Integrated Design Platform incorporating Multi-Disciplinary Early Information to Reduce Potential Delays in the Design Phase of Public Housing Projects

Ahmad Tashrif[1] and David Chua[2]

Abstract

This paper would discuss the conceptualization and prototype implementation of an integrated design platform that brings together key design information of different disciplines and provides analyzing tools to aid the early stage of the conceptual design process. Current practice does not provide the designer to check upfront the various design features on the concept model because those features are not available at the early phase. Yet, non-compliance of a regulatory requirement could actually lead to abortive work as the small, seemingly benign dimensional change needed to meet the requirement could potentially cascade down to many other parts of the model and affect the overall design. Reliance on past design models, common rule-of-thumb or buffered estimates and assumptions based on past similar experience are usual remedies, albeit with low confidence and would require multiple revisions. Hence the proposal for an integrated design platform that makes available the required design elements at the appropriate level of detail and appropriate data structure, which in turns, enables the required regulatory code checks. Automation has been applied to the most critical checks in terms of impacting the design model and tediousness when done manually. The initial focus on the prototype design platform has been on public housing projects due to the reduced complexity of designs and a high degree of standardization in terms of precast components usage as well as prototype designs, as compared to private projects. Thereby, a library of standardized and parameterized design objects, rich with in-built information allows the designer to specify elements in the model with minimal user input yet provides appropriate level of detailing, is implemented. Lastly, the completed and validated schematic model is exported to a Building Information Modelling (BIM) ready format for downstream work to take over. The key contribution of this effort is that it reduces the potential for delays due to rework in remedying preventable design errors and increased designer confidence in the design model meeting critical regulatory code compliance.

Keywords: automation, building information modelling, conceptual design, cross discipline, data structure, design objects library, design process, early information, integrated design, public housing, regulatory code compliance.

Purpose

The construction industry has been characterized for being too silo-ed. Coordination and information-sharing between disciplines are a day-to-day challenge. There is also the challenge of having to comply with a multitude of code, regulations and guidelines that

---

[1] Research Engineer, Dept. of Civil & Environmental Engineering, National University of Singapore, Block , E1A #07-03, No.1 Engineering Drive 2, Singapore, 117576, (65) 65164643, FAX (65) 67791635, Email:ceeats@nus.edu.sg

[2] Associate Professor, Dept. of Civil & Environmental Engineering, National University of Singapore, Block E1A #07-03, No.1 Engineering Drive 2, Singapore, 117576, (65) 65162295, FAX (65) 67791635, Email: ceedavid@nus.edu.sg

constrains the process of designing a building. The present software available out there may serve a particular discipline well but when the information requires to be shared, more often than not, the data exchange does not fully or correctly transmit to the receiving software thereby hampering further detailing or analysis. Gu and London (2010) noted the lack of support for integration of different project phases and suggested that improvements should be made in this area.

Howard and Björk (2008) discussed the gaps and suggested that property owners may hold the key in unlocking the benefits and demonstrating the success of BIM. The Housing Development Board (HDB) which develops public housing for over 80% of the Singapore population, holds considerable sway over the construction industry in effecting standards and new technologies. Hence with HDB onboard, the impact of this study promises to be highly relevant.

Introduced by Patrick MacLeamy in 2004, MacLeamy Curve (Figure 1) illustrates the shift of effort forward into the detailed design stage in a Building Information Modelling (BIM) based workflow (4). However, the downside is that the designers involved in the detailed design would see a jump in the effort needed. Their buy-in is key in this workflow and that the additional effort expended can lead to future payoff.

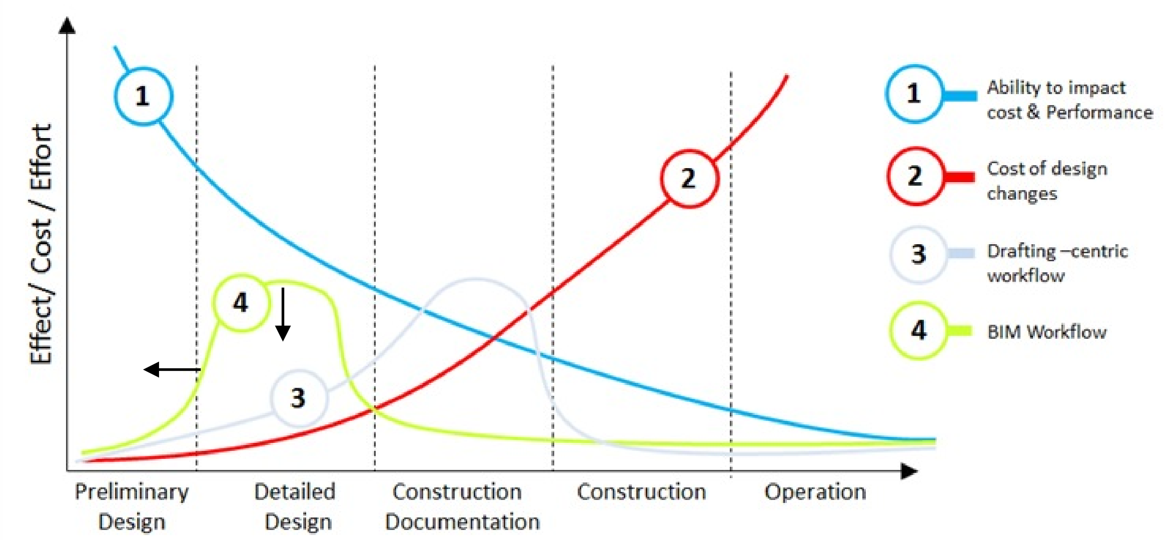


Figure 1 BIM workflow vs Traditional workflow (MacLeamy, 2004)

Hence, one way to tackle this challenge is to reduce the height of the “bulge” in the detailed design stage. In a public housing project, it is easier to justify standardization and parameterization due the pressure of cost-efficiency. Standardization may be harder to achieve when the nature of the project is not the standard public housing project but those that are deemed iconic or from the private sector.

The other way is to “smoothen the bulge” even further forward into the preliminary design. This is where the ability to impact the design performance is the greatest while the cost of design changes is the lowest. Therefore, the purpose of this work is to examine ways to reduce and bring forward the effort “bulge”.

The Integrated Project Realization (IPR) framework outlined by Chua and Yeoh (2015) which builds on the concept of Virtual Design and Construction (VDC) (Kam & Fischer, 2004) has provided the overall strategy in guiding the implementation. The 3 pillars are Information Management, Process Re-engineering and Intelligence & Automation.

Methodology

The empirical approach taken in this study provided an opportunity to listen and qualitatively analyze the experience of the industry practitioners and domain experts within HDB. This provided detailed information as to what are the possible and more importantly, critical improvements to be made. Based on the feedback gathered by the domain experts across disciplines, the regulatory codes and design guidelines were given a severity ranking in terms of downstream impact if the design feature was non-compliant as not all codes are applicable nor critical at the early design stage. Categorization of the codes in terms of the treatment required was also undertaken. Some codes and guidelines offer opportunities of standardization of the related design feature while others point towards automation to overcome the manual and tedious work.

The below points outlines the activities of the study:

1. Understand the different stages of the design and deliverables at each stage
2. Study the various responsibilities of the different disciplines and requirements of the various regulatory requirements, i.e. Fire Code, Strata requirements, Mechanical systems, Electrical systems and Telecommunications systems that can be brought upstream in the design phase and have spatial implications
3. Understand and translate, based on the requirements given, what components can be standardized or parameterized
4. Understand and translate checks that are at present done in manual fashion to automated form for increased productivity

Results

Design Stages

Based on the sharing by HDB, Figure 2 showed the 3 general stages of design for a public housing project in Singapore which is projected to take 26 weeks or 6 months.

Discipline	Wk1-5	Wk6-10	Wk11-15	Wk16-20	Wk21-25	26
Architectural	Conceptual Design Stage	Preliminary Design		Detailed Design Stage		
Civil & Structural, Mechanical & Electrical	To provide design consultation		Preliminary Design Stage	Detailed Design Stage		

Figure 2 Adapted from Step by Step BIM Guide for HDB Housing Projects Version 1.0 (Housing & Development Board and Building & Construction Authority, 2012)

1. **Conceptual Design Stage (9 weeks)**
   This stage primarily involves the architectural discipline only with 3 rounds of review with management to select a design option that would later be developed. At the end, the chosen design option would have a massing model plus the number of units.

2. **Preliminary Design Stage (6 weeks – Architectural, 4 weeks – Civil, Structural, Mechanical & Electrical)**
   At this stage, the model is shared to other disciplines to develop a schematic design. Current workflow would not allow comprehensive spatial checks at this stage.

3. **Detailed Design Stage (11 weeks)**

This stage is the longest at 11 weeks and building plan submission plans to occur on week 21. Once approved, the design is ready for tender.

In examining the design stages, the proposed solution should be done early in the conceptual design stage with the aim of trying to minimize the likelihood of abortive work downstream. This is when the ability to impact design performance and cost is the greatest while the cost of change following the MacLeamy Curve. At this early stage of the design, the overarching concern is whether sufficient spaces are allocated for various building components and sufficient setbacks based on regulatory constraints and guidelines.

Integrated Design Platform

An integrated design platform to tackle the previously mentioned challenges is conceptualized and implemented in a prototype form. It is designed for the conceptual and preliminary design stage so that considerations can be brought forward and addressed as early as possible. Figure 3 describes the conceptual system diagram showing the tight integration between the modelling and the validation aspects of the design model.

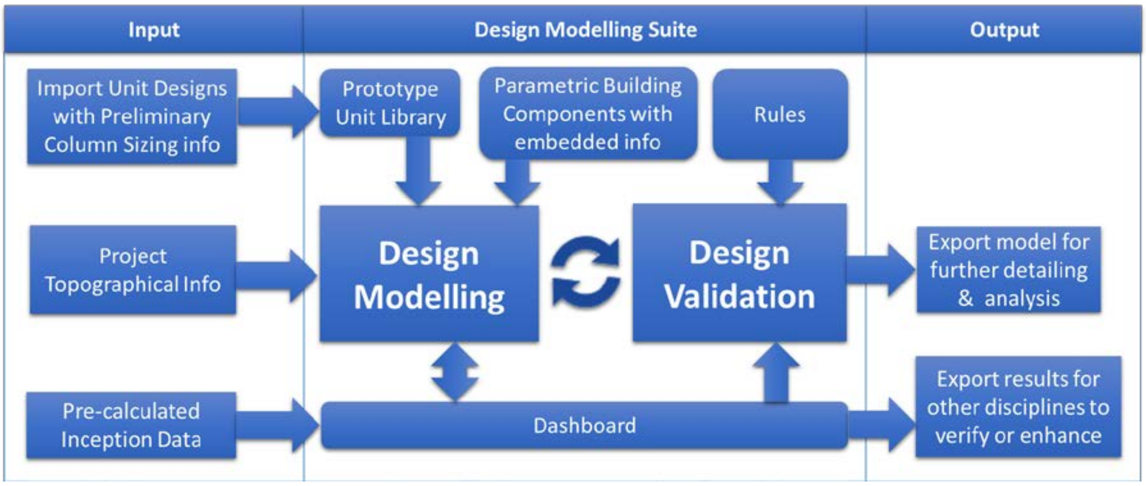


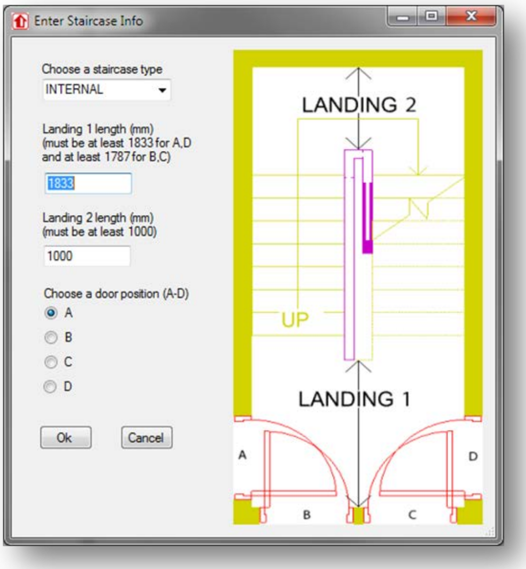
Figure 3 Conceptual System Diagram

Input
There are currently 3 main input sources for the integrated platform. First, a library of unit designs with preliminary column sizes for various building height is built up which allows structural considerations to be built-in early. Secondly, project topographical data is brought in so that the site boundaries can be defined and analyzed for setback and buildable space. Thirdly, pre-calculated inception data such as the number and height of blocks, and the flat mix is also brought in through a Dashboard interface so that the user can easily reference these numbers as they are modelling the schematic design.

Design Modelling Suite
With the library of unit designs and parametric building components, the user can easily and rapidly model a design that has the appropriate contextual information to undergo the design validation in an iterative manner. This removes the tediousness of manual inputs of parameters of the components.

Standardized and Parameterized components
Apart from unit designs, other components that were studied and offered potential to be standardized were the staircase and lift well. For staircase as depicted in Figure 4, the strict

requirements governed by the fire code necessitates a rather functional design. On the other hand, the lift well sizing is predetermined by a finite range of lift models governed by a few parameters such as height of building, lift capacity and number of dwelling units in the whole block.


Enter Staircase Info

Choose a staircase type: INTERNAL

Landing 1 length (mm)
(must be at least 1833 for A,D
and at least 1787 for B,C)
1833

Landing 2 length (mm)
(must be at least 1000)
1000

Choose a door position (A-D)
● A
○ B
○ C
○ D

Figure 4 Parametric Staircase

Quick feedback loop
Also, by this integrated arrangement, the user has a quick feedback loop on the feasibility of the design throughout the modelling process and not just at the end. This facilitates early and cost-effective adjustments to correct the design model rather than late, cost-prohibitive ones. Hence the probability of non-compliance for the final schematic model is minimized.

Greater control on the data integrity of the model
The advantage of having a single platform whereby the checking requirements drive the development of the modelling suite is that there is greater control of the model data that is required for checking which ensures no missing data. This is in contrast with model data that are imported from other software where certain bits of data can be *“lost in translation”* due to the detail not being modelled or the export format does not fully capture the required detail.

Using automation to eliminate tedious work
Another aspect of the design validation that leverages on the context-rich model to eliminate tedious and manual checking is the automated design check. Figure 5 is an example of a tedious check for adequate ventilation coverage from inferred openings along the corridor. This check is not only tedious but error prone when done manually. It is not uncommon to have the check miss a crucial need for an air well for proper ventilation resulting in major corrections in unit layouts and column positioning.

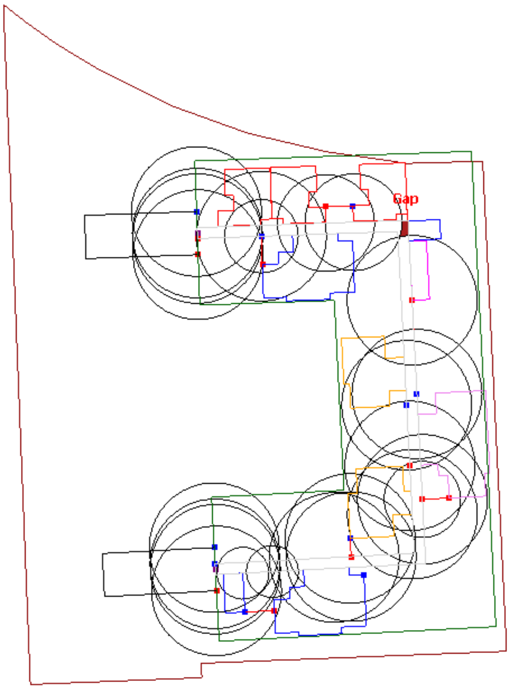


Figure 5 Identifying a gap in ventilation coverage automatically. The “circles” represent the maximal natural ventilation extent/reach from an inferred edge of a corridor opening to outside environment.

Rules in classes of checks

In the course of understanding the various regulations and guidelines that have to be complied with, those that have spatial implications can be decomposed into several main classes of checks.

1. Intrinsic object properties to be measured and checked such as length, height, area etc. This is the simplest and in the modelling suite, such requirements can usually be treated by the standardization of components.
2. Counts of types of components.
3. Chart-based requirements on the quantity or the spatial dimensions based on a number of parameters. The parameters can be gleaned or inferred from the available information from the model or via user input. Those input parameters are then referenced against the chart in a database.
4. Setback & Clearance requirements involves an enlarged or inner region from the outline of the component whereby any incursion into the region is tested.
5. Inferred objects that have specific requirements. It may not be a check by itself but is required prior to subsequent checks. For example, openings that are not marked or defined explicitly but are formed when two units are spaced apart from each other defining an outlet from the internal corridor to the outside environment.
6. Distance-based checks between two objects
    a. Direct and straight-line distance
    b. Along a defined medium (pathway/access way/corridor)
        i. Connectedness

ii. Path distance
iii. Number of bends on the path

The above mentioned rules can then be stringed together and applied in a combinatorial manner with elements that relates to a language. Elements such as comparison operators (greater, lesser, equal), logical operators (AND, OR, XOR), precedence bracketing and nestable conditional (IF-ELSE) statements would empower as much programmatic ability for the user to define and build up rules into a maintainable and extendable rule base.

Underlying Data Structure

The Eyeshot (devDept Software S.a.s., 2015) Viewport 3D visualizer is used for developing the modelling suite. It integrates seamlessly with the Microsoft Visual Studio development platform as a C# Control that can be added to a WinForm or Windows Presentation Foundation (WPF) project thereby enabling relatively easy application development. Every Eyeshot *Line*, *LinearPath*, *Region*, *Mesh* or any other type of *Entity* that can be graphical represented on the Eyeshot Viewport 3D visualizer has a property called *EntityData* which inherits the base C# *object* class. Through this, the functionality of the entity can be extended and embedded with class objects containing the relevant data. Figure 6 demonstrates the properties of some of the classes that has been implemented. Each of them contains a Global Unique IDentifier (GUID) that follows the Industry Foundation Classes (IFC) (buildingSMART, 2015) specifications.

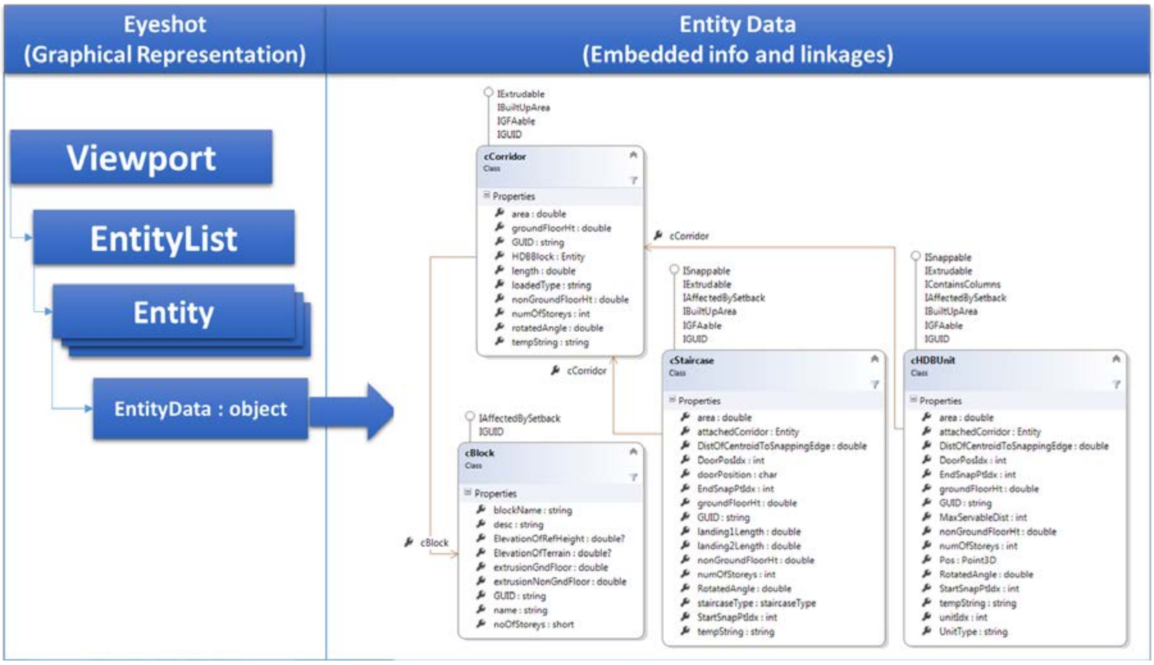


Figure 6 Entities and their linkages

The entities are also linked as shown conceptually in Figure 6 and physically in Figure 7. For instance, every unit or staircase would contain a reference to its attached corridor. This allows encoding of logical relationships that would be useful for design validation. The end result is a tree-like structure where the "leaves" are the components attached to the "branches" of the corridor. This typology generally captures most high-rise development projects, if not all.

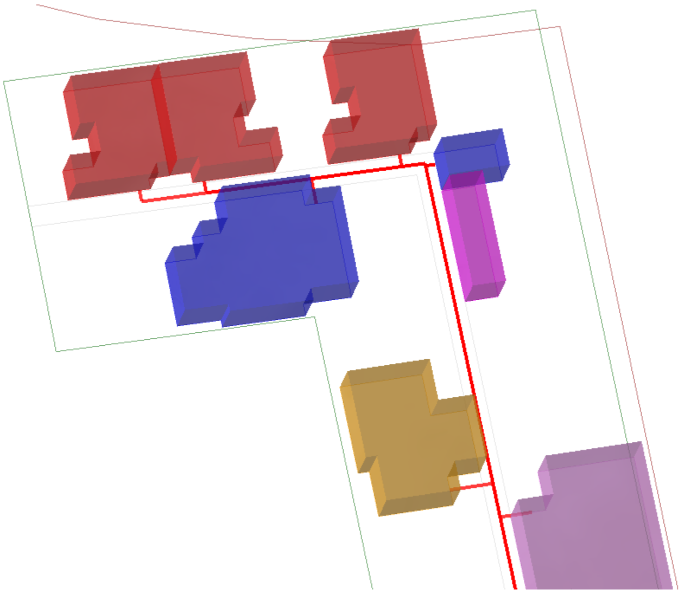


Figure 7 Linkages facilitate intelligent checking

Output

After a design model has been built up and validated to user satisfaction, the model would then be exported to the IFC format so that the detailed design phase can continue. Figure 8 shows the columns in the Design Modelling Suite exported as an IFC file and then imported into Autodesk Revit for further detailing or can be coordinated in Tekla BIMSight software when combined with other models.

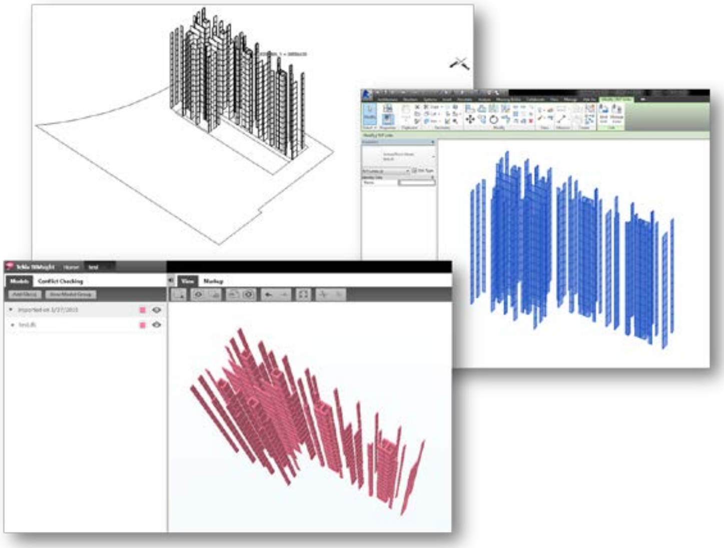


Figure 8 Exporting to Open Shareable Format – Industry Foundation Classes (IFC) and imported to other software

Exporting to IFC offers maximal flexibility, interoperability and reuse of the model for subsequent stages and for further detailing. In contrast, a closed and proprietary format can stifle options and tools available. While full interoperability may still be a work-in-progress, nonetheless the general future trend is likely to be in the direction that facilitates greater sharing.

One of the concerns raised by an Electrical Engineer is that the BIM Workflow has introduced additional workload or an effort “bulge” as mentioned earlier. It comes in the form of having to expend extra effort in contributing to the 3D building model without seeing any productivity gains on the individual. This has resulted in some pushback and reluctance to adopt BIM workflow. One way to address the additional burden is to unlock the value of their efforts and lessen the burden in other tedious activities that could be automated. An observation made was the tedious supporting role with regards to the calculation of mechanical and electrical provisions and services based on the designed building. With the designed model however, the quantities and calculations can easily be done and then exported from the Design Modelling Suite for verification or further analysis. For example, quantities and calculations such as electrical load and water provisions.

Conclusion

In this paper, a prototype of an integrated design platform that brings together different requirements from various disciplines early in the design stage was discussed. A generic programmatic language that could describe the rules that was studied was developed. This could potentially allow user maintainability and extensibility of validation rules which is the ultimate goal of automated code checking. The key contribution of this effort is that it reduces the potential for delays due to rework in remedying preventable design errors and increases designer confidence in the design model meeting critical regulatory code compliance. Also, tedious and complex checks have automated and integrated, bringing about significant productivity benefits. This will be measured when the system is deployed when completed. The potential for this platform to further extend its capabilities is also possible given it is a close integration of various disciplines into one platform that produces a schematic model that is BIM-ready for downstream applications. All in all, effort in this study has been directed to capture and digitize the knowledge and expertise from industry professionals so that it can be easily propagated to future development projects so as to “smoothen the bulge” on the MacLeamy curve.

Acknowledgements

We are very fortunate to be working closely with a dedicated team of public housing practitioners, Co-Principal Investigator and Principal Architect Alvin Chong, Senior Architect Chong Shyh Hao and Senior Engineer (Civil & Structural) Zhao Yu of the Housing & Development Board (HDB) Building Research Institute of Singapore in helping to understand practical perspectives of their current work processes and day-to-day interactions. Aside from that, we are thankful for the access given to the various experts within HDB, in land surveying, mechanical, electrical and telecommunication systems as well.

References

buildingSMART. (2015). *Standards Library, Tools & Services*. Retrieved from buildingSMART: http://www.buildingsmart.org/standards/standards-library-tools-services/

Chua, D. K., & Yeoh, K. W. (2015). Understanding the Science of Virtual Design and Construction. *International Workshop on Computing in Civil Engineering.* Austin, Texas: American Society of Civil Engineers.

devDept Software S.a.s. (2015, June 5). *Eyeshot, 3D Graphics and CAD components for the Microsoft .NET Framework.* Retrieved from http://www.devdept.com/eyeshot

Gu, N., & London, K. (2010). Understanding and facilitating BIM adoption in the AEC industry. *Automation in Construction, 19*(8), 988-999.

Housing & Development Board and Building & Construction Authority. (2012). *Step by Step BIM Guide for HDB Housing Projects Ver 1.0.*

Howard, R., & Björk, B.-C. (2008). Building information modelling – Experts' views on standardisation and industry deployment. *Advanced Engineering Informatics, 22*(2), 271-280.

Kam, C., & Fischer, M. (2004). Capitalizing on early project decision-making opportunities to improve facility design, construction, and life-cycle performance—POP, PM4D, and decision dashboard approaches. *Automation in Construction, 13*(1), 53-65.

MacLeamy, P. (2004). MacLeamy Curve. *Collaboration, Integrated Information, and the Project Lifecycle in Building Design and Construction and Operation (WP-1202).*