2019-05-25

The Automation of BIM for Project Information Formation, Creation, Verification and Validation: a Visual Programming Approach.

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Abstract−The introduction of BIM technologies in the AEC Industry have been identified as an advantageous tool in the production of accurate Project Information. However, these technologies have also changed the dynamic of existing office structures within the Architectural Sector of the AEC Industry and introduced new technological barriers.

The objective of this paper was to identify barriers present within the AEC Industry that were a result of the introduction of BIM Technologies. The Author then, through a mixed methodology, proposed a solution to these barriers in the form of an Automated Taxonomy that would allow for the Formation, Creation, Verification and Validation of Project Information in a BIM Model through a common file format single source datasets and Visual Programming Language. The Author then critically appraised this Automated Taxonomy within the Architectural Sector of AEC Industry through stakeholder interviews and 4th generation evaluation. The results of this paper found that an Automated Taxonomy, such as the one described above, could be used to accurately create BIM Model elements, and verify and validate said Model elements at a later date, publishing the results back to the single source dataset. Through the interview process, the Author came to the conclusion that such an Automated Taxonomy could be of benefit to the AEC Industry in breaking down Technological Barriers created through the introduction of complex modern BIM Technologies.

Keywords-Automated Taxonomy, Dynamo, Information Validation, BIM Technology.

I Introduction

With the introduction of Building Information Modelling (BIM) in the Architectural, Engineering and Construction (AEC) Industry and the current boom of BIM Technologies, inherent difficulties and barriers have arisen when trying to merge new and traditional process. One such barrier that has been observed is the lack of clarity amongst a Project Team (PT) with regard to Project Information within a BIM Model. An observed cause of this lack of clarity is the gap in required skillsets for constructing a BIM Model vs the required expertise attributed to experienced AEC Industry members who specify such Project Information [1, 2]. This research investigated the current technological arriers hindering PT Project Information workflows within the AEC Industry and critically appraised a possible solution which would allow all members within a PT to overcome such barriers.

The BIM process is defined as the creation and management of digital information on and throughout a construction project [3]. PAS 1192-2, a core UK document supporting BIM, specifies the information management process for the capital and delivery phase of a BIM construction project. Described in this document is the collaborative workings between a Design Team (DT) in a standardized process, otherwise referred to as "The Information Delivery Cycle", see Fig. 1. This cycle demonstrates the interactions between a client and DT while adhering to the BIM process. Relevant to all sectors within the AEC Industry, but from the perspective of the Architectural Sector, with the implementation of BIM in construction, there have been a number of new core documents which must be completed by a PT and Client. One such documents, which is typically created during the briefing stage of a construction project, is the Employers Information Requirements (EIR). The EIR is comprised of a series of sub-sections describing how a client would require a construction project to be undertaken and completed. One sub-section described in the EIR is the requirement for a defined Level of Detail (LOD), Level of Information (LOI) and Level of Model Definition (LOMD) at each project stage [3]. LOD describes the graphical information while LOI describes non-graphical information; these two elements are closely aligned and typically develop in tandem, progressing to the next model definition as defined in the NBS BIM Toolkit [4] as a project develops from one stage to the next i.e. Developed Design to Technical Design as seen in the RIBA Plan of Works Stages [5] and as seen Fig. 1. On a BIM Level 2 project, the requirement to adhere to a predetermined minimum LOD, LOI and LOMD can be requested by a client as a contractual obligation if the EIR is appended to the BIM Protocol. This requirement is a substantial obligation for an Architectural PT as adhering to this requires a developed skillset and experience in BIM technologies. Information exchanges amongst a DT, Data Drops to Clients, and minimum LOMD requirements are defined in the CIC BIM Protocol, Appendix A, in the form of a Model Product Delivery Table (MPDT). This document is incorporated into all direct contracts between a client and DT [3, 6].

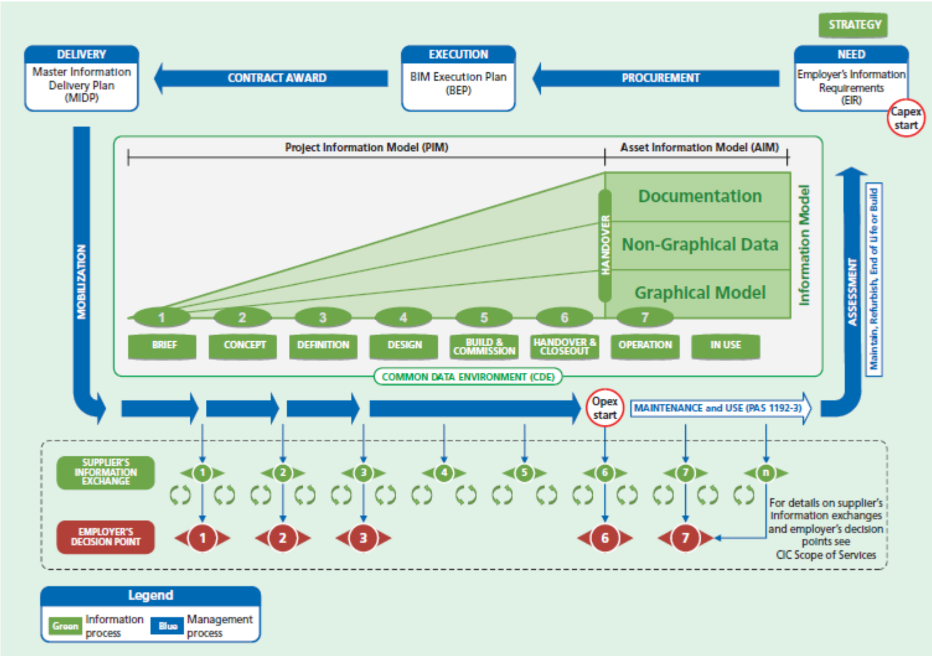

Fig. 1: The Information Delivery Cycle [3]

Although the stage has been set for the successful delivery and execution of BIM Level 2 on construction projects, such projects are still subject to inherent difficulties. The requirement to produce building information in the form of a 3D data rich Model has inherently led to the requirement of an entirely new skillset within the AEC Industry [7]. With the development of BIM technologies, the UK BIM Mandate of 2016, and future BIM Roadmap in Ireland, skilled BIM practitioners are becoming more prominent in the AEC Industry in the UK and Ireland [8]. This is due to upskilling of current AEC members, as an industry response to the lack of BIM Practitioners, through academic education programmes [9]. On a global scale, it can also be seen that there has been an Industry response to the uptake and implementation of BIM. Efforts are being made to develop and roll out BIM curriculum, training and professional development [1].

From the perspective of a PT tendering to a client, BIM competency can be seen as an advantageous tool in winning bids [10]. However, not all PT members within a “BIM Competent” PT are necessarily competent in BIM. This is because variations exist in the interpretation of “BIM Competence”. Moreover, typically a PT is capable of producing BIM as a collective, with PT members fulfilling the roles described in the CPIx Resource Assessment Form [11]. Skillsets in BIM technologies, see Table 1, amongst a PT can vary greatly within the inner levels of that team. These levels including Design Team Lead, Project Lead, Architects and Architectural Technologist. Senior PT members, who have an abundance of experience and a tacit knowledge in traditional industry processes, may not have the skillset required to operate current complex BIM technologies used to produce information in BIM Level 2 Projects. This can also be said for young native BIM practitioners, who are highly skilled in BIM technologies, but do not have the experience and knowledge of senior PT members. The skillsets to successfully complete a project may be present in the PT, but this is only through collaboration between individually skilled PT members [12].

Table 1: BIM Competency Definitions

Title	Definition
Non-BIM	Practitioner who have no experience using BIM Technologies or with the BIM Process.
Non-Native BIM	Practitioner who have prior experience in the AEC Industry but who have upskilled in order to gain knowledge in BIM Technologies and the BIM Process.
Native-BIM	Practitioners who have come into the AEC Industry with a base knowledge of both BIM Technologies and Process from academic degree.

Native BIM Practitioners in a PT work in tandem with non-BIM or non-native BIM Practitioners for the successful completion of construction projects through traditional industry standard processes and communications. However, as there is an information disconnect through technological barriers, accessing information for non-BIM or non-native BIM users can be difficult [13]. Project Information required in BIM Models can become fragmented, duplicated, and form independent silos which increases the likelihood of information discrepancies within a project [14]. Although modern BIM technologies have been developed to be user friendly, they still require an advanced skillset.

When delivering a project to a BIM Level 2 standard, data management pertaining to LOD, LOI and LOMD deliverables are typically structured in accessible common formats such as Excel Spreadsheets. This is evident with the MPDT, MIDP, TIDP, and NBS BIM Toolkit [3, 4]. Client requirements on construction projects also have the capacity to be conveyed through such formats. The benefits of this being:

- they require no extra skillsets in BIM
- the software is widely available
- they can be integrated with other professional writing tools.

These structured, yet fragmented documents containing critical Project Information suggested the research topic on which this investigation is based on.

Firstly, can an Automated Taxonomy be created through Visual Programming Language (VPL), BIM Technologies, and "Common Formats" for the Formation, Creation, Verification and Validation of Project Information in a BIM Model to contractually obligated LOI Definitions, from a single source Dataset?

And secondly, is a tool such as this necessary in the current AEC Industry, or does it only add to the perplexing world of modern BIM Technologies?

Section II and III of this paper will show the current gap in knowledge in the AEC Industry with regard to:

- prominent barriers regarding BIM Technologies
- automated information validation processes
- the gap in knowledge within the inner levels of a PT.

Section IV of this paper will describe a methodology for implementing the proposed Automated Taxonomy which will be tasked with overcoming current barriers in the AEC Industry identified in Section II.

Section IV of this paper will critically appraise what impact the proposed Automated Taxonomy could have on current PT workflows within the AEC Industry.

II Industry Background

a) Are BIM technologies an issue?

To many in the AEC Industry, there are still prominent barriers to BIM which clients and DTs find too great to overcome, and are therefore reluctant to address. The 2015-2018 NBS National BIM surveys note that the top 5 fundamental barriers in implementing BIM generally remain the same. These can be seen in Table 2.

Table 2: National BIM Survey Barriers 2015-2018

National BIM Survey Barriers				
Barriers	**2015**	**2016**	**2017**	**2018**
Lack of in-house Expertise	74%	NA	73%	71%
Lack of Training	67%	NA	59%	61%
No Client Demand	63%	NA	65%	69%
Cost	56%	NA	55%	50%
No Time to catch up	51%	NA	49%	47%

From 2015 to 2018, it can be seen that the leading critical barriers remain the same, with the agreeing survey participants only showing minor variations. One of these barriers which has dropped by 6% since 2015 and dropped to 8% at a lowest is “the lack of training” required to achieve BIM. This fall can be correlated to the increase in Native BIM Practitioners coming into the industry. This also correlates with a BIM adoption increase from 48% to 74% in the same period. Barriers to BIM are being broken down through an increase in Native BIM Practitioners in the Industry [2, 15, 16]. These trends in Barriers appear to be common on a global scale depending on the maturity of a respective nation’s BIM competency. Another report in 2015 by Liu, Xie, Tivendal and Liu found that critical barriers included a lack of national standards, costs in application, lack of skilled personnel, organisational issues and legal issues [17].

A BIM Macro Adoption Study undertaken by Hore, McAuley, West, Kassem and Kuang in 2017 noted that, in Ireland, BIM maturity is ranked highly with regard to technology infrastructure and learning and education. This was linked to the commitment of Higher Education Institutes to deliver BIM programmes in a direct response to the AEC Industry struggling to meet Information Communications Technology (ICT) requirements. [9]. This skills gap and commitment to Higher Education was also identified by McAuley and Hore in another study in 2019. It was identified that Digital Construction is a critical driver in navigating the Irish Construction Industry through the current skills shortage. It was concluded that there must be an inclusion Digital Design and Construction in second-level curriculum.[18]. An interview with Kirwan, a BIM Development Manager, in 2018 showed evidence of this upskilling and commitment to education in Ireland in effect. It was stated by Kirwan that currently BIM is becoming an integral part of many existing undergraduate courses, while also new postgraduate courses are being made available, which complement undergraduate programmes but also allow current industry members to upskill in BIM [19].

In Sweden, a report by Ghavamimoghaddam and Hemmati in 2017 came to the same conclusion on the barriers of BIM implementation. However, this investigation also identified that there may be a generation rift within the AEC Industry which perpetuated these barriers. It was suggested that senior PT members found it difficult to use computers and thus, BIM Technologies. They determined that the generation to which a user belongs can be a crucial factor in using BIM technologies. While BIM tools are used when required by senior PT members for coordination purposes, these same employees, on an individual level, reverted back to traditional methods of communication and creation as their personal experiences aligned with this method of production. Another barrier when implementing BIM observed in this report was the syncing of information changes into different construction elements within the BIM Model. The generation gap was again determined to be a factor in this barrier as there was a gap in both skills and experiences. Members with an expertise in identifying problems could not access or amend a model, and those who could access a model did not have the years of experience to be able to identify errors that are not visualized in a BIM Model. This report concluded that the hindrances to BIM implementation during the production phase of a project were due to lack of integration, unclear tasks and responsibilities, and unwillingness to changes [13].

The research in this study investigates if these findings are replicated in Ireland at this time.

b) What is being lost in the BIM Model?

It has been identified that one of the elements of traditional processes that is being lost to the BIM Model is critical Project Information relating to model elements. This is due to one of the few remaining critical barriers to BIM, the technological barrier, and moreover, the lack of access to Project Information within a BIM Model due to this barrier. A BIM Model can be host to a wide variety of Project Information requirements and deliverables, and in a perfect world, should be seen as a single source of truth. This, however, in the current AEC Industry is not seen to be possible due to these technological barriers.

On a BIM Level 2 project, information deliverables that can and should be found in a BIM Model are LOD, LOI and LOMD for BIM Model elements. As previously stated, this information can vary in development depending on project stage, however, it should adhere to minimum requirements [4, 6]. This is a crucial part of the BIM process during the production stage as shown in Fig. 1. Information within a BIM Model must be shared between the individual PTs of a DT in the form of “Information Exchanges” to ensure clarity and accuracy amongst the DT. This information is then shared with the client at the end of each project stage, an “Employers decision Point”, in the form of a Data Drop. Data Drops within a construction project typically act as a stage gate, data is analysed and decisions made on a project progression. Data must be delivered in a controlled manner with only certain information in certain formats being delivered. Information is delivered at particular stages of a project. These stages align with the RIBA Plan of Works and PAS

1192:2 project stages [3, 5]. Information typically included in Data Drops are as follow:

- Models (both IFC and native file format, in this investigation Autodesk Revit)
- Structured Data such as Schedules and/or COBie files
- And Reports, Native files and/or .pdfs.

These information drops allow a client to check and validate Project Information with the initial brief and EIR [20].

The process of conducting an information exchange between individual PTs within a DT follows a defined rigor to ensure accurate information is being produced. As a number of file types are being produced and shared, some with no direct link, an information validation process must be conducted to ensure accurate information is being exchanged. This is typically a manual process as there are limited technological links between a BIM Model and its supporting text documentation. Manual validation processes inherently suffer from human error, meaning information exchanges can be hindered due to inaccurate information within a PT being shared with all other PTs of a DT.

c) What can be done about it?

This problem of information checking, syncing, and validating is widely observed in the current AEC Industry, and a number of investigations have been undertaken in recent years to combat this information barrier. BS EN ISO 19650-1:2018, a superseding document to PAS 1192-2, also stresses the importance of, and proposes a method for, information Verification and Validation between Project Stages and DT members [21]. This information syncing and validation is critical due to the high levels of fragmentation within the current Industry. Carroll and McAuley determined that this could be combatted through the implementation of BIM and early Contractor involvement. The potential for BIM could be used to enhance data management processes while also being used to mitigate common construction issues such as construction element clashes, while improving quantity take off procedures, facilities management processes and project specifications production [22].

A recent study by Mecheri & West in 2017 [23] determined that information integration and synchronisation was essential to fully achieve and utilise BIM on construction projects. This investigation queried the possibility of managing and linking independent project data silos such as Excel Data Schedules and Revit Model Elements in an effort to reduce waste and improve productivity and efficiency. A methodology was not provided. It was concluded that at that time, dataflows in the AEC Industry were too disjointed and that multiple information silos existed in tandem due to lack of DT trust and PT BIM capabilities. A product of this was a necessity for data recreation. It was determined that for the potential of integrated BIM to be fully achieved, upskilling in the AEC Industry is required, coinciding with findings from Hore, McAuley, West, Kassem and Kuang in 2017 [9] . If a PT is lacking in BIM capable practitioners, a workflow must be present that would allow for the liberation of Project Information from a BIM Model, allowing all members of a PT access, and ensuring information verification and validation. It was also suggested that if independent data silos could be eliminated through unconstrained data integration across a project's lifecycle, the potential to achieve BIM Level 3 with regard to Project Information could be made possible. It was finally concluded by Mercheri and West that, due to a lack of software capabilities in 2017 in the AEC Industry, for the foreseeable future, limitations would remain in data interoperability. For an Industry wide workflow and software system to be created and implemented, it would stand to reason that an unrealistic and unmonitorable level of consistency and uniformity would be required within the existing Architectural Practices willing to implement such a workflow [23].

A step towards Project Information integration with BIM Models, and towards information verification, was highlighted in an investigation by Reilly, Montague, and Buckley-Thorp in 2017. In this report, a method was developed for model checking and information verification using a combination of Uniclass Classifications, LOD, NBS BIM Toolkit, Flux.io, Dynamo and custom web apps. This methodology was developed to verify the presence of Project Information and to report, but not validate information values. It was determined in this investigation that it was the responsibility of each PT to confirm the validity of Project Information. This absence of "Information Validation" from the scope of the Reilly, Montague & Buckley-Thorps investigation represents a gap that will be further investigated in this study, i.e. an Automated Taxonomy approach of Project Information Validation. Reilly, Montague & Buckley-Thorp agreed that a methodology such as theirs should also be able to create required parameters, populate required parameters, and trigger alerts when issues are found. However, this was omitted from the scope. The proposed methodology in this investigation looks to partially fill this barrier in current BIM technologies [24].

Another investigation into BIM Data Validation through VPL by Ghannad, Lee, Dinyadi and Solihin focussed on automated compliance checking with regard to building standards. This investigation determined that it was not only possible to use VPL in automated compliance checking, but that it can also greatly aid in reducing manual data checking which inherently reduces waste in time and inaccuracies regarding human error. This investigation was completed using open standard VPL as it removed the "Black Box" hardcoding limitations from current AEC Industry standard BIM technologies. By using open source VPL, an Automated Taxonomy could be created that could fit around existing Architectural Practice processes and structures without the need for Industry conformity to new processes, which can in itself be seen as a barrier to BIM. By integrating existing process into BIM via VPL, a smooth transition could be made towards BIM level 3 regarding project data integration [25].

Another investigation by Li, Li, Peng and Wu in 2018 reviewing current BIM technologies in the AEC Industry came to a similar conclusion. BIM Technologies should target a Client, and in particular their needs and requirements without introducing new barriers. BIM technologies need to focus on interoperability issues with regard to Project Information in order to further improve a Client's contribution to construction projects [26].

A recurring theme in recent investigations is the use of VPL, Dynamo, for the integration of Project Information within the BIM Model. Dynamo is used in these investigations as it allows users to create a defined path of information to and from a BIM Model in order to achieve a desired goal. Dynamo was used in this investigation for the same reason. A path could be defined linking existing office structures and process, known to the Author, to the BIM Model. As Dynamo is open source, the Scripts created could be designed to integrate such structures and as a product, remove the requirement to conform to any existing or future industry standard software systems as highlighted by Ghannad, Lee, Dnyadi and Solihin.

As made apparent by the literature critically examined in this section, while significant effort has been expended on eliminating boundaries within the current AEC Industry, barriers are still present which hinder Industry progression.

III The Gap

The goal of this investigation is to propose an Automated Taxonomy, using VPL, which will allow for the Formation, Creation, Verification and Validation of Project Information through a single source dataset, which has the potential to be populated by all relevant members of a PT, not just skilled BIM practitioners. Although there have been a number of recent investigations on BIM Model validation, automated code compliance checking, and BIM information mapping, the type of information this investigation will focus on is performances and specification requirements for construction elements.

The gap that this investigation aims to fill, is the gap created due to the lack of synchronisation within a PT, which is a product of barriers created by BIM technologies and the lack of integration in Project Information.

IV Automated Taxonomy

The approach to this Automated Taxonomy was developed as a Design Science, a technological rule and ICT solution that outlines procedures and workings of a proposed idea rather than a fully developed BIM interface [27]. The proposed Automated Taxonomy methodology comprised of 3 critical stages, as seen in Fig. 2. The overarching objective of this Automated Taxonomy was to create a single source Dataset in a common file format that could be used to create Revit System Family files populated with predetermined parameter values; and which could also be used to Verify and Validate such information throughout a projects progression. A visual breakdown of this methodology can be described as follows.

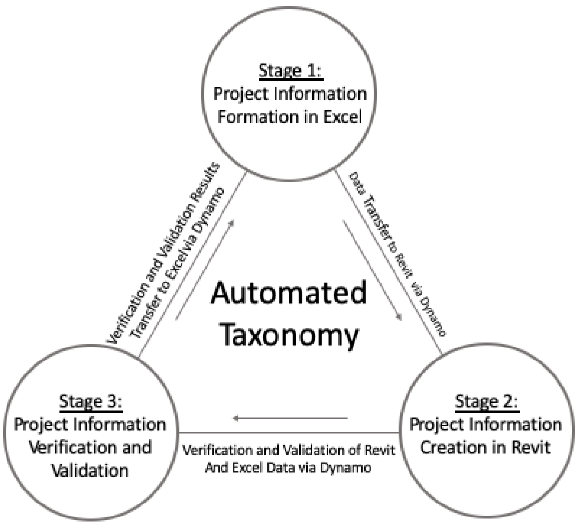

Fig. 2: Automated Taxonomy

a) *Project Information Formation*

The first stage of this Automated Taxonomy was to create a project template that could be used to host the common format dataset, this is referred to as the Project Template Dataset (PTD). For this, Microsoft Excel was chosen. The reason for using Excel as the PTD was that it could be fully integrated into BIM Technologies through the use of VPL; this also aligns with the proposed methodology outline by Mecheri & West [23]. The PTD in this investigation was also developed from existing office structures known to the Author, allowing for minimal reworking of existing workflows and minimum disruption to existing office protocols. Due to the nature of VPL, it was not necessary to conform with current Industry software, addressing and overcoming a critical barrier highlighted by Ghannad, Lee, Dnyadi and Solihin [25]. The PTD was developed to be both functional as an integrated BIM Dataset, and presentable as a publishable Project Document.

As the scope of this investigation was for 3 System Family Categories, 7 sheets were created in total. Each system category had a dedicated publishable sheet, and a linked data sheet within the PTD. There was also an additional sheet for the Verification and Validation of Project Information. These sheets were as follows:

- Wall Types
    - WT Project Data
- Floor Types
    - FT Project Data
- Ceiling Types
    - CT Project Data
- RVT vs XLSX Results

The sheets in the PTD were structured in such a way that each publishable sheet (Wall Types, Floor Types and Ceiling Types) would automatically populate their respective project data sheets via cellular linking within the PTD. For this investigation there were 3 System Family Categories, 6 System Family Types per Category, and each System Family Type had 7 unique Type Parameter Values. This created a Data Scope of 126 Data Instances. See example of Wall Type data in Fig. 3.

The Parameter Types chosen for each System Family Category were based on the requirements determined in the NBS BIM Toolkit for an "LOI Stage 3: Definition". The parameter values of this investigation aim to encapsulate this information through the user defined PTD. For example, the LOI requirements for wall types as defined by NBS [28] are as follows:

- Materials, components and details
- Strength, Internal Air Pressure Resistance and Racking Strength
- Fire Resistance
- Acoustic Performance
- Airtightness
- Compliance with Performance Requirements

These information requirements described in the NBS BIM Toolkit were then correlated with existing Family Type Parameters in the BIM Model. These Parameter Names were then set as column titles within the PTD, and would be used to direct Project Information once the PTD was targeted by the Dynamo Scripts described in part b.

Type Mark	Description	NBSReference	Acoustic Rating	Manufacturer	Fire Rating	URL
A1-01	Slab to Slab	25-15-25/135	49 RwdB	British Gypsum or equal and approved	NFR (inherently 60 minutes)	https://www.gyproc.ie/sites/default/files/GypWall.pdf
A1-02	Slab to Slab	25-15-25/135	53 RwdB	British Gypsum or equal and approved	NFR (inherently 60 minutes)	https://www.gyproc.ie/sites/default/files/GypWall.pdf
A1-03	Slab to Slab	25-15-25/135	57 RwdB	British Gypsum or equal and approved	NFR (inherently 60 minutes)	https://www.gyproc.ie/sites/default/files/GypWall.pdf
A2-01	Slab to Slab	25-15-25/135	49 RwdB	British Gypsum or equal and approved	1/2-HR (inherently 60 minutes)	https://www.gyproc.ie/sites/default/files/GypWall.pdf
A2-02	Slab to Slab	25-15-25/135	53 RwdB	British Gypsum or equal and approved	1/2-HR (inherently 60 minutes)	https://www.gyproc.ie/sites/default/files/GypWall.pdf
A2-03	Slab to Slab	25-15-25/135	57 RwdB	British Gypsum or equal and approved	1/2-HR (inherently 60 minutes)	https://www.gyproc.ie/sites/default/files/GypWall.pdf

Fig. 3: Wall Type Data

The final sheet within in the PTD, "RVT vs XLSX Results", was not populated manually with any data by the Author. This PTD sheet was to be populated later with parameter value Verification and Validation results for all System Family Files originally formed in the PTD and then automatically Created in the BIM Model.

b) *Revit System Family File Creation*

The software Packages used in stage 2 and 3 of the Automated Taxonomy were as follows:

- Microsoft Excel
- Autodesk Revit 2018.3
- Dynamo Revit 1.3.3
    - Clockwork 1.33.1

Stage 2 of this Automated Taxonomy was the Creation of Revit System Family Files by linking the PTD and BIM Model via Dynamo. This Stage had one Author-created Dynamo Script with 2 Author-created custom Dynamo nodes, this Dynamo Script, "Script 1: Model Element Creation", was developed using "Out of the box" Dynamo Nodes and 1 node from the Clockwork 1.33.1 Package, "FamilyType.Duplicate". In Script 1: Model Element Creation, there were 3 streams of nodes, each stream dedicated to one of the System Family Categories described in the PTD; Ceilings, Floors and Walls. For each System Family Category stream, there were a number of sequential functions, common to each stream, for successfully completion of the overall objective. This process can be seen in Fig. 5 for all System Family Categories, and for Wall Types in Fig. 4 and as described below.

1. Cell values were identified in the PTD and transferred to Script 1.
2. Cell values were listed and organised to the Authors requirements within the Script 1.
3. "Host" families which were pre-existing in the BIM Model Template, for example "9876_Walls_" as seen in Fig. 7, were identified and placed within the Script 1 for interrogation.
4. Host families were then duplicated to the number of System Family Types described in the PTD, 6 per Category.
5. Each host duplicate then had its family name overwritten to incorporate each PTD Family Types identifying Type Mark, for example "9876_Walls_A1-01" as seen in Fig. 8. Concurrently, each of these duplicates had their individual blank type parameter values overwritten by the values associated with the Type Mark as described in the PTD.
6. These new Type Families, which were originally defined in the PTD, were then published to the BIM Model, as seen in Fig. 6.

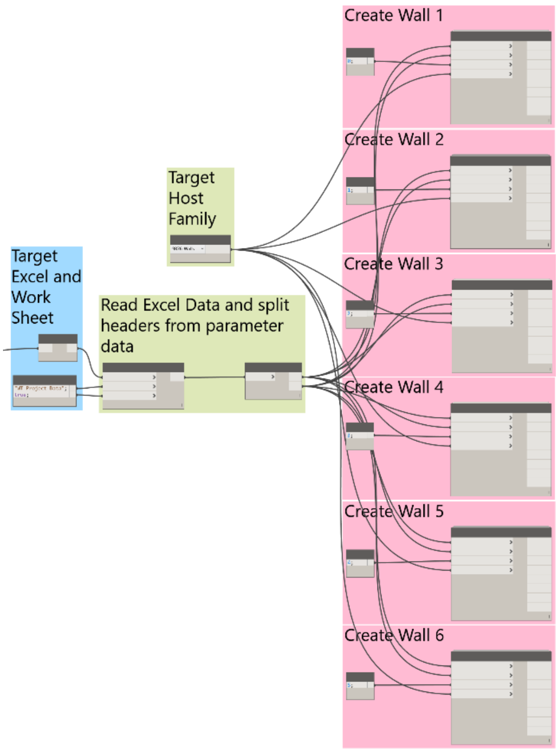

Fig. 4: Script 1-Model Element Creation - Wall Types

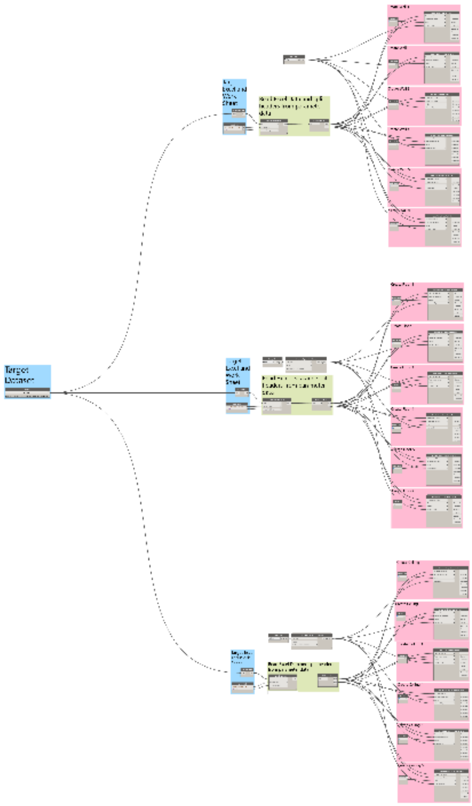

Fig. 5: Script 1 – Model Element Creation

The information in Fig. 3 row 1, directly corresponds with the information in Fig. 8*Fig. 8*. This is an example of how the Project Information, which was determined by the PT in the PTD, was identified, the host family in the BIM Model targeted, and the new family published to the BIM Model for use by BIM practitioners.

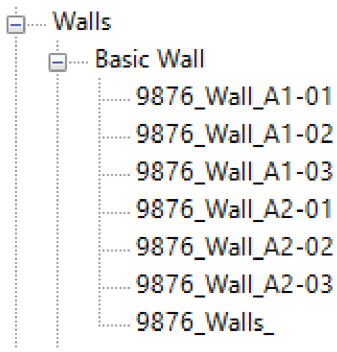

Fig. 6: Revit Wall Types Created

Fig. 6Fig. 6 shows these System Family Files automatically created and stored in the BIM Model under the Wall Type Category.

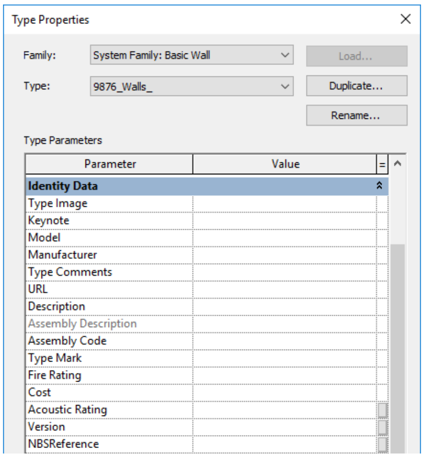

Fig. 7: Revit Wall Type Host Family

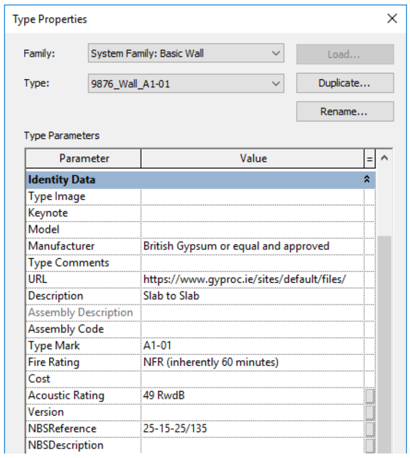

Fig. 8: Revit Wall Type Family Parameters

c) Project Information Verification and Validation

Stage 3 of this Automated Taxonomy was the Verification and Validation of Project Information within the BIM Model and the publishing of these results to the PTD. Now that these Revit System Family Files had been created from the input values in the PTD, they were an exact replica of the source information at the time of their creation, yet independent from the PTD from then on. To ensure synchronisation of Project Information hosted in both the BIM Model and PTD, the Parameter Values and Cell Values, were cross examined and validated.

This Verification and Validation process, like in Script 1: Model Element Creation, had 3 streams of information, each stream representing the System Family Categories described in the PTD and now the newly formed and corresponding Revit System Families in the BIM Model. This new Dynamo Script is referred to as “Script 2: Information Verification and Validation” This process can be seen in Fig. 10, and for Wall Types in Fig. 9 and described as follows.

- The PTD and BIM Model were targeted by Script 2 concurrently.
- The data in these information hosting formats was categorised by Type Mark within Script 2.
- The PTD Cell Values and BIM Model Parameter Values were associated with one another by linking the Type Mark Parameters in both locations.
- The linked data was then run through a set of nodes that would determine if each Parameter and Cell Value were equal to one another.
- The compared data was returned in “TRUE” or “FALSE” values.
- Values were published to the PTD, Sheet “RVT vs XLSX Results” creating an information loop.

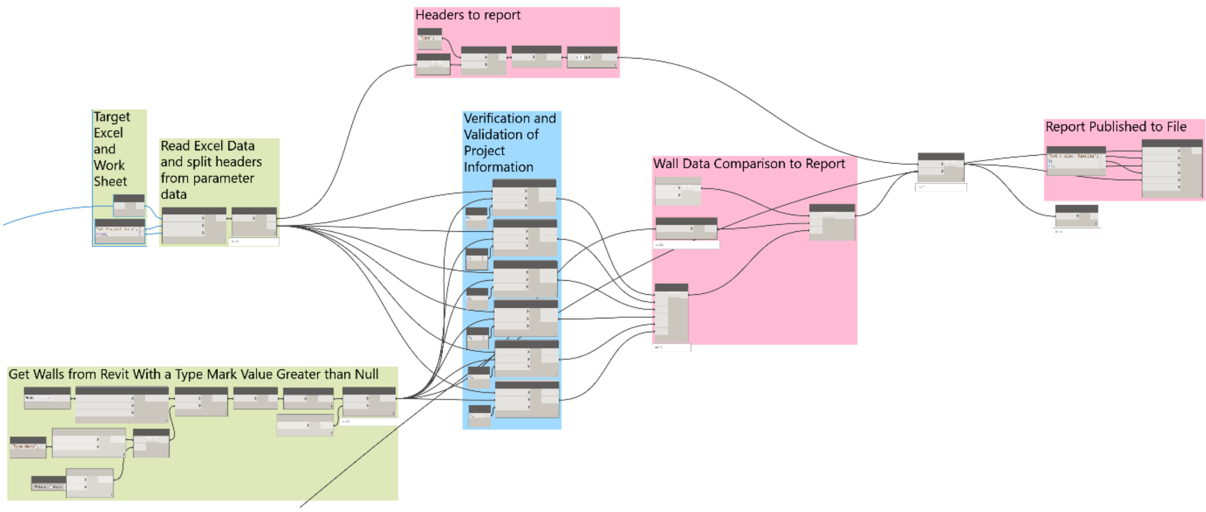

Fig. 9: Script 2 - Information Verification and Validation - Wall Types

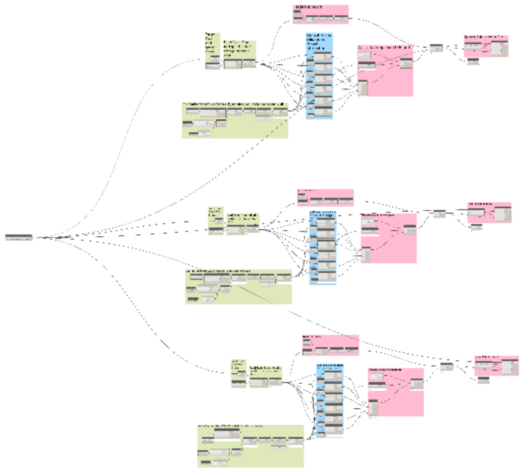

Fig. 10: Script 2 - Information Verification and Validation

This validation process was tested and debugged by introducing forced discrepancies to both the Revit Parameter Values and PTD Cell Values. By doing this at random to a number of Parameter and Cell Values, it was determined that each forced discrepancy was identified and published to the PTD. It could be determined that each Parameter Value, for each Family Type, for each System Category was reporting accurately and there were no false negatives or false positives. An example of these results can be seen in Fig. 11*Fig. 11*. It was also recorded that this Verification and Validation process took approximately 3 seconds to complete on a blank BIM Model template with no modelled data.

Wall Type Verification and Validation							
Type	Type Mark	Description	NBSReference	Acoustic Rating	Manufacturer	Fire Rating	URL
9876_Wall_A1-01	FALSE	TRUE	TRUE	FALSE	TRUE	TRUE	TRUE
9876_Wall_A1-02	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE
9876_Wall_A1-03	TRUE	FALSE	TRUE	TRUE	FALSE	FALSE	TRUE
9876_Wall_A2-01	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE
9876_Wall_A2-02	TRUE	TRUE	FALSE	TRUE	TRUE	TRUE	TRUE
9876_Wall_A2-03	FALSE	TRUE	TRUE	TRUE	TRUE	FALSE	TRUE

Fig. 11: Project Information Verification and Validation Results

As this process of Verification and Validation did not detect where discrepancies in Parameter and Cell Values originated, only that they were present, a methodology for such detection was proposed. This can be seen as follows:

- Archive the PTD once Stage 2 of the Automated Taxonomy has been completed.
- If information discrepancies arise, when completing stage 3, a manual validation of the archived and live PTD can be completed through visual checking.

Or,

- Complete Stage 3 of the Automated Taxonomy with the archived PTD. If the new Verification and Validation results show "TRUE" Values where they originally were "FALSE", the information discrepancy originated from the PTD.
- If these results remain "FALSE", the discrepancy originated from the BIM Model.

The end result of this Automated Taxonomy is a tool and methodology that could be used for the automatic creation of Revit System Family Files within a BIM Model from previously formed Project Information within the PTD, which can then be automatically Verified and Validated with published results going back to the original PTD in the form of an information loop.

V Is there an Industry Requirement?

The proposed Automated Taxonomy was taken to small sample size of 5 stakeholders, or interviewees. However, as each Interviewee had varying levels of BIM exposure and competency, and were at varying levels within their respective PTs, see Table 3, there was a good representative of the Architectural Sector present. Of the 5 Interviewees, 4 were from the same company and current colleagues of the Author, however, had not worked directly with the Author previously, while 1 Interviewee was a past colleague of the Author.

The interviews were conducted in the order shown in Table 3, with junior members of a PT being interviewed first, followed by more senior members. Each interview had open ended questions, and the predetermined questions were provided on the day each interview was conducted. The interviews were conducted in 2 stages with a brief intermission and demonstration of the proposed Automated Taxonomy between stages. Between each interview, there was 4th generation evaluation on the interview questions, carrying themes from the previous interviews into the next.

The aim of this interview process was:

a) to gain an understanding of what the current AEC Industry's experience was with BIM technologies, inherent barriers created by these technologies, and how these technologies have affected PT structures, and

b) to determine if an Automated Taxonomy, such as the one proposed, could be beneficial to the current AEC Industry in breaking down these technological barriers identified in Section II.

The 5 Interviewees not only had varying levels of BIM competency, but were also at varying levels within their respective PTs. These Interviewees were as follows:

Table 3: Interviewee Titles

Interviewee Number	Role in PT	BIM Level
1	Architect	Novice-Low
2	Architectural Technologist	Medium - High
3	Senior Technologist, Project Lead and BIM Coordinator	High-Expert
4	Architectural Technologist and BIM Coordinator	High - Expert
5	Associate Architect, Project Lead, Design Team Lead	Medium - High

In stage 1 of these interviews, a number of common themes relating to BIM within the Architectural Sector of the AEC Industry were identified amongst the Interviewees' responses. As these interviews were subject to 4th generation evaluation between Interviewees, these themes could be developed and expanded on. These themes were as follows:

- There was a greater knowledge of BIM Technologies than of BIM Process within the Architectural Sector of the AEC Industry.
- These BIM Technologies were seen to be a great benefit to the current AEC Industry with regard to the production and conveying of Project Information.
- Interviewees who had experience with producing Project Information within a BIM Model to a predetermined LOD and LOI (whether required as part of the BIM process or as an office standard) stated that it was a positive experience as it provided clarity amongst the PT and DT, which inherently meant better information was being produced.
- Project Information within a BIM Model is typically specified by a senior member of the PT, such as Project Lead, and then transcribed into a BIM Model by less experienced junior PT members.
- Senior members of a PT typically have limited understanding and capability with regard to BIM technologies, although there are exceptions to this rule.
- A Generation Rift was observed by the interviewees; this rift correlated with Ghavamimoghaddam and Hemmati [13] findings that senior members of the AEC Industry do not have the required skills to work with BIM Models. A Professional Rift was also observed. It was identified by 3 of the 5 interviewees that while senior PT members had limited understanding of BIM technologies, Graduate Architects also had a limited understanding compared to Graduate Architectural Technologists. Interviewee 1 stated "A generation rift is present due to new graduates learning BIM in college as a default. There is also a professional rift. Young undergraduate Technologists are exposed to BIM far before undergraduate Architects. Young Architects learn on the job, and therefore, are behind in BIM skills compared to technologists". This, along with other interviewee statements indicates that, there is a professional skills rift due to Graduate Architects received no training in BIM Technologies during their education, whereas Architectural Technologists received in depth training in BIM technologies as a direct response to the current industries requirements for skilled BIM Practitioners within the AEC Industry [9, 19].
- Within all interviewee's current workflows, there are multiple duplicates of critical Project Information hosted in multiple formats. Although it was determined by all interviewees that it is best practice to pull Project Information from 1 master data source, this was not always achievable due to project pressures. Interviewee 5 stated in their experience, "Project Information is always multiplied and scattered, even within the better BIM systems. The information must also be manually validated and checked by PT personnel". This manual validation process was correlated with the fact that an automated process did not exist within each Interviewees' existing office structures which could crosscheck such information hosting formats.

In stage 2 of the interview process, following a demonstration of the proposed Automated Taxonomy, it was determined by all Interviewees that such a tool and workflow could be of benefit to current processes within each Interviewees' respective PT. The interviews had 2 common threads throughout:

- Information on construction projects is fragmented and must be validated to ensure accuracy.

- On a PT, information is specified by Project Leads and senior PT members and filtered down to junior PT members. This information must also be manually transcribed to BIM technologies by junior PT members and manually validated.

The interviewees came to the conclusion that if the proposed Automated Taxonomy could allow Specifiers or Project Leads to have greater control over the Project Information going into a BIM Model, it stands to reason that the information being produced during the construction stage of a project would be better and more accurate. That being said, it was also stated by 2 of the 5 interviewees that there could be a new issue in relying on this information being correct in the first place. Blind reliance on others takes away from a professional's obligation to be due diligent in the production of their work. The Interviewees came to an overall conclusion that this Automated Taxonomy, when used as a tool to aid current processes in being duly diligent in the production of Project Information, it could only be seen as a benefit to the AEC Industry. The tool removed the factor of Project Information discrepancies within a PT. However, it could not address the problem that is currently also present for the Industry: is the information correct in the first place.

VI Conclusion

It can be concluded that the proposed Automated Taxonomy could be integrated into existing Architectural processes and could be used for the accurate Formation, Creation, Verification and Validation of Project Information within a BIM Model, thus allowing for the liberation of Project Information from BIM Technologies. The Automated Taxonomy successfully created 18 Revit System Family Files while populating each Family with 7 corresponding Type Parameters, for a total scope of 126 individual Family Type Parameters transferred to the BIM Model from the PTD. The proposed Automated Taxonomy also successfully Validated all 126 Parameters and published these results to the PTD as a readable and easily comprehensible format, as seen in Section IV.

As for the requirement of such a tool within the current AEC Industry, it can be seen in Section V, that all 5 Interviewees who received demonstrations determined this Automated Taxonomy would be of benefit. These interviewees not only found that such a tool would be of great benefit to their current Architectural processes within their respective PTs in its initial proposed function, but that it also had more benefits than previously attributed to it by the Author. In the opinion of Interviewee 5, a DT Lead and Associate Architect, the proposed Automated Taxonomy could also be used in the initial briefing stage or tender process of a project before a DT has been appointed. Clients could describe, in common text, Project Information requirements, as typically "the client writes the brief in words and an architect turns it into a building". This tool could "act as a validator to the brief as you go through the areas of employer decision points". This process, that could be started by the client, could then be developed under supervision and completed by the appointed PT members.

As previously mentioned, the benefits of such a tool could only be realised if it was treated as such, a tool. A thorough validation process and an individual's commitment to due diligence in ensuring Project Information is accurate is an essential task in order to produce valid and good information. This tool has been proven to aid in this task by combatting a lack of synchronisation with regard to Project Information currently evident in existing Architectural processes. What remains is ensuring that the information that is being specified is accurate in the first place. By breaking down barriers in current BIM technologies identified in Section II and allowing non-BIM practitioners access to such information, this Automated Technology makes this task achievable.

VI Future Works

The potential of a tool such as the one described in this investigation goes far beyond the current scope attributed to it by the Author. However, due to time constraints and limited knowledge in VPL, this scope could not be expanded further. Future works in this Automated Taxonomy would be to include a Room Data Sheet, Door Type Sheet, and Window Type Sheet. This Automated Taxonomy would also be adapted to link Project Information within the PTD with NBS Create. NBS Create has the function to export data in CSV file format, which could potentially be linked to the Validation process through VPL. By doing this, a true single source of data in a common format could be created which would have the potential to populate both Revit System Family Files and Specification Documents while ensuring synchronisation amongst the PT, and as a result, allow all members of a PT have access to Project Information, overcoming technological barriers.

VII References

[1] B. McAuley, A. Hore, and R. West, "BICP Global BIM Study-Lessons for Ireland's

BIM Programme," 2017.

[2] A. Malleson, "NBS National BIM Report 2018," NBS, England, 2018.

[3] *PAS 1192-2:2013*, British Standard Institute, 2013.

[4] S. Hamil. "NBS BIM Toolkit." National Buildings Specificaiton. https://toolkit.thenbs.com/definitions (accessed 15/03/2019, 2019).

[5] *RIBA Plan of Work 2013 Guide*, RIBA, 2015.

[6] Construction Industry Council, "Building information model (BIM) protocol,," *CIC/BIM Pro,* 2013.

[7] "To BIM, or not to BIM? That is the Questions!" BIM Ireland. http://www.bimireland.ie/2019/01/07/to-bim-or-not-to-bim-that-is-the-question/ (accessed 15-04-2019, 2019).

[8] B. Ireland. "BIM Innovation Capability Programme paves the way to Ireland's Digital Construction Programme 2018-2021." BIM Ireland. http://www.bimireland.ie/2018/02/08/bim-innovation-capability-programme-paves-the-way-to-irelands-digital-construction-programme-2018-2021/ (accessed 15-04-2019, 2019).

[9] B. McAuley, A. Hore, R. West, M. Kassem, and S. Kuang, "Ireland's BIM Macro Adoption Study: Establishing Ireland's BIM Maturity," in *CitA BIM Gathering 2017*, Ireland, 2017: The Construction IT Alliance.

[10] NBS, "National BIM Report 2016," Newcastle, 2016.

[11] *CPIx Resource Assessment Form*, CPI, 2011.

[12] N. Gu and K. London, "Understanding and facilitating BIM adoption in the AEC industry," *Automation in Construction,* vol. 19, no. 8, pp. 988-999, 2010/12/01/ 2010, doi: https://doi.org/10.1016/j.autcon.2010.09.002.

[13] B. Ghavamimoghaddam and E. Hemmati, "Benefits and Barriers of BIM Implementation in Produciton Phase," Masters Degree, Division of Construction Management, Chalmers University of Technology, Gothenburg, Sweden, 2017.

[14] B. Dave, A. Buda, A. Nurminen, and K. Främling, "A framework for integrating BIM and IoT through open standards," *Automation in Construction,* vol. 95, pp. 35-45, 2018/11/01/ 2018, doi: https://doi.org/10.1016/j.autcon.2018.07.022.

[15] A. Malleson, "NBS National BIM Report 2015," NBS, England, 2015.

[16] A. Malleson, "NBS National BIM Report 2017," NBS, England, 2017.

[17] S. Liu, B. Xie, L. Tivendal, and C. Liu, "Critical barriers to BIM implementation in the AEC industry," *International Journal of Marketing Studies,* vol. 7, no. 6, p. 162, 2015.

[18] B. McAuley and A. Hore, "Solving the Construction Industry's Shortage of Skills and Talent Gap," Ireland, 2019.

[19] THE EDITOR. "BIM People - Barry Kirwan, RYAN+LAMB Architects." BIMIreland. http://www.bimireland.ie/2018/07/31/bim-people-barry-kirwan-ryanlamb-architects/ (accessed 05/05/2019, 2019).

[20] R. McPartland. "Data exchange on BIM Projects: What are data drops?" NBS. https://www.thenbs.com/knowledge/data-exchange-on-bim-projects-what-are-data-drops (accessed 19-04-2019, 2019).

[21] *BS EN ISO 19650-1:2018* B. S. Institution, UK, 2018.

[22] P. Carroll and B. McAuley, "Establishing the key pillars of innovation required to execute a successful BIM strategy within a Construction SME in Ireland," Proceedings of the *3rd CitA BIM Gathering, Dublin, 23rd - 24th November, 2017* . 2017.

[23] A. Mecheri and R. P. West, "Breaking into the black box - Demystifying BIM data," in *CitA BIM Gathering 2017*, Ireland, 2017: The Construction IT Alliance.

[24] N. Reilly, R. Montague, and A. Buckley-Thorp, "Verifying BIM Delivables with Flux.io," in *CitA BIM Gathering 2017*, Ireland, 2017: The Construction IT Alliance.

[25] P. Ghannad, Y.-C. Lee, J. Dimyadi, and W. Solihin, "Automated BIM data validation integrating open-standard schema with visual programming language," *Advanced Engineering Informatics,* vol. 40, pp. 14-28, 2019/04/01/ 2019, doi: https://doi.org/10.1016/j.aei.2019.01.006.

[26] J. Li, N. Li, J. Peng, H. Cui, and Z. Wu, "A review of currently applied building information modeling tools of constructions in China," *Journal of Cleaner Production,* vol. 201, pp. 358-368, 2018/11/10/ 2018, doi: https://doi.org/10.1016/j.jclepro.2018.08.037.

[27] D. Kehily and J. Underwood, "Design Science: Choosing an appropriate methodology for research in BIM," Dublin Institute of Technology, Arrow DIT, 2015.

[28] S. Hamil. "NBS BIM Toolkit." National Buildings Specificaiton. https://toolkit.thenbs.com/definitions (accessed.