Almarri et al [52] see this as important as it leads to productivity loss and additional costs. An "unclear protocol for data sharing upstream and downstream to various parties" was also of concern.

In relation to risks involving other BIM participants, the concerns were much higher. Figure 7 shows the level of concern for these risks. Of most concern was a "lack of commitment by the parties involved in sharing information by using BIM collaboratively", with almost all participants being at least concerned. "Lacking contribution by stakeholders", "modelling participants not meeting the standard of care" and "users whose contribution to the design caused the software to alter model details being responsible for inaccurate changes", all ranked very highly also.

In terms of risks relating to liabilities, as seen in figure 8, "unclear responsibility for changes to the model" ranked highest. "Blurred responsibilities of the parties towards each other" and "risks of separate responsibilities between contractors and design team in their responsibilities and liabilities" also ranking high.

Figure 9 shows the risks relating to BIM contract documents. "Lack of clarity for how to deal with BIM documents' precedence" was the risk of most concern. Winfield & Rock [51] state that inconsistencies between BIM documents is common, making this a valid concern.

Figure 10 shows the risks associated with contractual issues. a "lack of legal/contractual agreements" was the risk of highest concern. "Lack of defining model responsibilities in the contract documents" and a lack of defining BIM risk allocation in the contract documents also were of high concern.

IX Discussion

As has been shown, barriers exist to model-based approval. But what are the conditions and requirements for such a process to be possible?

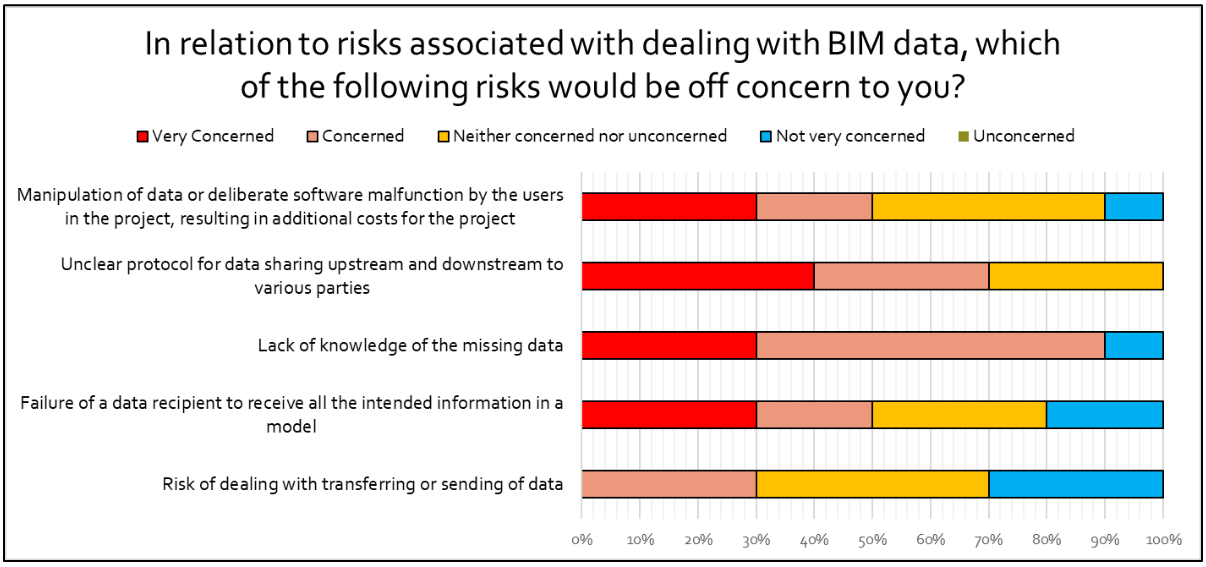

Figure 6: Respondents attitudes to BIM data

a) Contractual Issues

Almost all the survey respondents stated that a lack of legal contract agreements was the legal risk of most concern with regards to working with BIM. This aligns closely with the findings of Alamarri et al [52] who also found that this risk was of most concern to engineers and contrasted significantly with the concerns of architects on the same issue. An approval process that relies on BIM models instead of 2d drawings would have to be reflected in the contractual agreements. Most of the contract types used within the AEC industry are commonly used standard form of contracts with some amendments. In regions such as the UK, some of these standard form contracts are being updated to include BIM specific clause within the contract itself [51]. Another method to achieve the inclusion of BIM within the contract is with a BIM protocol, which can be appended to standard form contracts. One such example of this is the UK BIM Framework Information Protocol, which is the successor the CIC BIM Protocol. The Information Protocol is a flexible document which can be used to work as part of any contract or sub-contract and is intended for use at all supply chain levels. The protocol is designed to avoid conflict with the contract it is appended to, allowing the contract to take precedence when required [64].

The survey also found that structural engineers were also concerned with defining BIM risk allocation and model responsibilities within the contract. The Information Protocol has contained within it a schedule referred to as the Information Particulars. Appointment details and required BIM

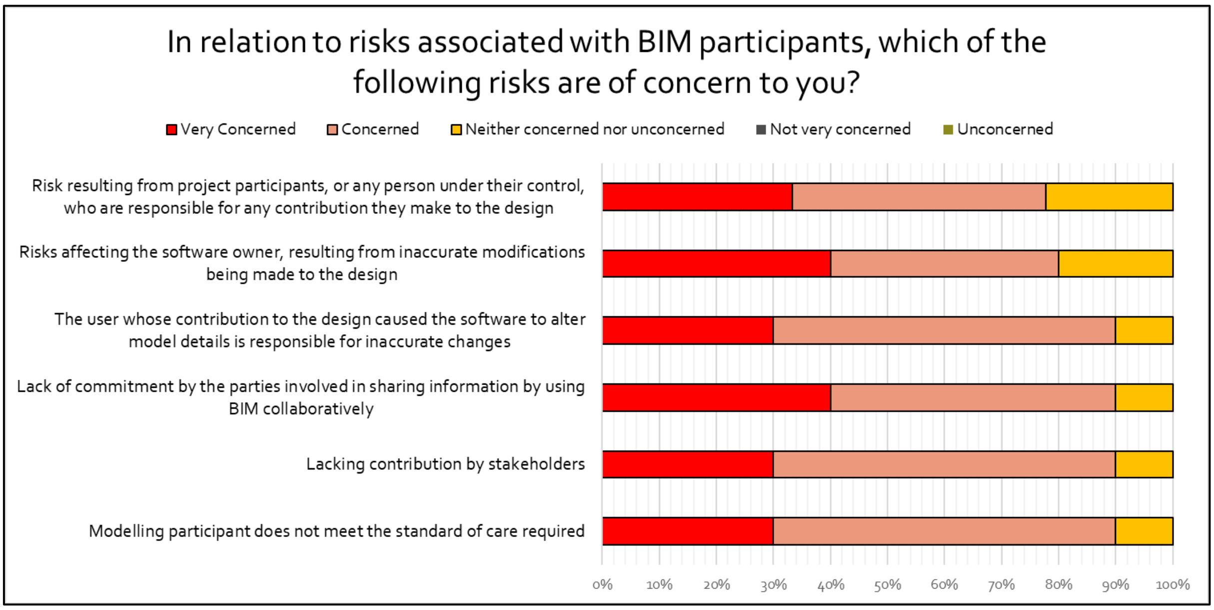

Figure 7: Respondents attitudes to BIM participants

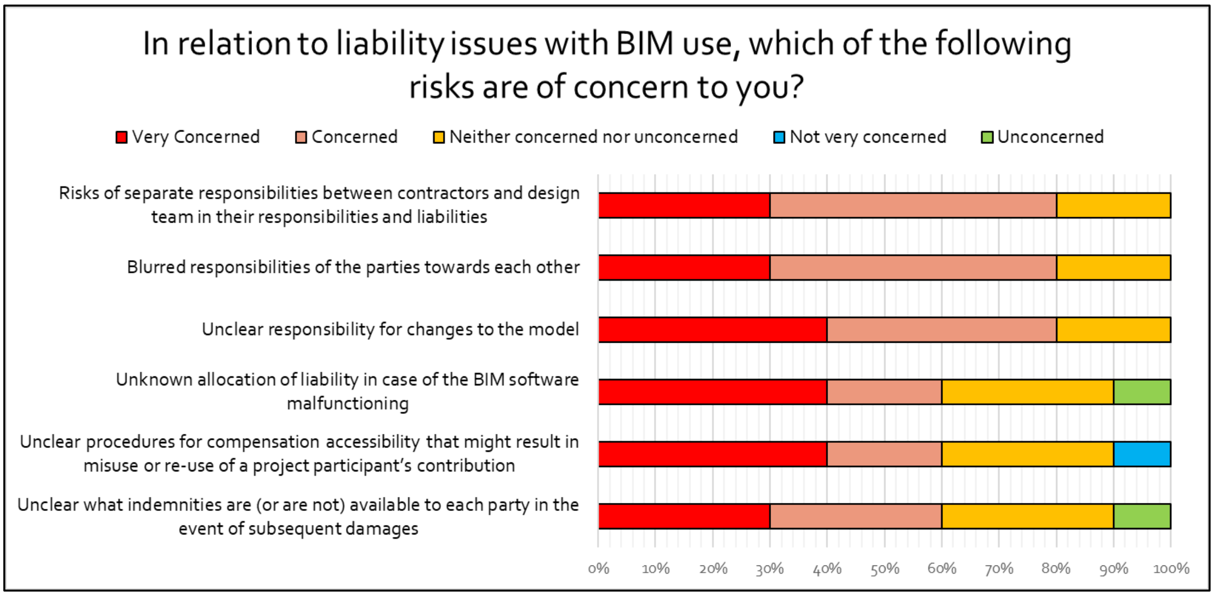

Figure 8: Respondents attitudes to BIM liability issues

documents, such as the BIM Execution Plan and Responsibility Matrix, are named in the Information Particulars, making them contractual documents. One issue with this however is that of timing. RIBA places specialist subcontractor design at stage 4 (Technical Design) of their plan of work [65], though this may differ depending on the project procurement method. In most cases, at the stage of the project that the steelwork contractor is joining at, the structural engineer would have been appointed at a much earlier stage. The decision to use a model-based approval process would have to be made at the time of the appointment of the structural engineer. Considering that agreeing a workable process would require input and agreement from both parties, a procurement method where the steelwork subcontractor is involved at a much earlier stage would be required.

b) Process Participants

The survey found that structural engineers would be concerned with the competency and commitment of the people they would be participating with through BIM. The risk of participants not meeting the standard of care was one of the highest concern in risks in BIM use and was also the highest concern for engineers found by Almarri et al [52]. Gayer et al [6] also noted that buy-in by all parties was essential. For a model-based approval process, this risk could be controlled by the capability and capacity review as per ISO 19650. This would ensure that participants have the necessary experience, skill and technical resources required for the process [48].

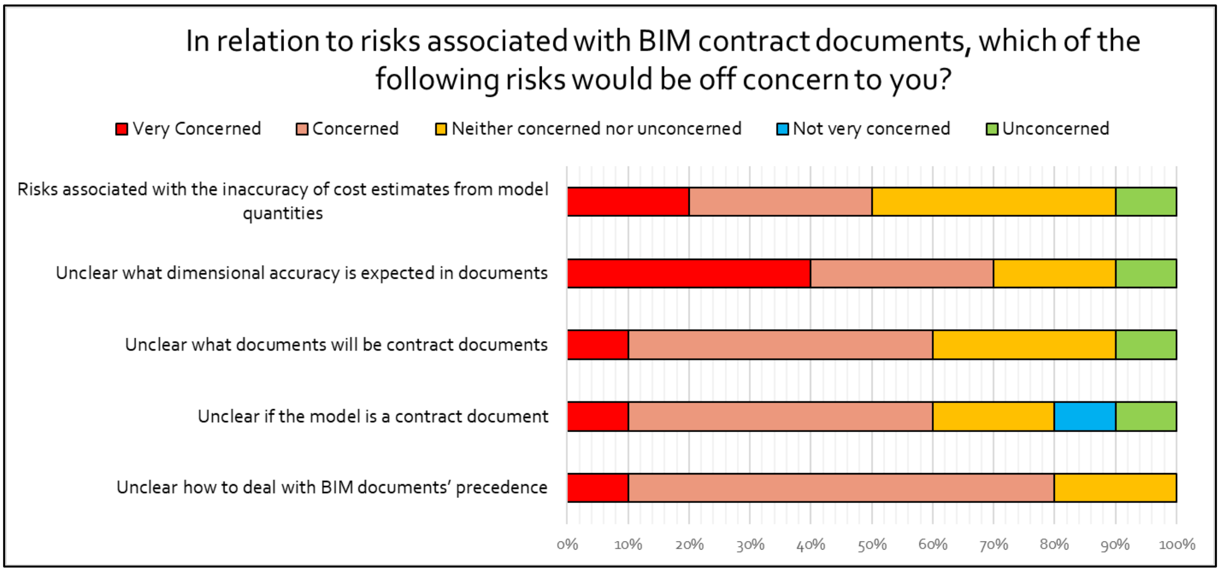

Figure 9: Respondents attitudes to BIM contract documents

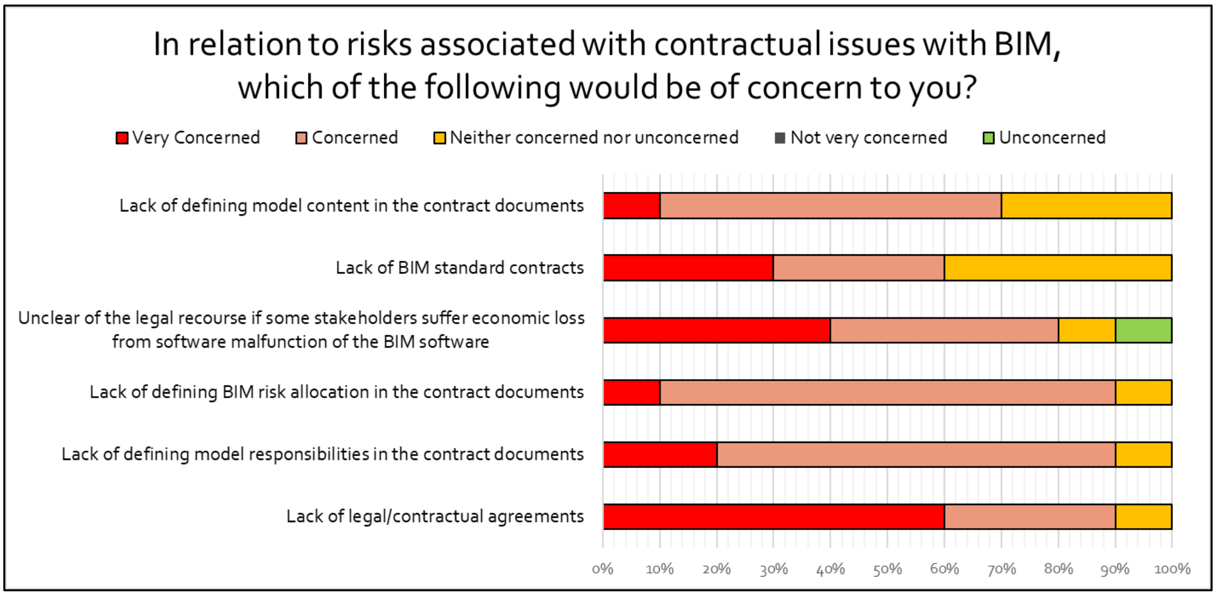

Figure 10: Respondents attitudes to contractual issues with BIM

c) Responsibilities

The survey found that liability issues relating to responsibilities between parties were of high concern. For a model-approval process, the responsibility matrices as required by ISO 19650 could be used to address this issue. ISO 19650 proposes two types of responsibility matrices, one dealing with information management activities and one for information deliverables [45]. BIM responsibilities and steel specific responsibilities such as connection design etc. could be detailed within the responsibility matrices. The Institution of Structural Engineers [14] recommend that design responsibilities between engineers across contractual boundaries are clearly defined and this would satisfy that requirement. An updated version of the BSCA document *Allocation of Design Responsibilities in Constructional Steelwork* [26] would be helpful to aid this.

d) Agreed Processes and Technologies

To make the processes and technologies they used work, Gayer et al. [6] agreed the process rules and wrote them into the engineer's specification. ISO 19650 provides processes which better manage this task. ISO 19650 requires the development of a mobilization plan which requires that technologies and processes be tested before the design work commences. The tested processes and technologies are documented in the BIM Execution Plan. Both documents are then listed in the Information Particulars to make them contractual.

e) Deliverables

The survey respondents were all in the belief that 2d drawings were essential for the approval of steel subcontractor design information. Considering this, an entirely model-only approval process may be still some way off. But this however does not mean that a complete set of traditional 2d drawings would be required if a BIM model is included within the approval process. Agreement could be made to allocate which information is acceptable to be represented in the model only, and which drawings and supporting documents would be required to complement this. Time intensive drawings such as connection details could be omitted. An agreed set of object attributes could be drawn up for each model object classification type. The full list of required deliverables would then be agreed and documented within the steelwork contractors Task Information Delivery Plan at the agreed level of information need.

f) Data Exchange Formats

The interoperability test showed that current IFC exports from a popular steel detailing software are overall good but lacking in some important areas to enable a complete OpenBIM model-approval process. This was also the opinion of Moor, AISC and Gayer et al [6, 31, 32]. Native formats fare much better as full fabrication information is included within the model. Also, software add-ins are already available to aid an approval process within native software. Use of native software however is costly and requires additional training. The survey results showed that half of respondent's organisations already used Tekla. A closedBIM process however will inevitably exclude some project participants from the information process. In any case, a steelwork contractors design information will have to be reviewed by Architects and other contractors and a process would be required for this also. For this reason, development of a robust OpenBIM workflow and technologies would be best.

The interoperability test showed that many of the required information can be transmitted via IFC successfully. Annotations are used successfully in 3d model-based approval systems within manufacturing and aerospace industries [53] and could close the gaps found in the interoperability test if they could be included within IFC. Known and understandable annotations like weld symbols would be very useful if they could be captured within IFC.

An approval system would be required for the IFC files also. IFC has within its schema allowances for approval states and roles within an approval process [66]. Software add-ins that write CDE states to model objects or groups of objects and then transfer this to IFC would be useful in this regard.

g) Quality Control

In the survey, a lack of knowledge of missing data was the risk of highest concern relating to dealing with BIM data. In the interoperability test, weld data was found to be lost in export, proving that this is a valid concern. A robust system of model quality checks would be required before issuing a model for approval. However, model quality control procedures can be at times cumbersome and unrealistic [67] and would need to be practical. Some form of checks on both sides of the transaction would be required at least initially. Displayed or reported errors may not be because of how the native software exported the IFC model. The viewing or importing software can also display or remove the data in error, even though it was captured correctly in export [10]. This could be achieved as part of the mobilization tests in ISO 19650.

The model would also require to be clash tested against other trades. Making clash checking the responsibility of subcontractors is good practice and motivates them to coordinate with other trades before they begin detailing [5, 68].

h) Communication

A model approval system would require a system of communication between parties. The BIM collaboration Format (BCF) is one such communication tool which could prove useful. BCF acts as a communication channel between IFC models and native platforms [34]. BCF links the communication entries directly to model objects within the IFC file. The platform has been implemented by many software vendors [61]. This platform could be used to communicate comments between a structural engineer and steelwork contractor during an approval process.

X Conclusions

Traditional 2d based workflows are still often used in the approval process of steelwork contractors design information even though the 2d information is derived from BIM software. These workflows are result in the Lean waste of over-processing, increasing cost to fabricators by generating additional drawings that are only used for the approval process. But is a model-based approval system without the need for 2d drawings achievable?

This research project was an attempt to answer this question. The literature review identified how traditional approval processes work currently within industry and identified what the required approval information was. The current attempts to address this problem were examined along with identifying what standard BIM processes would apply.

An interoperability test found that the IFC exports from the steel detailing software Tekla Structures were generally quite good but were lacking in some crucial areas.

Almarri et al. found that engineers had strong concerns towards BIM risks related to legal contract issues and other BIM participants and this was also the case in this research. This could explain the possible scepticism towards a model approval process shown in the survey.

The requirements needed to resolve these issues were explored and discussed. What was found was that many of the concerns in Almarri et al. and found in the survey can be addressed by the proper application of the BIM processes contained in ISO 19650. Recommendations were then made for what an OpenBIM format and process would require.

The answer to the research question is that a combination of resistance to change and technology shortcomings are barriers to the adaption of a steel model-approval process. The path forward requires several factors. Software vendors on both the BIM authoring and reviewing sides must further develop tools to enable a comprehensive reviewing process and commit to OpenBIM and the integration and development of IFC. The further development of steel specific Model View Definitions by steel industry representation groups would also be of benefit. Finally, the adoption of contract and procurement methods, such as Integrated Project Delivery, which allow for the earlier involvement of specialist contractors, reduce liability risks, and promote collaboration is required.

a) Limitations

The interoperability test was only performed on the output of the steel detailing software Tekla Structures. Other steel detailing software options are available from vendors which may produce better results.

b) Future Study

One area of future study which would aid the development of this process would be a case study lead by a Design-Build main contractor who is incentivized to identify cost reduction opportunities across traditional barriers. This would involve trialling a traditional 2d based drawing approval process against a model-based process and identifying what efficiencies would be gained.

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