BRIDGING THE PERFORMANCE GAP: INFORMATION DELIVERY MANUAL FRAMEWORK TO IMPROVE LIFE-CYCLE INFORMATION AVAILABILITY

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ABSTRACT

Buildings account up to one-third of all global energy, and it will more than double in the next 50 years. In order to accurately predict the energy performance of buildings and improve the analysis methodologies, researchers have developed hundreds of algorithms to simplify or semi-automate the analysis process.

However, there is significant evidence to suggest that buildings do not perform as well in practice as was anticipated at the design stage. Findings from a number of existing studies revealed that actual energy consumption is often twice as much as predicted. The major contributors to the performance gap are lack of available information that exists at different stages of the formal building life cycle and delivery process.

This paper proposes a framework to develop an integrated and seamless Information Delivery Manual (IDM) by extending the existing IDM approaches to identify and document the information required for building performance analysis.

INTRODUCTION

Buildings have extensive direct and indirect impacts on the environment throughout their life cycle and building sector is one major contributors to climate change (IPCC 2014). On the other hand, buildings also face multiple climate change impacts. Many buildings are vulnerable to progressive changes in climate and to extreme events and have already experienced big increases in damage over recent decades (Chalmers 2014). Therefore it is clear that decision-makers must tackle emissions from the building sector to meet the targets for GHG emissions reduction (UNEP 2009).

In order to support building policy setting and decision-making, a range of Building Performance Analysis (BPA) methodologies have been used for more than 50 years (Crawley 2008). BPA is the use of computer-based simulations to assess overall building energy performance and other characteristics of a building design. It allows for the analysis of various design considerations, in this way, energy modelling can help optimise alternatives and allow the design team to prioritise investment in the strategies that will have the greatest effect on the building's performance (Ryan & Sanquist 2012; CGEO 2011).

Although significant developments have been made over the last few decades in BPA technologies, there are some limitations associated with the use of them. Research has shown that using BPA tools takes a considerable amount of time to input data correctly even for qualified practitioners (Catalina et al. 2008) and can rely on potentially arbitrary model definitions (Bazjanac 2008). Moreover, it is still unclear whether BPA technologies can accurately predict buildings' energy performance and provide reliable output within an acceptable error margin (Mehta 2013; Torcellini et al. 2004). There is significant evidence to suggest that buildings do not perform as well as was anticipated at the design stage (Zero Carbon Hub 2014; The Carbon Trust 2012). According to the PROBE (Post-occupancy Review Of Buildings and their Engineering) research project, actual energy consumption in buildings will usually be twice as much as predicted (Bordass et al. 2001). More recent findings from the Carbon Trust (2012) have demonstrated that the operational energy use was up to five times higher than estimates during design.

Often the performance gap is caused by unclear allocation of responsibility; poor communication of information; and a lack of understanding, knowledge and skills (Wilde 2014). Suggestions on how to best bridge this gap presented in literature are generally aligned with the root causes across all life-cycle stages.

Regarding design, efforts to bridge the gap mainly take the form of development of design guidance and reports that aim to raise awareness (The Carbon Trust 2012). Specific efforts to address the performance in terms of its prediction methods and tools are part of the continuous work to improve the quality of these tools and methods in general (Wilde 2014). Within the construction process, efforts attempt to increase the quality of the delivery process which requires a change of culture across the whole supply chain and hence is, till now, difficult to achieve (Zero Carbon Hub 2010). During the operational stage, there is an awareness that current monitoring approaches need further improvement by considering system-level metering and Post-Occupancy Evaluation (POE) in order to gain more in-depth information (Menezes et al. 2012).

In parallel with ongoing efforts, the Building Information Modelling (BIM) has a potential role in the efforts to bridge the performance gap. BIM technology involves the creation and use of coordinated, consistent information about a building, and allows for better decision-making, documentation and accurate prediction of building performance. The fundamental concepts that make up BIM are founded in the consideration of design as the management of information that exists at different stages of the formal building life-cycle and delivery process (Karimi & Akinci 2009). BIM can also accelerate establishing a Common Data Environment (CDE) which is the single source of information for the project, used to collect, manage and disseminate documentation, the graphical model and non-graphical data for the whole project team (BSI 2013).

The current emphasis on high-performance buildings makes it important to leverage BIM-based BPA during design (Welle et al. 2011). However, there are a number of barriers to achieving seamless interaction between BPA and BIM. A challenge currently facing design teams is how to merge previous design strategies employed during early design and those made possible by BIM. The project team employing BIM-based technologies must acknowledge and account for the types of information that design teams will typically require and have available during different design stages in current practice. They should also account for the Level of Detail (LoD) and available format of that information to support early design BPA. In a sense, they are tasked with redefining what a design team could and should do during early design to generate the quality of information needed to make informed, intelligent decisions about how to meet their project performance goals (USGSA 2009).

Therefore, it is recommended that each project team create a shared manual document in the early design stage that clearly outlines the scope of the energy modelling activities to meet the project's goals as well as summarises all the relevant energy modelling inputs, assumptions, and results. This document referred to as Information Delivery Manual (IDM) should ideally contain a listing of all project team members involved, including specification of which team members will perform energy modelling, who will be responsible for providing required inputs to the energy simulations, and when the information transfers need to occur. Reference to specific LoD can assist this process (Volk et al. 2014).

To address the challenge, the authors previously investigated the interoperability between BIM and BPA tools that currently available, and discussed the limitations of information exchange (Hyun et al. 2015). In order to improve the information exchange that can avoid data loss, this paper proposes a framework to support integrated and seamless IDM development for BPA.

BACKGROUND RESEARCH

Limited life-cycle building information available

The major cause limiting the availability of life-cycle building information is interoperability that refers to the ability to make different systems talk to one another. At a technical level, interoperability might refer to the process of streamlining information exchange between two or more model authoring platforms. At an organisational level, it can refer to the ability for different stakeholders to work together based on a feedback process towards a common goal (Figure 1).

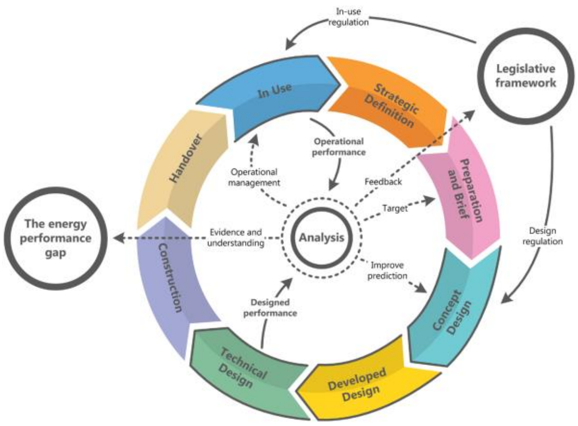

Figure 1 Feedback process in relation to the RIBA plan of work (Source: van Dronkelaar et al. 2016)

Poor interoperability in the sequential nature of building design and construction activities results in rework, restarts and risk of data loss. Adequate interoperability can therefore help rectify the problem illustrated in Figure 2, which is sometimes known as the BIM curve (Nawi et al. 2014).

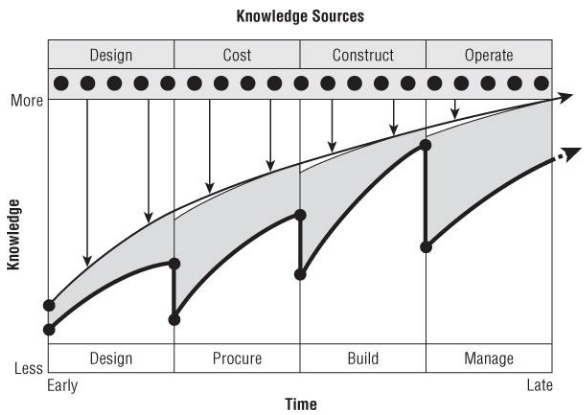

Figure 2 The BIM curve shows loss of data without interoperability at project milestones (Source: Bernstein, [adapted from Read et al. 2012])

Improving reusability of the information has always been the prime concern for all information modelling systems. However, data loss is found during the information exchange process as different software solutions have a unique approach towards data processing and management. BIM, on the other hands, aims to collect all the information on a single platform that can be used, reused, and improved along the lifecycle of the project.

A common language for information exchange

To transfer BIM information between different BIM applications while maintaining the meaning of different pieces of information in the transfer, Industry Foundation Class (IFC) and Green Building Extensible Markup Language (gbXML) are created as a common language. Both IFC and gbXML are currently two prevalent informational infrastructures in the AEC industry (Dong et al. 2007).

IFC model specification is the most comprehensive data model with an object oriented data-schema that provides support for collecting data from a project model in a neutral computer language and representing shared information in a wide range of Architecture, Engineering, Construction and Facilities Management (AEC/FM) industry processes (Froese et al. 1999). Ideally, they can capture information from all type of organisation involved in the project and all stages in the project life cycle including initial requirements, design, construction, maintenance and operation (Venugopal et al. 2012). The latest IFC release is IFC4 which has been released in 2013. It incorporates several extensions of IFC in building, building service and structural areas, enhancements of geometry and other resource components.

However, for a reliable data exchange, these definitions need to be implemented in software applications and thoroughly tested as the IFC schema does not define the information exchange requirements specific to different project stages and between different project actors and software applications which makes it difficult to develop useful IFC software interfaces (Kiviniemi 2007). Based on varying exchange requirements, different research and development groups propose model views definitions (MVD), as a solution for specifying exchange requirements (Venugopal et al. 2012). However, the current MVD methods, which are based on use cases leaves scope for different interpretations based on end-user requirements and lacks a formal framework. Moreover, the granularity and atomicity with which such model views are defined is not consistent across the AEC/FM industry (Venugopal et al. 2012). This adds to the overhead for software developers and hinders IFC based implementations (Eastman et al. 2011). Therefore, there needs to be a way to consistently specify IFC implementations based on exchange requirements. In order for that to happen, additional levels of specificity are required to define model exchange requirements and model views in a formal, consistent, modular and reusable manner.

Information Delivery Manual

In addition to MVD, development of the IDM has been a significant initiative to solve this problem by identifying the subset of IFC data model needed to support the user defined business processes (Wix et al. 2009). IDM was first proposed by Jeffrey Wix in 2005. In 2010, the method and forms for specifying IDM documents became an international standard, ISO 29481-1.

An IDM is composed of a project map (PM), exchange requirement (ERs), and functional parts (FPs). The IDM standard defines these elements and their relationships to one another as follows:

- Process map: Displays the flow of activities within a defined process.
- Exchange requirements: Define the information that needs to be exchanged.
- Functional part: Define the information that supports the exchange requirements.

The IDM framework defines the functionality-related exchange of process information in BIM through process maps, interaction maps and the associated exchange requirement model (ERM). Process maps describe the flow of activities within a particular topic, the actors' roles and information required, created and consumed, while interaction maps define roles and transactions for a specific purpose or functionality (BSI 2010). According to the buildingSMART, a number of IDM projects were started simultaneously as the methodology was developed. Several of the IDM projects have led to specifications that have been tested in real construction projects (Karlshøj 2011).

In order to increase the coverage of information requirements, Katranuschkov et al. (2010) suggested extending the IDM-MVD methodology to improve the functionalities of IDM and Liu et al. (2013) extended the IDM approach to identify and document the information requirements for performance analysis of heating, ventilation and air-conditioning (HVAC) systems. In order to improve the IDM development methodology itself, Lee et al. (2013) proposed a new extended Process to Product Modelling (xPPM) method for integrated and seamless IDM and MVD development.

Despite active efforts at IDM development and high industry demand, the current processes for IDM development are challenging. As IDM enforces the analysis and description of multiple perspectives of a process, and its context, which is necessary for developing an information system, the development process is very complex and laborious (Lee et al. 2013). It is also a challenge to make IDMs in some areas, because there is a lack of structured and well-documented processes (Berard & Karlshoej 2012).

IDM for BPA

Although a total of over one hundred IDM documents were under development as of February 2016, there is only a few IDMs proposed for BPA (Karlshøj 2011).

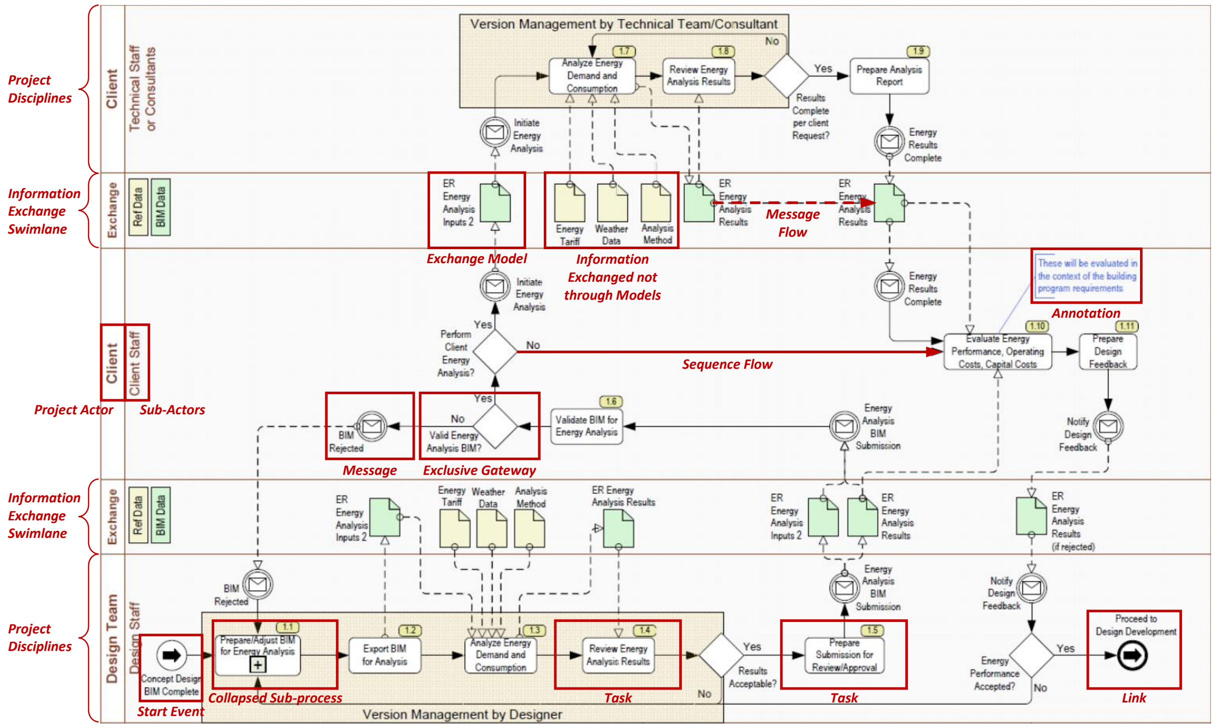

Figure 3 Concept design phase process map of DEPA (Source: USGSA 2009)

One of the IDMs for BPA is Design to Energy Performance Analysis (DEPA) proposed by U. S. General Services Administration (2009). DEPA IDM suggested a process of developing energy analysis throughout the design stage that is divided into two key parts – conceptual design phase and detailed design phase. The process map is developed to explain the various components and to achieve a common understanding among the project participants (Figure 3).

The more recent draft IDM for BPA developed by Liebich et al. (2013) is titled "Holistic Energy Efficiency Simulation and Lifecycle Management Of Public Use FacilitieS (HESMOS)". Liebich et al. (2013) pointed that some shortcomings of the current IDM methodology and explanatory materials were experienced while applying IDM to HESMOS, and there are no easily understandable and comprehensive manuals currently available.

Based on that limits of the current IDM methodology, HESMOS suggested not only an extended IDM and MVD development for BPA and a process map defining main interactions among the project participants, but also an extended ERM defining data exchange format (Figure 4).

Although there have been different efforts to develop IDM, a number of aspects need to be improved to use the IDM for actual projects.

Findings from the review of IDMs for BPA previously developed are as follows:

- Reference processes are divided in to only two or three main stages which does not allow focusing on detailed requirements at each design stage;
- No holistic and comprehensive requirements of information for BPA was defined for different purposes of BPA based on various type of benchmarking at different stage;
- None of IDMs developed for BPA so far defined an appropriate Level of Detail (LoD) for information exchange requirements at each stage;
- There are limited cases of IDM validation by applying it to actual projects.

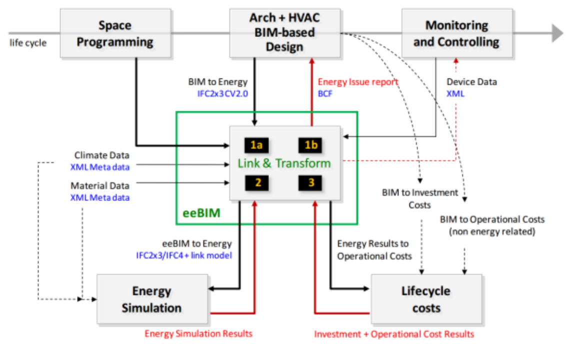

Figure 4 Common exchange requirements identified in HESMOS (Source: Liebich et al. 2013)

SUGGESTED IDM FRAMEWORK

In accordance with findings discussed, this paper suggests an extended framework of IDM-MVD for BPA by improving the existing IDM frameworks. The suggested framework will additionally have:

1) A reference process referring to actual project workflow;

2) Information requirements based on different purposes of BPA; and
3) LoD definition for information required at different design stages.

The targets of each step of the suggested IDM-MVD approach are as stated in Table 1 and the general process of IDM-MVD is illustrated in Figure 5.

Table 1 Suggested IDM approach

TARGET	DETAILS
Preliminary work	
Business target	Process optimisation to be established as a general business target, define process scope.
Reference process	Reference process to be selected prior to develop a process map
IDM	
Process map	Identify actors and roles, define main tasks of BPA and interactions between the participating parties based on reference map selected
Interoperability	Identify general information requirements for exchanges and locate the exchanges on the process map
Exchange requirements	Sort and specify the exchanges based on different purposes of BPA
LoD	Define level of detail for information required for each stage
MVD	
Standardisation	Target exchange format to be chosen based on suitability for each of the main exchange requirements identified in the previous step
Implementation	Define model views for the exchange requirements mapped to the data exchange format
Implementation	
Deployment and validation	Implementation and use of IDM-MVD, perform validation and verification

Reference process

A reference process is an identifiable basic unit of a process map that can be considered to have a universally consistent definition both in terms of its meaning and attributes (buildingSMART 2010). A reference process exists as a process type and may have many process occurrences within a building construction project. The purpose of capturing a reference process is to support the progressive definition of a reference process library from which future industry standard and locally specific process maps can be developed.

One of the representative design and construction process is the one developed by the Royal Institute of British Architects (RIBA). RIBA Plan of Work (PoW) is the definitive UK model for the building design and construction process first developed in 1963. RIBA seeks to make an important contribution to the recent transformation of the construction sector by developing a new RIBA PoW in 2013 (RIBA 2013). It incorporates sustainable design principles; provides the infrastructure to support BIM; promotes integrated working between project team members; and provides the flexibility to match procurement approaches to client needs.

The process map of the suggested framework for IDM will be developed based on the reference process referring to the content of stages stated in RIBA PoW 2013 which is also applicable when the project is based on locally specific or project specific process maps. The actual information that is within the process boundary is determined by the contents of the exchange requirements that support the activities within it.

Information requirements (IR)

To ensure projects are properly validated and controlled as they develop, data is extracted from the evolving building information model and submitted to the client at key milestones. This submission of data is described as a data drop. The IR define which information needs to be produced at each data drop together with the required level of detail and definition. Early on in a project, it can provide a helpful format for describing the key decision points that will be used to structure the project.

It is generally developed based around a series of simple plain language questions (PLQs) that the employer will wish to answer at specific stages to assess whether the project is developing as required, and whether it should proceed to the next stage. The information that the employer will need to procure from suppliers in order to answer those questions can then be identified. This can also help define roles and responsibilities, the need for appointments to be made, and the scope of services for those appointments and is a good basis for preparing the employer's information requirements which will become part of the contract documentation.

It is therefore essential that a standardised IR defined for different purposes of BPA or benchmarks is developed. This should not only consider the creation of information required for BPA at different stages, but it is also critical that the reuse of information be considered for the following stages. This includes minimising data loss and collating the measured data in In-use stage for feedback into design stages.

Defining LoD for information required

The term LoD refers to the level of detail of a building information model. It can be either described in terms of geometry or information requirements. PAS 1192-2 (2013) defined two components to the level of definition – levels of model detail which relates to the graphical content of models and levels of model information which relates to the non-graphical content of models. The LoD of a building information model increases as the project proceeds.

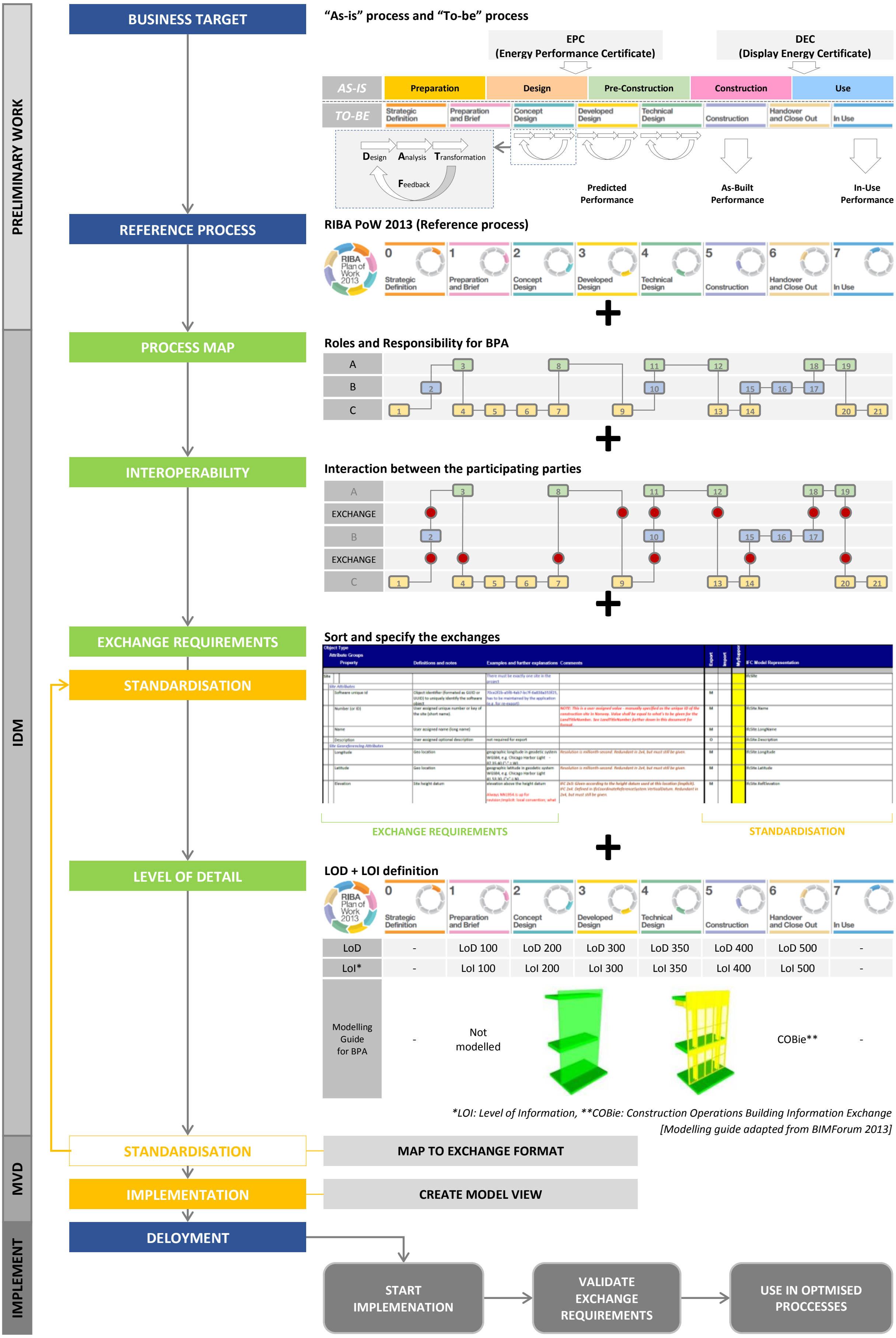

Figure 5 Initial framework of extended IDM-MVD development for BPA

Different aspects of the model may develop at different rates and originate from different members of the project team. Their development may pass from the employer, to consultants, to the contractor and suppliers and ultimately back to the employer.

It is therefore important that the project team defines the LoD that is required at each stage of development of the project. This not only ensures that the design is developing in sufficient detail, but also that only information that is actually required is developed. It also gives an indication of the reliability of information.

CONCLUSION AND FUTURE WORK

The first step towards bridging the performance gap is to improve the availability of life-cycle building information by allowing reliable data exchange between different stages and allow more accurate prediction of building energy performance.

Based on a review of existing IDMs for BPA, only a few IDMs have been developed so far. Furthermore, a review of results has highlighted the requirement for the improvement of the existing framework to enable it to be actively used for actual projects. In order to facilitate this, this paper proposed a framework of IDM-MVD development that can be applied at each design stage to guide information exchange required for BPA using BIM and can bring improvement in BIM implementation engaged from the early design stages.

The suggested framework of an extended IDM-MVD development for BPA therefore applies:

1) A reference process referring to RIBA PoW 2013;
2) Information requirements considering different purposes of BPA; and
3) LoD definition for information required at different design stages.

The suggested approach will have the potential to significantly contribute to the advancement of BIM implementation for BPA from early design stage. This will facilitate successful information exchange that supports the increased availability of information required to enable more realistic prediction of building energy performance.

To successfully implement the proposed IDM-MVD in actual practice, future work will seek to:

1) Develop a full list of information requirements with appropriate LoD based on IDM framework suggested that can be tailored to different purposes of BPA;
2) Promote engagement of manufacturers with product level information requirements;
3) Extend the proposed IDM to Construction and In-use stages in a proper format; and
4) Perform verification and validation testing of quality and quantity of information exchanged between collaborating parties.

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