MDM AS A TOOL TO IMPROVE BIM DEVELOPMENT PROCESSES

Gernot Hickethier[1,2], Iris D. Tommelein[2], Michelle Hofmann[3], Baris Lostuvali[3] and Fritz Gehbauer[1]

[1]Karlsruhe Institute of Technology, Germany
[2]University of California, Berkeley, USA
[3]HerreroBoldt Partners, USA

ABSTRACT

Building Information Modelling (BIM) refers to models of geometry of a facility to be designed and built. The goal of the BIM development process is to build an error-free model in an efficient way. The use of Plan-Do-Check-Act (PDCA) cycles has proven successful for adapting the BIM development process to the needs off the project, thus avoiding rework during development of the model. Integrated modelling of conflicts between building components (often called 'clashes'), the BIM development process, and the organizational structure of the development team with the Multiple Domain Matrix (MDM) enabled deduction of planned and actual communication flows in the organization. The two perspectives of communication were compared as part of 'Check' in the PDCA cycle. Comparison identified problems in the BIM development process, which were the starting point for root cause analysis.

Keywords: Multiple Domain Matrix (MDM), Virtual Design and Construction (VDC), Building Information Modelling (BIM), process mapping, Plan-Do-Check-Act (PDCA), lean construction design, collocation

1 INTRODUCTION

A challenge in the Architecture-Engineering-Construction (AEC) industry is to fit highly inter-connected systems into small spaces while meeting numerous functional requirements. Correct design of these dense spaces can be critical for project success. Designers and planners of construction projects have been using Virtual Design and Construction (VDC) (Fischer 2008) to manage building models, development processes, and the organization that develops them in order to meet customer value. They use Building Information Models (BIM) from which to extract different views, such as 3-D geometries at different levels of detail, time-scaled representations, cost models, etc. The widespread use of such modelling is a rather recent development in the AEC industry, when compared to other industries.

Some trades have for some time already been using 3D-modelling to design their share of a project, but up until recently they coordinated their systems with those of other trades using 2D-drawings. The ability of BIM software to import 3D-models from different modelling programs enables co-creation of an integrated 3D-model by different trades.

The efficient use of BIM necessitates changes in the design process. When project partners work in traditional 'siloed' structures they cannot harvest the full potential of BIM. In contrast, when they apply BIM in combination with Lean Construction (Koskela et al. 2002), and correspondingly use commercial terms that align their interests, they can more fruitfully collaborate (Lostuvali et al. 2010). The collaborative environment improves exchange of preliminary information and the search and discovery of design solutions that provide the best value for the owner of the project (e.g., Hickethier et al. 2009).

Contractual agreements may specify who is involved in the project delivery process, but it does (usually) not address the question "How will the model be built?" The process of developing the BIM model needs to be designed according to the characteristics of the project and the capabilities of those involved. Rework should be avoided while building the BIM, but value-adding iteration is to be encouraged (Ballard 2000).

2 MOTIVATION

BIM users aim to achieve an error-free model during design in order to avoid costly rework during construction. As a part of this, they perform clash detection (Eastman et al. 2008), that is, they use BIM to identify spatially conflicting building parts. 'Hard clashes' refer to parts occupying the same space, thus they would collide during construction. 'Soft clashes' refer to parts being within a certain range of each other, and this range can be set, e.g., to building code requirements: For example, in California no part of a building may be closer than 5 cm to the structural steel in order to not damage the fireproofing that coats the structural steel.

To resolve clashes, BIM users must then rework the contents of the model. Rather than doing so, lean practitioners will want to avoid errors (including clashes) upfront, while developing the BIM model. Clash avoidance needs a well-defined development process according to which to populate the BIM model. Specifically, the development process must (1) be designed to the characteristics of the actual project and people involved, and yet (2) allow flexibility for exceptions from the standard rules.

Regarding (1), BIM users may follow the Plan-Do-Check-Act (PDCA) (e.g., Deming 1982) cycle to continuously improve their BIM development process, so as to adapt it to the characteristics of the actual project as it unfolds through learning loops. Regarding (2), a process should allow for flexibility in case the proposed development sequence proves unpractical. BIM developers from different trade partners often find solutions for conflicts based on who can move their systems most easily (Lamb et al. 2009), and this solution can require deviating from the process as specified.

Use of the PDCA cycle requires a 'Check' of the development process in use. Here, we focus on communication pertaining specifically to BIM modelling meaning 'drawing of BIM components,' and not the activities defining how to organize the model or how to go about modelling. A comparison between the planned communication flows ('should' perspective) and the actually happening communication (real communication as it is taking place during the design process) ('as is' perspective) can test alignment between planning and reality. Differences between the perspectives can be used as a starting point for a 'Check' of the planned process and then be followed by 'Act'-ing to improve the process.

3 MODELLING APPROACH

BIM users will want to identify misalignments between the 'should' and 'as is' perspectives, and then find root causes for them, in order to improve their processes. Documentation of real communication is time consuming and impractical if not infeasible. However, the identification of conflicts in the BIM can be used as an indicator for communication between developers, because the resolution of each conflict will need communication between the developers who worked on the conflicting components.

Therefore, an integrated model for BIM modellers to identify misalignments consists of three domains: (1) conflicts between building systems, (2) the BIM development process, and (3) the communication flows between modellers (called 'organization' domain).

3.1 Modelling method

We applied the Multiple Domain Matrix (MDM) method to integrate models of these three domains and then analysed the dependencies between elements across different domains. Elements and dependencies between elements in any given domain are represented by a DSM (Browning 2001). Domain Mapping Matrices (DMM) (Danilovic & Browning 2004) then connect the DSMs. Together these matrices form the Multiple Domain Matrix (Maurer 2007).

Using MDMs, one can deduce indirect dependencies that connect elements of the domain in question through elements of other domains (Maurer 2007). For example (Figure 1), BIM developer A who develops system 1, and BIM developer B who develops system 2, are indirectly connected to each other when systems 1 and 2 clash with each other in the model. In this case developers A and B need to communicate with each other to resolve the conflict (Figure 1, 'as is' case). Also, the BIM development process connects the developers indirectly: When developer A works on task 1 and developer B needs task 1 to be completed in order to begin his work on task 2, then developer B depends on developer A's information (Figure 1, 'should' case).

Use of Maurer's (2007) deduction logics yields two DSMs for the organization domain: (1) the 'should' DSM is based on the indirect dependencies through the Process domain and (2) the 'as is' DSM is based on the indirect dependencies through the Conflicts domain. Comparison of these 2 DSMs shows misalignments between the perspectives (Figure 1).

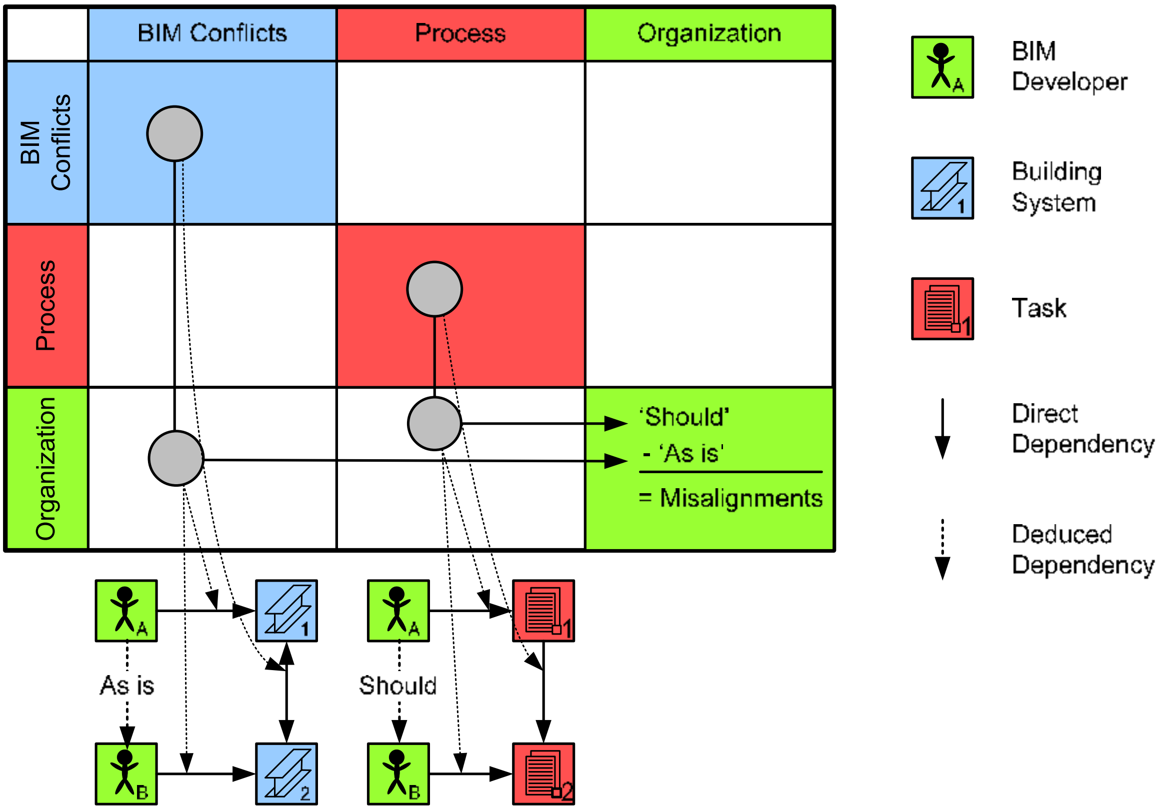

Figure 1. Deduction of 'should' DSM and 'as is' DSM of Organization Domain

3.2 Analysis of misalignments

Visual comparison of both perspectives through DSM and force-directed graphs fosters the understanding of differences between the perspectives. It is the starting point for finding root causes of misalignments by using the '5-Why' (Ohno 1988).

Root causes fall in two categories: (1) the BIM development process was unsuitable, and (2) the BIM development process was not followed by the developers. Causes from both categories can occur at the same time: an unsuitable BIM development process can cause BIM conflicts, e.g., because the process neglects certain development tasks or is not well sequenced. Consequently, the 'should' perspective and the 'as is' perspective can be inter-dependent. This complicates the analysis, because the 'should' perspective can cause conflicts which influence the 'as is' perspective. This relationship between the two perspectives must be considered during process analysis.

The organization domain as inferred in the model can also be compared against the actual organization involved in delivering the project. The structure of the actual organizational can then be adapted to the needs of the process, e.g., to increase the speed of communication.

4 CASE STUDY

4.1 Overview of BIM modelling approach

The setting of this case-study is the $1.7 billion Cathedral Hill Hospital (CHH) Project in San Francisco, California, USA. Due to seismic code regulations in California the design of hospitals is complex. The project is currently in the detailing phase of design. Designers are building an integrated 3D-model of the building using BIM. BIM developers of all trades, here called 'detailers,' are collocated in one office to enable them to communicate easily and to quickly solve conflicts.

BIM developers of CHH have identified 'system flexibility' as a key determinant of their modelling sequence. The least flexible systems (more physically rigid) shall be modelled first, and systems modelled subsequently shall adapt to the space constraints thus imposed (in other words, they will 'wrap around what is already in place'). However not all components in a systems are equally (in-) flexible, so modellers must adapt their process to the needs of the actual modelling task. They use PDCA to improve their BIM detailing process and they work in cycles, each cycle comprising the detailing of one floor of the building.

4.2 Problem analysis: Check of BIM development process

The starting point for root cause analysis was the BIM detailing process in use. In the first step translation of the process into a DSM revealed hidden iteration. In the next step, reports from clash detection of the BIM were translated into DSM to show conflicts between building systems. The Process–Organization DMM was derived from the detailers' responsibilities for detailing tasks and the Conflicts–Organization DMM was derived from detailers' ownership of systems during detailing. Both DMMs widely overlap; however the level of detail regarding system definition varies between the BIM development process and the BIM clash report. Development of Process DSM, BIM conflicts DSM, and the 2 DMMs completed collection of the native dependencies of the MDM.

In the next step two DSMs were deduced: (1) The 'should' perspective DSM, which shows the planned communication flows between detailers and (2) the 'as is' perspective DSM, which shows the communication flows between detailers regarding clash resolution activities. Detailers compared both perspectives visually using force-directed graphs (Figure 2).

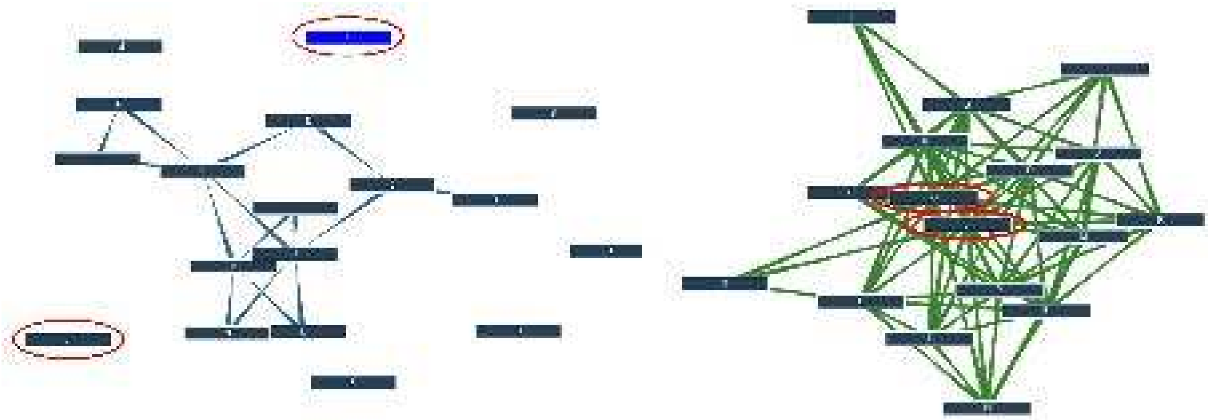

Figure 2. 'Should' perspective and 'as is' perspective of communication flows in organization domain (from left to right; force-directed graphs were partially manipulated to fit page)

Visual comparison directly shows structural differences of the graphs. The roles of detailers J and O raised special interest during root cause analysis with the project team: detailers J and O are not connected to the rest of the organization in the 'should' perspective, but they are in the centre of the organization in the 'as is' perspective. Comparison to the actual organization of the project yielded that detailer J is placed about 30 m away from the rest of the detailing team within the collocated office. Detailer O does not work from the collocated project office, but from an office several 100 km away.

Both detailers work on partitioning and discussion with the project team yielded that critical framing (which is part of partitioning and includes, e.g., studs that cannot move due to corner positions) was usually disregarded by other trades during the detailing process. Root-cause analysis yielded two reasons for the disregard: (1) critical framing was not part of the BIM development process at that time, and (2) detailers did not load the partitioning layer into their 3D-modelling program even though the layer already existed, because the loading time of this layer is exceptionally long.

4.2. Process design: Act to improve

These insights were the starting point to 'Act' in the PDCA cycle. The task of modelling 'critical framing' was integrated into the BIM development process. MDM deduction of the updated Process DSM yielded a new 'should' perspective of communication flows (Figure 3). Detailers J and O move into roles similar to the ones they had in the prior 'as is' perspective (Figure 2, left).

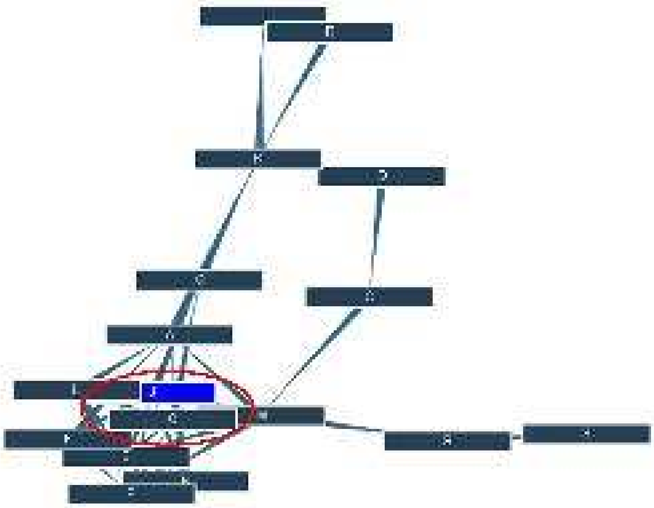

Figure 3. Updated 'should' perspective of communication flows after completion of PDCA cycle

Development of the partitioning layer is the first task of the updated BIM development process. Therefore, assuming there were no clashes during detailing, detailers J and O would be positioned at the periphery of communication flows. But due to the clashes with their system, which represent rework, they move them into the centre of communication flows (Figure 2 left). Feedback marks show this rework in the updated Process DSM. Deduction of the updated Process DSM moves detailers J and O into the centre of the updated 'should' perspective (Figure 3). The goal of the next PDCA cycles is to reduce clashes with 'critical framing', which would reduce rework and in turn remove the respective feedback loop from the Process DSM. Then, detailers J and O should move to the periphery of a future 'should' perspective of communication flows.

5 CONCLUSIONS AND FUTURE WORK

Combined application of MDM and the PDCA cycle improved BIM development. Integrated modelling of the domains product (represented through BIM clashes), BIM development process, and organization yielded a 'should' and an 'as is' perspective of communication flows between detailers. A visual comparison of the two perspectives, supported by force-directed graphs, aided the project team in identifying problems with their modelling process. These problems were the starting point of root cause analysis.

Consistent modelling of the different domains of the MDM is a prerequisite for comparison of perspectives. The presented approach focuses on communication flows pertaining to drawing in the 3D-model. Therefore, other tasks of the BIM development process may not be part of the process DSM. These tasks, e.g., group meetings to define clearances, must be cropped from the original BIM development process during translation into the Process DSM in order to make the 'should' perspective comparable to the 'as is' perspective.

Visual comparison of perspectives yielded beneficial insights, but application of structural criterions (Lindemann et al. 2009) may improve analysis in future work. Further, the current model only compares perspectives for one point in time. Tracking the changes in the Process DSM and the Conflicts DSM over time with the ΔDSM (de Weck 2007, Eben et al. 2008) may give insights on how inadequate processes cause clashes.

The current MDM approach analyzes the communication flows regarding drawing, which is only a portion of the work in 3D-modelling. Future work needs to amend the MDM with additional communication flows between modellers in order to make it more significant regarding the 3D-modelling process. The presented approach seems generally applicable to PDCA cycles, and further research is necessary on transferring it to other industries and within the lifecycle of a product.

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REFERENCES

Ballard, G. (2000) Positive vs. Negative Iteration in Design. In: *Proceedings of the 8th Annual Conference of the International Group for Lean Construction*. Brighton, UK.

Browning, T. R. (2001) Applying the Design Structure Matrix to System Decomposition and Integration Problems: A Review and New Directions. *IEEE Transactions on Engineering Management,* 48(3), 292-306.

de Weck, O. L. (2007) On the Role of DSM in Designing Systems and Products for Changeability. In: U. Lindemann, M. Danilovic, F. Deubzer, M. Maurer and M. Kreimeyer (Eds.) *Proceedings of the 9th International DSM Conference*, Munich, 16-18 October 2007, pp. 311-323.

Danilovic M. and Browning T. R. (2004) A Formal Approach for Domain Mapping Matrices (DMM) to Complement Design Structure Matrices (DSM). In P. J. Clarkson (Ed.) *Proceedings of 6th International Design Structure Matrix Conference*, Cambridge, UK, 12-14 September 2004.

Deming, W.E. (1982) *Out of the Crisis*. Massachusetts Institute of Technology, Cambridge, USA.

Eastman, C., Teicholz, P., Sacks, R., Liston, K. (2008) *BIM Handbook: A Guide to Building Information Modeling for Owners, Managers, Designers, Engineers and Contractors*. New Jersey: John Wiley & Sons.

Eben, K., Biedermann, W. and Lindemann, U. (2008) Modeling Structural Change over Time – Requirements and First Methods. In M. Kreimeyer, U. Lindemann and M. Danilovic (Eds.) *Proceedings of the 10th International DSM Conference*. Stockholm, Sweden.

Fischer, M. (2008) Reshaping the life cycle process with virtual design and construction methods. In: P. Brandon and T. Kocatürk (Eds.) *Virtual Futures for Design, Construction and Procurement* (pp. 104-112). Blackwell Publishing, Oxford, UK.

Hickethier, G., Parrish, K., Tuholski, S., and Tommelein, I.D. (2009) Evaluating Value Generation of Rebar Delivery Processes with DSM. In: M. Kreimeyer, J. Maier, G. Fadel and U. Lindemann (Eds.), *Proceedings of the 11th International DSM Conference*, Greenville, SC, 12-13 October, pp. 357-367.

Koskela, L., Howell, G., Ballard, G., and Tommelein, I. (2002) The Foundations of Lean Construction. In: R. Best and G. de Valence (Eds.) *Design and Construction: Building in Value*. Butterworth-Heinemann, Oxford, MA.

Lindemann, U., Maurer, M., Braun, T. (2009) *Structural Complexity Management. An Approach for the Field of Product Design*. Berlin: Springer.

Lamb, E., Reed, D., Khanzode, A. (2009) *Transcending the BIM Hype: How to Make Sense and Dollars from Building Information Modeling*. AECbytes Viewpoint #48 (September 22, 2009), available at http://www.aecbytes.com/viewpoint/2009/issue_48_pr.html.

Lostuvali, B., Love, J., and Hayleton, R. (2010) Lean Enabled Structural Information Modeling. In: J. Underwood and U. Isikdag (Eds.) *Handbook of Research on Building Information Modeling and Construction Informatics: Concepts and Technologies* (pp. 619-637).

Maurer, M.S. (2007) *Structural Awareness in Complex Product Design*. TU Munich, Lehrstuhl für Produktentwicklung, Dissertation.

Ohno, T. (1988) *Toyota Production System: Beyond Large-Scale Production*. Portland, OR: Productivity Press.

Contact: Gernot Hickethier
Institute for Technology and Management in Construction
Karlsruhe Institute of Technology
Am Fasanengarten 50.31
76131 Karlsruhe, Germany
Tel.: +49 721 608 48235, +49 721 695245
e-mail: gernot.hickethier@kit.edu, www.tmb.kit.edu/lean

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[1]Karlsruhe Institute of Technology, Germany
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Virtual Design and Construction

- One challenge of complex projects is to fit highly interconnected systems into small spaces while meeting numerous functional requirements.

- Virtual Design and Construction (VDC) is the management of building model, modelling process, and modelling organization in order to deliver customer value.

INVEST ON VISUALIZATION

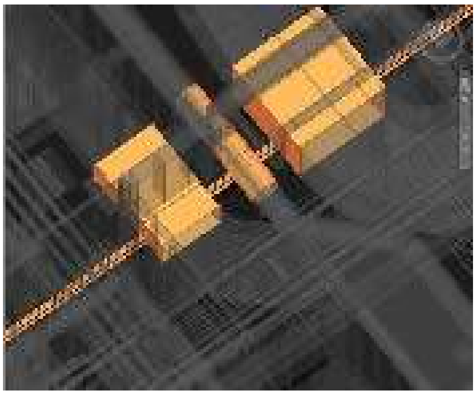
Building Information Modelling

- Building Information Models (BIM) contain, among other data, 3D-geometries at different levels of detail, time-scaled representations, and cost-models.
  - Widespread use of such models is rather recent, when compared to other industries.

- Collaboration is a prerequisite for efficient modelling.
  - Alignment of interests of project partners through commercial terms, e.g., Integrated Project Delivery, increases collaboration.

- But: How will the model be built?

BIM Development Process (1/2)

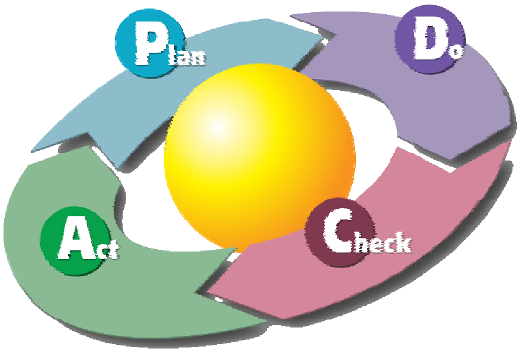


- Goal of the BIM development process is to build an error-free model in the most efficient way.
- Clashes are spatially conflicting objects in the model. Clash detection
  - reduces risk of rework during construction, which is costly,
  - but rework of 3D-model is necessary, if clashes are found.

BIM Development Process (2/2)

- The BIM development process should avoid clashes.
  - Goal: Use clash detection to approve correctness of 3D-model.
  - Base the modelling process on system flexibility: Model the least flexible (or most physically rigid) system first. Following systems must 'wrap around what is already in place'.
- Apply the PDCA cycle to improve the BIM development process continuously in order to reduce clashes.

Plan-Do-Check-Act Cycle during BIM Development



Source: Diagram by Karn G. Bulsuk (http://blog.bulsuk.com)

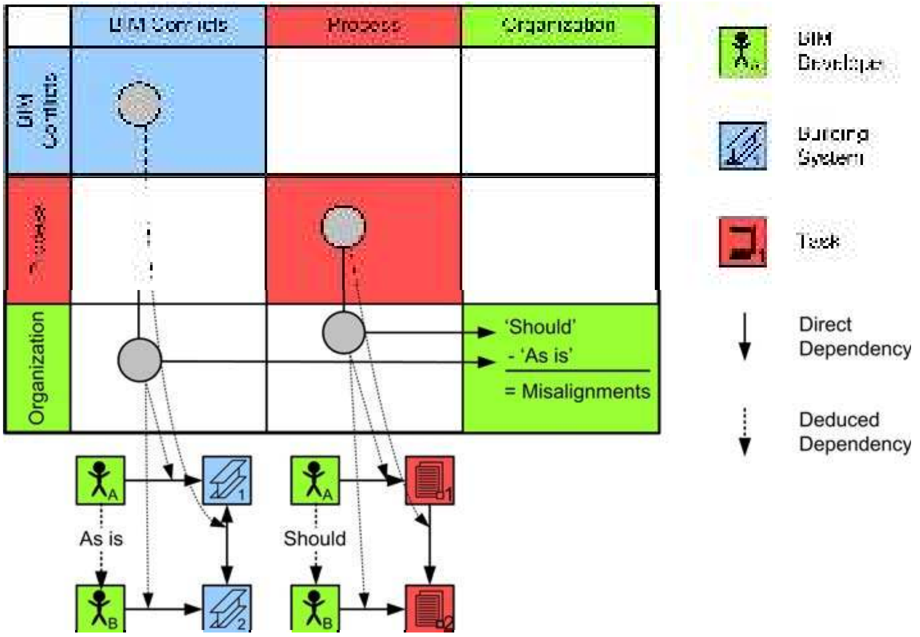
- Plan
  - Establish BIM development process.
- Do
  - Apply process during modelling.
- Check
  - Compare actual results of modelling against expected results with + / Δ list.
- Act
  - Analyze cause for differences and adjust BIM development process.

Question: How can we make 'Check' more objective?

MDM Application during 'Check' of PDCA (1/2)

- Build a Multiple Domain Matrix which consists of 3 domains:
  - BIM: clashes between components in the model
  - Process: current BIM development process
  - Organization: communication flows between modellers.
- Deduce planned communication flows in organization domain from BIM development process.
  - 'Should' perspective.
- Deduce actual communication flows in organization domain from BIM clashes.
  - 'As is' perspective.
- Compare 'should' perspective and 'as is' perspective of communication flows to 'Check' the modelling process.

MDM Application during 'Check' of PDCA (2/2)



INVEST ON VISUALIZATION

Case Study

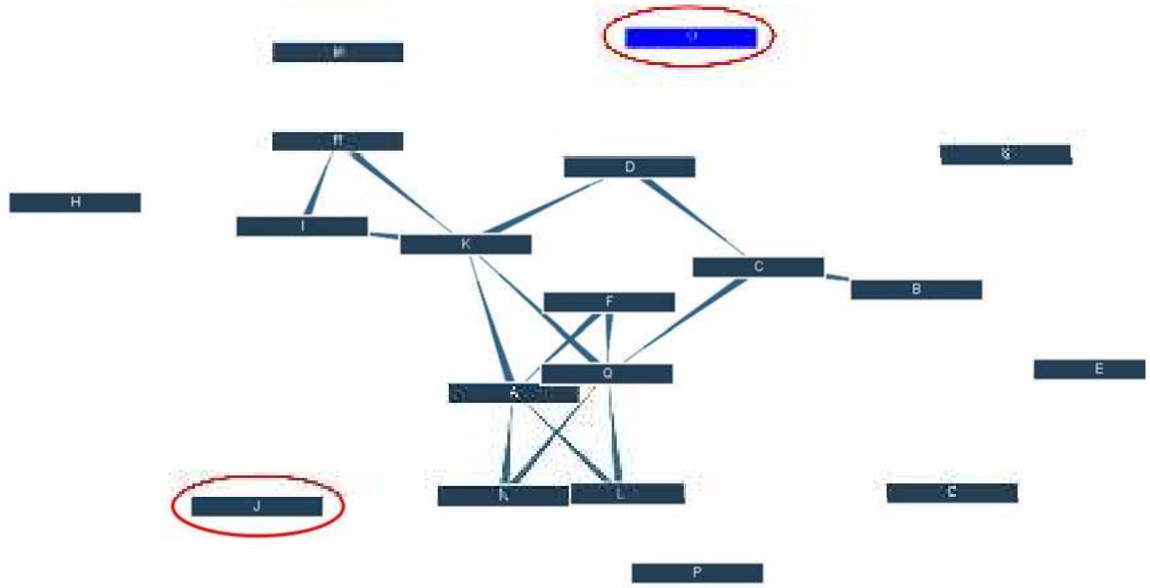
Cathedral Hill Hospital Project

Source: Smith Group

- Located in San Francisco, CA
- $ 1.7 billion
- 555 beds
- 18 stories
- 915,000 sq. ft.
- Currently in detailing phase
- Complex design due to seismic code requirements
- Use of Lean Construction, Building Information Modelling, and Integrated Project Delivery

INVEST ON VISUALIZATION

‘Should’ Perspective – Communication Flows between Modellers Deduced from BIM Development Process



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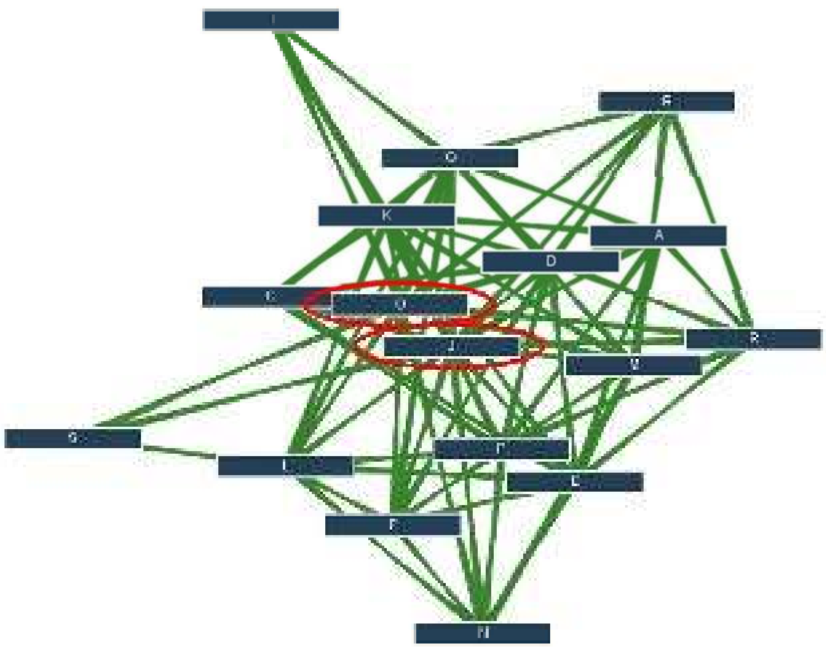
‘As Is’ Perspective – Communication Flows between Modellers Deduced from Clashes



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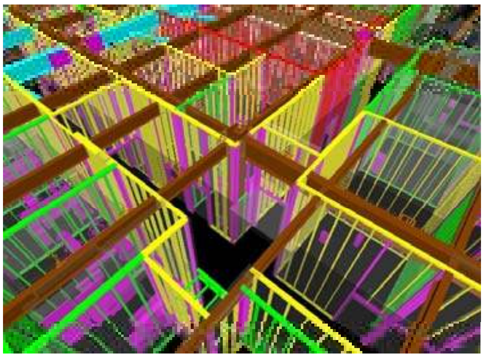
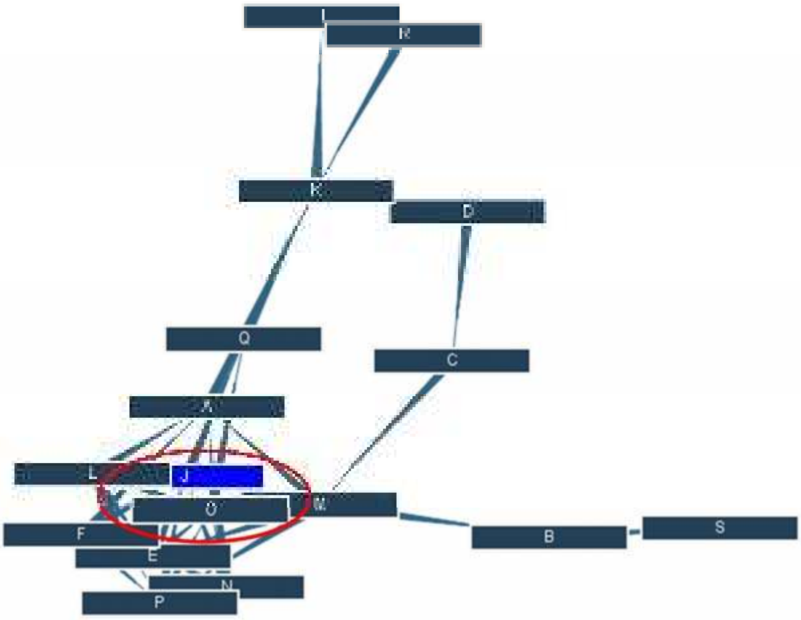
Results of Root-Cause Analysis

- Detailers O and J's task (modelling 'Partitioning') was not part of the current BIM development process
  - Partitioning should be the first task of the BIM development process, because it has the least flexibility (e.g., corner studs).

- Other detailers did not load the partitioning layer into their modelling programs
  - Loading time for this layer is exceptionally long.



Updated 'Should' Perspective



Conclusions

- Combination of MDM and PDCA proved successful for improving BIM development.
- Visual comparison of perspectives helped in finding root causes of problems.
- Comparison between modelled organization domain and actual organizational structure of project team yielded beneficial insights.
- Modelling approach for MDM deduction must be consistent through all domains
  - Crop activities from BIM development process that do not reflect drawing in the BIM.
- Improper BIM development process can cause clashes
  - Consider origin of clashes during root-cause analysis and implementation of solutions.

Future Work

- Apply criteria for structural analysis of communication flows.
- Track changes of communication flows over time with ΔDSM
  - Find relation between improper BIM development process and clashes.
- Extend model to more domains of communication to make view of communication flows more complete.
  - BIM clashes represents only a subset of communication flows between modellers.
- Analyze impact of feedback loops of the BIM development process on planned communication flows.