Facilitating Compliance with BIM ISO 19650 naming Convention through Automation

Abstract

Purpose: *To foster effective implementation of Building Information Modelling (BIM), it is guided by standards and protocols that require files naming in a format, containing a string of letters and digits in a tightly defined manner, which is perceived to be time-consuming, error-prone and serves as a barrier to BIM adoption. In this paper, a BIM-based plug-in solution (Auto-BIMName) that facilitates automated naming in compliance with BIM standard is presented.*

Method: *The Auto-BIMName portal has an Information Management System (IMS) for generating Master Information Delivery Plan (MIDP), which serves as pre-requisites to effective file naming. Once the naming schema is implemented through text input controls for a project name, volume, level and number, the Revit plugin communicates with its IMS to fetch the name string or concatenate the string in line with the ISO 19650 convention, where the IMS is unused. The system was validated through a simulated collaborative project.*

Findings: *System testing and evaluation confirmed that the Auto-BIMName will ease the process of file naming, thereby facilitating collaboration efficiency, naming consistency across project teams and lifecycle stages, ease of file naming, time-saving, and inducement for BIM implementation, among others. By linking information from MIDP in BIM execution plan (BEP), the platform enhanced information management processes and improved coordination across project teams and lifecycle stages.*

Originality/Value: *Apart from demonstrating how the autonomated naming platform enhances project performance, information management and coordination, the paper provides a practical demonstration of how the construction industry will benefit from enhanced digitalisation and process automation.*

Keywords: *Building Information Modelling, AutoBIM, IT in Construction, ISO 19650, Revit Plug-in.*

Introduction

The construction industry accounts for a significant portion of gross domestic products (GDP) across nations, and it is one of the largest employers of labour. In the UK, the industry contributes about 6-10% of GDP, employs over two million people (HM Government, 2016), and it remains indispensable to the smooth running and productivity of other industries that rely heavily on construction outputs – including roads, buildings, and other infrastructural facilities. Notwithstanding its contribution to the economy and other sectors, the failure of the industry has become alarming in recent times (Jang et al., 2019; HM Government, 2016), with the industry having the least labour productivity index when compared to many other industries (ONS, 2019) and significantly failing to deliver most projects on time and budget (HM Government, 2013). McKinsey Global Institute (2017) suggests that the industry's value-added cost could rise by $1.63 trillion a year, boosting global GDP by 2% and meeting half of the world's annual infrastructure needs, by addressing productivity issues affecting the construction industry. The UK government's Construction Strategy 2016-20 suggests that increased productivity of the industry will facilitate efficiency savings of £1.7 billion within five years (HM Government, 2016). This was similarly echoed by early reports commissioned by the UK government into the performance and productivity of the industry, such as Latham in 1994, Egan in 1998, Barker in 2004 and Framer in 2016, all of which suggests the need for improved productivity, enhanced collaboration, standardization, and digitalisation, among others, within the industry.

To address the multifaceted challenges bedevilling the construction industry, government across nations have advocated for increasing adoption of Building Information Modelling (BIM), which is a digital representation, storage, management and sharing of both physical and functional characteristics of an asset in a collaborative environment (Eastman et al., 2011; Ajayi et al., 2015). Addressing such challenges essentially became important to the UK government as the government remains the largest client to the industry, with over a quarter of construction outputs being a public sector project and central government being the biggest single client (HM Government, 2016). In the next 10 years running into 2027/28, for instance, an estimated £600bn will be spent by the UK government on infrastructure, and £190 billion worth of projects already in the pipeline for 2020/21 according to the UK National Infrastructure and Construction Pipeline. BIM, as a collaborative project delivery tool and methodology, was conceived as a means of addressing productivity issues as well as poor procurement practices that subsequently create waste and inefficiencies within the industry (Eastman et al., 2011). The UK Government envisioned that with BIM adoption, significant improvement in cost, value and carbon performance can be achieved through open, sharable, asset information. To further reinforce its benefits, the government Construction 2025 strategy lists BIM as a key element for achieving its goal of 33% lower cost, 50% faster delivery, 50% lower emissions and 50% improvement in export target (HM Government, 2013).

Meanwhile, the implementation of BIM is guided by some standards and protocols that are aimed at facilitating standardization, collaborative working and seamless information exchange while working in a common data environment (CDE) among project parties. Introduced by the Construction Industry Council (CIC), BIM protocol was first published in 2013 and later edited in 2018, as a guide for supporting the adoption and implementation of BIM level 2 as required on all centrally procured projects since 2016 (Gledson and Greenwood, 2017). In preparation for the government's mandate for BIM implementation, PAS (Publicly Available Specifications) 1192 suites of standard were published to set out the requirements for level of details, level of information, model definition as well as model information exchange requirements. Generally, the suite addresses the requirements for collaborative production of AEC information. For instance, PAS 1192-2:2013 and PAS 1192-3:2014 focus on construction (CAPEX) and operational (OPEX) phase respectively, by specifying requirements for level 2 maturity at each stage. PAS 1192-4: 2014, on the other hand, provides the code of practice for collaborative production of information to fulfil the employer's information requirements. In a similar context to the PAS 1192 suites, countries such as Canada and the US also developed AEC protocol and LOD specification respectively (Chen and Jupp, 2019). The PAS 1192 has now been commissioned into an international standard as BS EN ISO 19650 suites, with suite 1 and 2 already published and others in the pipeline.

One of the requisite practices for meeting the requirements of the ISO 19650 suites, and for effective collaboration among project stakeholders, is compliance with file naming convention. Whilst the naming convention seems straight forward, the repetitive nature of the naming, as well as the long string of letters and digits in a tightly defined manner, implies that it could easily become highly complex, time-consuming and error-prone. According to a wide range of literature, a major barrier to BIM adoption and effective implementation is the steep learning curve and financial investment associated with its implementation, one of which is the correct naming in compliance with the standards (Chan et al. 2019; Crowther and Ajayi, 2019; Eadie et al., 2014; Bew and Underwood, 2010).

This study demonstrates how advances in digital technology and open innovation software platforms such as Autodesk suites facilitate automation of file naming in compliance with BIM standards. Thus, this study aims to develop a BIM-based software plugin solution (Auto-BIMName) to facilitate automated naming of file in the collaborative digital environment. The study seeks to address the challenges associated with manual file naming, thereby mitigating potential errors, reducing time requirements and facilitating BIM adoption. To achieve the aim of this study, its specific objectives include:

- To develop an Information Management System, containing a central repository, to facilitate unique naming of files across projects in compliance with Employers Information Requirements (EIR).
- To formulate heuristics for automating naming convention in compliance with ISO 19650 and integrate the Auto-BIMName tool into BIM software.
- To test the Auto-BIMName platform and evaluate its potential for facilitating improved collaboration and project performance.

To develop the Automated file naming platform, participatory action research was used to develop the proof of concept and involve industrial collaboration with a leading UK construction firm and their supply chain. The collaborative research and development approach facilitated two-way input through which the development and testing of the digital platform were tailored to the industry needs and best practice. The next section of the paper presents a review of extant literature, which is then followed by the methodological approach to the study, covering the design, development and testing of the automated naming platform. Discussion of the study is then presented before culminating the paper in a conclusion and implication for practice.

2.0. Optimisation, standardization, and digitalisation in the construction industry

Due to its consistent performance in a way that is thought to be wasteful and less productive when compared to other industries, successive review of the construction industry, starting from Latham (1994), through Egan (1998) and to others in the new millennium have advocated for a more collaborative and digitalised approach to project delivery. With the advent of the industry 4.0 era, which brings with it a plethora of opportunities, many industries have benefited immensely from enhanced digitalisation and automation. For some, it has resulted in entirely new ways of working, new products and services, and enhanced productivity, among others (Degryse, 2016), with digital technology increasingly recognised as a game-changer for competitive advantage across industries (Gruber, 2019). However, some industries like construction still lag in comparison with digital leaders such as information and communication technology, finance and other industries (Woodhead et al., 2018). Despite up to 80% of construction projects having cost overrun, a report by McKinsey Global Institute (Gandhi et al. 2016) suggests that the industry is one of the least-digitised, only better than agriculture out of 22 industries considered. Similarly, the construction industry has the second-lowest investment in technology, and it is categorised as being rudimentarily digitised, only better than the oil and gas industry, according to Accenture top 500 study (NBS, 2016).

2.1. Enabling Digital Innovation Through BIM

Awareness of the positive impacts of digitalisation for the construction industry has challenged stakeholders who are coming up with different digital innovation, towards enhancing both the images and productivity of the industry. Due to the project-based nature of the industry, BIM as a collaborative working approach is seen as a requisite to any meaningful innovation (Crowther and Ajayi, 2019), especially as the poor collaboration and its characterised "over the wall syndrome" is the bane of productivity challenge that is facing the industry (Ajayi et al., 2016; Meng, 2012). BIM advocates for a single point of truth throughout the entire lifecycle of an asset, and it is underpinned by the creation and exchange of shared 3D model along with structured and intelligent data that is attached to them. The technology offers a holistic process for creating, coordinating and managing construction project information, in a common format and collaborative environment right from the earlier stage of the project, through design, construction and operation to the end of life stage (Gelder et al., 2013). To attain the level of BIM benefits envisioned by the government, it is expected that there would be a federated file-based electronic information with some automated connectivity of architectural, structural, fire and building services, among others. The level of detail and information accompanying the 3D model will, however, depend on the BIM maturity level, which is the quality, degree of excellence, and complexity to which a team is deploying BIM in delivering a project (Wong and Fan, 2013). This maturity as well as the level of adoption will depend on the client or owner in construction projects (Porwal and Hewage, 2013).

Despite the clear benefits of BIM as envisioned by its proponents, including the potential improvement in project cost, value and carbon performance (Bryde et al., 2013), its adoption and actual implementation in line with the standard is low. According to Chan et al (2019) and Piroozfar et al. (2019), this is because additional resources the complexity around the needs for additional resources by originators, industry fragmentation, management and transfer of data as well as joint authorship in the industry known for poor collaboration, among others. In addition, there is generally a sense of belief that there is high-cost implementation (Azhar et al., 2012), with others assuming that the overall effectiveness is still not completely justified (Jung & Joo, 2010). Other potential barriers and challenges to BIM implementation as identified in the literature include issues around interoperability, lack of contractual document, inadequate knowledge and lack of corresponding technology (Piroozfar et al., 2019). Notwithstanding these challenges and potential barriers, BIM technology is increasingly recognised as the industry standard, with its adoption becoming a “do or die” affair for company’s survival.

Due to the increasing popularity of BIM-enabled/compliant project delivery, there have been more software solutions for facilitating project implementation and delivery within BIM environment. The multi-faceted nature of the construction industry implies that different solutions are needed by various stakeholders, and at different stages of project delivery process (Ajayi et al., 2015). According to the national BIM report by NBS (2017), the top software used in the industry includes Autodesk Revit, Bentley Architecture, Graphisoft ArchiCAD, Nemetschek Vectorworks, Bentley Microstation, Nemetschek AllPlan, Trimble SketchUp, Bentley AECOsim Building Designer and others. In addition to these, there are other BIM-compliant and interoperable analysis tools that are widely used within the construction industry. These include IES, Green Building Studio and Ecotect for lighting, thermal, emission, airflow, acoustic, energy and shading analysis, among others (Akinande, 2017). Some BIM plug-in solutions are fast becoming standards of their own within the global construction industry. Popular among these solutions is the COBie extension for BIM tools such as Revit, which enables Construction, Operations Building Information Exchange (COBie) file input and output from BIM models (Anderson et al., 2012; Teicholz, 2013). Dynamo is another plugin solution that has become an official built-in tool in Revit, which extends BIM with the date and logical environment of a graphical algorithm thereby facilitating data manipulation, exploration of design option and process automation (Kensek, 2014; Khaja et al., 2016).

With BIM being the standard means of information exchange and project delivery across nations, it is becoming increasingly essential to construction digitalisation (Singh, 2018). As a result, many innovative construction approaches and technologies are either spiralling from BIM technology or are becoming increasingly associated with BIM (Crowther and Ajayi, 2019; Singh, 2018). Literature is rife with the potential transformative impacts of combining BIM with various digital technologies such as Augmented and Virtual Reality (AR/VR), Internet of Things (IoT), Drones, 3D Printing, Digital Twining, Big Data Analytics and Machine Learning, among others on Construction projects (Tay et al., 2017; Bilal et al., 2016; Singh, 2018). Singh (2018) further suggests that several reports, commissions and white papers that assess the future of the industry came to the same conclusion that the combination of BIM with these technologies provides a positive outlook for the industry. For instance, Ding et al. (2019) proposed integration of BIM with reverse engineering technologies for renovation projects, Lu et al. (2019) reinforced the requisite of BIM to digital twin, and Akinade et al. (2015) and Ajayi et al. (2015) established the significance of BIM to designing out waste in construction projects. These sets of studies, reports and position paper have established the needs for further investment and investigation into optimal BIM implementation, which in turn serves as a vehicle for technological innovation in construction. Not only will digital construction through BIM system change construction project delivery pattern, but it will also drive re-engineering of construction businesses (Mihindu and Arayici, 2008).

2.2. BIM Naming Convention

An important step towards a fully collaborative working and common data environment in BIM is the use of standardized, consistent and understandable naming convention, which becomes important as more information is shared digitally. Initially introduced as part of BS1192 in 2007, the convention sets out how drawings, model file, documents and data files are expected to be named. File naming in compliance with BIM standard is a central core of project BIM implementation. Through this, information loss, which is one of the main cause of delays and reworks will be prevented (Chelson, 2010). In addition, the clients or their representative will understand and be able to trace the ownership of different documents, which could quickly become overwhelming in complex projects. The PAS 1192, which has now been integrated into the new ISO 19650 requires that each file gives information regarding:

- Project name/number – two to six characters, e.g. HS2
- Originator, that is, the company or code representing them – three to six characters in letters and/or numbers, e.g. BAL
- Volume or System, representing a logical portion or section of the work – one or two characters, e.g 00.
- Levels/Location, representing the level that the file represents or location within the whole, where level is not applicable – two characters, such as GF, 01, etc.
- Type of information, which is further explained in the standards. Examples include M3 for 3D mode, DR for 2D file, VS for visualisation file, etc.
- Role – information about the originator's role within the project, e.g. A for Architect, C for civil engineer, Q for Quantity Surveyor and K for the client.
- File number, which is the unique number when concatenated with file type and discipline, e.g. 00001.

Although other optional entry such as suitability and revision status, among others, could be added, it usually follows the pattern of *Project–Originator–Zone–Level–Type–Role–Number*. An example of a naming pattern is presented in Figure 1.

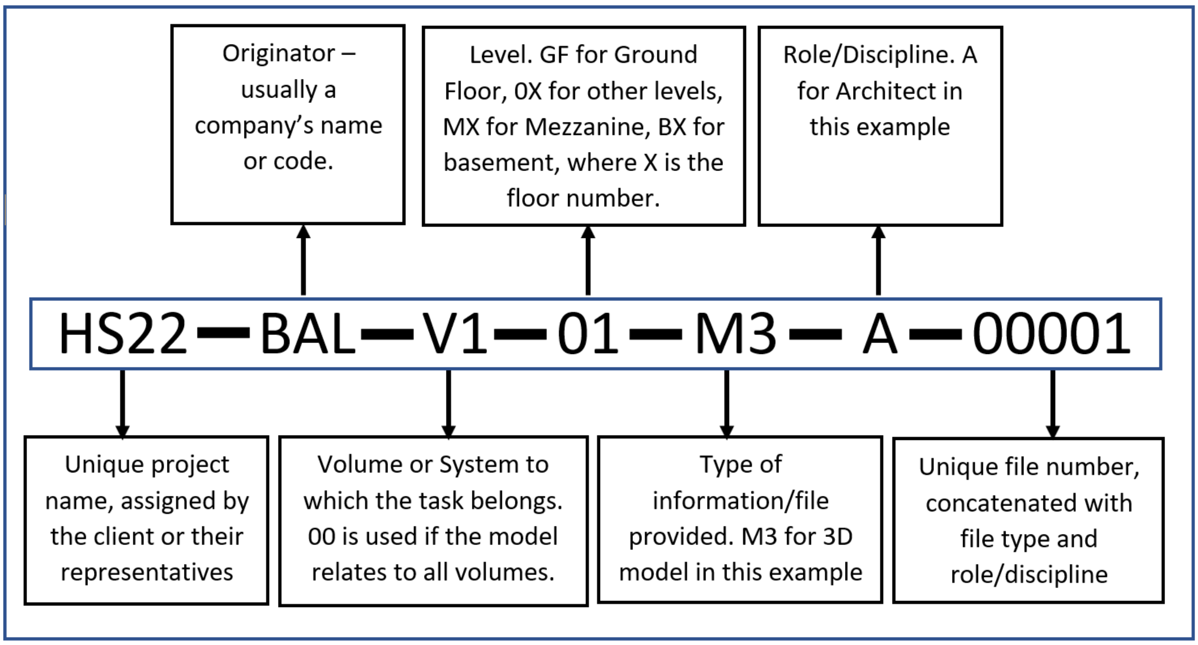


Figure 1: Sample of a BIM Naming Convention

Meanwhile, before file naming in compliance with the standard, certain processes are essential to getting the naming itself started. For instance, the actual project name that forms the first string of the naming convention will be supplied by the client within the Employer Information Requirements (EIR) or through the project information manager who will convey it to all parties involved (Pittard and Sell, 2016). In response to the EIR, prospective suppliers will produce a pre-contract BIM Execution Plan (BEP) which will be subsequently developed into post-contract-award BEP once the contract is awarded. A key part of the BEP is the Master Information Delivery Plan (MIDP), which is a collation of individual Task Information Delivery Plan (TIDP) that are prepared by all teams (Barnes, 2019). The TIDP, and by extension, the MIDP, includes the detail of what project information is to be prepared, who will be responsible for producing the information, by when, using which protocol and procedure and in which format will it be (Eynon, 2016). Information deliverable will normally include the model, specifications, project schedule, equipment schedule, drawings and room datasheet, among others, all of which are named in compliance with the BIM standard. This implies that the file naming convention does not commence with the actual design or production of task information, it essentially starts with the MIDP, where the project number, as well as the unique file numbers, are established. Thus, an automated naming platform within Revit or other BIM platform is expected to be connected to information regarding the MIDP to facilitate adequate collaboration and unique name allocation.

2.3. Automating File naming convention

Although the BIM standard clearly defines the convention for file naming, requiring a string of letters and digits in a tightly defined manner, which can be perceived as an easy task, it could become very complex, time-consuming and prone to errors, especially in a multi-team project environment. As a result, automating the processes of file naming offers opportunities for enhancing the accuracy and efficiency of the information management processes. However, existing BIM software such as Revit only label file based on the file view such as Level 1, Site and 3D, among others, users are only able to manually edit their file names in line with the BSI naming convention. While previous studies have automated different non-BIM and BIM-related processes, there has been no attempt to automate file naming convention. This is notwithstanding the significance of the correct naming convention to other BIM processes.

The existing sets of studies and automated platforms usually involve the use of applications that are external to the main software solutions to manipulate features of the design environment using programming. These plug-in solutions are developed for a variety of purposes including structural design and analysis, MEP design, analysis and simulation, building performance analysis, productivity analysis, conversion and design components, among others (da Silva et al. 2017). For instance, Akinade (2017) developed a waste analytics and prediction plug-in solution for BIM using Adaptive Neuro-Fuzzy Inference System (ANFIS) model. The plug-in solution can predict and suggest measures for mitigating waste right from the design stages. Similarly, Chen and Nguyen (2019) developed a material supply chain management system as a plugin solution, using BIM Application Programming Interface (API). The system synergises BIM and Web Map Services (WMS) to provide not only a platform for comparing different materials option but also a transportation planner to determine the easiest, quick, cost-effective and sustainable option. In line with this, Parn and Edwards (2017) also developed a plug-in solution, named FinDD, which integrates Facility Management (FM) requirements into BIM model in a way that enables FM data in a 3D object. A solution that is similar to the proposed automated file naming platform was developed by Chen et al. (2017) to automate naming of BIM objects. While the study devised a useful semiautomatic approach that facilitated standard BIM object naming, the aim of the study was not to facilitate compliance with the standard naming convention, and it was limited to BIM objects. Hence, this study offers an automated BIM naming platform for facilitating compliance with ISO 19650 naming convention, which in turn enhances information consistency and its management processes across project lifecycle stages and team.

2.4. Developing BIM-based plugins

Autodesk Revit has remained the most popular BIM design software that is widely used in the AEC industry (Chen and Nguyen, 2019), with the software solution having about 31% of the UK CAD software share according to RIBA (2016). Akinade (2017) suggests that the popularity of Revit in the industry is motivated mainly by its intuitive user interface, a huge set of product library and powerful drawing production tool. In addition to its being a drawing tool, Revit supports various forms and analysis and simulation, including environmental impact analysis, energy simulation and quantity take-off, among others. Other benefits of Revit that increased its popularity include extendable API that allows customisation, and compatibility with several BIM and CAD platforms (Akinade, 2017). This is especially because of its compatibility/compliance with several popular data exchange formats such as IFC, gbXML, DWG, DXF, SAT, ASDK, FBX, ODBC, and others. As a result, several BIM-based software plug-in solutions are developed as plug-ins within Revit. For instance, materials supply chain management solution by Chen and Nguyen (2019), ANFIS-based Waste Analytics by Akinade (2017), BIM-DAS by Akinade et al. (2015), FinDD by Parn and Edwards (2017), design optimiser by Bilal et al. (2019) and BIM-based whole-life performance estimator (BWPE) by Akanbi et al. (2018) were developed as plug-in solutions for Revit.

Different programming languages could be used within BIM environment. These generally include C#, VB.NET, VC++, F#, C++, Ruby, C, and Python (Akinade, 2017). Autodesk Revit has a .NET API, which implies that any of the .NET compliant programming languages such as C#, VB.NET and F# could be used to develop plug-in solutions within Revit environment. Regardless of the various possibilities, C# is believed to be a natural choice, provided there is no organisational restriction in the choice of programming language. This is not only a result of its easy-to-learn and easy-to-use features; it also has the capacities for leveraging the power of the underlying .NET framework. In line with this, Irizarry et al. (2013) used C# in their design of a system that integrated BIM and GIS into a unique system for tracking supply chain status. Oti and Tizani (2015) similarly used C# in their development of BIM extension for sustainability appraisal of conceptual steel design. In their development of Revit2Modelica and Revit2Radance solutions for thermal modelling and daylighting prototyping respectively, Yan et al. (2013) used C# as a programming language using Revit Application Prototype Interface (API). In line with this consistent practice, C# programming language was chosen for Auto-BIMName plug-in solution development within Revit environment.

3.0. Research Method and Formulation of the Automated BIM Naming Platform

This study involves the use of participatory action research (Coghlan and Brydon-Miller, 2014), which enables the research team and the potential Auto-BIMName users to work collaboratively towards studying the challenges associated with the naming and proffering a holistic solution for automating the process. Thus, the process involved an iterative cycle of research, action and reflection (Kemmis et al., 2013) to ensure usability, compatibility and effectiveness of the system. As a result, five stakeholder workshops were carried out in the process, involving stakeholders from large construction firms and experts from BIM consultancy firms. In addition to the research team's understanding of the naming convention as well as its associated challenge, two stakeholder engagement workshops were carried out to specify system needs and understand the prevailing mode of manual operation within the industry. This resulted in the development of requirement specification in natural language, which was subsequently reviewed by the stakeholders. The other three stakeholder engagement workshops were carried out during the process of system development, testing and refinement to address further needs requirement and facilitate seamless integration with existing systems.

3.1. Developing the System Architecture

Given the lessons learned from requirements gathering, the different components that would make up the system were identified, and a system architecture describing the interaction of all components was developed. Specifically, the system comprises a plugin that sits within Revit as a window desktop application and a web application. Revit was selected partly as it is the most widely used BIM design tool (Chen and Nguyen, 2019; Akinade, 2017), and specifically as a consensus from the stakeholder engagement workshop. In line with BIM standard, the web application doubles as a platform for automating TIDP/MIDP as well as the database for the desktop application. As such, the users interact with both the plug-in system and web application. Figure 2 shows the System Architecture.

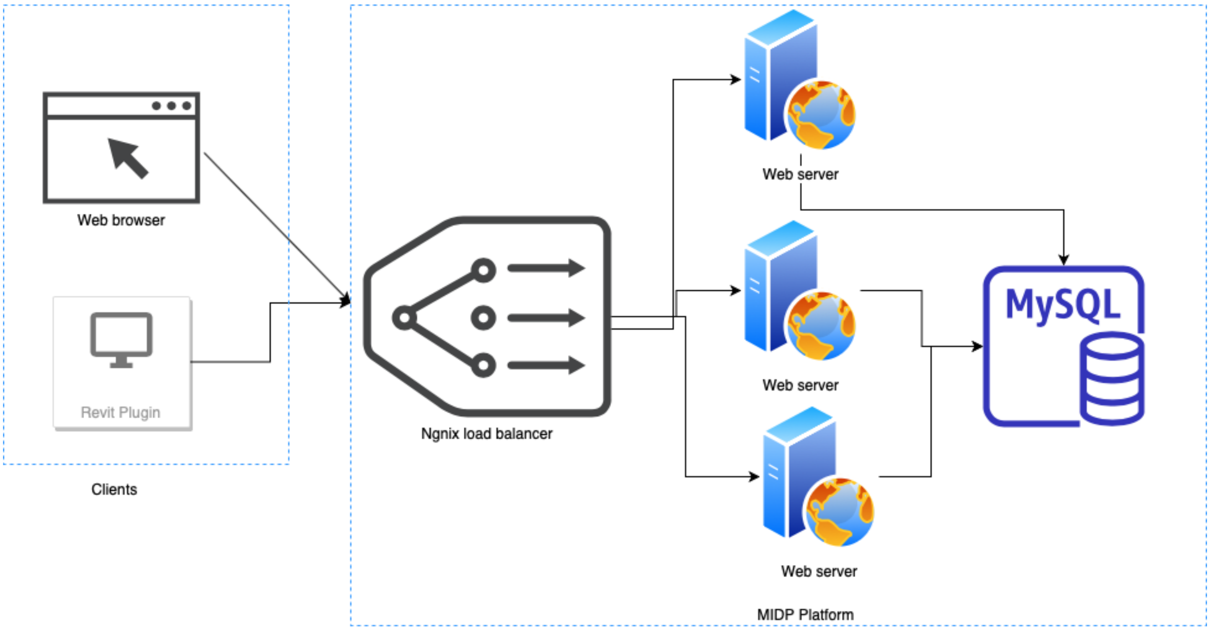


Figure 2: The System Architecture

3.2. Conceptualizing Database Design

Asides from entities such as users and groups, related to access control, six other entities were identified after designing the entity-relationship diagram shown in Figure 4. The data entities identified were highly relational with one-to-many, many-to-many and on-delete cascade relationships, making the choice of database management system easy. MySQL database server was chosen as the choice of a relational database management system that guarantees the referential integrity of our data (Codd, 1989).

3.3. Formulating the System Development and Testing Protocol

A Model-View-Controller pattern was employed to develop both systems, that is, the web application and the desktop application plug-in. This ensures that the different components handle the user interface, the data and the link between them (Holovaty and Kaplan-Moss, 2009). This separation of concerns is important as it decouples the systems from any choice of implementation. This implies that it will be easy to replace the database with another vendor or change the way the user interface is presented to users with minimal effort. This becomes an essential requirement as the increasingly changing digital construction environment implies that different stakeholders collaborating on a project could choose to use different BIM software.

In addition, since the Revit plugin would need to communicate with the web application, exposing relevant RESTful APIs was settled on. This is as it makes for a cleaner and modular interface (Gutierrez, 2014) since both systems would use the same API to access the database. For software testing, both unit and integration tests were written to ensure that code works efficiently and that the different pieces of the modules work together as a whole unit. As a means of fostering collaboration between developers and for versioning, Git was used, as it enables tracking of changes in source coding during the process of software development.

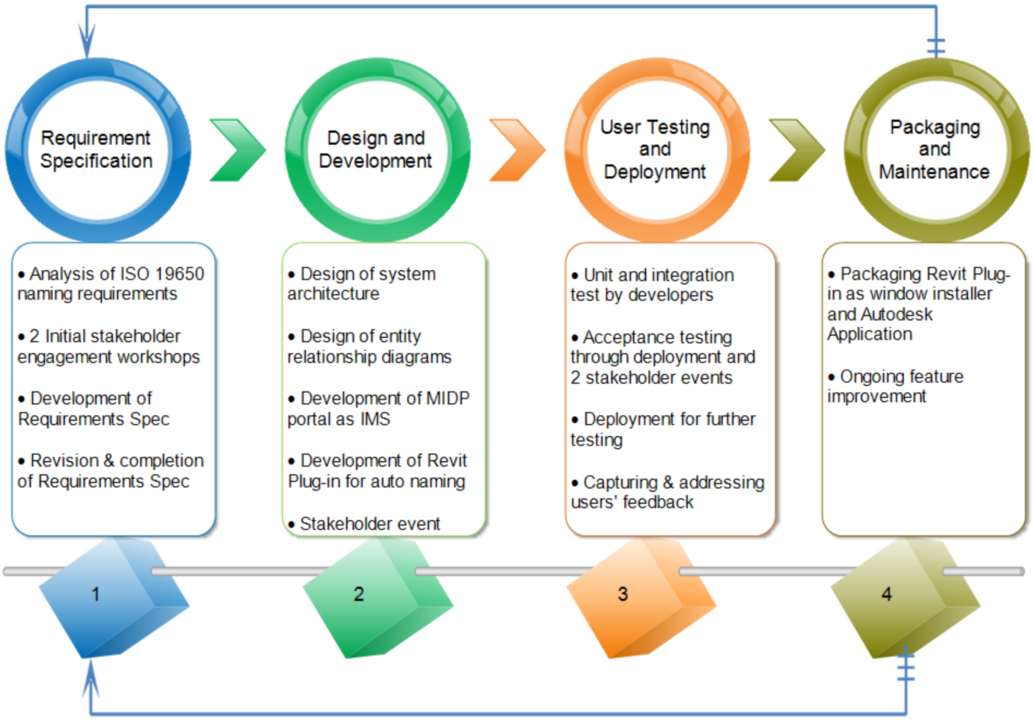


Figure 3: Auto-BIM development and implementation processes

4.0 Development of Auto-BIM Plug-in solution.

This section explains the development of the Auto-BIMName platform, covering its IMS, heuristics formulation and API development.

4.1. Development of the information management system.

As previously established in the literature review section, the TIDP, as a federated list of information deliverable by each task, holds the required schema for effective file naming within models (BSI, 2013). This is especially as it includes all the required information for file naming, including the project name, originator, volume or system, level, type and role when describing a task. Thus, the project team along with the parties involved in the stakeholder engagement activities concluded that the MIDP system should serve as the IMS for the automated naming platform. From practitioners' point of view, this ensures that the file naming is in line with what would have been used in the BIM Execution Plan (BEP) ahead of making any design.

Following on from the design of the entity-relationship diagram, where a highly relational nature of the entities was established, a set of PRIMARY and FOREIGN keys for each entity was needed to capture the relationship. This is akin to a parent-child relationship, where a parent such as the Projects table would have children (consisting of tasks) in the Tasks table. To ensure referential integrity, checks were enforced to make sure no parent record (e.g. Project) could be deleted when there existed Tasks. Since there is no domain-specific attribute that could be used as PRIMARY/FOREIGN key, using the auto-incremented sequence number provided by database systems was resorted to, as this is sufficient for the system need. An entity-relationship diagram showing relationship between elements of the IMS is presented in Figure 4.

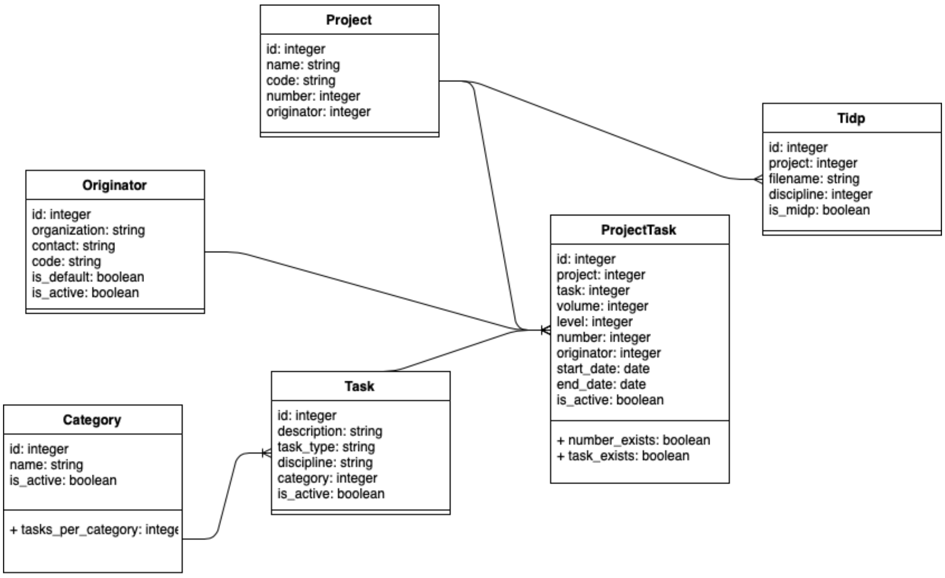


Figure 4: Entity Relationship Diagram

Meanwhile, it was decided that the MIDP portal should be developed as a web application due to its ease of development, maintenance and deployment. In addition, unlike the Revit plugin, it had no dependence on any desktop software. For its development, Django framework, a battle-tested framework for developing enterprise applications that run on the web, was used. Django supports the Model-View-Controller (MVC) design pattern out of the box, asides from the separation of concerns feature, and it allows easy testing of the different components of the system (Holovaty and Kaplan-Moss, 2009). The Model handles the data entities and their storage in any chosen database. The View renders a graphical user interface for users to interact with, while the Controller ferries information back and forth between the Model and View. Another benefit of MVC is that it readily allows changing of the user interface without changing other parts of the system (Leff and Rayfield, 2001). For example, as this is a web application, it is expected to support both desktop and mobile version. Slight modifications to the View will allow users to achieve both, making the software usable on mobile browsers.

4.2. Formulating the Heuristics

The UNIQUE record feature that characterises most relational database management system was beneficial to ensuring the uniqueness of the ISO 19650 naming string. A composite key on the ProjectTask table, consisting of project code, role, level, volume and number, was defined in line with the requirements for both MIDP and BIM task and file naming convention (BSI, 2013). With the use of MySQL, as a relational database (Codd, 1989), the uniqueness of every element of a typical MIDP is ensured. This is such that if a duplicate entry is to be made, the database will throw an error, which is then handled, and the users altered that they need to provide a unique name. For a better user experience, the likelihood of entering a duplicate name was pre-empted by automatically suggesting to the user the next available number for the combination of project code, role, level and volume they provided. Figure 5 presents an activity diagram for task creation, showing the level of checking and validation required for enabling unique naming.

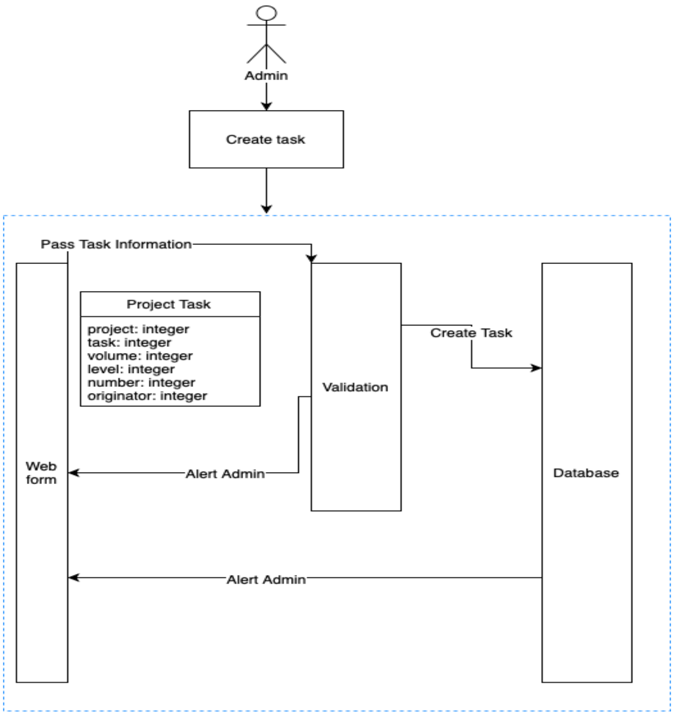


Figure 5: Activity diagram for creating tasks

4.3. Development of Auto-BIM API

Since the Revit plugin needs to communicate with the MIDP portal to fetch and validate the task details associated with an ISO 19650 name, RESTful APIs was built to facilitate the communication. Using REST means that the advantages of a simple communication protocol, HTTPS, was taken and that the internals of the API could be changed without any modification on the part of the Revit plugin (Masse, 2011).

The system described can easily be grouped into a backend and frontend. The backend being all the code that runs behind the scenes to make the whole system work, which is the part that is chiefly serviced by Django and MySQL database server. On the other hand, the graphical user interfaces the user interacts with is the frontend, which was developed using HTML, JavaScript and CSS. Asides from styling the web pages and other aesthetics provided by CSS, it was also used to dynamically vary the rendered webpage based on the device being used to access the web application. To achieve this, Bootstrap, which a free and open-source CSS framework directed at responsive, mobile-first front-end web development, was used. Users' experience was enhanced using JavaScript for client-side validation to ensure data being input into forms are of the correct format before sending them to the webserver, thereby reducing the number of HTTP requests and user wait time.

Equally as important as other stages of the development were how the web application will be deployed. While Django does come with an in-built web server, it is found insufficient as a result of the needs for high availability and security. Consequently, a Reverse Proxy architecture where HTTP requests are sent to an Nginx server, and these requests forwarded to a uWSGI server was rather selected. The user only sees the interaction with the Nginx server. Since Nginx is a high-performance server (Chi et al., 2012), using this architecture makes it very easy to handle many HTTP requests. Figure 6 presents the use case diagram, incorporating the Revit plug-in (Auto-BIMName) and the MIDP portal to be used by both admin and other collaborators.

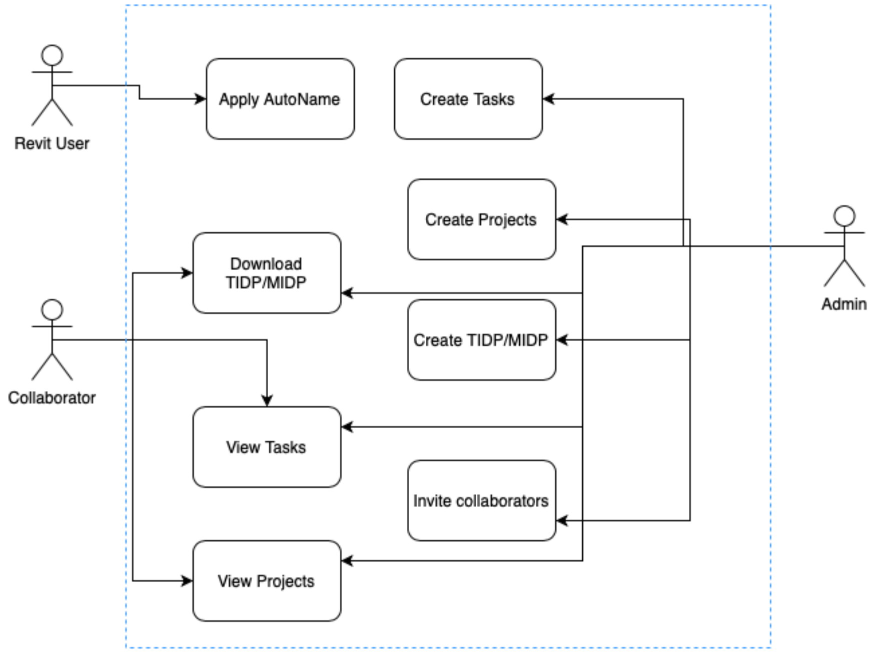


Figure 6: Use case diagram for MIDP and Revit Plugin

5.0. Application and Benefits of the Auto-BIMName System

The development, testing and validation of the autonomated BIM file naming platform was client-driven, with the end-users being involved throughout the four stages of planning, development, testing and packaging as shown in Figure 3. This section discusses the Auto-BIMName platform use case and validation, as well as its implications for practices.

5.1. Using the Auto-BIMName System

Since BIM project delivery processes, as encapsulated in the BIM protocol, requires the appointment of an information manager who sets up and manages the CDE (BSI, 2013), the MIDP portal facilitates project creation with automated generation of both TIDP and MIDP. The MIDP portal allows the BIM manager to create a project and invite role-specific task manager, such as architects and civil engineers, to collaborate in creating their TIDPs, which will be automatically amalgamated to create the project MIDP. This sends out an email to the specified email, providing them with a link to register. The invitation is limited such that invited users can only access projects on which they were invited to collaborate, while the Information Manager also retain the power to revoke an invitation to align with the provision of security-minded BIM (PAS 1192-5: 2015). The collaborators can then go ahead to fill in the respective details for the tasks on which they were assigned to work, each of which forms the Task Information Delivery Plan (TIDP). Once the BIM Manager verifies all the information requested for the tasks have been provided as expected, they can export the tasks list into a MIDP and TIDP. This generates a Microsoft Excel sheet with one sheet for each Discipline, known as the TIDP, and the MIDP as the combination of the generated TIDP documents. Apart from serving as the IMS platform for the Auto-BIMName, the TIDP portal facilitates automatic generation of tasks in different categories and enables compliance in the generation of BIM Execution Plan and Responsibility Matrix in response to the Employers Information Requirement. In addition, it also has a feature to foster collaboration on projects. Figure 7 shows an overview of the MIDP platform, which automates task creation and naming string generation.

The Auto-BIMName is a Revit plug-in solution, which is accessible via an icon set in the menu bar of Revit. Clicking the icon displays the Auto-BIMName dockable panel with a form. The panel has text input controls for a project name, volume, level and number in line with the ISO 19650 naming convention as presented in Figure 1. It has drop-down controls for originators and discipline, which are pulled from the MIDP portal, in line with the standard. In the event the plugin is supported by the MIDP backend, the user will input the project code, role and name the views according to the task name created in the TIDP and place the views in sheets, where required. Text input and drop-down selections are validated according to the guidelines provided by ISO 19650. When the user is not using a MIDP backend to support naming, the user is expected to enter information into all the controls in the form, without which the user is alerted about the omission that requires remediation before applying the schema.

Clicking the Apply button fetches the ISO 19650 name declared for the task and names the sheets accordingly. In each scenario highlighted above, after naming the sheet(s), the plugin also renames the Revit file on the filesystem in line with the standard. The inputs to the form are concatenated to form a valid ISO 19650 name with file type and discipline as required (BSI, 2013). The number specified in the form is incremented for each sheet ensuring that uniqueness is maintained across sheets. Figures 8 and 9 demonstrate how the ISO 19650 naming convention is applied using Auto-BIMName plug-in solution.

5.2. Whole System Evaluation in Users' Environment

Apart from continuous users' engagement throughout the development stages, from the requirements formulation stage, final system testing was carried out by six experts, including two BIM trainers/consultants, two BIM managers and two architects. Using a collaborative project involving different stakeholders across companies, the team used the plug-in solution in a simulated project environment. This facilitated feedback and system improvement as part of the project's participatory action research method. The main goal of the final testing was to evaluate the system and compare it against manual file naming processes. As a result, two treatment processes were used for the created project. These include the conventional process and treatment process, involving manual naming process and use of the plugin, respectively. According to the users, the ease of implementing the naming protocol was a major benefit of automating the file and sheet naming processes. The automated naming platform simplified the naming processes by automating what users frankly described as a "quite laborious" and "error-prone" process that is sometimes left for BIM coordinators to sort out (Scheffer et al., 2018). It was suggested that although many users will think that it is a very small task, it can quickly become overwhelming as the drawings grow in number, with users often need to refer to guidance documents for correct file and sheet naming. The platform removes the need for any reference to the guidance document, once the users input the project code and other initial information required, with the newly added file automatically named in line with the ISO 19650 requirements. This was confirmed to save time required in checking the guidance document, as well as the time that would have been used by BIM coordinators in correcting usual errors and lack of coordinated naming across project parties. Close alignment with the MIDP as well as the BIM Execution Plan and Responsibility Matrix were also found beneficial by the users.

5.3. Implications for Project Performance and Collaborative Working

One of the major impacts of this study and the plug-in solution is its ability to facilitate compliance with ISO 19650, which Winfred (2020) described as the panacea for digital revolution within the construction industry. This naming compliance is also widely seen as the first step towards BIM implementation and collaborative working, as it ensures conventional naming for file identification and sharing. In addition, since the file naming is expected in a well-defined manner, using a string of letters and digits, knowledge of the naming convention, as available in ISO 19650, is essential for achieving the task of file naming. However, an automated approach, as presented in this study removes the needs for a full understanding of file naming standards. Thus, an automated approach to BIM task completion addresses the knowledge and adaptability barriers that have been widely acknowledged as a barrier to BIM implementation (Siebelink et al. 2020; Ajayi et al., 2019; Tan et al., 2019). In addition, the naming process autonomation eliminates the potential errors associated with manual input of the long string of letters and digits.

Apart from the general benefits of BIM-based plugin solutions as established in several studies, Auto-BIMName users agreed that file naming is one of the first steps in BIM adoption and implementation, as it serves as the baseline for effective collaboration, which Chelson (2010) suggests that is essential to preventing information loss. However, the complexity of naming in line with the convention is often believed to be laborious, time-consuming and in need of special training, which is perceived to be cost-intensive (Azhar et al., 2012). With the level of automation facilitated by the platform, when compared to the manual process, it was suggested that the automated naming system has supported the first step towards BIM adoption and achievement of BIM level 2 maturity level, which is considered as one of the major technical requisites for BIM adoption and implementation (BSI, 2019). Thus, the AutoName platform serves as an inducement for BIM adoption and implementation, especially for SMEs.

Meanwhile, file naming within the BIM environment cuts across one user organisation, as all stakeholders involved in a project, including the clients and their representatives are meant to apply ISO 19650 to all project documentation. As a result, adequate coordination of project documents among all stakeholders is essential to BIM implementation (Eastman et al., 2011). Collaboration efficiency and consistency across the project team was another benefit of the automated naming platform when compared to the manual naming process. Unlike manual process that requires manual coordination of the file and sheet names, especially when two parties have the same project role (such as architect, civil engineer, and so on), the plug-in solution recognises the naming pattern as available in the Master Information Delivery Plan (MIDP). Specifically, the users perceived the ability to extract file names from the MIDP, which is created ahead of the 3D drawings, as a key benefit of the automated naming system, as it ensures consistency across project lifecycle stages while preventing number duplication.

While there are other optional elements, such as classification, revision, and suitability, among other features of the naming convention, that could be used in differentiating file and sheet naming as the project develops through its lifecycle stages, the seven main elements of the naming convention, as shown in Figure 1, remains throughout the project lifecycles (BSI, 2019). A major benefit of the automated naming platform is its ability to facilitate collaboration efficiency and consistency across project lifecycle stages. This is especially as AutoBIMName communicates with its information management system to pull the naming schema that is already applied to project documentation in the BIM Execution Plans (BEP), ensuring consistency of the naming format throughout the project lifecycle stages. Thus, the Auto-BIMName plugin solution performs more efficiently than the conventional and manual approach to the BIM file and sheet naming process as it ensures time-saving, error minimization, collaboration efficiency, ease of use, inducement for BIM implementation, and consistency across a project, as confirmed through control experiment and users' feedback.

The benefits associated with an automated or semi-automatic approach to completing design, or construction-related activities has led to an emerging area of research activities in BIM-based plug-in development. For instance, Chen and Nguyen (2019) developed BIM-WMS, a web map service plugin tools that support materials selection, cost and schedule planning, and calculation of location-related credits for a sustainable design appraisal system. Using a client-driven approach, Parn and Edwards (2017) similarly developed FinDD system, which integrates BIM and Facilities Management (FM). Other studies, such as Bilal et al. (2015), Collins et al (2014) and Chen et al. (2018) have also developed plug-in solutions or framework for process autonomation within BIM environment. One common outcome among these sets of studies is that they all pointed out timesaving, accuracies and little knowledge requirements as key benefits of the different BIM-based solutions developed. With the enhanced performance and productivity brought about by this approach, it is clear that the construction industry would substantially benefit from enhanced automation through the adoption of digital technologies.

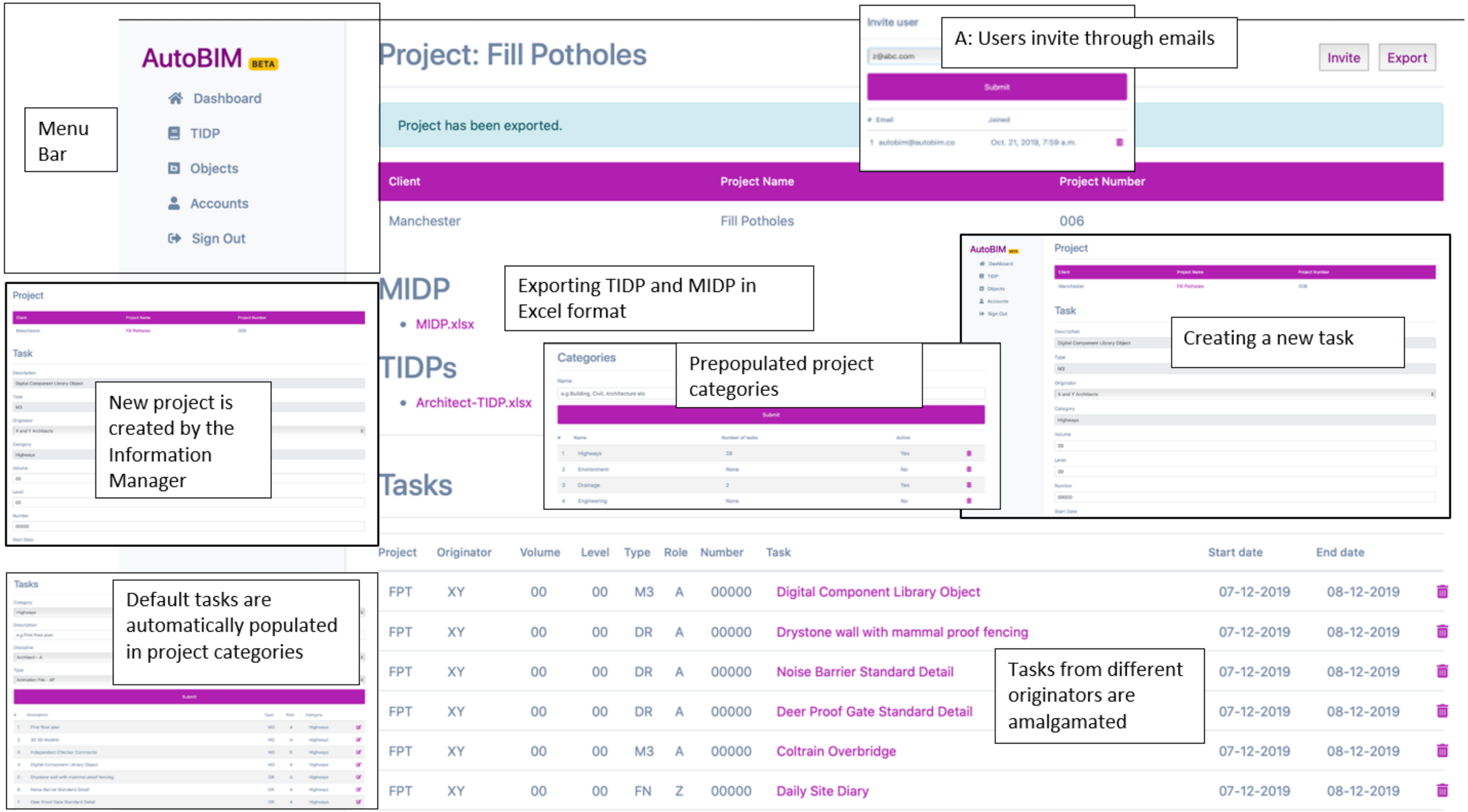
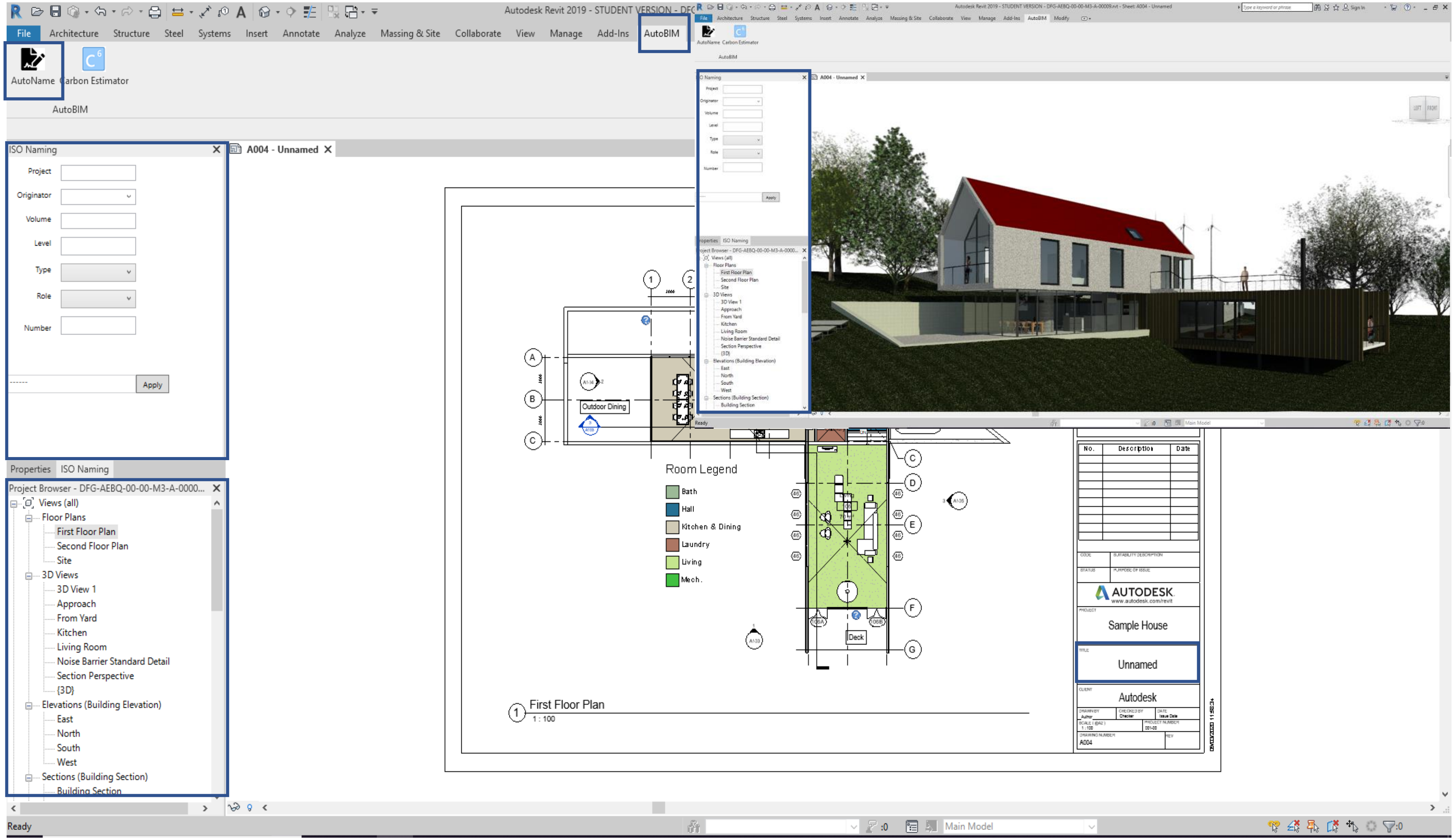


Figure 7: An overview of the Information Management System – TIDP/MIDP Portal


Autodesk Revit 2019 - STUDENT VERSION
File
Architecture
Structure
Steel
Systems
Insert
Annotate
Analyze
Massing & Site
Collaborate
View
Manage
Add-Ins
AutoBIM
AutoName
Carbon Estimator
AutoBIM
ISO Naming
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Views (all)
Floor Plans
First Floor Plan
Second Floor Plan
Site
3D Views
3D View 1
Approach
From Yard
Kitchen
Living Room
Noise Barrier Standard Detail
Section Perspective
{3D}
Elevations (Building Elevation)
East
North
South
West
Sections (Building Section)
Building Section
Outdoor Dining
Room Legend
Bath
Hall
Kitchen & Dining
Laundry
Living
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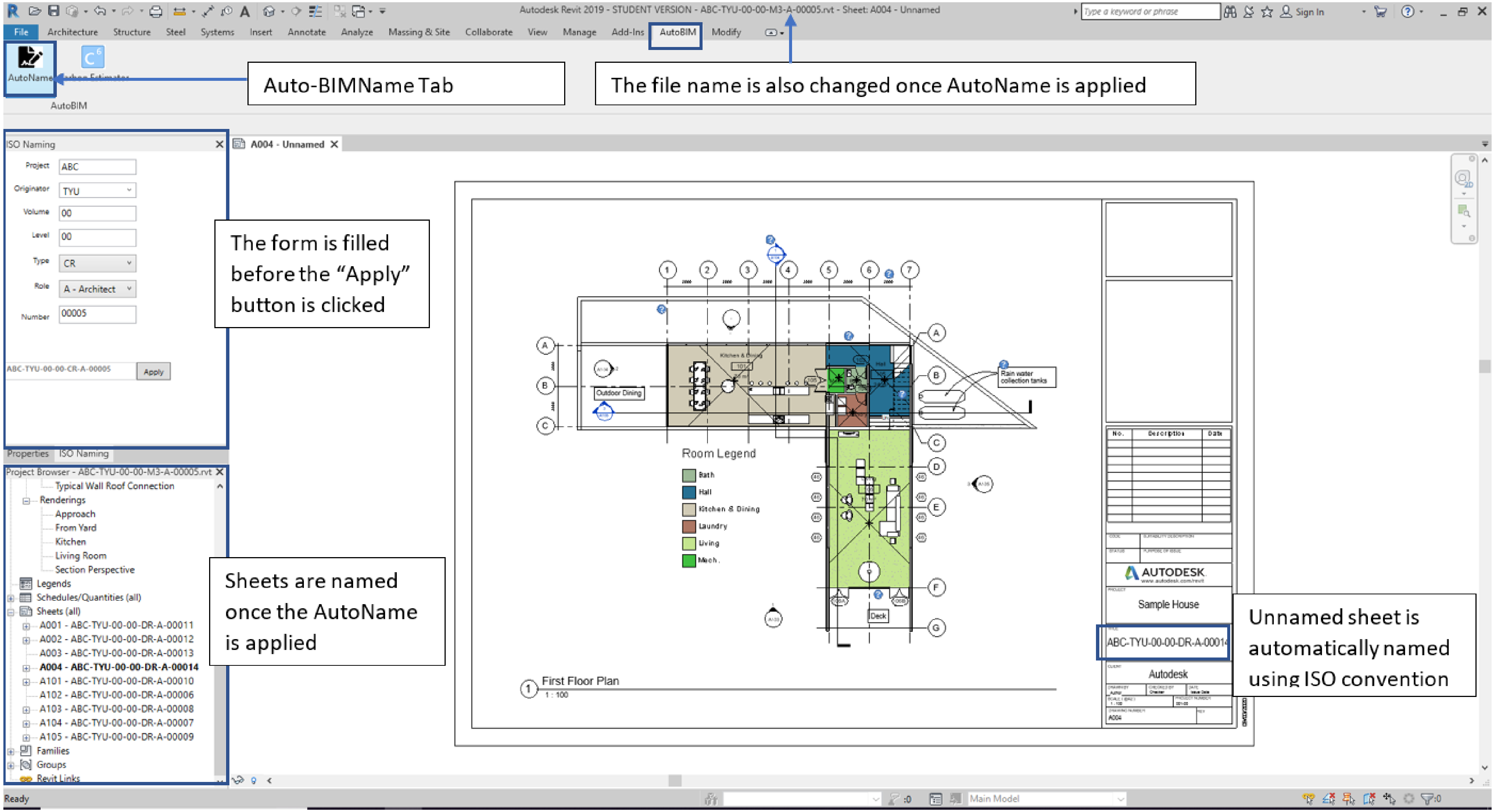

Figure 8: Image showing the completion of Auto-BIMName form and its implementation to automated file and sheet naming.

6.0. Summary and Conclusion

BIM is envisioned as a digital collaborative approach that is capable of revolutionising the global construction industry by addressing some of the multifaceted challenges, such as cost and time overrun, poor collaboration and information loss, among others that are affecting the industry's productivity. To make BIM works as hypothesised, its implementation is guided by a few standards and protocols that are aimed at facilitating standardization, collaborative working and seamless information exchange while working in a common data environment (CDE) among project parties. One of the requirements of BIM standards, originally captured in PAS 1192 suites of standard, and now as a part of ISO 19650, is the need to name file and sheet in a certain format, consisting of a string of letters and digits in a tightly defined manner. Apart from being prone to error and time-consuming, naming in compliance with the ISO 19650 is found to be one of the barriers to BIM adoption. To address this challenge, this study develops a BIM-based software plugin solution (Auto-BIMName) to facilitate automated naming in a collaborative digital BIM environment.

Through participatory action research, involving BIM experts and construction professionals, the Auto-BIMName plug-in, which was supported by a TIDP/MIDP portal as its Information Management System (IMS) enables the automation of file and sheet naming. This is achieved once the AutoName users input basic project information, including the project name, originators, file type and discipline that match the pattern in the database through which the unique file number for each file and sheet is then concatenated. The demonstrated use case proves that the Auto-BIMName can help designers and other project teams in fostering effective collaboration, as required for BIM Level 2, by naming files and sheets in line with the requirements of BIM standards. In addition, the information management system developed as a part of the automated naming process does not only serve as the IMS, but it also enables automation of TIDP/MIDP, allows task managers to be aware of tasks to be carried out and foster early collaboration among the project team.

Although the Auto-BIMName and its associated database system demonstrate how the advancement in digital technology and open innovation software platforms such as Autodesk suites facilitate automation, BIM adoption and compliance with BIM standards, future work could explore how the plug-in solution could be made compatible with other BIM-based software solutions. While Revit remains the most widely used BIM software for construction projects, other platforms that could be explored through the standardized, vendor-neutral, International Foundation Class (IFC) include Bentley Architecture and Graphisoft ArchiCAD, among others.

Data Availability Statement

Some or all data, models, or code that support the findings of this study are available from the corresponding author upon reasonable request.

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