ROOT CAUSES OF CLASHES IN BUILDING INFORMATION MODELS

Iris D. Tommelein[1] and Sepide Gholami[2]

ABSTRACT

Building Information Models (BIM) support designers and builders in creating and coordinating system designs and planning work. In practice—out of necessity—this includes checking that systems do not clash, but what constitutes a clash? How do clashes come about? Do clashes relate to design-, buildability-, or building-performance qualities? How does a clash detection process fit (or not) in lean project delivery?

In this paper we describe our findings from research into clashes. Our sample is biased in that a number of the people we spoke with have been working in Integrated Project Delivery (IPD) teams, with commercial terms spelled out in an Integrated Form Of Agreement (IFOA). Many are co-located on their project site—at least some part of each week—so that they can work together closely as their thoughts on design and construction unfold. It is common practice for these teams to share their BIMs, each discipline-specific model having been developed by a specialist design- or contracting firm, and integrate them in a big-room setting. Nevertheless, this integration process invariably appears to include the identification and resolution of clashes. When viewing these BIM development practices from a 'lean' perspective, we found that many are far from lean. Accordingly, we present opportunities for process improvement when using of BIM in pursuit of lean ideals.

KEY WORDS

Building Information Model (BIM), BIM pathology, clash detection, root-cause analysis, design management, tolerances, constructability, contingency, waste

INTRODUCTION

Building Information Models (BIMs) can support owners, designers, and builders in their creation and coordination of the design of building systems and planning of construction work, in their processes for fabrication and building, and in their processes for operating and maintaining, as well as decommissioning their facilities. We view the development- and use of BIMs as efforts that can support the work of lean construction practitioners, however, these efforts can also be void of lean-ness. Sacks et al. (2010 p. 670) studied potential relationships between Lean and BIM and noted: "It emerges from this review of existing literature and research efforts that even if many interesting connections have been pinpointed, there is a lack of systematic exploration between BIM and lean construction and that further efforts are needed to bridge this gap in knowledge." With our paper, here, we aim at helping to fill this gap.

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We use the term BIM to refer to a product, not a process. A BIM is a computer database with building components and related information, accessed using graphical- and other user interfaces. We call it a product because we can be clear on the features of products resulting from the use of a specific BIM software package. In contrast, an infinite number of modeling processes can be followed when deploying any one of them.

BIMs can be used in all phases of project delivery. As a project evolves through different delivery phases, BIMs also evolve through different so-called Levels of Development (LOD) (e.g., AIA 2008). Our ongoing study, with early findings presented here, focuses on BIMs used towards the end of the design phase (LOD 300 or 400), in what we call the work of the Last Designer (Sadonio et al. 1998). This work refers to the last acts in design (the last steps in virtual product design)—or the first acts of construction (e.g., Pietroforte 1997)—namely the detailing step that takes place before parts get procured or physically realized in a fabrication shop or on site. Such detailing work may pertain to, for example, showing the placement of light-gauge steel components, identifying locations for deck inserts and hangers (Figure 1), sizing and positioning bracing, and noting the volumes that will likely be filled with fireproofing. Last Designers may be working for design-, contracting-, or other firms.

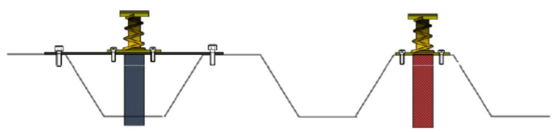


Figure 1: Deck Inserts for Mechanical Duct
(Source: Ben Tapparo, Southland Industries, Inc.)

In a process called BIM coordination (and many such processes are possible, some leaner than others, whether or not the project uses Integrated Project Delivery)(e.g., Khanzode et al. 2007), Last Designers—each presumably having developed a different, specialty-specific building-system model—integrate their models, e.g., using NavisWorks Manage (www.autodesk.com/Navisworks-Manage) or Bentley Navigator (www.bentley.com/en-US/Products/ProjectWise+Navigator/). In this context, the verb 'to clash' refers to the practice of identifying clashes in an integrated BIM. BIM coordination processes are inter-disciplinary efforts that can serve many purposes. One purpose of BIM coordination is to check interferences in order to detect and resolve clashes, as these indicate potential future problems. Clash detection is one of several quality checks performed before Last Designers release their BIMs to their respective downstream delivery processes. Another purpose of BIM coordination is for Last Planners to structure forthcoming construction work. Last Planners may differ from Last Designers in that the latter certainly must be highly skilled in the technicalities of operating whichever BIM software they use.

In this paper we focus on clash detection while addressing a number of questions, namely: What constitutes a clash? How do clashes come about? Do clashes relate to design-, buildability-, or building-performance qualities? And finally: How does the clash detection process fit (or not) in lean project delivery?

WHAT CONSTITUTES A CLASH?

We have reviewed the literature, viewed online media, made first-hand observations of industry practices, took notes during presentations made by BIM developers, and conducted interviews with practitioners (many of whom are involved in the design and construction of healthcare facilities and commercial buildings) in order to learn what constitutes a clash. With numerous sources of information available, some more formal than others (e.g., Eastman et al. 2008, Kymmel 2008), a certain looseness as well as arbitrariness in language use appears to exist in regards to how people talk about clashes.

For example, clashes appear to be mentioned in one fell swoop together with errors and omissions in a BIM (e.g., http://www.virtualbuild.com/FAQs 5/2/2012: “BIM’s distinct ability to detect errors, omissions and clashes prior to construction allows you to analyze risks/benefits more accurately—and much earlier—in the development process.”). At the same time, some clashes identified in the process of BIM coordination get dismissed, as if they were computational flukes. This is often the case when components within any one, same system clash: a person responsible for the design, modeling, or construction of that system presumably will take care of resolving this clash. Only clashes involving system components designed/modeled/built by different parties (clashes between component types or sets of BIM templates used in different scopes of work) require extra, inter-disciplinary coordination and conversation.

In our view, clashes point at waste in the production system. We need to be more precise in our word use if we want to be able to identify actionable root causes of clashes.

DEFINITION OF ‘CLASH’

Some BIM coordinators use the term ‘clash’ to refer broadly to one of several kinds of spatial conflicts discovered in a BIM, that is, they characterize the clash based on the nature of its existence. For example, they differentiate ‘hard clashes’ from ‘soft clashes,’ and ‘time clashes’ (e.g., Mangan 2010). Other BIM coordinators highlight clashes, not only based on their existence, but also based on the process used to act upon them. For example, Gijezen et al. (2010) use a work breakdown structure and define ‘relevant clashes’ as those that lead to change orders. Whichever is the case, clashes point at conflicts that demand the attention of Last Designers and, as needed, also of others in the project delivery process.

We next propose definitions of terms to characterize the clashes based on their existence (not on follow-on process use). Suggested improvements of these are welcome.

- A ‘**hard clash**’ refers to one building component physically yet unintentionally penetrating another building component; that is, two (there could be more) components compete for the same physical space (volume). Figure 2 illustrates a hard clash between pneumatic tube (purple) and waste and vent (W&V, red).
- A ‘**soft clash**’ (aka. a ‘clearance clash’) refers to components (subsystems) that are closer than a certain distance (a minimum clearance) from one another (e.g., distance in-between outer cylindrical surfaces of two pipes). Figure 2 illustrates a soft clash between pneumatic tube (purple) and fire pipe (red).
- A ‘**time clash**’ refers to spatial challenges (components potentially occupying the same space) anticipated when considering constructability or operability of the facility. A time clash may be modelled as a kind of clearance requirement, but one that has a temporal component to it.

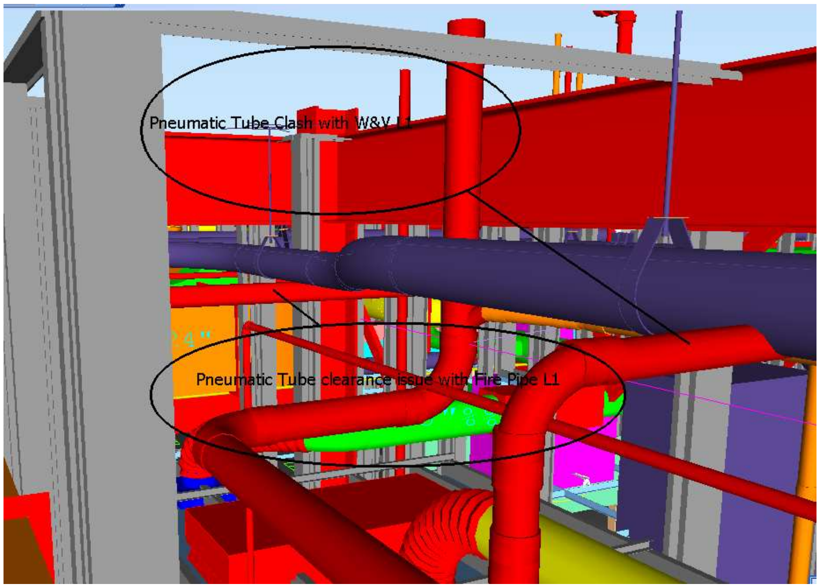


Figure 2: Hard Clash between Pneumatic Tube (purple) and Waste and Vent (W&V, red), and Soft Clash between Pneumatic Tube (purple) and Fire Pipe (red) (Source: Eric Osterling, Unger Construction)

HOW DO CLASHES COME ABOUT?

FLEETING NATURE CLASHES

Before highlighting what might cause a clash, we should like to point out that clashes tend to be fleeting by nature: they get resolved on the spot (in a BIM coordination meeting or elsewhere) and seldom is a permanent record made of their occurrence. This makes it difficult to learn to the fullest extent from clashes previously encountered.

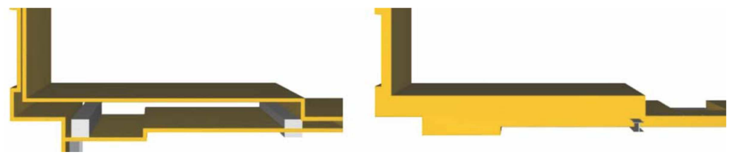
Clashes are like problems discovered at the end of the assembly line, before the product is released to the customer. The assembly line is the design process. The customer can be anyone involved in procurement, fabrication, construction, or operations. Clashes occur (= product quality failure), they get pointed out (= inspection process step), and they get fixed (= repair process step). Due to the urgency with which the BIM often-times must be released to Last Planners and other customers, little if any time is available during BIM coordination to characterize clashes or to document the causes they mask. As a result, no root causes are analyzed and thus no actions can be taken to prevent the problem from recurring. The version of the BIM that was defective gets overwritten by a corrected version, and the coordination team moves on.

BIM PATHOLOGY

Lean practices can significantly improve many of the BIM coordination practices we have studied to date. Admittedly, it is quite likely that a number of thoughtful BIM users already have taken actions that prevent clashes from recurring, however, the published literature on how to avoid clashes in BIM is notably sparse. Research opportunities abound in this area, which first author calls ‘BIM Pathology.’

DETECTION, CAUSES, AND RESOLUTION OF HARD CLASHES

Provided BIM objects were modeled as occupying a volume in space, computer algorithms can easily compute occurrences of hard clashes in a design and highlight them automatically. But are BIM objects modeled in this way? The GSA (2007) illustrates alternative modeling approaches: "Spaces between walls (e.g., furrings, unknown spaces behind walls), should be considered as walls. Thus, instead of having a space between two walls, the entire void will be considered as one thick wall. Walls configured such that voids are created to enclose building services shafts, columns, or other non-occupied spaces are typically referred to as cavity walls. Such wall/void conditions can be modeled in two basic ways as shown in … [Figure 3]. The optimal method for modeling such conditions is often dependent upon design circumstances." So what *is* vs. *is not* open space, is a modeling decision.



Method A Method B

Figure 3: Alternate Methods for Modeling Cavity Walls (Source: GSA 2007)

So what causes hard clashes? In a way, hard clashes are 'dumb' to have; they often are obvious and should not have occurred in the first place. Some root causes of situations called out as hard clashes, and thus pointers at means to resolve them, are:

Design uncertainty: A designer may put a placeholder component in the model, not knowing what the exact component looks like, leaving that to be determined later and possibly by someone else (e.g., a specialty contractor)(Spittler 2012). The placeholder presumably will reserve sufficient space for the exact component to fit but may end up causing a hard clash whereas the exact component will not.

Failing of design rules: i.e., lack of specificity, agreement, or adherence to, prior to- and during design, on how specialty systems are to be developed relative to others so as to avoid invading each other's space. It used to be that different building systems each could be assigned to remain within one or several certain volumetric layers in the building space but, especially at turning points and in congested areas, such confining layering may not be feasible. In contrast, today's projects are usually complex and delivered under time pressure. Specialty designers therefore work concurrently on developing their design, even though they lack a-priori clarity on which space their system can/will occupy vs. which space other specialty systems can/will occupy, and they weak—if any—systems-interface definitions. Clashes mask such problems.

Design complexity: IPD team members may intentionally leave clashes to occur in areas of great complexity (e.g., where no design rules can be articulated)(Nguyen 2012). For example, knowing that other building systems in a specific area are subject to change, they may place their system in that area just to show design intent, knowing that clashes may happen. This practice is common in the Conceptual Design- and in the Design Development phase, but clashes may continue into Detailing.

Balancing effort in resolving the dilemma between model accuracy vs. meeting a deadline (Nguyen 2012): Designers may tolerate some clashes while trying to meet a submittal deadline, planning to resolve them later.

Design error: e.g., the dimension or location of one or several components is not as the designers intended. Note that not all so-defined design errors can be detected using computer algorithms. In particular, when a wrongly-dimensioned or wrongly-positioned component remains unobstructed, a computer program cannot highlight a hard clash. Likewise, when one component is physically yet erroneously enclosed by another one (e.g., a small object inside a hollow pipe), no physical penetration can be computed as there is no space contention. Clearly, it is not because a BIM is clash-free that the design automatically is error-free.

CAUSES AND RESOLUTION OF SOFT CLASHES - CONVERSATION STARTERS

Circumstances that lead to hard clashes, may also lead to soft clashes, and vice versa: the distinction between causes warrants further investigation. A soft clash may be caused by:

Blocking out space surrounding the physical volume occupied by an object: the object is not modeled with its true geometry, but rather by a geometry that encloses it as defined based on someone's judgment. When blocked-out space of one object overlaps with blocked-out space of another, a soft clash gets called out.

As was the case for placeholders, one reason to show a block-out is to save modeling time at an abstract LOD: e.g., a valve may be represented using a conical shape rather than a more detailed handle on a stem. Other reasons for defining space block-outs may reflect design-, construction-, or operations-related concerns. Components may be so close to one another that their spacing does not allow for adequate construction access (e.g., concrete formwork), placement of components or application of materials not shown in the BIM (e.g., spray-on fireproofing), maintenance access (e.g., equipment with a door that opens to allow for maintenance access, such as a filter change), or the like. Furthermore, a block-out may recognize concern for the manifestation of construction tolerances, i.e., the fact that no component will 100% exactly be in the location where, nor exactly of the dimension the BIM may show it to be.

Last Designers address such situations by introducing an allowance in the model to block out the 'needed' space (Figure 4) or by modeling systems with spatial dependencies, e.g., maintain 5 cm (2") clearance between components X and Y (Figures 5 and 6). They may then enforce the allowance in the BIM coordination process or, as is the case for allowances put into the model to recognize the manifestation of construction tolerances (Milberg and Tommelein 2005), they can judiciously select a construction process with suitable capability so that the soft clash does not become a problem during construction. An alternative is to count on individual- or teams of contractors to 'deal' with the potential clash in the field, using their construction process capability and availability of 'tricks of the trade' (e.g., flexible inserts to bridge gaps, Figure 7).

What struck us in our research exploration is that no agreement appears to exist from one project to another as to what clearance requirements ought to be. Requirements may also be adjusted as a design unfolds: designers may start with assumed values (Figure 5) but then validate (and change) them as more of the design gets revealed (Figure 6). Furthermore, we were told that some clearance requirements are attributable to code requirements but, barring some, we found code requirements hard to pin down specifically.

Whether or not space blocked out to 'protect' one system can intersect with space blocked out to 'protect' another system requires people to investigate. The soft clash, so identified, serves as a conversation starter. It flags the need for Last

Designers (and possibly others on the project) to discuss their design intent, detailing approach, construction means and methods and potential alternative configurations.

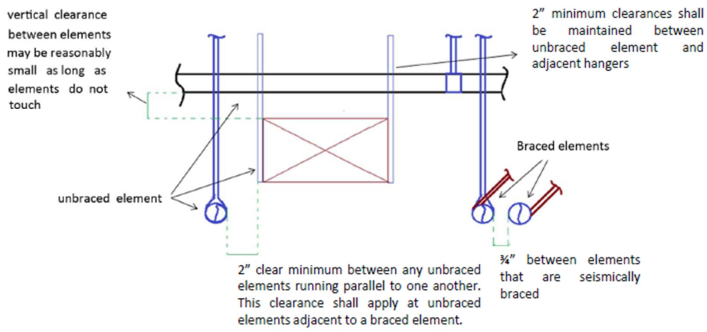


Figure 4: Component clearances (Source: Eric Osterling, Unger Construction)

To illustrate, an engineer we interviewed about the rationale underlying the value of 2.5 cm vs 5 cm (1" vs 2") for a specific clearance requirement, responded (paraphrased): "If it were me, I'd specify a 7.5 cm (3") clearance. That way, when anyone comes close to my system, they know they'll have to come talk to me." Such a practice suggests that clearance specifications are a contingency built into the design- and BIM coordination process. Interestingly, we have some anecdotal evidence that members of lean IPD teams (commercial terms spelled out using an Integrated Form Of Agreement) may specify values for clearances that are smaller numerically than those non-integrated team members might specify. It takes further research to confirm whether that is indeed the case more generally, and if perhaps this reduced contingency may reflect lower uncertainty, that is, greater confidence in team capabilities (Howell 2012).

Min Clearances in Inches	Medium Pressure Supply	Low Pressure Supply	Exhaust Duct	Flex Duct	VAV Boxes and HeatCraft Coils	Fire Sprinkler piping	Hydronic Piping	DCW Piping	DHW Piping	Med Gas Piping
Fire Sprinkler Piping	1	1	1	1	1	X				
Hydronic piping	1	1	1	1	1	1	X			
DCW Piping	1	1	1	1	1	1	1	X		
DHW Piping	1	1	1	1	1	1	1	1	X	
Med Gas Piping	2	2	2	2	2	2	2	2	2	X
Waste Piping	1	1	1	1	1	1	1	1	1	1
Vent Piping	1	1	1	1	1	1	1	1	1	1
Rain Water Leaders	1	1	1	1	1	1	1	1	1	1

Figure 5: Sample clearances for building systems coordination used in early design (Source: Andy Sparapani, HerreroBoldt)

Acoustical Ceiling Supports[6]	Acoustical Ceiling Tile	Curtain Wall	Metal Panel	Exterior Stone	Viscous Wall Damper	Structural Steel +2.00in for fire proofing	Clearance (in)
6.00	sp	sp	sp	sp	sp	sp	Electrical Equipment[4]
6.00	3.00	C	C	C	sp[b]	2.00[c]	Electrical Conduit
6.00	sp	sp	sp	sp	sp[b]	sp	Lighting
6.00	C	C	C	C	sp[b]	C	Low Voltage Cable[5]
6.00	3.00	C	C	C	sp[b]	2.00[c]	Fuel Oil
6.00	3.00	2.00[a]	2.00[a]	2.00[a]	sp[b]	2.00	Fire Protection[3] beam penetrations are 2.00in
		C	C	C	sp[b]	0.00	Metal Framing
	sp					0.00	Head of Wall part of the metal framing

Figure 6: Sample validated clearances for building systems coordination (Source: Andy Sparapani, HerreroBoldt)

CLASH DETECTION VS CLASH AVOIDANCE

IPD teams may be more keen than others to pursue a strategy of clash avoidance in lieu of clash detection (Nguyen 2012):

- **Clash detection** is a reactive, after-the-fact approach: the BIM coordinator assembles BIMs from specialists after they finish a portion of their work in order to detect clashes and coordinate the resolutions.

- **Clash avoidance** is proactive: the IPD team develops a work flow (i.e., sequencing of the design of systems based on their level of flexibility, with systems with less flexibility having priority) and determines work chunks and hand-offs. Each Last Designer imports the models released to him/her into his/her BIM and designs around the previously-released systems. When he/she cannot go around and touch other systems, the Last Designers must coordinate their work. The ideal result is to have no clashes when the Last Designer of the last system finishes their BIM. The role of the BIM coordinator during the detailing process then is minimal, as issue identification and resolution have already been taken care of.

CAUSES AND RESOLUTION OF TIME CLASHES

Space allowances, leading to the identification of time clashes, can be resolved in different ways: e.g., by judicious construction sequencing or operations sequencing as a result of studying alternatves using Virtual First Run Studies (aka. Model based sequencing/scheduling)(Nguyen 2012). For example, construction sequencing is considered by identifying Priority Walls (e.g., Mikati et al. 2007) (Figure 8).

Figure 7: Flexible duct connection absorbs dimensional variation (Source: Iris D. Tommelein)

Figure 8: Priority Wall on Camino Project (Source: DPR Construction, Inc. Redwood City, CA)

Priority Walls are full-height walls where the framing and drywall contractors get work-sequencing priority over mechanical contractors. Typically the opposite would be the case, but at Priority Walls, access to framing studs (as needed to install the drywall) would be blocked by mechanical ductwork if that ductwork were to be installed first. Exactly how much minimum clearance should exist between the drywall and the duct, before a Priority Wall is called out, appears to be a matter of negotiation among BIM coordinators.

DO CLASHES RELATE TO DESIGN-, BUILDABILITY-, OR BUILDING-PERFORMANCE QUALITIES?

Based on what we have said, no question should remain as to whether or not clashes relate to design-, buildability-, or building-performance qualities: the answer is unequivocally 'yes.'

HOW DOES THE CLASH DETECTION PROCESS FIT (OR NOT) IN LEAN PROJECT DELIVERY?

Clash detection—the identification of waste—is a justified process in lean project delivery, while striving for perfection and aim for BIMs to be flawless (a lean ideal!). Lean practices such as clash avoidance and pull scheduling (Figure 9) can support implementation. However, a lot more needs to be done, to not just remedy-, but eradicate clashes in BIMs. Fleeting in nature, clashes must be made visible, characterized, and have root cause(s) identified. We must develop systematic ways to constructively improve design processes so as to reduce future occurrences of clashes. Hicketier et al. (2012) offer but one example, among many possible, of how one might learn from clashes and correspondingly restructure a big room layout and team communication.

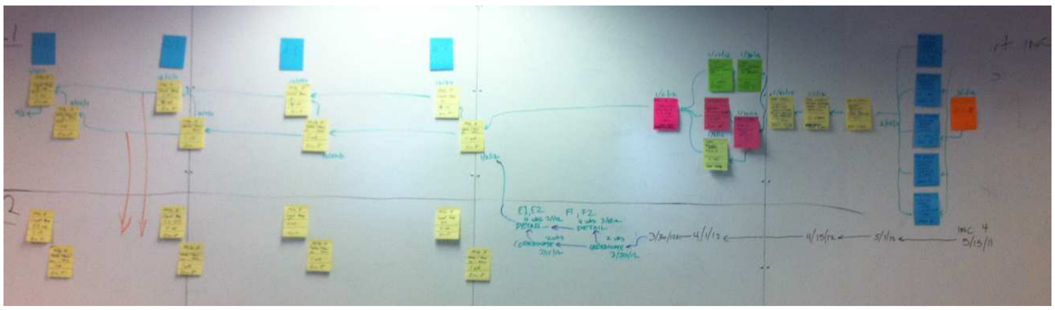


Figure 9: Pull Schedule for BIM Coordination (Source: Eric Osterling, Unger Constr.)

CONCLUSIONS

Relatively speaking, we are outsiders to the BIM community, yet we hope our observations will resonate with those in the field. Opportunities abound for making BIM coordination a lean process. In fact, it is very likely that efforts in that direction are underway, though results may as of yet not have been published. We here took a pass at defining some types of clashes and the related, underlying practices they mask. We believe that not only establishing a common language but also vigorous experimentation, documentation, analysis, and sharing of lessons learned, will further advance practice and development of theory, including design methodology.

ACKNOWLEDGMENTS

We owe many thanks to Andrew Sparapani and Hung Nguyen (HerreroBoldt), David Ring (OSHPD), Ben Tapparo (Southland Industries), Lauri Spitler (Turner), Eric Osterling and Jason Martin (Unger Construction), and others unnamed for sharing their thoughts on BIM coordination practices with us.

This research is funded in part by gifts made to the Project Production Systems Laboratory (P^2SL) (http://p2sl.berkeley.edu). All support is gratefully acknowledged. Any opinions, findings, conclusions, or recommendations expressed in this paper are those of the writers and do not necessarily reflect the views of the P^2SL members.

REFERENCES

AIA (2008). *AIA Contract Documents BIM Protocol Exhibit E202-2008.* American Institute of Architects, Washington, DC.

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

Gijezen, S., Hartmann, T., Veenvliet, K.Th., Hendriks, H., and Buursema, N. (2010). *Organizing 3D Building Information Models with the help of Work Breakdown Structures to improve the Clash Detection Process.* Univ. of Twente, The Netherlands, 30 pp., http://essay.utwente.nl/59401/1/scriptie_S_Gijezen.pdf, visited August 31.

GSA (2007). *BIM Guide for Spatial Program Validation, Volume 2.* US General Services Administration, Washington, DC, May.

Hickethier, G., Tommelein, I.D., and Gehbauer, F. (2012). "Reducing rework in design by comparing structural complexity using a Multi Domain Matrix." *Proc. 20th Ann. Conf. Int'l. Group for Lean Constr.*, San Diego, CA.

Howell, G. (2012). "Uncertainty and contingency: Implications for managing projects." *Proc. 20th Ann. Conf. Int'l. Group for Lean Constr.*, San Diego, CA.

Khanzode, A., Reed, D., and Fischer, M. (2007). "Benefits and Lessons Learned by Implementing building VDC Technologies for coordination of Mechanical Electrical and Plumbing Systems on a Large Healthcare Project." *ITcon*, 13, 324-342.

Kymmell, W. (2008) *Building Information Modeling, Planning and Managing Construction Projects with 4D CAD and Simulations.* McGraw Hill.

Mangan, J. (2010). *BIM Clash Detection.* Virtual Build, http://www.youtube.com/watch?v=gTGquTcmScU uploaded 15 Jan. 2010, visited 10 April 2012.

Mikati, S., Roller, T., Tommelein, I.D., and Khanzode, A. (2007). "Priority Conversations: A Case Study On Priority Walls." *Proc. 15th Ann. Conf. Int'l. Group for Lean Constr.* (IGLC 15), 18-20 July, East Lansing, MI.

Milberg, C. and Tommelein, I.D. (2005). "Application of Tolerance Mapping in AEC Systems." *Proc. Constr. Research Congress*, San Diego, CA, 5-7 April, ASCE, Reston, VA, 10 pp.

Nguyen, H. (2012). HerreroBoldt, Personal communication, email dated June 18.

Pietroforte, R. (1997) "Communication and governance in the building process." *Constr. Mgmt. and Econ.*, 15, 71-82.

Sacks, R., Koskela, L., Dave, B., Owen, R. (2010). "Interaction of Lean and Building Information Modeling in Construction." ASCE, *J. Constr. Engrg. and Mgmt.*, 136 (9) 968-980.

Sadonio, M., Tommelein, I.D., and Zabelle, T.R. (1998). "The LAST DESIGNER'S Database-CAD for Sourcing, Procurement, and Planning." *Proc. Computing Congress '98*, ASCE, pp. 364-375.