A Cloud-based Collaborative Ecosystem for the Automation of BIM Execution Plan (BEP)

Abstract

Purpose

Master Information Delivery Plan (MIDP) is a key requirement for BIM Execution Plan (BEP) that enlists all information deliverables in BIM-based project, containing information about what would be prepared, when, by who, as well as the procedures and protocols to be used. In a well-conceived BEP, the MIDP facilitates collaboration among stakeholders. However, current approaches to generating MIDP are manual, making it tedious, error-prone, and inconsistent, thereby limiting some expected benefits of BIM implementation. The purpose of the present research is to automate the MIDP and demonstrate a collaborative BIM system that overcomes the problems associated with the traditional approach.

Design/methodology/approach

A BIM cloud-based system (named Auto-BIMApp) involving naming that automated MIDP generation is presented. A participatory action research methodology involving academia and industry stakeholders is followed to design and validate the Auto-BIMApp.

Findings

A mixed-method experiment is conducted to compare the proposed automated generation of MIDP using Auto-BIMApp with the traditional practice of using spreadsheets. The quantitative results show over 500% increased work efficiency, with improved and error-free collaboration among team members through Auto-BIMApp. Moreover, the responses from the participants using Auto-BIMApp during the experiment shows positive feedback in term of ease of use and automated functionalities of the Auto-BIMApp.

Originality/value

The replacement of traditional practices to a complete automated collaborative system for the generation of MIDP, with substantial productivity improvement, brings novelty to the present research. The Auto-BIMApp involve multidimensional information, multiple platforms, multiple types, and levels of users, and generates three different representations of MIDP.

Keywords: Building Information Modelling, TIDP, MIDP, Plugin, Construction, Collaboration.

Introduction

Building Information Modelling (BIM) as a collaborative digital information management approach to construction project delivery, is touted as an effective way of addressing issues affecting the productivity of the construction industry (Yin *et al.*, 2019). A complete BIM model is an augmentation of geometric and non-geometric information of all objects (i.e. architecture, assets, materials, etc.) involved in a construction project. Although there has been an increase in BIM adoption, companies still find it difficult to implement "real" BIM and realise the expected benefits (Wang and Lu, 2021). Some of the reasons are the lack of integrated management and flow of information among stakeholders, naming convention in line with PAS-1192 (BSI, 2013), and the need for adequate building information to accompany 3D-representation of building materials/elements/products in a collaborative environment. Addressing these issues, the Publicly Available Specifications (PAS)-1192 is the specifications that specify the BIM execution plan (BEP) for managing the delivery of the project. The BEP provides a foundational framework for the optimization of work and model flow across the project through information management. This is unlike the traditional approach to project delivery, which is focused on optimizing isolated interests of teams or individuals. A major outcome of the BEP is the master information delivery plan (MIDP) which enlists all information deliverables within the project containing information about what would be prepared, who will prepare, when it will be prepared and what procedures and protocols shall be used for every stage of the project. There are several benefits from implementing the BIM/BEP/MIDP, especially as it provides a sense of the virtual reality of the building that when transformed into a physical entity will bring control, quality and cost-saving to the whole construction process. The concise information shared through the MIDP reduces the effort required from a team by eliminating redundant work due to design errors and it supports decision making and optimization. These benefits are possible only with a well-conceived BIM execution plan developed at the inception of the project.

The current approach to generating MIDP is manual through pre-designed templates using text processing Software such as Microsoft Word or Excel. Managing information manually as with current practices invites several challenges. The main challenge remains getting everyone involved in collaborative projects to use construction design and engineering (CDE) and to ascertain the exact level of (and the specific) information required for different aspects/types of assets. Thus, some projects on which BIM is claimed to be used ended up without useful information for construction, in the short term, and asset management in the long term. In addition, maintaining consistency and uniformity of the information across the project requires dedication and strong collaboration among all participants of the MIDP. The PAS-1192, now revised as ISO 19650 (the digitization and management of information about architecture, engineering, and construction), has recommended the consistency aspect through standardization of naming convention for information artefacts that are presented in a MIDP. An important recommendation of the PAS-1192 is to use structured, consistent, and human & machine-understandable naming conventions for information managed by the BIM (Al-Saeed *et al.*, 2019, 2020; Chen *et al.*, 2017). This can be achieved by associating every BIM information/object with a unique identifier (name) that can be used to link the object throughout the project lifecycle. The naming convention just not only supports asset management but also supports planning, task management, design process, facility management and a key item for a collaborative workplace (Bortoluzzi *et al.*, 2019). Without a standardized naming convention, it is difficult for BIM users to work collaboratively and consistently on a single piece of information which ultimately leads to mismanagement and confusion among stakeholders.

The present work thus aims to design and implement a complete collaborative BIM cloud-based system (named Auto-BIMApp (Auto-BIMApp, 2021)) for automating BIM execution plan (BEP) involving naming that follows the convention in line with PAS-1192 and handles the need for adequate building information to accompany 3D-representation of building materials, elements, or products. Existing proposals have addressed automation within BIM, which bring novelty to the present work. Moreover, a collaborative environment for managing and generating MIDP is the present need of the industry. To develop the automated BEP cloud platform, participatory action research was used to develop the proof of concept and involve industrial collaboration with a leading UK construction firm and its supply chain. The collaborative research and development approach facilitated two-way input through which the development and testing of the digital platform was tailored to the industry needs and best practices. The strength of the proposed system is the integration of planning with BIM as well as working on tasks in an integrated environment. 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 automated naming and MIDP generating platform. Discussion of the study is then presented before culminating the paper in a conclusion and implication for practice.

Related Work

In this section, an exhaustive review of existing literature on BIM execution plans and naming conventions is provided.

BIM execution plan (BEP)

The BIM Execution Plan (BEP) is a protocol that indicates the key factors the team should follow during the project, recognizing the limitations of the project, the stakeholder agreements and requirements, and technical and collaborative aspects to consider during the project (Scheffer *et al.*, 2018). With the maturity of the BIM approach, it has been realized that the design process itself will not change within BIM, rather the entire construction life cycle involving all linked processes will also change. Designers will need additional skills to work with a new set of tools that support BIM (Heaton *et al.*, 2019). These skills are not just limited to using software, it includes data management and processing at large. In a BIM environment, all participants work together in a collaboration that requires careful attention toward data sharing, the scale of information, accuracy, input, and output produced (Pruskova and Kaiser, 2019).

Authors have addressed BEP in terms of public-private partnership (P3) (McArthur and Sun, 2015) with a focus on operation and maintenance components. Their research has shown cost-effectiveness using well planned BEP as compared to traditional practices. Another work is related to BEP for quantity surveying (Wang *et al.*, 2021). A pre-contract BIM execution plan for facility management was proposed by the authors (Lin *et al.*, 2016). As opposed to a traditional approach, the authors have proposed to involve the facility management team at earlier stages of the project, which is demonstrated through their proposed BEP. A major objective of the BEP is to provide a customization facility to project owners for monitoring and controlling project costs. The design and development of the BEP were carried out through qualitative study using interviews as the instrument for selecting seven core elements for the BEP. These seven core elements are formation of an implementation team, strategy, documents, processes, information collection, models inspection, and rules development. The present proposal encompasses all these elements in the proposed collaborative system.

Integration of BIM execution plan to the project management process has been reported by Delmiro and Serrano (Cajade Sánchez and Solar Serrano, 2019). Authors have enlisted items of integrations with their short details such as managing cost, time, human resources, requirements of stakeholders, defining scope and objectives, collaboration, quality control, technological and non-technological infrastructure, and deliverables. A short brief for every item identifies a way to integrate it within the BIM execution plan. However, this work provides surface-level definitional details about integration without addressing the implementation details. The provided recommendations for integrating collaboration are managing the documents shared among teams, defining information transfer methodology, frequency of meetings, location, and directory listing of all team members (external or internal) (Cajade Sánchez and Solar Serrano, 2019).

Naming conventions

The importance of standardized naming convention for objects of the building information modelling (BIM) was realized very early by researchers and practitioners (Barbosa *et al.*, 2016; Ruokamo and Heikkilä, 2020). As BIM objects are at the core of the whole process (from design to delivery) which represents the physical and functional characteristics of a building, the building blocks of the BIM are these objects. Moreover, they provide support for storing, managing, and visualizing building information (Heaton *et al.*, 2019). The architecture, engineering, and construction (AEC) researchers and practitioners consider BIM objects as a representation of the domain knowledge (Al-Saeed *et al.*, 2019). Considering the importance of BIM objects, several efforts have been made to formalize the naming convention of the BIM objects. Realizing the importance of the naming convention in BIM, there are few attempts made to formalize it such as Autodesk Revit object labelling (Autodesk, 2021), DOA/BIM (DOA, 2012), National Building Specification (NBS, 2019) and most recently PAS-1192 (BSI, 2013). Revit is a BIM software that provides a unified environment for all aspects of AEC whereas, NBS is a UK-based organization managing an online platform for design, supply, and construction activities.

Whilst the naming convention seems straightforward, 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 (Ajayi *et al.*, 2021). 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 (Bew and Underwood, 2010; Chan *et al.*, 2019; Crowther and Ajayi, 2019; Robert *et al.*, 2014). As a result, many construction companies and practitioners are not widely using these naming conventions due to the involvement of manual work required for naming objects (Ajayi *et al.*, 2021). Moreover, labelling manually is highly prone to errors and localizing naming conventions is incredibly tedious, especially for modern complex construction projects.

Table 1: Summary of the BIM naming conventions

	(Belsky *et al.*, 2016)	(Pasini *et al.*, 2017)	Open Geospatia l	Revit	RIBA	NBS	CIBSE	(Chen *et al.*, 2017)	(Zhang *et al.*, 2017)
Functional Type	✓						✓	✓	
Geometry	✓	✓	✓	✓		✓	✓		
Attributes		✓	✓					✓	
Relationship			✓						
Material	✓	✓		✓		✓			✓
Identification	✓		✓	✓	✓	✓			✓
Classification		✓		✓					✓
Manufacturer				✓	✓	✓	✓		
Authorship					✓	✓			
Description and Reference		✓			✓	✓			
Sustainability, Operations & Maintenance							✓		
Location		✓						✓	✓
Sequential Number								✓	

The Industry Foundation Classes (IFC) platform is working on the standardization of BIM objects and formulating a common exchange format between different applications. The data model of the IFC is an object-based file format designed for interoperability in the AEC industry. Recently, it extended to serve as a format for collaboration in BIM applications. Several countries such as Denmark and Finland have adopted IFC as a mandatory requirement for their construction industry. The IFC data model tends to address certain flexibilities for data exchange; however, it possessed several inconsistencies with the commercially available formats. A project named buildingSMART (buildingSMART, 2019) is recently developed based on the IFC data model having two components i.e. the information delivery manual (IDM) and the model view definition (MVD). IDM is the nontechnical details whereas MVD is the technical explanation to the data exchange. IFC based project is currently at its early stages and substantial advancements are required to fully realize its potential.

Uniform naming of the BIM objects is a fundamental requirement for the design of a collaborative system. Table 1 provides a summary of the existing research related to naming conventions and collaborative platforms for the BIM. A system for collaborative modelling to support design integration between two types of teams (inter and intradisciplinary) has been developed by Chen & Hou (2014). The system provides an online collaborative platform for the team members to share design models. The system contains few elements of the naming conventions; however, these are not utilized for the collaborative purpose. Collaboration is based on the system's local identification of BIM objects that limits the data exchange capability with other applications. Edwards et al. (2015) developed a multi-player game-like environment for design collaboration between pairs of users. The game-like environment is developed as a Revit plug-in. Users can start or join a local server for communicating and sharing content with others currently present within the server. An online file sharing platform was developed by Kim et al., (2017) which is similar to commonly available file servers but the only difference is that it is accessible through Revit plug-in. Users can upload and manage access rights to their shared design files.

The proposal of the present work also addresses associating design files from the local machine to the cloud provided task list. Researchers have incorporated the reusability of building objects by associating semantic information using ontologies in a web-based platform (Yang and Zhang, 2006). This semantic information contains elements for naming convention such as location, material, and object identification. A similar semantic enrichment approach was proposed by Belsky et al., (2016) in a system named SeeBIM. The SeeBIM enriches semantic information from a geometric model of the building and provides inference rules to generate a new IFC file. Autodesk BIM 360 is a commercial platform that provides several collaborative functionalities such as issue coordination, design review, and deliverables management. However, it is propriety software that mainly supports integration between Autodesk applications.

Naming the building objects in BIM is a way to improve the efficiency of the overall lifecycle of the building process (Pasini *et al.*, 2017) as presented by researchers through a web portal named INNOVance. INNOVance was developed to manage, use, and search information retrieved from building process technical datasheets and structure it under a defined coding scheme. A clear detail about the coding scheme is lacking in the research but an in-depth analysis shows that researchers have partially adopted PAS-1192-2:2013 specifications. Additionally, access to the online portal (INNOVance) is unavailable. An attempt to formalize naming convention for building objects identification and their interoperability was made by the researchers (Chen *et al.*, 2017). A semi-automatic naming convention was proposed through literature review and a qualitative study conducted with industrial practitioners. The proposed naming convention was brief and only encode functional, geometry, and location information as the object name. Authors (Chen *et al.*, 2017) have highlighted the need for a collaborative platform containing central workspace and associated client application's plug-ins to accomplish a real BIM environment.

An online BIM objects repository is developed by the NBS to enable industrial practitioners to search, download and reuse objects in their projects. NBS aims to standardize the object format so that any object created by any designer, or a manufacturer can seamlessly be used by others. A common standard will enable collaboration and meaningful information exchange among stakeholders, that subsequently bring efficiency to the whole building process. The naming convention followed by NBS defines geometry, information, behavioural and presentational attributes of the BIM objects. The object representation and data exchange of these objects are in NBS local format named BIM Object Standard (BOS). The complete NBS is a technology platform backed by the Royal Institute of British Architects (RIBA). Another commercially available Revit plug-in that helps manual naming of BIM objects is Ideate BIMLink. With BIMLink, a user can export all the building objects of a working design as a Microsoft Excel sheet. Users can then add unique names of every object and through BIMLink, the modified sheet can be imported back to the working file. This method of exporting and importing data for naming purposes is laborious and cumbersome especially linking the dependencies between BIM objects that are exported as separate files. A similar approach is followed by the Chartered Institution of Building Services Engineers (CIBSE) for associating processable description with BIM objects using MS Excel spreadsheets called Product Data Templates (PDT). CIBSE is a UK-based chartered association that represents building service engineers. In the past, several proposals were made for naming BIM objects but none of them has been widely adopted by the industry. The primary reason is that any structured, consistent, and understandable naming convention proposed earlier require a large amount of manual work for naming the objects.

Auto-BIMApp: Automating BIM execution plan system

The present work aims to develop and implement a cloud-based BIM system that automates the process of collaboratively generating MIDP, an important element of the BEP. The proposal also addresses the requirement of the naming convention in line with ISO 19650 and handles the need for adequate building information to accompany 3D-representation of building materials, elements, or products. The realization of the proposed system came into being because non-consistent/inadequate project information is preventing the true benefits from the BIM. By facilitating auto-population of building information, adequate information will be provided in a structured/consistent format, providing sufficient task-specific information to better-inform construction workers. This will improve the time/quality and reduce errors/reworks.

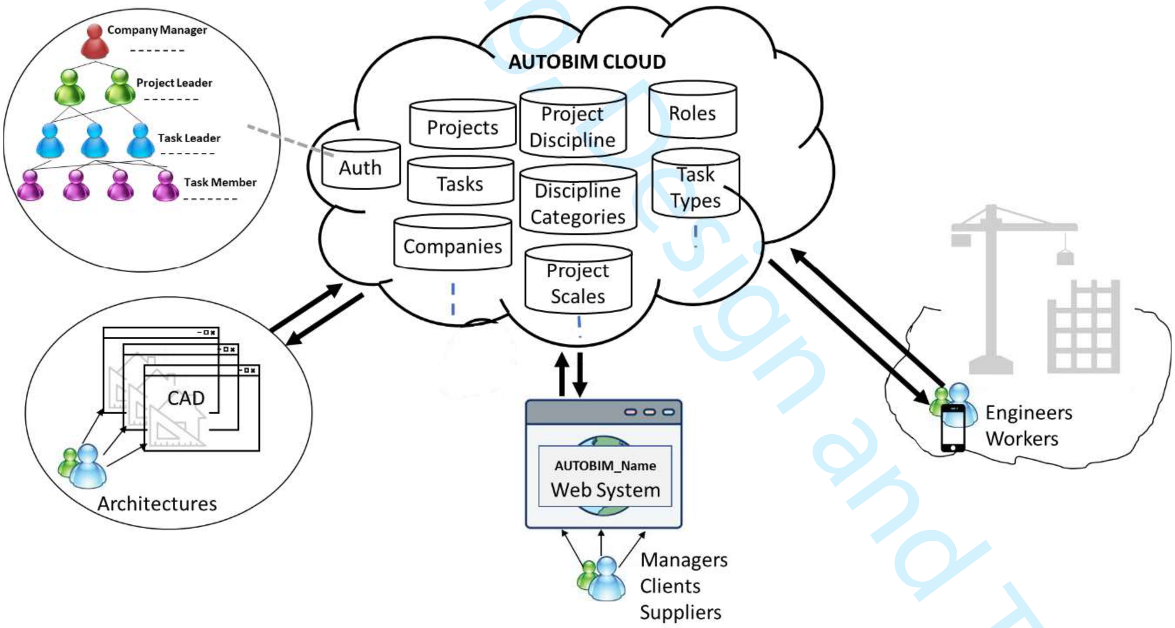

Figure 1: Overview of Auto-BIMApp cloud architecture

Auto-BIMApp is implemented on a cloud Software-as-a-Service (SaaS) architecture to support the needs of different types of users and to ensure naming uniformity throughout the whole building process ranging from planning to its completion. A high-level cloud architectural diagram of the Auto-BIMApp system is shown in Figure 1. SaaS implementation provides universal access to software or, more general services to its end users. With cloud

SaaS, the end-user uses an application on his desired platform seamlessly without knowing the details of the underlying services infrastructure providing the required information and processing operations. The proposed Auto-BIMApp cloud services serve at the same time the information requirements of the software applications such as computer-aided design (CAD), web applications and mobile applications.

Above all information and processing at the Auto-BIMApp cloud, the authorization and access level layers are implemented to provide individual workspace to its users. Multiple companies can register with the system using the web-based interface. Project leaders are the personals looking at the whole project and they can be registered with the system or be invited by a company manager to initiate a project or review supplier's provided information (building execution plan). A company can have multiple project leaders. Moreover, project leaders can initiate multiple projects. Project leaders then invite task leaders to handle and process tasks of their relevant expertise within a project. Task leaders are people with specialized expertise such as architecture, land surveyors etc. as defined by Uniclass 2015. To implement a complete collaboration among different types of users, the proposed system facilitates the invitation of task leaders from another registered company as well as an individual within or outside the project leader's company. With this kind of authorization, different task leaders having different expertise can work together under a single project to complete their respective tasks. Task leaders can further invite task members to assist them in the completion of their assigned tasks. Task members can be from within the same company or invited as an individual. Comments and notes can be associated with all actions carried out by the users which provide strong communication among all super and subordinates. The strong authorization and access policy implemented within Auto-BIMApp administers the requirement of data privacy and protection, which is an important aspect of any collaborative environment, in line with ISO 19650-5:2020 security-minded approach. Auto-BIMApp creates a separate workspace for every individual project that collates documents, information, and team members of the respective project. The sharing and ownership information for every piece of information is associated with the item and is visible to only those members who have access to it. All activities performed by team members are logged for tracking purposes.

ISO 19650 (Information management) is a specification document that specifies the requirements for achieving Level 2 BIM. Above level 0 (unmanaged CAD) and level 1 (managed CAD), BIM Level 2 is more concerned with the collaborative environment with associated data from different discipline models. However, the real focus of BIM is level 3, which is. a single universal collaborative environment that host and create data together for all stages of the construction lifecycle starting from contract, planning, and cost to delivery. The present proposal addresses the requirements of level 3 BIM through cloud SaaS infrastructure in-cooperating support for different applications and platforms and user management including access and authorizations.

Table 2: Prestored information in Auto-BIMApp

Information title	**Items**	**Examples**
Project Disciplines	8	Building Project, Civil Engineering Project…
Task Types	215	Application (AP), Contract (CC), Proposal (P), Database (DB),…
Roles	387	Architect (A), Building surveyor (B), Civil engineer (C), Interior designer (I),….
Discipline Categories	18	Accommodation, Commercial, Defence and Custodial, Education, Health, ….

The Auto-BIMApp process starts by registering a company with a company manager account or the project leader account through an online web system. The company manager or the project leader can set up a project. To enforce the uniformity among projects and tasks, a large amount of information is pre-authored or stored in the cloud such as project types, project discipline, and task types, among others as defined in Uniclass 2015. For example, a specific type of project involves a list of the specific type of tasks, materials and require a specific person with expertise. The selection of project type provides convenience to the user as the proposed system automatically populate the mandatory set of information for the selected project type. As compared to other BIM systems (NBS, 2019), the proposed Auto-BIMApp manages information under a multi-context structure for every role type, task type, file type, project discipline and discipline category. Previous BIM solutions work with only one role type for viewing and reviewing project information. However, in the proposed BIM system, an individual with a specific role can be invited to collaborate at any level of detail. With this, within the proposed system, every user can see only the specific part of the project where he needs to contribute accordingly to his expertise. Table 2 shows a snippet of information items stored within the system for populating baseline information for any given project type. However, the system provides a facility to tailor these items or add new items for their projects. The company manager can invite a site admin to do such configuration. On adding a new item, the system asks for consent to add this newly added item to the main/collective repository. If allowed, the newly added item can be made a part of the central repository after reviewing by the super administrator or left as a custom-build item for all users associated with the company.

The data storage layer is implemented using a scalable relational database management system (RDBMS). Some of the relations (tables) are shown in Figure 1. The overall database schema of the Auto-BIMApp is designed in a way that it satisfies the cardinality requirements of database design. Metadata, project, tasks and other information are stored in the database while items in the form of electronic documents are stored as files but are linked with the database records. Direct access to any resource is restricted. Sharing of information and resources is done by assigning access rights to a member and sending notification to all stakeholders. Information and resource items are not shared in a way that they are exported out of the system, rather shared members need to access them within the system. However, lead members can only export the information if required. All connected client applications retrieve information from the cloud servers through Restful API, which is a standardized protocol for inter-communication between software applications. Restful API provides both the data transfer and the execution of procedural commands.

Auto-BIMApp Cloud System

An important aspect of the ISO 19650 specifications is the BIM execution plan (BEP – as shown in Figure 2) for managing the delivery of the project. The pre-contract phase of the BEP addresses the procedure for awarding the contract to a supplier based on his capability, competence, capacity, and proposed approach. In the pre-contract phase, the supplier submits the details required to fulfil the employer’s information requirement (EIR). EIR is a pre-tender document that defines information standards and procedures to be delivered and required by the employer within an organization or directly from the suppliers. A part of the employer's information requirements is included in the procurement documents. Iterative development of EIR is implemented in the proposed system starting from a basic information requirement process map that models key decision points within the project and what information is required to make those decisions. Further, information about materials, floors, facilities, performance, and functional aspects of the building is added to the EIR. With design maturity, specific needs and components' information is gathered. Finally, details about maintenance, operations, and installations are added. The current proposal has implemented a high-level EIR within the Auto-BIMApp system however, designing and developing a much detailed and complex EIR is still future research.

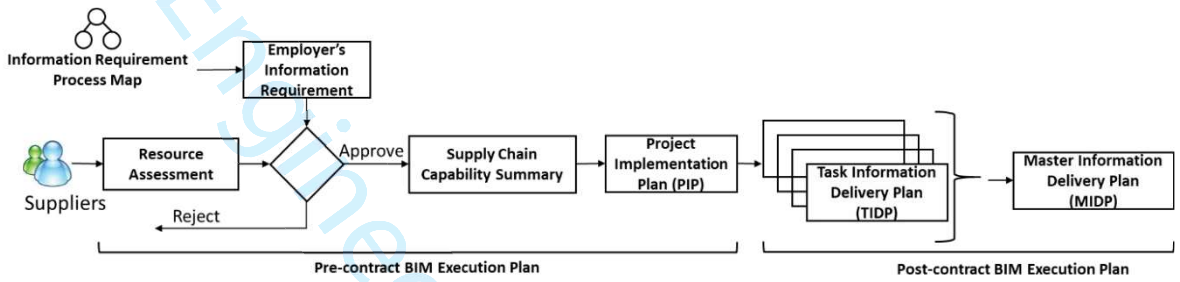

Figure 2: BIM execution plan

In addition to managing the pre-contract phase, the proposed system handles, manage and generate the master information delivery plan (MIDP). MIDP enlists all information deliverables within the project containing information about what would be prepared, who will prepare, when it will be prepared and what procedures and protocols shall be used for every stage of the project. MIDP serves as a protocol document that involves all contract forms. MIDP support information exchange between suppliers (contractor) and employers and manage various tiers of the supply chain. The information exchange is mainly carried out through various forms of documents; the proposed system organizes this information exchange among all stakeholders through MIDP. Master information delivery plan is collated from a series of federated lists of information deliverables called task information delivery plan (TIDP). Each task team assigned with a specific responsibility sets out their information deliverable as TIDP that includes tasks, documents, responsibilities, and timelines. The proposed system provides a facility for every project leader to form a designated team for a separate TIDP. This collaborative working environment implements a real BIM Level 2 system. Every TIDP activity serves as a milestone for the task teams. The progress information of every individual TIDP is visible to all members that give a clear indication of the overall progress of the whole project. With the MIDP, the company manager or the project leaders can easily identify the cause and effect of delays incurred by any individual task team.

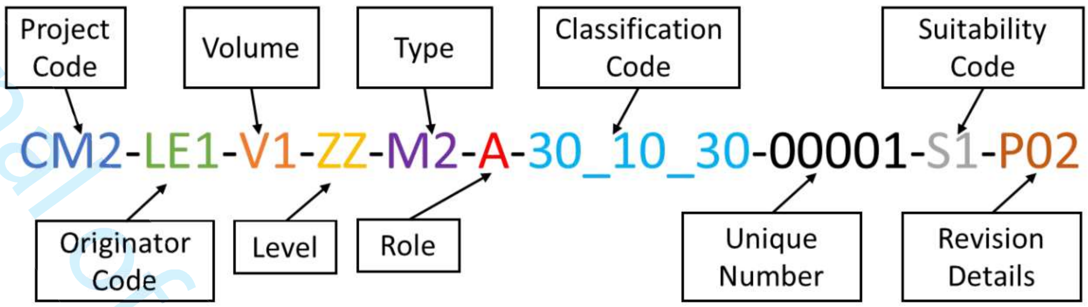

Figure 3: Segments of the naming convention used by Auto-BIMApp

A key aspect of the proposed system is to enforce BS EN ISO 19650 naming convention for the tasks, documents, and information. The main reason for a naming convention is to synchronize and structure the collaboration among task teams that is understandable for all members at every stage of the project. A survey of the construction industry has revealed that varied forms of naming conventions are being used by the industry and especially it is done manually which require a huge amount of time. The proposed automated method for the standardised naming convention has cut the huge time required to do naming manually to only a few clicks.

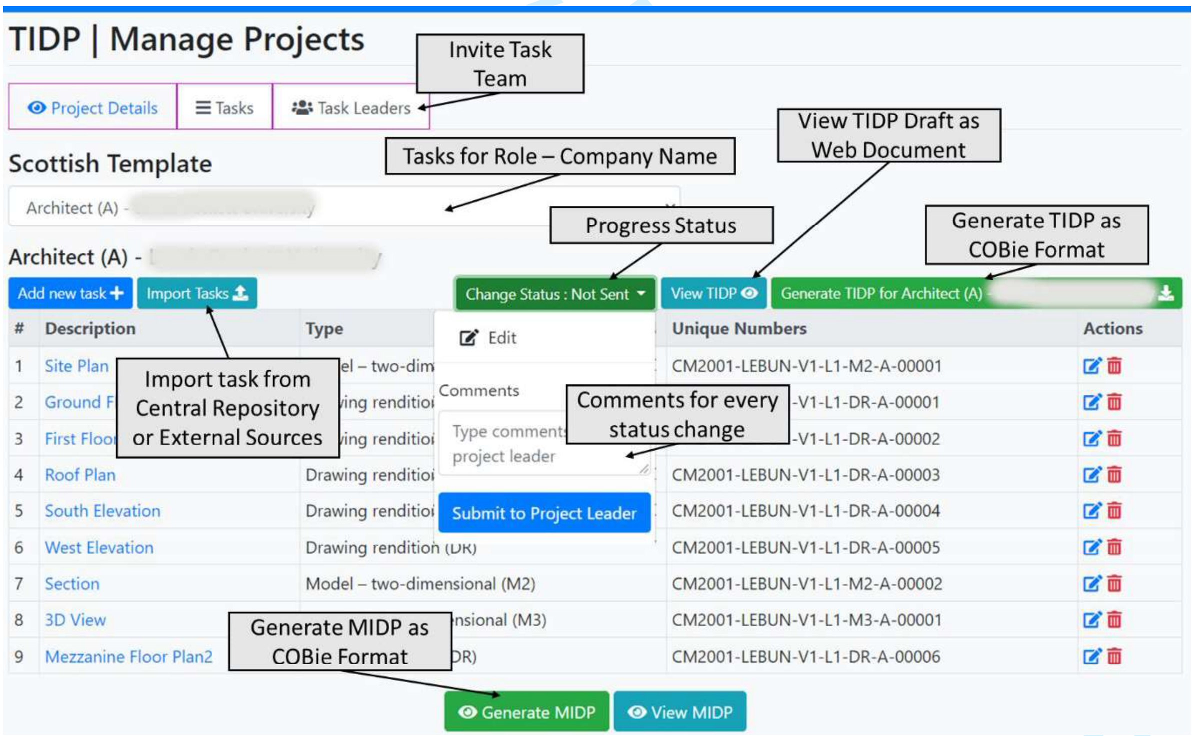

Figure 4: An overview of the Information Management System – TIDP/MIDP Portal

Figure 3 shows the naming convention implemented by the proposed system. The naming convention is adopted from multiple state-of-the-art based on the rigorous analysis provided in the related work section. The unique name starts with the project code. The system associates the project code automatically as every task comes under a project and similarly, EIR also has the same project code. Members of different organizations or companies working as task teams on the same project will be assigned a project code. The second part is the information originator code i.e. unique code of the organization producing this information. Project and originator codes are recommended to be six-length alphanumeric characters. The volume and level after originator code are two length characters showing spatial and technical sub-division of the project. Based on necessities and organization, the project leader can split the project into subsequent volumes. Different task teams can be assigned different volumes to work concurrently under the same project. An autogenerated appendix of volumes based on volume sub-division is shared among all members. The proposed system performs clash avoidance based on volumes information. Sub-divided information based on volumes is finally collated to form the overall project information. The level part of the unique name shows the location of the object where it is being placed. Levels can be represented as numbers (01,02,..) or letters (GF, M1, B1,..). The type after level represents recognition of the unique information of a task i.e. location model, drawing, assembly or documents. A few examples of the type information are DR for 2d drawing, M2 for 2d model file, VS for visualization, CP for cost plan, FN for file note, etc in line with Uniclass 2015.

The role part of the unique name after type information represents the standard code for a role such as architecture, civil engineer, etc. There are 387 roles with their unique codes stored in the central repository of the proposed system. Companies can add new roles of their choice, but they will be accessible within their own project space. Every project leader can invite a task leader based on an assigned role. The classification part of the unique name is an optional item that represents the asset selected from the reference dictionary. The next part of the unique name is the sequential number that uniquely represents the task if all previous items remain the same for any given task. Moreover, these sequential numbers form a group based on type information. This sequential number is always five characters long and trailing zeros are used for smaller numbers. The final two parts of the unique names are suitability and revision codes that are internally managed by the proposed system. Suitability code is used by the Auto-BIMApp system for status information of any given task such as suitable for review, suitable for coordination, approval, return etc. Whereas the revision code is used to maintain the revision history of every individual task.

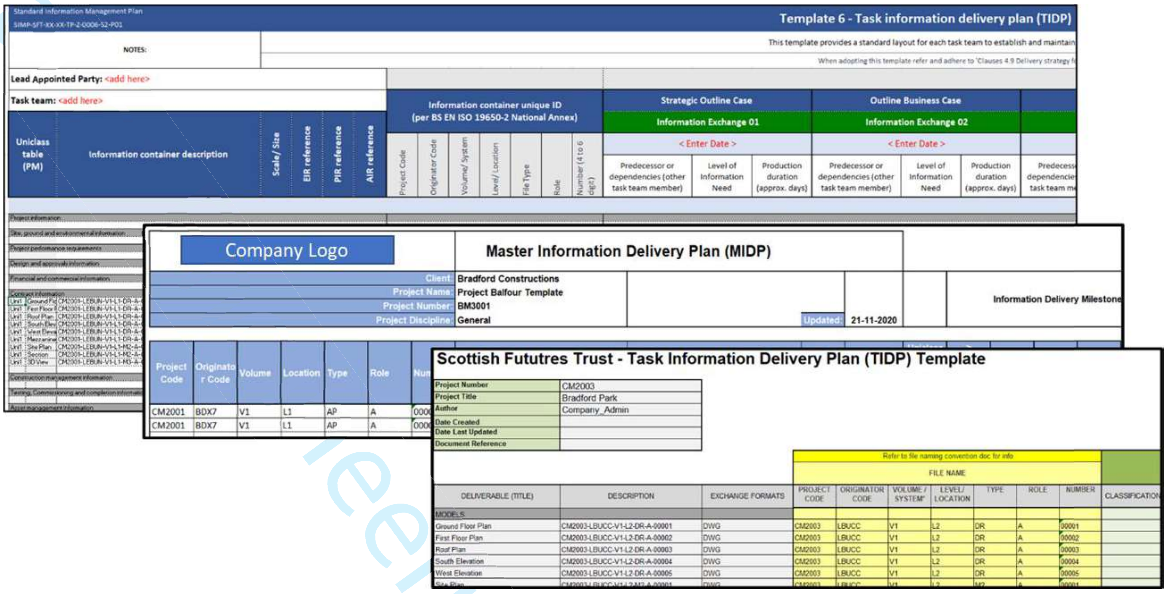

Figure 5: Auto-BIMApp output as three different templates

Figure 4 shows the working space for the team members to work in collaboration on an assigned TIDP. This screen follows from a project list page. On the TIDP screen, a user first selects his assigned role with an organization to populate the list of tasks assigned for completion. An individual with the same role can be invited by multiple companies under multiple projects. The screenshot shown in Figure 4 is TIDP after the completion of the task but not yet submitted to the project leader for review and approval. The status flag shows the current status of the TIDP. The status can be according to the suitability guidelines of the naming convention. At any status change, the task team must post a comment or a note for the whole team. This serves as internal communication among team members and similarly, these comments are pushed as notifications to all members within the system or through email. Members of the task teams can add any new task if required or they can import a batch of tasks from the central repository against a given role or import from an external file. The import formats are comma-separated values (CSV) or the JavaScript object notation (JSON). Task teams can generate their TIDP as construction operations building information exchange (COBie) format file or they can view an online version. The system generates COBie exchange data (shown in Figure 5) following all available types of TIDP templates provided by the Scottish foundation, BIM UK, a Tier 1 Contractor and Construction information project committee (CIPC).

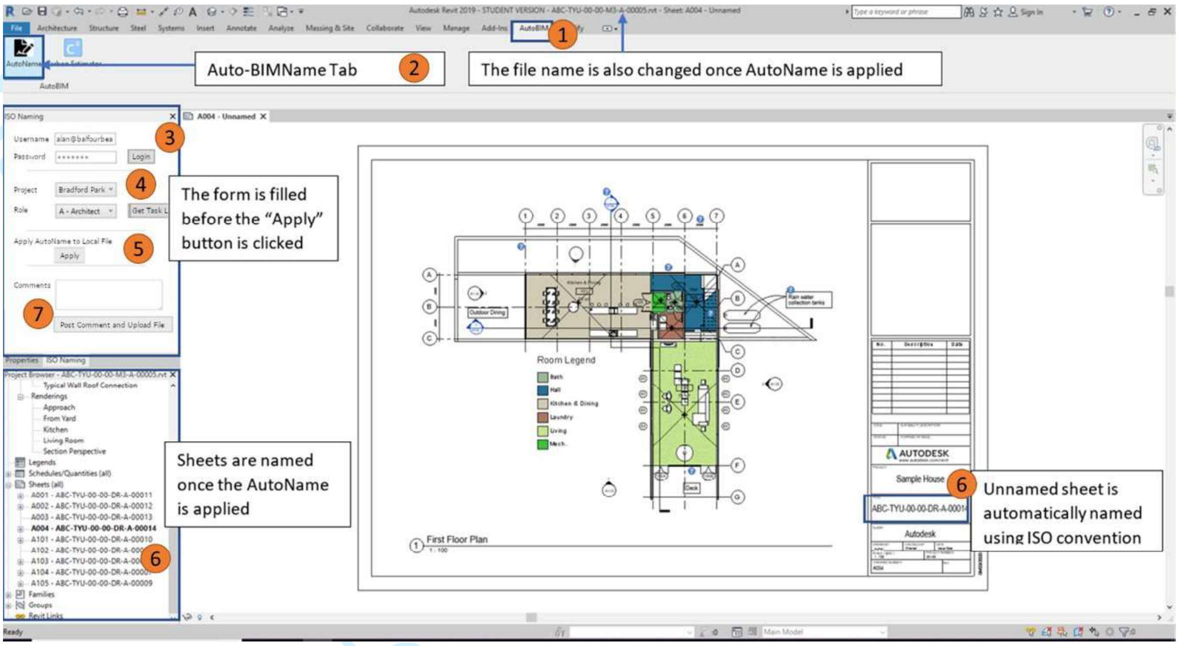

Figure 6: Auto-BIMApp Revit client

Auto-BIMApp Revit Plug-in

The proposed Auto-BIMApp system is comprised of backend and frontend tiers. The backend is the cloud storage and management whereas the frontend can be any client application either web, mobile or any software plug-in. To demonstrate and implement a complete cycle of collaboration among teams to produce MIDP, a Revit plug-in as the frontend of Auto-BIMApp is developed. The plug-in can communicate with the backend cloud services for the retrieval and modification of tasks under a given project. The plug-in is developed using C# .Net framework. Figure 6 shows the user interface of the Auto-BIMApp Revit plug-in. The MIDP documentation is a continuous process in a BIM-based project. It is essentially an "information" delivery plan, which is the backbone of the whole Building "Information" Modelling. The way it connects with the other stages is that it helps all project stakeholders with the correct file naming in line with the ISO 19650 convention. For instance, in Figure 6, we demonstrated how the information fetched from the MIDP portal helped in naming files within Revit (a drawing tool) to ensure consistency across/among project partners.

Every user i.e., team leader, task leader or task member need account information to access the central cloud repository. For this reason, the plug-in provides a login box for signing in to the Auto-BIMApp cloud. This access authorization information can equally be used for all types of client applications. The plug-in was built on RESTful API with JavaScript Object

Notation (JSON) for seamless communication among applications. Using REST means that the advantages of a simple communication protocol i.e., hypertext transfer protocol (HTTP), was taken and that the internals of the API could be changed without requiring any modification on the part of the client-side application (Revit plugin). On successful login, the plug-in retrieves the list of projects and roles that are assigned to the user. The list of projects and roles are populated as selection boxes. Auto-BIMApp provides support for different roles under different projects for the same user, and it depends on the team members as well as how they invite the user under the project. Selecting a project from the project list will populate the roles of the user assigned under the selected project. The user then selects the role and click the 'Get task list' button to retrieve all tasks from the cloud that are assigned to him. The list of tasks is shown as sheets sub-items in Figure 6. Users can select and apply the name to the current working file from the provided names list. Once applied, the local file shall get renamed accordingly. Finally, the user can post back the file to the central system for the completion of the MIDP task. Moreover, the facility to post comments provides a means of communication among team members is available in the plug-in.

Results and discussion

This section presents the results of two experiments carried out to validate the proposal. The first experiment is performed to evaluate the accuracy and supportiveness of the proposed system while the latter one evaluates the performance of the system in terms of time-saving for the whole MIDP process.

Case study for validation

As a case study, the TIDP and MIDP processes of a real transport-related construction project have been completed using the Auto-BIMApp system to validate the system's accuracy and supportiveness. The data containing all TIDP and MIDP files of the said project is collected from a Tier 1 UK construction company that has completed this project in the year 2019. The collected MIDP file of the project contains 1442 tasks in total. TIDP files of six different disciplines are combined to form this final MIDP file. The project has involved 18 different roles where the RD, GE, and ST roles have assigned the highest number of tasks. Similarly, the project tasks contain information of 258 unique locations. The highest document type used for the tasks were DR, M3 and M2.

A team of five members was formed to experiment, with three members from the academics and two from the industry. The members from the academics include a leading researcher who had previous experience of working in the construction industry. While the other two members from the academics are researchers with background in IT who have worked on the Auto-BIMApp project for over a year. The team members from the industry are civil engineers with engineering software expertise. Both were previously involved in the planning of the transport-related construction project. The hierarchy of roles is defined as the leader is assigned a 'company admin' account to initiate the project and invite project leaders to complete the project. The system generates separate login credentials for every role and delivers them to team members through email. The system has the provision to invite many members under the same role or a single member for different roles. All team members have access to centrally shared copies of the TIDP and MIDP files of the project. All participants have used the Auto-BIMApp system from their own workplace serving different project roles for the purpose of system evaluation. Auto-BIMApp has an internal messaging system for team communication. In addition to that, participants have also used video conferencing for their meetings.

The team has collaboratively worked using the Auto-BIMApp system and finally generated six TIDP files and one collective MIDP. The tasks information of the generated MIDP is shown in Figure 7. Figure 7(a) shows the total number of tasks assigned to every role involved in the project. The task members who are performing the completion of the tasks within the system are drafting dummy files (dwg, Xls, CSV etc.) and uploading them. Figure 7(b) shows the distribution of tasks against different document types. Similarly, Figure 7 (c) shows the defined volumes and their number of tasks. Finally, Figure 7(d) shows the number of tasks in a TIDP file against six different disciplines. The highest number of tasks were in highway discipline and the least was in the legal discipline.

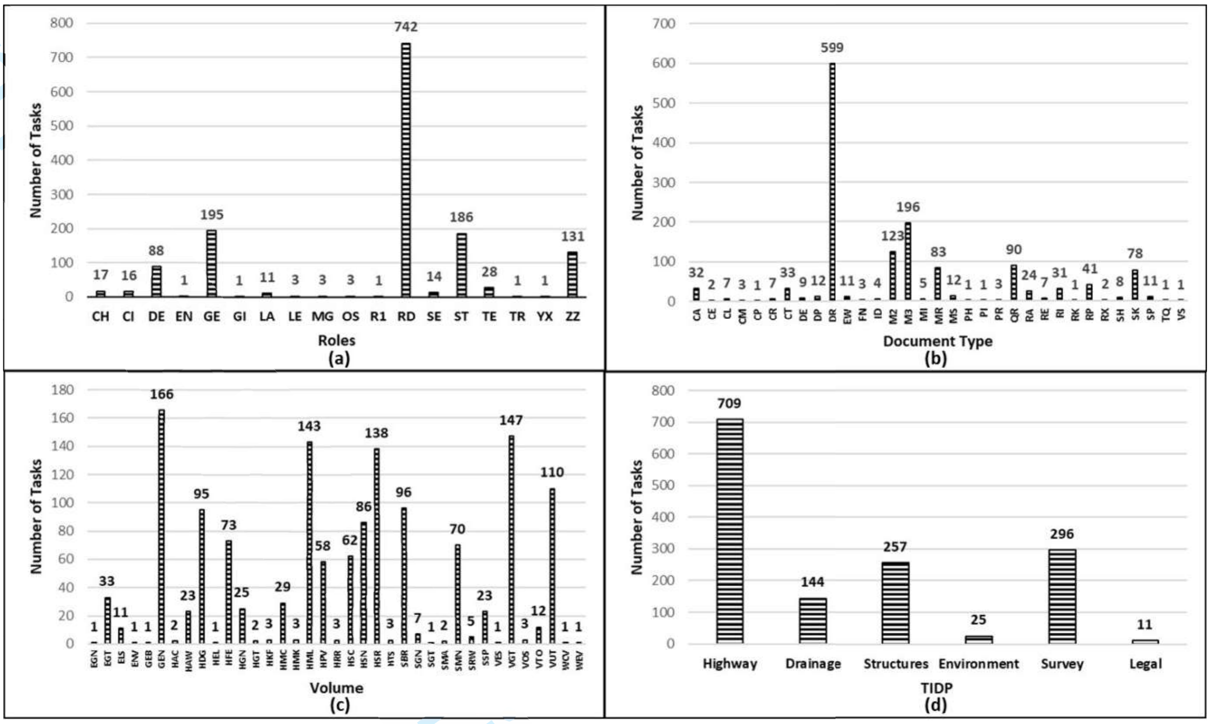

Figure 7: Task distribution in Auto-BIMApp generated MIDP and TIDP files

The accuracy of the system is evaluated by comparing the output of the Auto-BIMApp project with the original MIDP and TIDP data (manually created) of the project. The accuracy evaluation is performed collectively by all participants of the experiment in a group meeting. The results of the evaluation show that the system has accurately generated both TIDP and MIDP files without having any mistake or loss of information. Above that, it has been observed that the manually created MIDP file has over 23 MB of file size with hundreds of rows and tens of columns for the task information. Every revision for a given task is logged as a new column containing notes from the reviewer. The huge size of the file makes even the latest desktop computer slow to process e.g., copying and pasting information between columns takes a noticeable time. However, on the other side, the Auto-BIMApp provides an efficient and user-friendly interface with most of the information preloaded for the user. This experiment also served as the system testing involving the end-user. The team members are highly satisfied with the overall process carried out through the Auto-BIMApp system. This user satisfaction provides evidence about usability and user acceptance of the system which is an important aspect of software engineering.

Industry feedback

The present research is conducted under a UK government-funded project that involved both academic and industrial partners. Taking the advantage of the funded project, the proposed Auto-BIMApp system is experimented with for a real ongoing project being carried out by the industrial partners. The experiment is conducted to evaluate the effectiveness and performance of the proposed system. The production of a master information delivery plan (MIDP) through the use of the proposed application was measured as compared to the current practice of using spreadsheets. The evaluation concluded with an investigation of the effects of the proposed application in terms of collaboration and its usefulness.

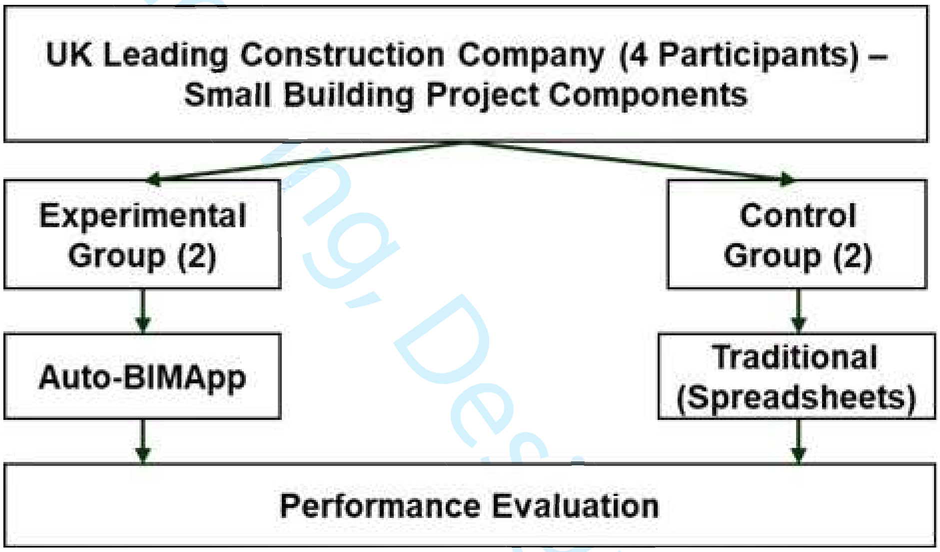

Figure 8: Design of experiment conducted for performance evaluation

For the experimentation purpose, a small set of building components of an ongoing project is selected for which the participants need to prepare the MIDP. The experiment overview is shown in Figure 8. The industrial partner of this project has several regional offices at different locations. A total of four employees from the industrial partner's organisation were selected as participants for the experiment. Participants are divided into two groups i.e. an experimental group (EG) and a control group (CG). Both groups are located at different locations to avoid knowledge sharing between them. However, participants of both groups have the same level of experience and knowledge and are highly experienced in producing and processing MIDP/TIDP. All four participants have more than three years of experience in the construction industry and mainly work in the planning division. The building components assigned for the experimentation purpose are foreign for both groups to eliminate any bias or previous familiarity. Members of each group are instructed to work as a team for the preparation of the MIDP.

The experimental group has prepared the MIDP using the proposed software whilst the control group followed their routine practice of using spreadsheets. A short training session for about 30 minutes was conducted to brief members of the experimental group about the Auto-BIMApp system. One participant of the experimental group has registered himself as project leader for their company which was already registered with the system. The other member is being invited as task leader by the project leader.

The experimental group initiated MIDP production by creating a project and selecting the roles required. The Auto-BIMApp has auto-populated several pre-stored tasks against the selected roles. Later, they have created several other tasks as per requirement. Logs of every action taken by the members of the experimental group were recorded by the system. These logs provided data for analysis. The logs showed that both the project leader and task leader has not deleted any of the pre-populated tasks from the list, which shows these tasks were important and relevant to the selected roles. However, a longitudinal study with several other projects will guide us to update the pre-stored task list. Auto-BIMApp provides support to save the work at any stage. Incomplete and completed flags guide a user to start again from the last save point. In Auto-BIMApp, dependencies among tasks are easily managed by selecting the predecessor or the successor task while completing an underlying task. Within Auto-BIMApp the information is filled in a stage-wise manner which gives the user a sense of progress. On the other hand, the control group has started with creating a new spreadsheet containing a blank template of their choice. A separate TIDP file is created for every role required for the project. Project details were filled in the respective columns of all TIDP files. Then a single MIDP file is created for the same project. At first, the members of the control group fill every individual TIDP file with tasks relevant to a given role. However, a substantial amount of time is spent naming individual tasks according to ISO 19650 standards. Moreover, managing dependency requires moving back and forth among different files to get the unique identifier of a dependant task. Finally, merging all TIDP files to form a single MIDP file is the tedious job of all. Sorting tasks according to the role, task category and task type in both TIDP and MIDP files require intense attention. For every new template (three in our case), the control group has to repeat the whole process. The members of the control group have divided the work by assigning task completion related to a single role to an individual member. However, working in isolation does not support MIDP production as TIDP files require linked information from other files for which the team members have to consult each other repeatedly. This lack of collaboration in traditional practices is also a major hurdle in achieving better performance. The control group has used previously stored tasks from their other spreadsheets along with several new tasks created to suit the requirements of the given project. However, renaming previously stored tasks to get accommodated in the new project took them an ample amount of time. For this reason, one of the control group members prefers to insert the tasks in the template from scratch as it takes the same amount of time as adopting them from other project files.

Table 3: Results for Auto-BIMApp performance evaluation

Group	Time Spent (mins)	MIDP Templates	Roles	Total Tasks
Control Group (CG)	97	3	2	318
Experimental Group (EG)	19	3	2	338

As shown in Table 3, the experimental group using Auto-BIMApp has taken less time to complete the production of MIDP as compared to the traditional approach. The time spent shows the throughput time for MIDP generation taken by both groups. The primary reason for this performance improvement by the proposed system is the automation of naming conventions and collaboration support among team members. Utilization of previously stored tasks helps in the timely completion of the overall process. The difference in the total number of tasks between the control and experimental group is because Auto-BIMApp has populated a detailed task list for selected roles whereas, the control group has added the needful tasks but additional tasks that are relevant to details were missed. With Auto-BIMApp the experimental group has generated all three templates of the MIDP by adding some extra information relevant to a template. On the other hand, the control group has taken a long time to create separate files for every MIDP template and complete it with additional information related to the template. Auto-BIMApp provides a facility to clone previously completed projects if users think the new project has similarities with a completed project. However, Auto-BIMApp automatically renames all cloned information/objects to reflect the new project.

Although the MIDP could help in managing risks (while also providing a basis for project management by providing information about what is required at what time). However, MIDP, as a key BIM requirement, is not a risk or project management documentation. What it does, as we explained in the background of the study, is to help the project team to know which information is required to be produced by who at what time. This serves as the basis for the whole Building Information Modelling. In Figure 6, we demonstrated how the naming convention from MIDP would help all stakeholders to name their files in a consistent format (and automatically). The naming pattern generated in the MIDP would help the designers in file naming. It would also help the contractors and other stakeholders, including clients and their representatives to ensure proper file naming. One of the limitations of the Auto-BIMApp is that at present it only follows the same set of naming conventions for every object. However, a dynamic naming convention can easily be implemented within Auto-BIMApp that provide the facility to configure the components of naming convention i.e. ordering, adding or removing elements. This configuration facility will provide Auto-BIMApp with the ability to accommodate any new revision to the naming conventions in future.

Conclusion

The paper has demonstrated the automation of a BIM execution plan (BEP) through a cloud-based collaborative platform. The present work has implications towards academic and industrial practices. An academic review of overall BIM execution plan and naming conventions for reusing BIM objects has been presented here along with the needs and problems of the current practices that are followed by the industry. Moreover, the development details of the cloud based collaborative eco-system will benefit both academia and industry. BEP carried out by the delivery team mainly concerned about information management including processes for the creation of information models for the client's employer’s information requirement (EIR). The proposed system name Auto-BIMApp generates MIDP as the outcome of the BEP in three different templates. MIDP models all the roles and responsibilities of individuals involved in the project. It serves as a facilitator or a means for collaboration among project stakeholders. Auto-BIMApp has implemented multi-level hierarchical user management and information sharing for the collaborative generation of MIDP. To keep the information consistent across the project life cycle, Auto-BIMApp follows the standardization recommended by the ISO 19650 for naming the information artefacts. The present work provides a detailed review of state-of-the-art naming conventions. Moreover, the automated naming facility implemented by the Auto-BIMApp has accurately supported the collaboration among users and have improved the efficiency of the project teams as shown in the results. Cloud-based services can be accessed from a different platform such as web, desktop application or mobile. A Revit plug-in has been developed as part of the Auto-BIMApp to demonstrate multi-platform collaboration supported by the proposed system. The system is evaluated for accuracy and performance by executing two real projects.

Notwithstanding the productivity benefits of the automated platform, it has some limitations. One of such limitations of the present work is the size of project (tasks) managed through the Auto-BIMApp, which would keep growing, and the number of participants involved in the experimentation. Moreover, Auto-BIMApp has not been experimented with the users having no professional or specialized knowledge about construction management. Tooltip help which can help users in understanding procedures and actions that they can perform within the system is currently lacking throughout the system. The present work has implications for academic and industrial practices. An academic review of overall BIM execution plan and naming conventions for reusing BIM objects has been presented here along with the needs and problems of the current practices before the development of the automated platform for the industry. Moreover, the development details of the cloud based collaborative eco-system will benefit both academia and industry. The present work has implemented a high-level MIDP generator within the Auto-BIMApp system; however, designing and developing a much detailed and complex EIR is still a direction for future research.

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