Application of BIM in Safety Analysis through a Factor Modeling Approach

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Abstract

This research studied current practices of safety analysis in the construction industry. It had a glance on conventional safety practices that do not contribute designers in studying safety of construction workers. This research focused more on recent safety studies that consider safety of construction workers early in the design as well as pre-construction phases. The research scope is limited to construction workers falls from heights. The identified available tools and their knowledge databases made the departure point of the research journey. The researchers studied the probable hazard scenarios in the aforementioned tools. The outputs of the literature review resulted in the impact factors of hazards within the research scope. These impact factors are used in the factor modeling approach. The impact factors are extracted from the recorded hazard scenarios in the past projects, as well as the checklists of the current safety study tools. Since the study is still ongoing, this paper presents the research methodology of the study as well as the preliminary results and the future steps. It leaves the research final results and the proposed framework for another venue. The authors claim that this approach is generic enough to be used for the hazards within the determined research scope.

Keywords: BIM, DfS, safety through design, DPFS, CHPtD, PtD

Introduction

The construction industry is on the top list of hazardous industries. This justifies the importance of safety research in this industry. A review of the literature identified “falls” as the top mortality source in the construction industry. Therefore, this research focuses on falls from heights.

Conventional safety practices have held designers responsible for safety of the end-users, and considered constructors responsible for the safety of construction workers. Design for Safety – along with its similar ideas e.g. Safety in Design, Prevention through Design, etc. – is an emerging idea to have designers consider construction workers’ safety early in the design phase. The philosophy of the Design for Safety is based on the idea that applying changes early in the design phase rather than the construction phase is more effective. Szymberski’s (1997) time-safety influence curve explains how construction workers’ safety can be influenced in the different phases of construction. Szymberski depicts that the ability to influence safety diminishes as the design to construction to operation phases progress.

This research is inspired by the Design for Safety (DfS) concept. It aims at “design”ing and “engineer”ing safety in the design as well as construction phases. BIM and parametric modeling are the tools that this research considers when designing its road for future developments.

Literature Review

History of safety in design roots back to 1985, when the International Labor Office (ILO) recognized the need for design professionals to be involved and to consider construction safety in their work. They recommended that consideration be given by those responsible for the design to the safety of workers who will be employed to erect proposed buildings and other civil engineering works (ILO, 1985). The continuation of this approach is seen in different regulations in the world mainly:

- The European Union Directive mandating consideration of safety in the design (CEC 1992)
- The United Kingdom's Construction (Design and Management) Regulations (HMSO 1994)
- Similar responsibilities that are placed on designers in some regions of Australia (Bluff 2003)
- The American Society of Civil Engineers (ASCE) policy on construction site safety (Policy Statement Number 350)

There are no rules or regulations set in the U.S. to enforce consideration of safety of construction workers in the design phase. Gambatese et al. (2005) believe that voluntary implementation of the concept in practice will likely depend on the benefits received from designing for safety compared to the effort and resources necessary for its implementation. Researches have been undertaken to study pros and cons of implementing DfS concept in practice. Studies by Whittington et al. (1992) and Suraji et al. (2001) showed that planning, scheduling, and design can have a significant effect on avoiding construction hazards. On the other hand, studies by Hinze and Wiegand (1992), Gambatese (1998), Gambatese et al. (2003), Hecker et al. (2004), and Toole (2004) identified various industry, project, and educational barriers to its implementation. Incorporation of construction safety knowledge in the design phase; and making design for safety tools and guidelines available for use and reference are the two key changes that Gambatese et al. (2005) mention for implementation of the concept in practice.

The rich literature of fatality studies in the construction industry shows a varying rate of mortality during the past decade. From 1980 to 1989 the construction industry had the highest annual average rate of deaths resulting from falls (Janicak 1998). NIOSH announced a rate of 6.56 per 100,000 workers (NIOSH, 1993). Nelson et al. (1997) presented the U.S. fatality rates in 1994 as U.S. construction workers experienced a death rate of 15 per 100,000 employees, the third highest fatality rate by major industrial categories (Bureau of Labor Statistics, 1995a). 29.9% of occupational fatalities in construction workers were due to falls (Nelson et al. 1997). It was the most common cause of death for workers in the construction industry (Bureau of Labor Statistics, 1995b). Huang and Hinze (2003) presented the statistics between 1990 to 2001 in Figure 1.

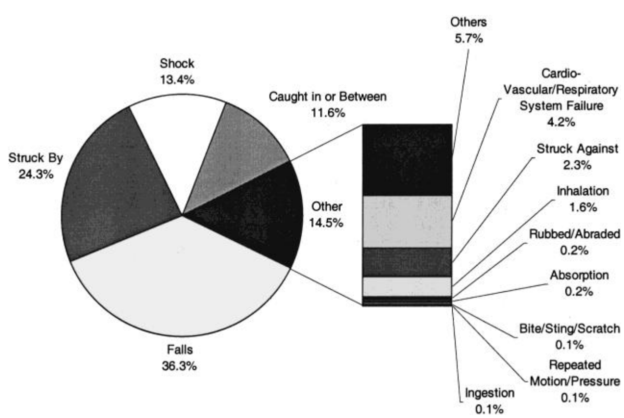

Figure 1. Causes of construction fall accidents investigated by OSHA (1/90-10/01)

There are scattered falls studies in some specific states of the U.S., e.g., Washington (Nelson et al. 1997) and Hawaii (Johnson 1998). Some other studies investigated the accountability of falls in each year. Cattledge et al. (1996) published the following statistics in their time of investigation: Occupational falls account for over 40% of all injuries (combining both fatal and nonfatal injuries) in the construction industry (Keyserling 1988; National Institute for Occupational Safety and Health 1993). Approximately

50% of all occupationally-related fatal falls occur in the construction industry and these falls represent 23% of all fatal injuries (United States Department of Labor 1991; Cattledge et al. 1993; Kisner and Fosbroke 1994).

Research Characteristics

Research Goal; To define a framework for hazard identification in BIM that will support the development of a BIM based hazard recognition tool. The intended BIM tool, that will be the scope a future research, will help construction designers to integrate hazard identification into the design process.

Research Question; What are the factors contributing to workers' falls from heights, and how should they be modeled in BIM applications in order to help safety analysts study them better?

Research Scope; This research studies falls from heights – as the primary source of injury and death in the construction industry – on construction projects. The research develops a framework for representing factors relevant to fall risks within a BIM environment by utilizing proposed algorithms, instructions, and methods that allows falls from heights to be included in the Design for Safety (DfS) process. The framework will allow future research for a BIM based tool. Programing and modeling the proposed BIM tool is beyond the scope of this research and can be covered in another research that uses the current research as the input. Proposing design alternatives or safety solutions is out of the future BIM tool's scope. Proposing alternatives and solutions is left to designers' discretion.

Research Deliverables; The deliverables of the research are twofold:

1. A framework for product/process modeling to analyze the impact factors of falls from heights. The framework is composed of a series of algorithms, instructions, and methods to identify and analyze the sources of falls. The research deliverable will be presented in the form of data structure and logic diagrams a comprehensive algorithm that guides software developer to develop the software.
2. Contributing factors of construction workers' falls from heights as the framework's inputs.

Research Contribution; The research helps software programmers to develop a parametric BIM tool that improves collaboration of designers and constructors in implementing DfS concept.
The state of the art software applications present generic and raw data of the probable hazards in construction projects. The currently available software applications do not engage the user in analyzing the data. They passively visualize the hazardous conditions without a clear identification of the specific hazards in the under-the-study project. The flowcharts presented in this research describe the properties of a model in a parametric BIM application that actively engages designer and constructors in collaborative study and analysis of construction projects.

This research presents its properties an intended parametric BIM model. This intended BIM model will have all the temporary and permanent objects pre-modeled in its library. Some of the objects come with their activities – that are necessary for safety study – embedded in them. The intended model automatically identifies fall hazards and reports them to the safety analysts.

Research Methodology

The goal of the study is to understand how BIM can support falls hazard identification. The research started with a literature study of the Design for Safety (DfS) concept. When this literature study showed a lack in the availability of the developed tools for DfS, the study steered towards investigating the researches and the available tools for the DfS concept. The developed tools for this concept can be categorized into different groups including ICT tools. This group uses 3D modeling, visualization, and BIM as the basis for information analysis in the identification and study of safety.

Three different sources are identified in the library study for identifying falls impact factors: CDC database, CHAIR, and ToolBox. These three sources are studied and summary notes of each hazard scenario are taken. Categorizing the scenarios and grouping them based on the similarities narrow them down towards identifying the falls impact factors. Presenting the impact factors through real examples helped identify the requirements for modeling these impact factors. Those requirements assisted the researcher in developing algorithms and flowcharts for the preliminary framework.

The preliminary results of the library studies are used to capture expert knowledge of design risks on falls hazards. An expert panel is selected to verify and expand the preliminary falls hazard factors and to establish the relationship between the factors.

Feedback of the expert panel will be added to the preliminary framework. It will help further develop the preliminary framework and turn it to the final framework. That framework comprehensively describes properties of a BIM model which will not be coded in this research.

The users of the final proposed framework (research deliverable) are the software developers in order to develop a BIM tool with the specified properties explained in the framework.

The final framework will be validated by a second expert panel. This second expert panel will evaluate how the proposed framework fulfills its goal, and how it contributes to the state of the art knowledge in the DfS field. At the end, the research will recommend the future directions for the research trend to be continued by other researchers.

The first panel's expected responsibility is to review and feedback on the developed framework as well as the contributing factors and the procedures taken. The first panel's feedback will be reflected in the preliminary framework and will guide further development.

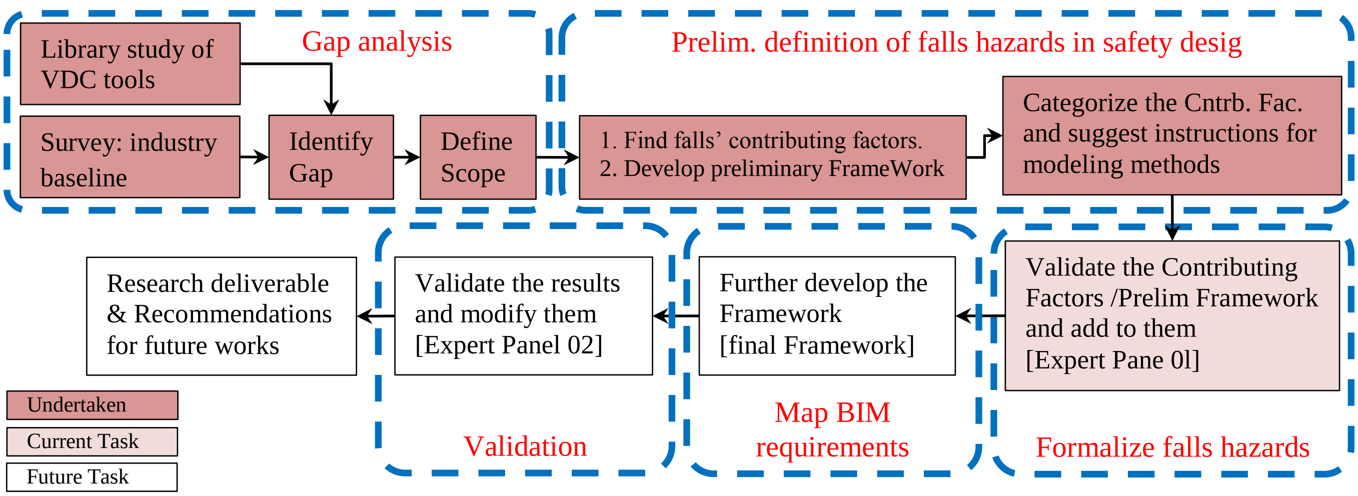

Figure 2. Research Methodology

Research Background

Occupational Safety Studies in Construction

Previous studies present a rich literature in occupational safety and health especially for falls in construction. There are two general groups of studies in this regard: traditional safety engineering and management that deals with on-site safety techniques, and recent safety studies that consider safety in design.

Since the scope of this research investigates shortcomings of IT tools in the DfS concept, the literature review focuses on this limit. Table below summarizes different types of ITC tools that assist construction safety. An extended explanation of each one is presented in the appendix 1.

Table 1. Comparative analysis of the current safety tools

No.		Functionality	Improvement	Shortcoming
1	Information-less Geometries	3D visualization of the building components	Better understanding of the building and spaces. Precise visualization of the critical components.	Does not consider the processes.
2	Information-less Geometries	Adding time to the 3D model of the building	Better understanding of how the components are put together, and the physical status of the building at any time	Does not show the method and process of constructing the building. Does not show temporary works and equipment. Time consuming procedure.
3	Information-less Geometries	Adding temporary equipment to the model	Visualize the construction process more in detail. Show how equipment and procedures cross over each other.	Equipment are not smart objects. They are places for playing with geometries of the building component/ equipment without any intellectuality in them. Most of the shortages of previous approaches still there exist, e.g. not showing the actual process of the construction.
4	Information-less Geometries	Adding movement paths of the objects	Illustrating the processes more clear and showing cross-over of the objects in the model	Not precise. Hard and time consuming to define.
5	Information-rich Geometries (BIM)	Adding historical hazard data of each object to its geometry	Exposes the analyzer to the probable hazards by walking through the model. It is a checklist which implements computer graphic (CG) for better illustration of the issue.	Does not simulate anything except the static geometry of the building. Induce this feel in the analyzer that all the hazards are in the data base while it is not.
6	Information-rich Geometries (BIM)	Adding data of the equipment to the VR environment	Analyzes the discrete events of construction processes with intelligent objects and equipment. Easier mock-up of the process.	Hard and time consuming. Just helps in the limited events which are simulated.
7	Information-rich Geometries (BIM)	Software automatically identifies some specific hazards	The software catches the hazard. It is not dependent on the analyzer's knowledge and expertise.	They are not advanced enough.

Researchers by Koo and Fischer (2000) shed light on a new direction of software development in the construction industry. Their conclusion implied that the construction industry needs a platform where the user can create and interact the information-rich components in a 4D (3D+time) environment. Bansal (2011) interpreted this need as a preface for a major revolution of BIM in the construction industry. He hopes this revolution will overcome the fragmented nature of the state of the art 4D CAD and BIM. Aouald et al. (2007) define the core concept of BIM as a single environment in which every component is described only once. This premise brings modeling, scheduling, and construction sequencing together to simulate the construction activities in a single environment for safety analyses.

Data Collection for the Framework

Data resources

Falls' impact factors are the main input component of this research. A review of the literature identified different resources for the study of falls hazards. The researcher studied the following resources and summarized the falls' scenarios.

- *CHAIR*

CHAIR01 is for design phase and has 119 bulleted prompted words. CHAIR02 and CHAIR03, which are for construction and maintenance phase, were studied as well. CHAIR02 and CHAIR03 have 38 and 11 prompted words respectively.

- *ToolBox database*

  This database was collected and stored during a long period between Sep09-Aug10. The collected database has 738 hazardous conditions and design alternatives.

- *Center for Disease Control & Prevention database (CDC)*

  This is a free online safety database that is developed by NIOSH. It contains a database of fatal construction accidents for a long period of time (since 80's). It is categorized based on different factors. The one being studied for this research is a 324 page report of all reported fatal falls in US construction industry from the 80's.

A prompt word or a sentence is written down from each scenario or checklist item, and in the second phase, they are grouped together and narrowed down to get them closer to the pure impact factors to consider. After a thorough study of them, the researcher found how he can reflect the concept of product modeling, process modeling, and geometric reasoning on these memos. Since the question was about having a "resource loaded model" for studying such hazards, the researchers tried to find relations between those memos and modeling objects and processes in the BIM world.

Table 1. Memos taken from CHAIR

Scaffold	Working Height	Public Movement	Lifting and Carrying Over Exertion
Material Handling	Sequence	Traffic	Combine Construction & Lifting Sequences
Delays	Obstruction	Object Properties	Stepping on or striking against objects
Access	People & Equipment Movement	Dust etc. Emissions	Dismantling/Erection
Roll Over	Entry/Exit points	Light/Visibility	Confined Space
Size / Width / Height	Extreme Weather (when close to edge)	Temporary Instability	

CHAIR database is made up of "Prompt Words", which are words or sentences that prompt the discussion between panel members in each session. This research extracted the prompt words that are related to falls from heights. Table 1 presents memos taken from CHAIR.

Table 2. Memos taken from ToolBox

Store / Ducking areas	Concrete forms	Wood temporary connections	Overhead work -> pipe (restraint cable along them)
Pip/duct passes over opening/edge	Lift Height (steel / pour / forms)	Side walk / stairway around elevated work	Drain – slipping – falling
Masonry work	Egress	Ceiling system	Pre-Paint/insulated pipe
Offsets of Varying Sizes in floor plan -> not repetitive work	Mechanical Equipment / Valve Location -> Obstruction / Clear Zone / Edge / Crane / Lift	Precast-CastinPlace concrete placement + procedure	Tank -> harness
Valve: clear zone / edge	Reuse of concrete form	Group openings	Ladder slope
Existing Structure – Integrity	Window sill	Steps in the floor	Ladder cage
Timely erection of stairway / handrail / permanent vs. temporary	Ramp / Stairway exposed to weather at north side -> unsheltered – parallel to structure	Roof opening away from edge of the structure/openings	Skylight away from rooftop Mech
Heavy Equipment Entering the Building / Placement	Column splice connection	Minimize roof pitch	Ladder length extend top of edge
Prefab on Ground and	Perimeter Beam and lifeline	Window installation process /	Ramp

Erection Process -> edges	support	maintenance	
Exterior Wall Structure (prefab / integrate with structure / asap in schedule)	Complicated work in height -> beam to column connection / reinforcing steel-form fabrication	Roof mechanical equipment away from edge of the structure/openings	Areas exposed / adjacent to open weather -> extend roofline / provide covering

ToolBox is developed under a research funded by the Construction Industry Institute (CII). That research included an investigation of the designer's role in construction worker safety. The research effort has identified and developed over 400 design suggestions. Table 2 summarizes safety notes related to falls from heights taken in the current research.

Table 3. Memos taken from CDC

Scaffold and window installation/maintenance.	When designing skylight see how strong sth/sb may fall on it (when it is in place) not to broken when sb/sth falls on it. worker steps/stands on skylights. They should tolerate the load.
No opening! Fall because panel broke at panel installation.	for Beam/Joist workers on height, provide tie-off points for worker who work in height – simulate to see where hookup points are needed and study the length of lanyard
When prefab type panels are being used, they would be placed and then fixed. Before they get fixed, they cover the opening but are not safe.	Material Dragging path
Roofing operation inspected for every single activity.	Replacement/Maintenance of windows (screws inside/outside)
Column installation should be investigated in detail i.e. how people detach column lift/harness cables when column is in place.	Study if truck crane and basket is being used for ppl transportation in height? It might hit things and cuz fall of whom working on them.
Working on a net of beams either with holes or holes covered by not-strong panels (insulation) is dangerous. Besides, working with very large panels is harder than smaller ones and diverts the attention from themselves to just controlling and placing panels.	When using tie-offs/lanyard, study how the workers are protected when they are moving (1. Why they are moving 2. How they are attached all the times)
Study people movement in congested area / confined space.	When placing mechanical units on consecutive openings, study the procedure of de-guarding the opening and safety condition at that time.
Roof work / anchorage ---- wood roof sheeting	Occasional access points i.e. access to storage, mech facility shouldn't be like an unprotected opening in floor --> makes hazard during maintenance.
Complicated work (column to beam connection) in height	Detail simulate every single second of flooring/roofing
Does the worker sometimes need to detach lanyard for a while? OR does the lanyard reach everywhere?	For placing beams and plates, study tie-offs for every single second + movement ability.
Carry large heavy materials on roof beam net	Attach/Detach of tie-offs when moving – feasibility
When securing an edge minimize the exposure time by changing the sequencing	Materials that cover the floor should have enough strength to support the expected load. If different materials are being used, the border should be clear and distinguishable.
Step on stack of shingles in roofing process	Tie-offs should not limit worker's maneuverability.
Study the process of installing safety tools	

Table 3 presents the summary notes taken the scenarios related to the scope of the current research.

Since the goal of the research was set to map the memos with the concepts of product modeling, process modeling and geometric reasoning, themes of categorizations were set based on these three concepts. A thorough study of the three aforementioned tables showed that those factors are related to at least one of these two groups:

1. Relate to Object; meaning that their representing parameters can be modeled in an object in the simulation / model. These predefined parameters can be activated automatically by catching their relevant factors in the surrounding conditions, or they need to be manually identified through a user.

2. Relate to People; meaning that their representing parameters are just related to human and cannot be modeled in the object in a suitable way. Agent based Modeling can be used for modeling and simulating them.

In the appendix 2, the items belong to the first category are showed by "O". The items belong to the second category are showed by "P". When the item belongs both first and second groups is marked by "O/P".

Tables 5-7 take one of the most effective steps towards mapping the previous categories to the three basic concepts of implementing this research. The intended modeling strategies in this research are product modeling and process modeling. The closer these strategies are to the geometric reasoning, the better the object modeling concept satisfies them. Reviewing them from this point of view groups them into three general groups:

1. Installation (INS)

   The items in this group should be modeled based on the concept of process modeling. The object families' construction processes are embedded in each family. Once an object family is called from the object library, its construction processes can be selected manually or the default of the program can be used. The model uses these processes for visualizing and studying installation of the object, and the hazards related to the object's installation process.

2. Movement Path (MP)

   The items covered in this group cover the hazards that originate from the movement path of either people or materials and how movement paths will create hazards. This group needs a 4D model to present them during the construction phase with their safety utilities installed. The movement path should be defined manually. A combination of product modeling and process modeling can represent this group in a BIM model.

3. Location (LOC)

   This group covers the hazard sources/factors that can be created by the objects and how they are statically located in the model. Product modeling fits the best for modeling this group in a BIM model.

Table 4. Installation (INS)

Working height close to edge / opening	
Temporary scaffold / ramp	Erection
Floor finishing (flat/sloped)	Material placement (layer by layer) Material processing / finishing
Study the process of safety tools installation	Guarding / De-guarding
Panel placement (prefab)	Placing Fixing (scaffold if needed)
Concrete forms vs. people position	Install (work in height) Tear down (work in height)
Exterior wall placement	Layer by layer
Need for complicated work in height	Beam to column connection Reinforcing Form
Type and number of works in heights	Pipe Place and install Finishing (paint, insulate, etc.) Suspended ceiling

Table 5. Movement Path (MP)

Material and Heavy Equipment	Movement Path Lift / Convey
Temporary scaffold / ramp	People movements (go in/out of scaffold around the work subject)
Other subs' movements close to edge	Material delivery People moving Between floors Within the same floor
Floor finishing (flat/sloped)	Material delivery in place
Panel placement (prefab)	Lifting
Concrete forms vs. people position	Move in Move out
Exterior wall placement	How people move
People transportation in height (if by truck crane)	People transportation in height (if by truck crane)

Table 6. Location (LOC)

Material and Heavy Equipment	Stacking location Placement (stack/install) adjacent to opening / edge Edge Conditions
Study the process of safety tools installation	Exposure time
Study tie-off	Points Lanyard length Area needed to be accessed (worker movement) Attach/Detach sequence Maneuverability
Panel placement (prefab)	After panel fixing If strong enough to step on If to avoid it Place then fix (unstable between placing & fixing)
Exterior wall placement	Where people stand
Offsets of varying sized in floor plan	Offsets of varying sized in floor plan
Number of openings	Number of openings
Length of edges	Length of edges
Proximity of mass work to the edges (Mech equipments, openings, etc.)	Proximity of mass work to the edges (Mech equipments, openings, etc.)
Stair	Exposure to weather Geographical side Edges Parallel / Perpendicular
Weather (snow/ice) and Edges	Weather (snow/ice) and Edges
Column splice / Edge protection (surrounding columns)	Column splice / Edge protection (surrounding columns)
Roof pitch and harness system / stopping edges	Roof pitch and harness system / stopping edges
Steps in floor close to edges / openings	Steps in floor close to edges / openings

Table 4, Table 5, and Table 6 helped researchers further direct the memos towards the model-able factors for the final framework of the research. “Related to People” can be interpreted as “Process Modeling” whereas “Related to Object” that can be interpreted as “Product Modeling”. The memos for “Related to People” are split into the “Work Space”, “Work Surface”, and “Movement Path”. The memos for “Related to Object” are split into the “Temporary Safety Structure”, “Discrete Model Checking Codes”, and “Lanyard Analysis”. However, some of the memos could not be placed easily in one of the six groups. They required Complex process maps of thinking, and none of the groups could satisfy them.

The following seven subgroups further narrow down the impact factors and present them closer to a framework’s instructions and algorithms:

Sp: Work Space
Su: Work Surface
MP: Movement Path
G: Temporary Safety Structure (Guardrail Placing)
MC: Discrete Model Checking Codes
LY: Lanyard Analysis
Cmplx: Complex process maps of thinking

The scenarios that did not fit in any of the top six subgroups are discarded from the scope of the proposed framework. They are marked as "cmplx" in the previous tables. Analyzing MC (Model Checking Codes) is already undertaken in similar studies (Qi1 et al. 2011), and its commercial software is already developed (Solibri™). Appendix 1 shows the scenario lists of the seven categories.

The remaining five categories are named "Pentagonal Groups." This research studied each of the pentagonal groups (as the research scope). It studies these groups to identify the elements (factors) that safety analysts need to beware of. The future BIM model is expected to (1) present those elements to the safety analysts and (2) simulate their interactions.

In order to reach this goal, each of the pentagonal groups is studied discretely. Appendix one summarized and narrowed down the falls scenarios (in form of the short notes) for each of the pentagonal groups (Figure 3).

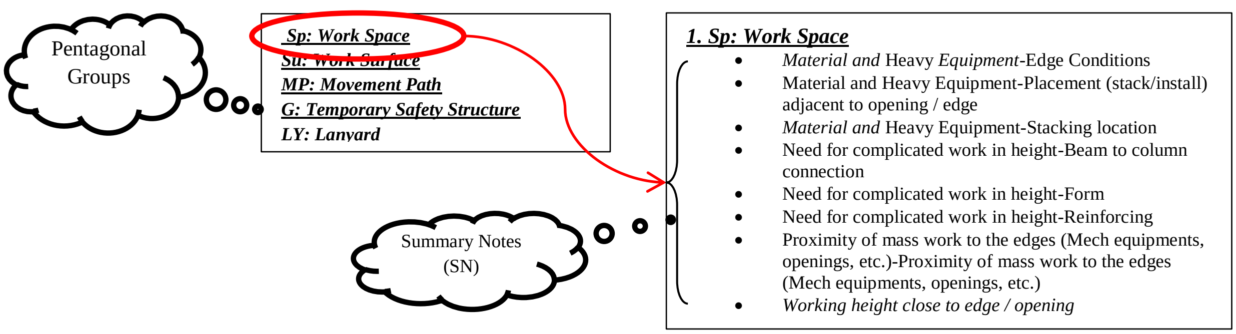

Figure 3. What are pentagonal groups and what are the summary notes (SN)

Within each of the pentagonal groups, one or more example scenarios will be developed. Those example scenarios should cover almost the entire realm of each group (Figure 4). Each example will explain hazardous conditions and the expected information to the safety analyst for the illustration and simulation. Hazard elements (impact factors) will be studied in that example and a SketchUp interface-model will illustration how the future BIM model will simulate the impact factors. Based on that example, a flowchart will be presented for each of the pentagonal groups. These flowcharts will guide a software developer to develop the BIM model.

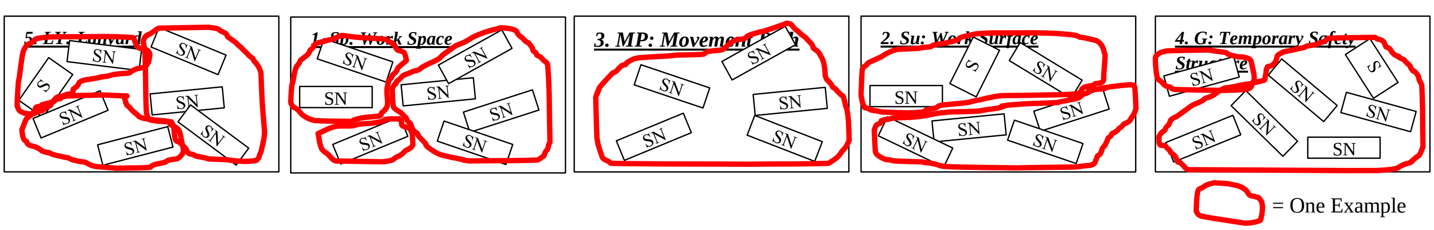

Figure 4. How the examples will cover the answer space

Searching for commonalities and governing rules in each group, the researchers tried to propose the most generic and comprehensive example in each group. These examples came from the scenarios, checklists, and prompt words that are summarized in the form of summary notes. Once all the flowcharts of each of pentagonal groups are developed, they are put together and are generalized for that group. The goal is looking for commonalities of these groups to reduce the flowcharts in each group.

All five pentagonal groups' flowcharts will be put together at the end in order to present the final deliverable of the research. The final comprehensive flowchart is planned to be presented to an industry panel. The feedback from the industry panel will add to the research findings and will open the road for further development.

Conclusion

When a new technology such as BIM emerges and makes the practitioners satisfied with its functionalities, researchers try to disseminate its application to the entire realm of the industry. A review of the state of the art DfS tools revealed a lack in the available ICT tools for DfS. They are mostly limited to visualization of the products as well as a limited visualization of some of the processes. Most of these tools are manual, project specific, and time consuming. While the current practices of ICT tools for DfS are passive practices and their visualization is manual, the goal of this research is to make them more interactive, and to make their simulation (vs. visualization) more automated.

Opposite to the current tools that visualize the interfaces and are more project specific, future tools should be more generic and should simulate the core (vs. visualize the interface) of the hazards. Modeling the impact factors is the approach this research implemented to take one step towards simulating the core of the hazard analysis in construction safety studies.

Since this research is part of a PhD dissertation and a master's thesis, and professional publications have presentation limits, the researchers decided to split the work into more than one paper. This paper presented the data collection and data categorization as well as the preliminary results. Future works will continue the mission of this research and will present the final results of the study.

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Appendix One

1. Sp: Work Space

Material and Heavy Equipment-Edge Conditions
Material and Heavy Equipment-Placement (stack/install) adjacent to opening / edge
Material and Heavy Equipment-Stacking location
Need for complicated work in height-Beam to column connection
Need for complicated work in height-Form
Need for complicated work in height-Reinforcing
Proximity of mass work to the edges (Mech equipments, openings, etc.)-Proximity of mass work to the edges (Mech equipments, openings, etc.)
Type and number of works in heights-Pipe (Place and install / Finishing (paint, insulate, etc.))
Type and number of works in heights-Suspended ceiling
Working height close to edge / opening

2. Su: Work Surface

Covering with large panels / carrying large heavy material when openings are on the way-Covering with large panels / carrying large heavy material when openings are on the way
Exterior wall placement-Layer by layer
Exterior wall placement-Where people stand
Floor finishing (flat/sloped)-Material placement (layer by layer)
Floor finishing (flat/sloped)-Material processing / finishing
Panel placement (prefab)-Placing
Panel placement (prefab)-After panel fixing-If strong enough to step on
Panel placement (prefab)-After panel fixing-If to avoid it
Panel placement (prefab)-After panel fixing-Place then fix (unstable between placing and fixing)
Panel placement (prefab)-Fixing (scaffold if needed)

3. MP: Movement Path

Exterior wall placement-How people move
Floor finishing (flat/sloped)-Material delivery in place
Material and Heavy Equipment-Lift / Convey
Material and Heavy Equipment-Movement Path
Other subs' movements close to edge-Between floors
Other subs' movements close to edge-Material delivery
Other subs' movements close to edge-People moving
Other subs' movements close to edge-Within the same floor
Panel placement (prefab)-Lifting
People transportation in height (if by truck crane)-People transportation in height (if by truck crane)
Temporary scaffold / ramp-People movements (go in/out of scaffold around the work subject)

4. Complex process maps of thinking → out of scope

Concrete forms vs. people position-Install (work in height)
Concrete forms vs. people position-Tear down (work in height)
Roof pitch and harness system / stopping edges-Roof pitch and harness system / stopping edges
Study column / roofing process in detail-Study column / roofing process in detail
Temporary scaffold / ramp-Erection
Concrete forms vs. people position-Move in
Concrete forms vs. people position-Move out

5. G: Temporary Safety Structure
Study the process of safety tools installation-Exposure time
Study the process of safety tools installation-Guarding / De-guarding

6. LY: Lanyard
Study tie-off-Area needed to be accessed (worker movement)
Study tie-off-Attach/Detach sequence
Study tie-off-Lanyard length
Study tie-off-Maneuverability
Study tie-off-Points

7. MC: Model Checking → out of scope
Column splices / Edge protection (surrounding columns)-Column splice / Edge protection (surrounding columns)
Length of edges-Length of edges
Number of openings-Number of openings
Offsets of varying sized in floor plan-Offsets of varying sized in floor plan
Stair-Edges
Stair-Exposure to weather
Stair-Geographical side
Stair-Parallel / Perpendicular
Steps in floor close to edges / openings-Steps in floor close to edges / openings
Weather (snow/ice) and Edges-Weather (snow/ice) and Edges

Appendix Two

Material and Heavy Equipment		
	O	Movement Path
	O	Stacking location
	O	Lift / Convey
	O	Placement (stack/install) adjacent to opening / edge
	O	Edge Conditions
Working height close to edge / opening	O/P	
Temporary scaffold / ramp		
	O	Erection
	P	People movements (go in/out of scaffold around the work subject)
Other subs' movements close to edge		
	O	Material delivery
	P	People moving
		Between floors
		Within the same floor
Floor finishing (flat/sloped)		
	O	Material delivery in place
	O	Material placement (layer by layer)
	O	Material processing / finishing
Study the process of safety tools installation		
	O	Guarding / De-guarding
	O/P	Exposure time
Study tie-off		

	O	Points	
	O	Lanyard length	
	O	Area needed to be accessed (worker movement)	
	O	Attach/Detach sequence	
	O	Maneuverability	
Panel placement (prefab)			
	O	Lifting	
	O	Placing	
	O	Fixing (scaffold if needed)	
	O/P	After panel fixing	
			If strong enough to step on
			If to avoid it
			Place then fix (unstable between placing and fixing)
Concrete forms vs. people position			
	O/P	Move in	
	O	Install (work in height)	
	O	Tear down (work in height)	
	O/P	Move out	
Exterior wall placement			
	O	Layer by layer	
	O	Where people stand	
	P	How people move	
Offsets of varying sized in floor plan	O		
Number of openings	O		
Length of edges	O		
Study column / roofing process in detail	O/P		
Proximity of mass work to the edges (Mech equipments, openings, etc.)	O/P		
Stair			
	O	Exposure to weather	
	O	Geographical side	
	O	Edges	
	O	Parallel / Perpendicular	
Weather (snow/ice) and Edges	O		
Column splice / Edge protection (surrounding columns)	O		
Need for complicated work in height			
	O/P	Beam to column connection	
	O/P	Reinforcing	
	O/P	Form	
Roof pitch and harness system / stopping edges	O		
Steps in floor close to edges / openings	O		
Type and number of works in heights			
	O	Pipe	
			Place and install
			Finishing (paint, insulate, etc.)
	O	Suspended ceiling	
Covering with large panels / carrying large heavy material when openings are on the way	O		
People transportation in height (if by truck crane)	P		