BUILDING INFORMATION MODELLING (BIM) IMPLEMENTATION FOR MEP SYSTEMS IN BUILDINGS: A CONCEPTUAL FRAMEWORK

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ABSTRACT

The challenge in coordination of Mechanical, Electrical and Plumbing (MEP) systems is a common problem peculiar to the MEP industry. Although the traditional Two-Dimensional Computer Aided Design (2D CAD) has been used in the industry to resolve the problem of coordination, it has not been effective. Therefore, the aim of this paper is to develop a conceptual framework for Building Information Modelling (BIM) that can be implemented in the MEP Industry. This will facilitate a seamless transition to BIM and solve the MEP coordination problem of the traditional 2D CAD project delivery approach.

The conceptual framework was developed and refined through an extensive review of the literature concerning BIM. The framework developed is a model based collaboration framework that will allow MEP firms to collaborate to produce the coordinated construction model during the MEP coordination process. The framework has the potential to be used as a practical methodology for guiding the MEP firms that intend to implement BIM.

***Keywords**: Building Information Modelling (BIM); Construction Industry; Framework; Mechanical, Electrical and Plumbing (MEP).*

1. INTRODUCTION

The challenge in coordination of Mechanical, Electrical and Plumbing (MEP) systems is a common problem peculiar to the MEP industry. Although the traditional 2D CAD has been used in the industry to partially resolve the coordination problem, this has not been very effective. The process is done by manual superimposition, which is usually slow, time consuming and often results in project delay and increased project cost (Korman *et al.*, 2008). The 2D coordination process is highly fragmented and takes place on an as-needed basis (Korman *et al*., 2008). To overcome this situation, Building Information Modelling (BIM) facilitates easy coordination and collaboration during the design and construction stage.

BIM constitutes a paradigm shift in the construction project delivery approach in recent times. The benefits in terms of good return on investment (Smart Market, 2014), improved construction productivity and efficiency (Glick and Guggemos, 2009), increased coordination and collaboration (Autodesk, 2011) and reduced costly rework on projects (Smart Market, 2014) have been well established in the literature.

In view of the aforementioned, this paper intends to develop a conceptual framework for BIM implementation for the MEP building design and construction professionals in order to facilitate a seamless BIM transition and to solve the MEP coordination problem of the 2D project delivery approach.

2. LITERATURE REVIEW

MEP is an acronym that has been used historically to describe the mechanical, electrical, and plumbing systems in building and industrial projects. With an increase in the functionality and complexity of the systems, projects now include much more than just the traditional mechanical, electrical, and plumbing systems. The scope of

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the MEP activity has been extended to include additional systems, such as fire protection, controls, process piping, and telephone/data. Although these additional systems seem to fall under the historical categories of mechanical, electrical, and plumbing, they are most often installed by individual specialty contractors (Tatum and Korman, 1999).

The most common specification found in the design-bid-build contracts states that it is the MEP contractor's responsibility to coordinate the multiple building systems between the trades. Therefore, once the shop drawings have been produced, the coordination process begins. During this process, all the MEP contractors meet to determine the exact location of each system. This process becomes very intense as each system location is compared with each other system to determine where interferences and conflicts occur (Tatum and Korman, 1999).

2.1. LIMITATIONS OF THE TRADITIONAL 2D COORDINATION PROCESS

i. The Coordination is Slow and Expensive

Many problems exist with the current practice in the construction process. The construction teams need to meet a lot for coordination meetings. The coordination process is slow and expensive. The coordination of the MEP systems often delays the project and increases the cost for all those involved in the process. Coordination is often not budgeted for in the construction cost and remains a hidden cost in the design category. The sequential and iterative process is very slow because only slight progress is made at each meeting, and these coordination meetings consume valuable human resources (Korman *et al.,* 2008).

ii. The Coordination Process is highly fragmented.

Design and coordination take place on an as-needed basis and are often not performed sequentially. The desired scenario is for design changes to initiate coordination changes quickly and vice versa. Another complication is the lack of knowledge and understanding of the multiple disciplines involved, which often gives rise to systems that need redesigning to meet the coordination criteria (Korman *et al.,* 2008).

2.2. POTENTIAL OF BIM FOR IMPROVING MEP SYSTEM COORDINATION

There are many challenges to improving the current work process for coordination of the MEP systems. When performed manually, the coordination of the MEP systems requires considerable time from scarce experts, who have specialised knowledge about the design, construction, operation, and maintenance of the equipment systems. Building Information Modelling software is a new tool that provides the potential to improve the current work process for coordination of MEP systems (Korman *et al.,* 2008). BIM facilitates a new way of working: creating designs with intelligent objects. Regardless of how many times the design changes or who changes it, the data remain consistent, coordinated, and more accurate across all stakeholders. Cross-functional project teams in the building and infrastructure industries use these model-based designs as the basis for new, more efficient collaborative workflows that give all stakeholders a clearer vision of the project and increase their ability to make more informed decisions faster. Models created using software for BIM are intelligent because of the relationships and information that are automatically built into the model. The components of the model know how to act and interact with one another (Autodesk, 2011).

BIM tools have provided the feature to identify the clashes or collisions when integrating MEP systems with the architecture model and the structure model into one single platform (Wang *et al*., 2016). The visualization capabilities enable the specialty trades, designers and coordinators to review and detect these conflicts faster, better and more accurately (Wang *et al.,* 2016).

BIM models allow an inclusive and collaborative relationship to take place between all the interested parties, such as architects, engineers, consultants and contractors (Xia *et al*., 2011). Planners can select optimum sites. Architects can produce more accurate designs with fewer errors, less waste, and closer alignment to the owner's vision. Engineers can increase coordination with the architects and other engineering disciplines, thereby improving the reliability of their design (Autodesk, 2011). The contractor can input their data and information into a collaborative process that becomes a part of an integrated construction model (Xia *et al.,* 2011). Contractors can make sure that constructability issues are flagged early on when changes are less expensive to make. Ultimately, owners will be able to use the models far into the future as the basis of a comprehensive facilities and asset management program (Autodesk, 2011).

BIM implementation requires proper planning, patience and full commitment from all levels of the organization. Successful BIM implementation within a company starts with the shared vision of change and buy-in from all members of the organisation. Senior leadership needs to support the change and be willing to sacrifice a little in the beginning to reap the future rewards (Infocomm, 2013). The key to success in any BIM project is the collaborative effort among all the team members, which includes, but is not limited to, the project owner, the design team, general contractor, subcontractors and vendors/suppliers. Information data must flow freely among all the BIM project team members to obtain maximum advantage in a BIM project. The project owner plays a central role in leading the discussion and decision-making process when it comes to applying BIM to his/her project (Infocomm, 2013).

3. RESEARCH METHODOLOGY

A conceptual framework was developed for the study through an extensive review of related literature concerning BIM from previous studies. The unique framework developed was adapted to suit the MEP Design-Bid-Build project delivery requirements. The main literature that was reviewed included referred academic journals, conference proceedings, BIM textbooks, trade publications and authorised courseware on BIM Revit MEP.

4. RESULTS AND DISCUSSION

The scope of this framework is a multidisciplinary model based collaboration framework that will allow MEP firms to collaborate to produce the coordinated construction model during the MEP coordination process. The framework is tailored towards the Design-Bid-Build project delivery method. The MEP Design and Build firms can also use this framework for their BIM based workflow, albeit there will be some changes in terms of design roles and responsibility.

This framework consists of six phases following the project life cycle approach. The overview of each phase is explained in the subsequent subsections and the overall framework is depicted in Figure 1. The full details of the framework are shown in Table 1.

4.1. AWARENESS PHASE

To successfully implement BIM in any organisation, awareness needs to be created. Awareness is required to gain the buy-in of all BIM stakeholders into the BIM strategic goals. The awareness phase starts with the identification of all BIM stakeholders, organising BIM awareness corporate training, developing a BIM business case and creating a BIM project charter that will authorise the start of a BIM project in an organisation. The details are shown in Table 1.

4.2. PLANNING PHASE

During the planning phase, an organisation will define how is going to successfully introduce and integrate BIM technology into its current system, and how to execute and control BIM activities at various developmental stages of the project life cycle. At the planning phase, two documents are developed*: the BIM Preliminary Assessment Plan and the BIM Execution Plan*. *The BIM Preliminary Assessment Plan* is used for internal decision-making purposes within the organisation that wants to make the transition to BIM. The plan contains a detailed assessment of the current process, technology and staff roles and responsibilities, identifying BIM requirements in terms of current and future needs, identifying the gaps between the current technology and skills inventory and the required BIM requirements, and making a concrete plan concerning how to fill the gaps. *The BIM Execution Plan* is used during the design and MEP coordination stages. It gives details of how BIM activities in those stages are planned, executed and controlled. It also forms part of the bidding award documentation issued to potential MEP contractors that will participate in BIM projects. The details of the Preliminary Assessment Plan and BIM Execution Plan are shown in Table 1.

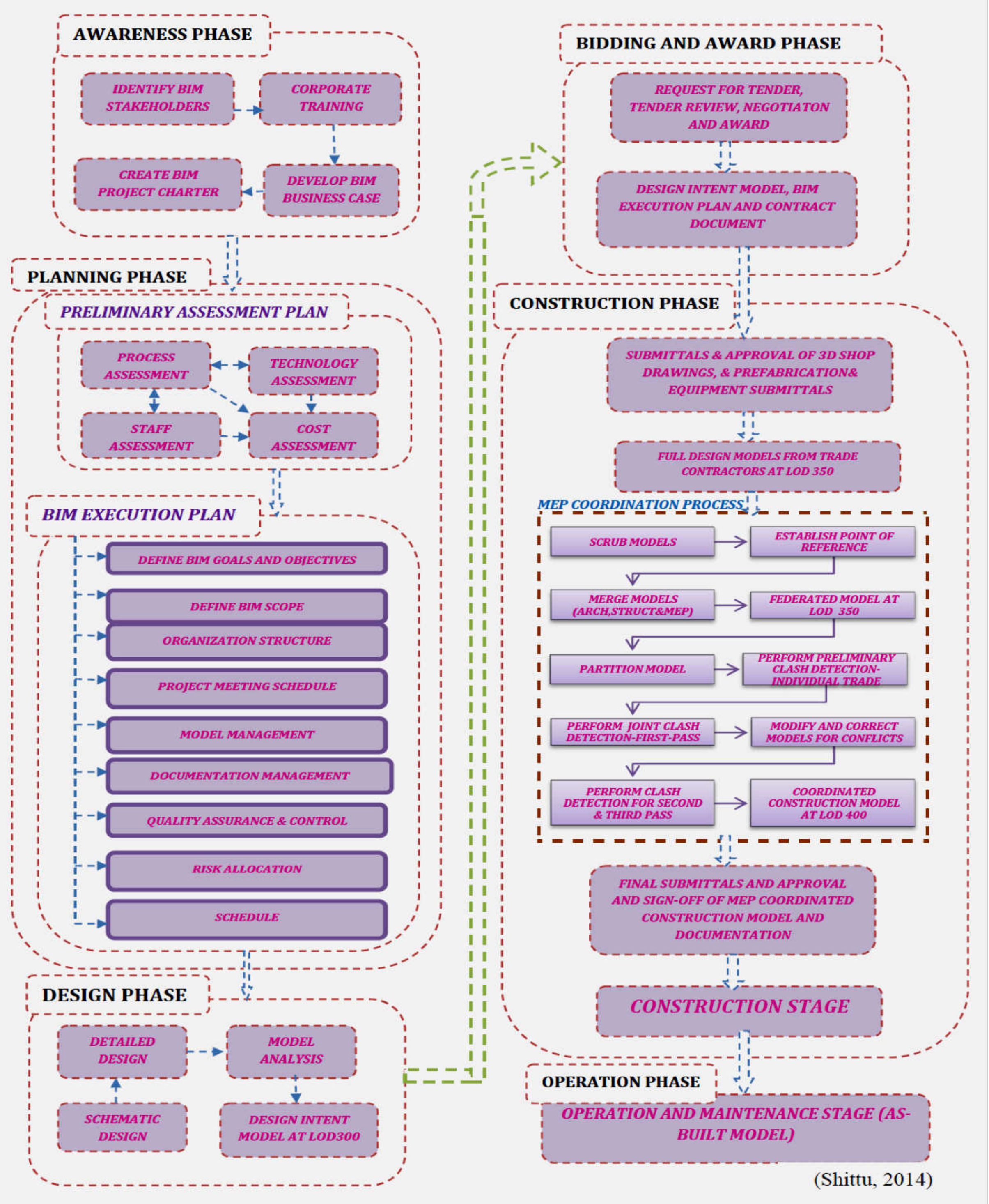

Figure 1: Conceptual Framework for BIM Implementation for MEP Systems in Building

Table 1: Details of Conceptual Framework for BIM Implementation

BIM PHASES	DETAILS	REFERENCE
1. AWARENESS PHASE **A. Identify BIM Stakeholders**	– Identify the potential BIM stakeholders that will support and drive the implementation of BIM in your organisation and from your clients; individual, private or public sectors	
B. Corporate Training	– The purpose is to create shared vision of change and buy-in from all members of the organisation. – Establish an affiliation with BIM experts, vendors or consultants – Organise BIM awareness corporate training to the top management, project sponsor and managers in your organisation. – Organise BIM awareness corporate training to the middle management and lower management in your organisation.	Infocomm, 2013
C. Develop BIM Business Case	– The business case captures the business need; it explains why the project was selected, how it fits into the organisation's strategic goals, and how it will bring business value to the organisation. – The purpose is to present the business value and cost benefit analysis to implement BIM, to your clients or project owners.	Mulcahy, 2013
D. Create BIM Project Charter	– Every project should have a project charter, so – BIM projects should not be an exception. – BIM charter will authorise the start of BIM project and gives authority to the Project Manager – It documents business needs, BIM objectives and initial requirements.	PMI, 2013
2. PLANNING PHASE **A. Preliminary Assessment Plan**	– This aspect of BIM planning gives a detailed review, analysis and assessment of the current process, technology and personnel. – It will identify the gap between what is existing and what is required to meet the current and future BIM requirements – Preliminary assessment plan will be used for internal purpose within an organisation for decision making on BIM requirements and implementation.	Quigley, 2013
I. Process Assessment	– Conduct detailed analysis of existing internal and external business processes. – Assessment of existing workflow in term of documentation process, data exchange and project information communication. – Determine the BIM based workflow requirements.	Infocomm, 2013
II. Technology Assessment	– This involves taking inventory of existing hardware, software and network facilities used by your organisation. – Determine the BIM software, hardware and network requirements. – Evaluate and select software, hardware and network server.	Quigley, 2013

BIM PHASES	DETAILS	REFERENCE
III. Staff Assessment	– This is a detailed personnel assessment of roles and responsibilities. – It answers the questions such as : – What are the current roles of your project teams? – Who will need to be trained with the new software? – What level of training will each type of employee require? – How will the new requirements of a BIM-based project modify the current make-up of your teams? – Create schedule of BIM roles and responsibilities for BIM projects. – Develop a schedule of BIM software product training for each staff that will participate in BIM project, based on their roles to play.	Infocomm, 2013
IV. Cost Assessment	– Prepare cost estimate for : • BIM hardware upgrade • BIM Software procurement • Network Server Upgrade • Product training for staffs	Infocomm, 2013
B. BIM Execution Plan	– The main purpose of BIM Execution Plan is to define and communicate the "rule of the road" to all participants in the coordination process.	Quigley, 2013
I. Define Goals and Objectives	– The BIM execution plan should define goals and objectives as they relate to the project. The BIM goals can be : – To improve communication between all stakeholders – To reduce the schedule of design and construction. – To improve design and field efficiency – To increase productivity	Quigley, 2013
II. Define Scope	– BIM execution plan will define scope of activities of BIM processes through different stages of project development. – Define the stage level of BIM to be implemented.(e.g. BIM stage 1 or 2 or 3) – Describe the deliverables to be produced at each phase of project lifecycle. – Define the Level of Development (LOD) for each domain-specific deliverables. – Describe the list of receivables that the design team will provide the coordination team.	Quigley, 2013 Quigley, 2013
III. Organisation Structure	– Identify the project participants for coordination process. – Define the required skills and responsibilities of each person. – Define the expected degree of involvement of each project participant including anticipated starting and disengagement point during the process. – Some of the Key BIM roles include: (a) **Project Coordination Manager**. His responsibilities include: • Managing the Coordination Team to ensure full participation and adherence to the BIM Execution Plan • Creating the coordination schedules. • Obtaining and distributing all contract drawings and documents, design change drawings and document and all CAD and Model files that the coordination team needs to create the initial models.	Quigley, 2013 Quigley, 2013

BIM PHASES	DETAILS	REFERENCE
	• Acting as liaison between the Coordination Team and Architects, Engineers and Owner. **(b) Model Manager -**His responsibilities include: • Setting up and maintaining a secure online files sharing site. • Assembling the initial master model • Setting up the initial file structure of the Model folders and establishing convention for naming project files. • Establishing elevations and the point of origin (insertion point) for all models. • Maintaining the model throughout the project. • Performing interference/clash - detection checks. • Generating clash detection reports. • Communicating information to the coordination team **(c) BIM Manager -** His responsibilities shall include: • Managing the BIM processes • Supervising coordinators and detailers • Working internally with estimators, project management, and field personnel and externally with Architects, Engineers, General Contractor, Construction Managers, Trade contractors and Owners. • Establishing schedules and budgets. • Monitoring the processes to measure compliance with quality requirements and any other metrics established and defined by the organisation. • Filtering clashes and evaluating clash reports prior to coordination meeting. **(d) Detailers** - His responsibilities shall include: - Detailing sections of the model. • Incorporating design-intent models, contract documents and specifications, and the project team's request and expectation into a virtual detailing model that represents the intended MEP installation for the building. • Understanding and interpreting architectural and structural details as they affect the MEP installations. • Identifying interferences with the architectural, structural and other MEP elements. • Generating contract and internal company deliverables from the models.	Quigley, 2013 Quigley, 2013
IV. Project Meeting Schedule	– BIM execution plan should provide basic information about project meetings • Which meetings are required? e.g. Kick-off, spatial planning meeting, coordination meeting and sign-off meeting. • When and where these meetings will be held? • Who is expected to attend and how often will be held?	Quigley, 2013

BIM PHASES	DETAILS	REFERENCE
V. File format & compatibility (interoperability)	- List the electronic file formats (proprietary or open standard) that will be supported. - Identify the native files of project participants and do testing to confirm that the data files are compatible. - Adopt open-standard format for file sharing such IFC file format of Building SMART Alliance. - If a proprietary file format is specified in the contract, it should be clarified at the bidding phase.	Quigley, 2013
VI. Documentation Management (Configuration Management)	Documentation management in the BIM Execution plan should address the following: - Managing changes to the documentation about the deliverables and processes of the project. - Making sure every project team knows the latest version of project documentation. - Archiving documentation from BIM process • Complete version of the BIM data and associated deliverables should be copied into an archive location and stored as a record that should not be altered. - Setting up data security protocol • A data security protocol should be established to prevent any possible data corruption, virus infections and data misuse or deliberate damage by the project member, other employee or outside sources. • Adequate access right should be estimated to prevent data loss or damage during file exchange, maintenance and archiving. • BIM project data residing on the network server should be subjected to regular back-ups.	Mulcahy, 2013 Mulcahy, 2013 BCA, 2013 BCA, 2013
VII. Quality Assurance and Quality Control	- Quality Assurance and Quality Control is an integral part of BIM Execution Plan. The following activities should be considered in ensuring quality assurance and control in a BIM project : • Ensure that the model is created based on the modelling guidelines and CAD standards. • Ensure that the dataset are populated with correct data. • Detect any clashes between two building components using Clash Detection software. • Validation of BIM data to be used for Cross-Disciplinary Model Coordination:	BCA, 2013 BCA, 2013 BCA, 2013 BCA, 2013 BCA, 2013

BIM PHASES	DETAILS	REFERENCE
	– All drawing sheets and extraneous views should be removed from the BIM; – Each model file should be checked, purged and compressed; – Model files are up-to-date, containing all users' local modifications; – Model files are detached from central file; – Any linked reference files have been removed and any other associated data required to load the model file is made available; – Model is correctly assembled through visual inspection; – Any changes since the last issue are communicated to the project team.	BCA, 2013 BCA, 2013 BCA, 2013
VIII. Risk Allocation	– The BIM execution plan should clarify how risk will be allocated. The very nature of BIM introduces additional risks that must be allocated among the project participants. The liability of shared decision should also be clarified. – BIM Addendum specified that each party is responsible for any contribution made by them. – It also specified that each party agreed to waive claims against the other parties, over the Governing Contract for consequential damages arising out of, or relating to the use of access to a BIM Model.	Porwal and Hewage, 2013 Richard and Jason, 2010 Richard and Jason, 2010
IX. Schedule	– The BIM Execution plan should have a realistic schedule for the BIM Coordination process. – A detailed timeline is required to ensure that the overall strategy is being implemented in a timely and organised manner. – Coordination time should be factored into the project schedule. – Coordination should start after approval of submittals.	Infocomm, 2013 Quigley, 2013

4.3. DESIGN PHASE

During the design phase, BIM processes constitute a single disciplinary collaboration platform. The MEP design team jointly produces the design intent model that represents all the MEP Systems. The model is at the level of development (LOD) 300 (Quigley, 2013). The design intent model is detailed enough to prepare a tender or bid document. Table 2 shows the details of the BIM activities during the design phase.

4.4. BIDDING AND AWARD PHASE

During the Bidding and Award Phase, the tender or request for proposal documents produced during the design phase are used to prequalify MEP contractors through a competitive bidding process. After the bidding and negotiation process is completed, the selected MEP Contractors are issued the Contract documents, Design Intent Model and BIM Execution Plan.

4.5. *CONSTRUCTION PHASE*

During the construction phase, the major BIM activities comprise the MEP coordination process. The coordination starts very early during the construction phase immediately after the award of contract, and is completed before the actual construction starts. The selected MEP contractors use the design intent model issued with the contract award document to produce 3D Model fabrication shop drawings giving more details on the design intent model. It usually includes installation and prefabrication details at a level of development (LOD) 350. After completion of the shop drawings, they are sent for consultant approval along with other equipment submittals. The approved 3D Model shop drawings, which are now the full design model, are used during the coordination process.

Table 2: Details of Conceptual Framework for BIM Implementation

BIM PHASES CONT.	DETAILS	REFERENCE
3. DESIGN PHASE **I. Schematic Design**	– The details of design phase deliverables should be highlighted in the BIM Execution Plan. The deliverable shall include Design Intent Model and Bidding and Award documents. – Provide Schematic Modelling, analysing and system iterations as Design Model continues to develop	BCA, 2013
II. Detailed Design	– Create Discipline Specific Models and Analysis – Perform Preliminary Clash Detection – Finalise Discipline Specific Design Models, Tender documents and specification and code compliance.	BCA, 2013
4. BIDDING AND AWARD PHASE	– Send Request for Proposal or Tender to potential MEP Contractors – Perform Bidders' Conference for clarification on the tender documents. – Collect Contract responses and perform tender review. – Perform negotiation and select MEP contractors using the selection Criteria – Award contract and issue contract documents, design intent model at Level of details (LOD) 300 and BIM execution plan to successful Contractors	Mulcahy, 2013
5. CONSTRUCTION PHASE **I. 3 D Model Shop Drawing**	– Produce Full Design Model at LOD 350 through the 3D Model fabrication shop drawing.	

4.5.1 MEP COORDINATION PROCESS

For the development of this framework, we apply the definition given by the National Institute of Building Science (NIBS, 2013) for the spatial coordination process, and the guides from Quigley (2013) and Bokmiller, Whitbread and Hristov (2013) for the MEP coordination workflow. According to NIBS (2013), spatial coordination performed under contract is a collaborative process executed between the primary installation contractors and overseen by the general contractor or construction manager. This practice of spatial coordination seeks to integrate objects, systems, and components into spaces allocated in the contract documents. Quigley (2013) gave a summary definition of MEP spatial coordination, as a cooperative and collaborative effort between the design professionals, owner, general contractor or construction manager, and the trade contractors. Normal and expected spatial coordination performed by the trade contractors after the execution of contract is not design. Rather, it is a reflection of the design in a three-dimensional model. Trade contractors rely on complete and accurate designs when bidding for projects in order to provide an accurate bid price. In return, trade contractors using that design are able to produce reliable models from which the project can be constructed in a more efficient, timely and cost effective manner. The deliverable of the MEP coordination process will be a coordinated constructed model at LOD 400. This model will be used during the construction stage. The details of the MEP coordination process are shown in Table 3.

4.6. OPERATION PHASE

The operation phase starts after the completion of the construction, commissioning and handing over of the MEP system deliverables. The coordinated model used for construction is updated with any construction changes and used to produce the As-built model that is used during the operation and maintenance period of the project.

Table 3: Details of Conceptual Framework for BIM Implementation

BIM PHASES CONT.	DETAILS	REFERENCE
II. MEP Coordination Process Scrub Model	– Perform maintenance check on the design model by purging any unused items from the file to keep the file size minimum for easy sharing	Bokmiller *et al*., 2012
Establish Point of Reference	– Establish common point of reference before starting to link models – ON Revit MEP platform, it is recommended to use Auto-Origin to Origin of Positioning drop down menu of Import/LinkRVT dialog box to establish point of reference unless a shared coordinate system is required.	Bokmiller *et al*., 2012
Merge Models (MEP, Architectural & Structural)	– Merge Models to produce federated construction model at LOD 350.	Quigley, 2013
Perform Preliminary Clash	– Class detection can begin when all requirement of the BIM Execution Plan have been developed, reviewed and acknowledged by the coordination team, and a schedule for the program is developed and agreed.	Quigley, 2013
Detection - Individual Trade	– Individual trade should start with identifying and resolving clashes within their control	Quigley, 2013
Perform Joint Class detection –First Pass	– Best practices stipulate that the clash detection process for commercial facilities begins by resolving gross conflicts and work its ways to minor conflicts. – Non-movable systems, large-volume components (such as duct mains), and gravity system take precedence in space claiming and clash resolution. – Modify and correct Model for conflicts.	Quigley, 2013 Quigley, 2013
Perform Joint Clash detection - second and third pass	– The second pass identifies remaining conflicts, new conflicts created by addition of new support or seismic components into the model or non-resolved conflict from the initial pass – The third pass will identify and resolve the remaining conflicts.	Quigley, 2013
Coordinated Construction model at LOD 400	– The deliverable of MEP coordination process will be Coordinated Construction Model at LOD 400	Quigley, 2013
III. Construction Stage	– Coordinated Construction Model produced during the coordination process will be used during the construction stage.	
6. OPERATION PHASE	– The Coordinated Construction Model used for construction will be updated with any construction changes and used to produce As-Built Model that will be used during the operation and maintenance period of the project	

5. CONCLUSIONS

This research developed a conceptual BIM framework that will serve as a useful methodology for seamless transition from the traditional 2D CAD workflow to one that is BIM based and provides a solution to the problem of traditional 2D MEP Coordination. The framework developed emphasised the need for BIM awareness corporate and product training. Through the corporate training, more awareness about the potential of BIM will be created for all BIM stakeholders. Furthermore, it will allow the organisation to gain buy-in and support of their BIM stakeholders. Through the product training, BIM competency will be developed for the BIM project team.

The framework recommended developing a BIM preliminary assessment plan and BIM execution plan to overcome the challenges in the planning and executing BIM processes. Both plans will help the organisation to understand all the requirements needed to transition to BIM based workflow, monitor, and control BIM processes during the design and construction phase of project life cycle. This BIM framework will be of great benefit to the MEP firms where BIM implementation is still in the infant stage or even where there has been no transition to BIM. The framework can also serve as a checklist tool for those that had already transitioned to BIM based technology. It will help them for continuous improvement in their BIM processes and/or workflow.

To this end, it is noteworthy that this BIM framework developed is conceptual in nature. To ensure the practicability of the framework, it is therefore recommended that future research should be carried out to validate the framework to become a standard BIM framework in future for the MEP industry.

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