Tuning Up BIM for Safety Analysis
Proposing Modeling Logics for Application of BIM in DfS

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ABSTRACT

The construction industry is on the top list of hazardous industries. This justifies the importance of safety research in this industry. 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 such as Safety in Design, Prevention through Design, etc. – is gaining attention with the emerging paradigm of Integrated Project Delivery which promotes collaboration between designers and constructors through the entire delivery process. With Design for Safety concepts, designers and constructors can work together to enhance construction workers' safety early in the design phase. The philosophy of Design for Safety is based on the idea that eliminating hazards 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 phases from design to construction to operation progress.

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

This research limits its scope to construction workers falls from heights. The research presents a framework for representing falls hazards for future implementation in a BIM model in order to help the designers and constructors better study and analyze safety of construction workers. The research studied falls accidents recorded from past projects and proposed rules and properties for hazard identification in a BIM / parametric model. These rules and properties were abstracted and presented in the form of flowcharts and validated by an expert panel. The flowcharts will guide software developers for incorporating hazard identification functions into parametric BIM environments in future research.

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Table of Content

List of Figures

List of Tables

Chapter One

Introduction

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 will be the scope of future research and 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 represented in BIM applications in order to support hazard identification?

Research Scope

This research aims to contribute to the realm of safety as its ultimate target. However, construction safety is too broad of afield to cover all aspects of safety here. Therefore theresearcher attempted to limit the scope and to identify a safety hazard that has design implications to study in more detail.. A review of the literature identified falls as the main source of hazard in the construction industry. Falls are presented in three major groups in the literature (refer to chapter two).

- Falls of objects and materials from heights
- Falls of construction workers from heights
- Falls of construction workers in the same level

This research studies falls of construction workers from heights through openings and unprotected edges in construction projects. The research develops a framework for representing factors relevant to fall hazards 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 hazard identification tool. Programing and modeling the proposed BIM tool is beyond the scope of this research and can be covered in future research that uses the proposed framework as input. Generating design alternatives or safety solutions is beyond the scope of the proposed tool and Designers can use the proposed outcomes of this tool to manually develop safer design alternatives

Research Deliverables

The deliverables of the research are twofold:

1. A framework for representing falls from heights hazards. The framework is composed of a series of rule-based algorithms, instructions, and methods that are abstracted from analyzing the sources of falls. The research deliverable will be presented in the form of logic diagrams that integrate geometric data, non-geometric data properties and safety utilities.
2. Contributing factors of construction workers' falls from heights as the framework's inputs.

Research Contribution

Contribution of this research is to develop a framework for representation of falls hazards for future implementation into a parametric BIM tool that improves collaboration of designers and constructors in implementing the DfS concept.

The state of the art software applications present generic and raw data of the probable hazards during construction. Besides, 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. It can specifically identify the hazards in a specific project regarding its specific conditions. The literature review, chapter two, presents an argument that this issue needs to be more fundamentally addressed.

One of the most advanced researches in the literature is the research by Huang et al. (2007). They developed a prototype for studying a 70 story office building in Hong Kong. The prototype associated the building components with their construction activities. The temporary safety utilities were modeled as well, and coordinated with their associated building components. The model presented a platform for studying safety-constructability in that specific project. That prototype was completely manual, and as it is mentioned in its conclusion, modeling all the temporary and permanent components, as well as the activities associated to them is very time consuming.

The proposed BIM-based hazard identification model presumes that all temporary and permanent objects are pre-modeled in its library. Some of the building objects have embedded construction activities that are necessary for safety study. The intended model automatically identifies falls hazards and reports them to the safety analysts.

Following, the state of the art safety tools are explained and their shortcoming and the identified gaps are analyzed. Contribution of this research is presented in more detail afterwards.

State of the Art

A review of the literature delivers the current methods of utilizing BIM-VDC (Virtual Design and Construction) for construction workers' safety. They can be categorized in the following groups:

- Walking the safety analyst through the building model as it is designed to have him/her guess on the probable hazards of the construction phase based on their personal knowledge.
- Walking the safety analyst through a 4D model of the construction phase to have him guess on the probable hazards of the same phase. This model only illustrates the permanent components of the building but no safety utilities or temporary structures

- Connecting the model components (in their final mode) with a depository of relevant hazards. This model enables the safety analyst to walk through the building as it is designed and to review a list of probable hazards associated with individual building components by clicking on it.
- Manually modeling each part of the building in the expected level of detail with its required temporary components. The model visualizes a snapshot (or a series of snapshots) to the safety analyst (discrete event simulation).

The literature study revealed shortcomings of the current VDC/BIM tools for safety. The first and second categories are primarily used for design and construction planning purposes but not specifically intended for safety analysis. The third category incorporates construction safety considerations similarly to conventional checklist but links it to a 3D model. The fourth category involves safety utilities, temporary structures into a 4D model thus allowing more specific visualization of spatial and time conflicts. However, hazards recognition is still prompted by the safety analyst's personal knowledge. Thus, current BIM-VDC systems lack hazards information or fail to effectively present hazard information to promote hazard recognition. The software focuses on general construction planning or design issues but and does not engage with analysis of the hazards.

Contribution of the Research

The step this research takes beyond the state of the art is to change the passive visualization and presentation of the generic data of hazards to an active (vs. passive) visualization and analysis (vs. presentation) of hazards' information (vs. generic data).

The research proposes a framework for developing a representation of falls hazards in construction to integrate with BIM models. The components of the proposed model embed their spatial-temporal data as well as their relevant temporary safety utilities. This model visualizes a 4D simulation that simulates the building in the construction phase with the temporary and permanent components, as well as analyzes how the impact factors of falls interact with each other. It is important to emphasize that the framework presumes temporary safety utilities and safety factors are embedded in the "object families" by the software programmer, and the modeler/analyst does not need to manually model them. Once a permanent object is "called" from the "library", its relevant features, such as the safety utilities, the impact factors, and how they should be represented, are already called into the model. As a result, the 4D simulation presents them together in their proper time and illustrates the results to the safety analyst either through visualization or an exported report.

This research neither claims to identify all the impact factors of falls from height, nor claims to develop a framework that incorporates all the identified impact factors in the literature. The scopes of the impact factors and the framework are described in their relevant section. Scope delimitation is presented twice and the hazard identification area is narrowed down by following the delimitation logic.

Examples of the analyses of the impact factors are: auto analyzing when, how, and why the edges are safe/unsafe; clearance of material delivery paths; adjacency of the work with the edges; efficiency and applicability of the PPE; etc.

Contribution of this research are (1) the identification of a gap of hazard identification in the DfS and BIM literature; (2) the identified contributing factors to falls from height hazards– come from the research sources and ; (3) the representation of hazards in BIM environments and (4) the proposed approach of the framework which is replicable to other construction hazards representation in BIM environments

Research Methodology

The goal of the study is to understand how BIM can support falls hazard identification. The research started with the study of the Design for Safety (DfS) concept. When the shortcoming in the availability of the developed tools for DfS was identified, the study steered towards investigating existing research 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.

Parallel to the literature review, a survey of the construction industry was conducted. 70 general contractors, sub-contractors, and designer companies with the main focus on the south east region were selected as the survey pool. The survey asked them about their familiarity with the DfS concept and how they implemented it in their processes. The survey is explained in detail in a paper by Ku and Taiebat (2011).

Through the study of the literature and the industry survey of DfS a gap in the existing tools was identified This defined the research scope and inclusion / exclusion of the topics. Three different sources were identified in the library study for identifying falls impact factors: CDC database, CHAIR, and ToolBox. They were studied and summary notes of each hazard scenario were taken. Categorizing the scenarios and grouping them based on the similarities narrowed them down towards identifying the falls impact factors. Presenting the impact factors through real examples helped identifying the requirements for modeling them. This assisted the researcher in developing algorithms and flowcharts for a preliminary framework.

The preliminary results were used to capture expert knowledge of design risks on falls hazards. An expert panel was selected to verify and expand the preliminary falls hazard factors and to establish the relationship between the factors. The proposed categories along with the developed flowcharts needed to be validated by an expert panel through a structured process for collecting and distilling knowledge from a group of experts with controlled opinion feedback (Adler and Ziglio, 1996).

The best choice for the expert panel was a group composed of designers and constructors who are engaged in hazard identification in design-build with the DfS as the project requirement. More detail description about the data validation was presented in the next section.

Feedback of the expert panel was added to the preliminary framework. It helped to further develop the preliminary framework and turn it to the final framework. That framework comprehensively describes properties of a hazard representation for a BIM model.

The users of the final proposed framework (research deliverable) are software developers and construction modelers who can incorporate the specified properties for falls hazard identification explained in the framework.

The final framework was validated by a second expert panel. The expert panel evaluated how the proposed framework fulfills its goal, and how it contributes to the state of the art knowledge in the DfS field. Recommendation for future directions were collected.

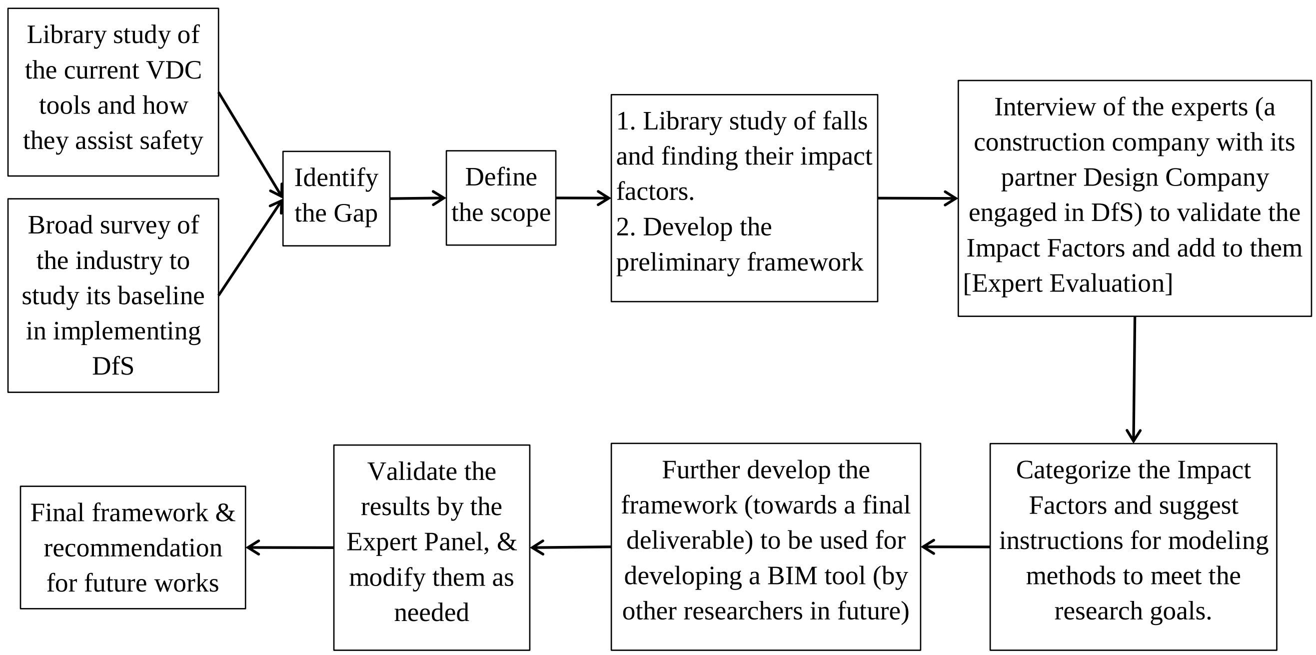


Figure 1. Research methodology

Data Validation

The “Research Deliverables” section talked about the final outputs of this research. The research keeps a specific parametric BIM model in mind, and sheds light on its required “properties” for hazard representation through the presented flowcharts. This research explains the ‘properties” that are necessary in a BIM model for falls hazards representation in the design and construction planning phases. Flowcharts, which are the final deliverables, are used to explain such properties.

The research included visualizations of specific falls from height scenarios to illustrate the required properties for hazard representation. Instead of developing a proof of concept prototype, this research involved an Expert Panel that validated to proposed hazard representation framework.

The first step to set up a proper panel for this research was to identify the expectations of the research from the panel. The first step was to select a panel with the following expertise:

- *General Construction Knowledge:* this skill is the fundamental requirement for understanding and criticizing the context of the research.
- *Safety:* since this research is about Design for Safety, expertise in knowledge (administration) and practice (implementation) of safety is required for the reviewing panel. This research needs input from an expert in hazard identification in the design or preconstruction phase.
- *BIM:* this research develops an intermediate tool for developing a BIM application in the future. Understanding of BIM is the basic tool for evaluating this research.
- *Parametric Modeling:* the objects in the intended future BIM model will be modeled based on the concepts of parametric modeling. The objects identify themselves to each other and understand their surrounding conditions through the parameters.
- *Clash Detection:* clearance of Movement Paths (MP) is studied through the Boolean calculations of the interferences in the future BIM model. Knowledge of Clash Detection can help the reviewer validate accuracy of the assumptions of the framework.
- *4D Planning:* the framework studies construction safety in a 4D simulation of the model.
- *Design:* the research studies Design for Safety (DfS) and the contribution of preconstruction planning in the safety. Therefore, design – as the representative of a group of stakeholders – needs to have a voice in the reviewing panel.

The panel's required skillsets were used as the expert panel members' selection criteria The suggested members had the skillsets had diverse enough backgrounds to allow exchange of ideas. This resulted in a more comprehensive feedback on the developed framework. The proposed panel had the following experts:

- *Safety Expert:* this expert will be chosen from the Virginia Tech Safety Center.
- *General Contractor:* a general contractor that has a good track of implementing safety design in the preconstruction phases of the construction will be chosen for the panel. The industry baseline survey is a proper source to look for such expertise.
- *Subcontractor:* a subcontractor that works with moving materials in the building and works in height is required for this panel. This best choice can be identified by the participating general contractor.
- *BIM Software Developer:* this expertise can help in evaluation of programmability of the framework and its compatibility with BIM and parametric modeling.

- *Designer:* the intended BIM model is expected to work for a designer. Therefore, a designer can be a voice of a group of the stakeholders.

The panel's expected responsibility was to review and feedback on the developed framework as well as the contributing factors and the procedures taken. Their feedback was reflected in the preliminary framework and further developed.

The final framework was presented to a (second) panel. The second panel had more experts in order to eliminate the bias of the first panel. The first panel recommended additional experts who were included in the second panel. The framework was presented to both panels in a summarized form either in person or remotely. The presentation was set up before the panel sessions and the panel was set up through video conferencing and members who were physically present on the Virginia Tech campus. A safety expert – from the Virginia Tech Safety Center – led the sessions.

Dissertation Structure

After chapter one presents the outline of the research, chapter two reviews safety literature in the construction industry.

Chapter Two starts with a history of falls from heights and their mortality record. Occupational safety studies in construction are reviewed in two sections to explain and compare traditional safety studies and recent changes in researches' attitude towards safety in the construction industry. The concept of Design for Safety and similar concepts are studied and compared in a table. Necessity of the DfS for improving safety in construction is discussed there. Later on, current tools developed to support DfS concept are studied. The advent of IT tools is specifically explained in detail and their properties are described. Abundance of concepts similar to DfS led the researcher to define a specific term Design and Planning for Safety (DPfS) and explain it in detail and define its inclusive/exclusive factors. The research will be based on the DPfS concept.

Chapter Three identifies the data sources for hazard records in the construction industry. It identifies three different sources: one hazard record, one safety checklist, and one safety review prompt-word series. The researcher reads through those sources and summarizes any hazard clue or hazard scenario. Considering the concepts of product modeling and process modeling, the researcher categorizes the summary notes into seven groups. Two groups out of these seven groups are set out of the research scope. "Scope Delimitation" justifies why the scope is redefined. The remaining five groups, called pentagonal groups thereafter, are forwarded to chapter four for more detailed studies.

Chapter Four starts by explaining the chapter's mission, which is turning hazard summary notes into flowcharts. Those flowcharts explain the properties of the "intended model." This section explains how chapter four accomplishes its mission. The next section explains the structure of the chapter's remainder. It starts with giving a general description of the intended model and its basic properties. These basic properties are considered to develop the pentagonal groups' requirements in the intended model.

Each of the pentagonal groups turns into flowchart in five steps. The first step, Information Analysis, presents a general overview of the group and the hazard aspects the group deals with. Second step clarifies the specific goal of the intended model that the current group is trying to fulfill by explaining its properties. The third step depicts an example of one of the most common shortcomings that the current group aims to cover. Analysis Procedure, step four, explains the properties the intended model has to have, and clarifies how the model meets the goal. The flowcharts illustrated at the end are the abstractions of the procedures explained in step four in the form of a diagram.

Contribution of this research in the knowledge of BIM's application in DfS is the developed framework as well as the identified contributing factors – come from the research sources – and the proposed approach that this research took for reaching to the framework.

Chapter Five explains how the first and second panels are selected and they are set up. It further talks about the discussions of the panel members. This chapter categorizes the discussions and makes conclusions out of the discussions and comments between the panel members. It creates the final flowchart and represents it from different perspectives in order to make it easier to understand.

Chapter Six reviews the whole research and presents conclusions from the research. It explains a tangible meaning of the research to the reader. This chapter recommends future directions for this research.

Chapter Two

Research Background

Introduction

Designing for construction safety entails addressing the safety of construction workers in the design of the permanent features of a project (Gambatese et al. 2005). As an intervention, it is supported by the hierarchy of controls common to the safety and health professions which identifies designing to eliminate or avoid hazards as the preferable means for reducing risk (Manuele 1997). This breakthrough idea for improving construction site safety, as noted by Korman (2001), is gaining support in the construction industry. History of safety in design roots back to 1985, when the International Labor OYce (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)

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 (Gambatese et al. 2005). While studies by Whittington et al. (1992) and Suraji et al. (2001) showed that a significant number of hazards can be avoided upstream of the construction process during planning, scheduling, and design, numerous industry, project, and educational barriers to its implementation have been cited (Hinze and Wiegand 1992; Gambatese 1998; Gambatese et al. 2003; Hecker et al. 2004; Toole 2004). 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.

Falls in Construction Industry

Although safety is one of the very concerns of human being, the construction industry is one of the most unsafe places to work (Carter and Smith 2006). Statistics from the Health and Safety Executive (HSE) show that U.K. construction workers are approximately five times more likely to be killed and two times more likely to be seriously injured compared to the average for all industries (HSE 2000; Whitelaw 2001). U.S. construction workers are over three times more likely to be killed than the all-industry average, and one in six construction workers can expect to be injured every year (Kartam 1997). The rich literature of fatality studies in construction shows a varying rate of mortality during the past decade. However, those rates always showed high rates of fatalities for the construction industry.

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. (1996) 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). Injury and illness rates in the same year was reported 11.8 per 100 employees, the second highest of all major industrial categories (Bureau of Labor Statistics, 1995). 29.9% of occupational fatalities in construction workers were due to falls (Nelson et al. 1996). It was the most common cause of death for workers in the construction industry (Bureau of Labor Statistics, 1994). Huang and Hinze (2002) presented the statistics between 1990 to 2001 in the following Figure 2.

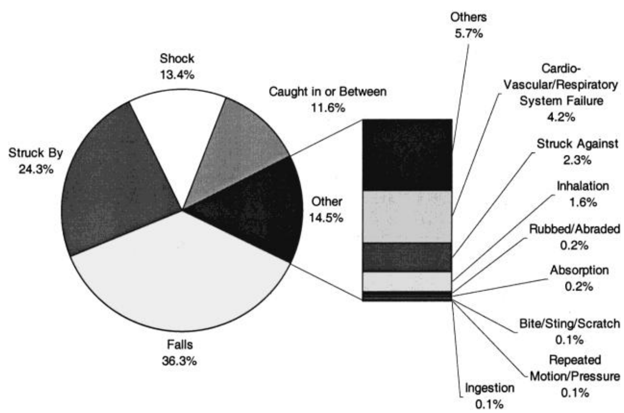


Figure 2. Causes of construction fall accidents investigated by OSHA (1/90-10/01)

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).

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.

Traditional Safety Studies

Huang and Hinze (2003) categorize the previous construction workers' safety studies, and present one sample study from each:

- Singh (2000) investigated fall accidents occurring on low-rise roofs and evaluated some innovative fall protection measures. He concluded that no single method of fall prevention would prevent all falls on low-rise roofs, but determined that prefabrication was the most promising method, followed closely by the personal fall arrest system (PFAS) and its variants.
- Duncan and Bennett (1991) reviewed the performance of various fall protection systems and concluded that both active measures (those that prevent workers from falling, for example, guardrails) and passive measures (those that protect workers after falling, for example, safety nets) are useful in reducing fall injuries.
- Vargas et al. (1996a, 1999b) developed an expert system that analyzed the causes of construction falls by using fault-tree methods and concluded that guardrails, safety nets, and PFAS can all be inadequate, under differing circumstances.

Zou et al. (2008) believes that traditional approaches to safety risk management have been focused on techniques and management tools related to the identification of on-site work hazards; developing safety management systems, safety procedures and standards; improving physical working conditions such as the selection of plant and machinery and site access; training site workers; developing better work methods; and providing personal protective equipment (Hinze and Harrison, 1981; Holmes et al, 1998; Reese, 2003; Biggs et al, 2005).

Besides these groups, there are some other studies that prepared input for the aforementioned studies. They collected fatality and injury records, and identified the hazard sources and their share in the fatality and injury records (Huang and Hinze 2003; Cattledge et al. 1996; Janicak 1998; Nelson et al. 1997; Derr et al. 2001).

Janicak (1998) studied construction fatalities in the following categories:

1.Structural collapse	2.No fall protection present	3.Fall protection not attached
4.Damaged fall protection	5.Improper work surface	6.Erecting/dismantling scaffolding
7.Fall from ladder	8.Other	9.Unknown

Recent Safety Studies

Design for Safety (DfS) is a new concept that suggests considering safety during the upstream phases of the construction – the design phase. Studies range from basic concepts such as the viability of the concept and proving the link between design and construction workers' safety (Gambatese et al. 2005; Gambatese et al. 2008). Subsequent studies focused on the importance and effectiveness of the DfS concept and its advantages and disadvantages on construction projects and its productivity (Hecker et al. 2005). Proximity of the DfS concept with emerging concepts in construction such as green construction and sustainability (Behm et al. 2009; Sathyanarayanan 2006; Gambatese and Rajendran 2007) expands the DfS literature. Design for Safety is evaluated and criticized from different angles. The general goal of these studies was to justify the different aspects of the concept.

Tradeoff study between safety and cost (El-Rayes and Khalafallah 2005), interaction of safety and quality (Das et al. 2008), DfS and designer liability (Gambatese 1998; Behm 2008), and contractual risks of implementing DfS concept (Loosemore and Mccarthy 2008) as well as its insurance risk (Braun 2008) are some of the aspects studied in the literature of Design for Safety. The goal of such studies was to justify the viability of the DfS concept from different points of view. The studies were undertaken further in detail and investigated the role of designers /engineers (Gambatese et al. 2008), constructors (Mills 2009), and owners (Gambatese, J., 2000; Huang and Hinze 2006) in their collaborations. The concept is also studied from the contractual side (Loosemore and McCarthy 2008) to understand thecontractual risks.

When the researchers investigated the ground for the DfS concept and shed light on it, applied research sought ways to incorporate decisions pertaining to occupational safety design (Manuele 2008). Several tools, mainly checklist based (Gambatese et al. 1997; Navon and Kolton 2006), are developed in order to assist the designer and safety analyst in identifying hazards, proposing design alternatives, and changing the means and methods of construction. Some researchers looked at DfS as a whole process and shed light on required research issues in DfS as well as the trajectory of DfS for the future of the construction industry (Toole and Gambatese 2008; Gambatese 2008).

Concept of DfS

Designing for construction safety as an intervention is supported by the hierarchy of controls common to the safety and health professions which identifies designing to eliminate or avoid hazards as the preferable means for reducing risk (Manuele 1997). Codes and standards keep designers responsible for the safety of the final building, and constructors for the safety of construction workers. The literature of safety in design goes back to the European Union treaty on 1992 which mandates consideration of safety in design (CEC 1992). The United Kingdom's Construction (Design and Management) Regulations (HMSO 1994) established to comply with the EU Directive. Some states of Australia place similar responsibilities on designers (Bluff 2003) for consideration, evaluation, and control of occupational safety and health during construction (NSW Construction Policy Steering Committee 2000). In the U.S., the American Society of Civil Engineers (ASCE) states in its policy on construction site safety (Policy Statement Number 350) that engineers shall have responsibility for "recognizing that safety and constructability are important considerations when preparing construction plans and specifications." Manuel (2008) believes that the Prevention through Design (PtD) initiative, which is a similar concept to DfS, is based on the premise that "one of the best ways to prevent and control occupational injuries, illnesses and fatalities is to design out or minimize hazards and risks early in the design process" (NIOSH 2008). This definition limits activities to "early in the design process."

At a July 2007 workshop that brought key PtD stakeholders together, many participants called for the concept to be extended to include redesign activities, much as the following definition does: "PtD: Addressing occupational safety and health needs in the design and redesign processes to prevent or minimize work-related hazards and risks associated with the construction, manufacture, use, maintenance and disposal of facilities, materials, equipment and processes" (Manuel, 2008). The National Institute for Occupational Safety and Health (NIOSH) has recognized PtD as a highly promising safety approach. In 2006, PtD became one of ten focus areas of the National Occupational Research Agenda (NORA) Construction Sector Council (National Construction Agenda 2008).

While the merits of designing for construction safety are evident, implementation in practice throughout the United States is minimal to nonexistent (Gambatese et al. 2005). Numerous barriers to its implementation and key changes needed for implementing the concept in practice have been cited (Hinze and Wiegand 1992; Gambatese 1998; Gambatese et al. 2003; Hecker et al. 2004a; Toole 2004, Gambatese et al. 2005). One of such beneficial key changes is to make design for safety tools and guidelines available for use and reference, which is the subject of this research.

Definition of DfS and Similar Terms

The necessity of the topic led activists to pursue the intervention of designers in construction workers' safety. An initiative was funded by NIOSH named as <u>Prevention through Design (PtD)</u>. Designing for construction safety as an intervention is supported by the hierarchy of controls common to the safety and health professions which identifies designing to eliminate or avoid hazards as the preferable means for reducing risk (Gambatese et al. 2005; Manuele 1997). Gembatese et al. (2005) state: <u>Designing for construction safety</u> entails addressing the safety of construction workers in the design of the permanent features of a project. The design defines the configuration and components of a facility and thereby influences, to a large extent, how the project will be constructed and impacts the consequent safety hazards (Gambatese 2000).

The NIOSH mission is to reduce the risk of occupational injury and illness by integrating decisions affecting safety and health in all stages of the design process (Manuele 2008). A definition of PtD was written that limited the activity to "early in the design process." At the July 2007 workshop of NIOSH, a large number of participants wanted the concept extended to include the redesign activities in which they are participants. A revised definition is written later. Prevention through Design (PtD): Addressing occupational safety and health needs in the design and redesign processes to prevent or minimize the work-related hazards and risks associated with the construction, manufacture, use, maintenance, and disposal of facilities, materials and equipment (Manuele, 2008).

The definition as presented above from the NIOSH workshop does not provide a clear definition. In other words, it is not obvious which aspects are included and which aspects are excluded, who is involved and who is not. In a paper published one year after this recent definition, Behm (2008) disputed the definition and its scope: With many different views of what PtD is, and questions about who should engage in it, and at what sequence in the construction life-cycle it should be put into practice, a great need exists for NIOSH to define PtD in the construction sector. Some of the many queries are: Is it design or is it redesign? Are all engineering controls considered under the umbrella of PtD? For example, if someone designs a better scaffold, is that PtD? Or is PtD about seeking methods to reduce work at heights through better project design? Or are both examples of PtD? For these reasons, one recommendation is that NIOSH, or some other consensus body (i.e., the American National Standard Institute (ANSI)), should define PtD in the construction sector. Stemming from whatever that definition is, a consensus for PtD standard needs to be developed (Behm, 2008).

While Toole and Gambatese (2008) define Construction Hazards Prevention through Design (CHPtD) as a process in which engineers and architects explicitly consider the safety of construction workers during the design process, Manuele (2008) gives a more detailed definition: Addressing occupational safety and health needs in the design and redesign processes to prevent or minimize the work-related hazards and risks associated with the construction, manufacture, use, maintenance and disposal of facilities, materials, equipment and processes. The second definition expands the borders of PtD to the following phases of construction e.g. maintenance and disposal.

Design for Safety (DfS) is another topic stemming from the same concept and overlaps PtD in some areas. ASSE (1994) defined DfS as: Designing for safety (DFS) is a principle for design planning for new facilities, equipment and operations (public and private) to conserve human and natural resources and, thereby, protect people, property and the environment. DFS advocates systematic processes to ensure state-of-the-art engineering and management principles are used and incorporated into the design of facilities and overall operations to ensure safety and health of workers, as well as protection of the environment and compliance with current codes and standards (ASSE, 1994). This definition covers more than worker's safety. It includes property and environment as well.

Safety through Design is another term that is broader than the NIOSH PtD initiative. Manuele (2008) defines it as: The integration of hazard analysis and risk assessment methods early in the design and redesign processes and taking the actions necessary so that the risks of injury or damage are at an acceptable level. This concept encompasses facilities, hardware, equipment, tools, materials, layout and configuration, energy controls, environmental concerns and products.

Some pioneers tried to compare this topic with "Constructability Review". Gambatese (2000) defines constructability review as: Project constructability involves the incorporation of construction knowledge in a project's design. He encourages the reader to think of safety constructability as a subset of overall project constructability. "Addressing construction safety in the project design" is what he means by safety constructability. Toole and Gambatese (2008) forego the adjacency of these two concepts and look at the PtD concept as another aspect of designing for constructability, i.e., the design is reviewed to ensure it can be constructed safely, and meets cost, schedule, and quality goals.

Table 1 summarizes some of the dominant terms in the "Safety in Design" realm and compares their similarities and dissimilarities.

Table 1. Similar terms for Safety-in-Design concept, and their properties

Term	Target	Phase of working / Tool	Phase of effect
Design For Construction Safety	Construction worker	Design/ReDesign Permanent feature	*Ambiguous!*
PtD (Prevention through Design)	Construction worker	Building, material, equipment (all)	Life cycle
CHPtD (Construction Hazard Prevention through Design)	Construction worker	*(Context implies)* Design	*(context implies construction but) Ambiguous!*
DfS (Design for Safety)	People, Property, Environment	Design Planning	Life Cycle
Safety Through Design	All type of Injury & Damage	Design/ReDesign	Life Cycle

Necessity of DfS

The safety record of the construction industry continues to lag behind all other industries, except for agriculture and mining (NSC, 1998), and a mindset still exists within the construction industry that construction work is inherently unsafe. For example, in 2004 the construction industry employed 7% of the workforce, yet accounted for 23% of all work-related fatalities in the United States (Bureau of Labor Statistics, 2004; NIOSH, 2004). In addition to fatal injuries, workers in these industries are at risk of injury or illness due to 'contact with' objects, falls to a lower or same level, overexertion and excessive noise. Specifically in the US nearly 100 laborers death per month is reported (Behm 2008).

Although the concept of PtD was under discussion earlier, it came officially into the NIOSH July 2007 workshop, which led to an initiative in this context. The goal of this initiative, founded on the need to "create a sustainable national strategy for prevention through design," is to "reduce the risk of occupational injury and illness by integrating decisions affecting safety and health in all stages of the design process." Prevention through Design (PtD) has been recognized and implemented internationally as a feasible method to reduce construction worker risk (HMSO, 1994; WorkCover, 2001).

Designing to eliminate or avoid a hazard is given higher priority than simply controlling the hazard or protecting the workers from the hazard (Manuele, 1997). Szymberski's time-safety influence curve (Szymberski, 1997) illustrates how safety can be influenced to the greatest extent in the early phases of a project. Gambatese et al. (2005) showed the general relationship between design efforts and the associated additional project costs in figures similar to Figure 3.

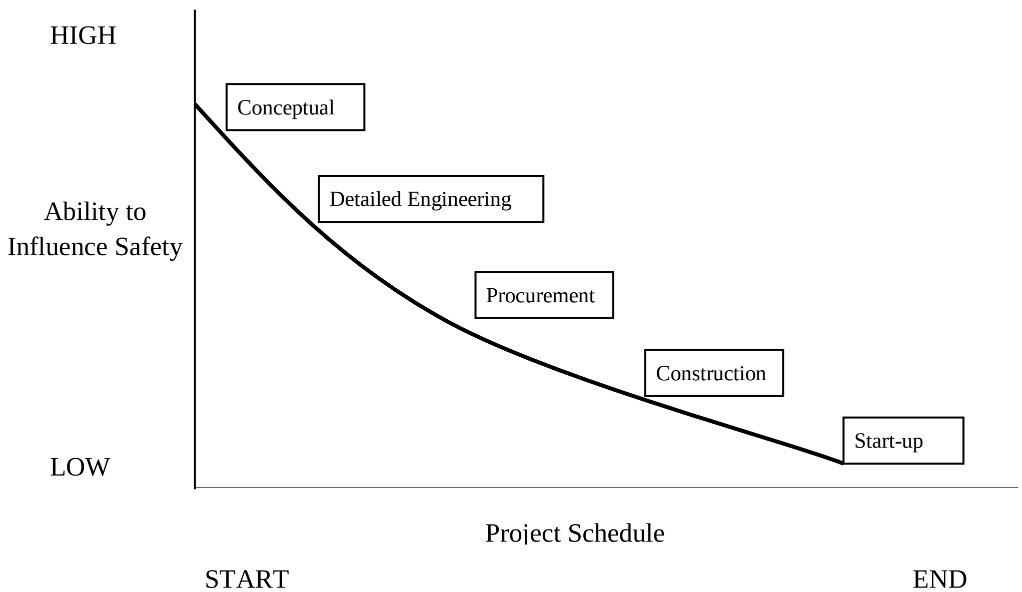


Figure 3. Time/Safety Influence Curve. The ability to influence safety diminishes as schedule goes to end.

Yam et al. (2007) refer to CDM and HSE texts that emphasize on "combating risk at the source" and "consider the risk from the hazards which arise as a result of the design being incorporated into the project; if possible, alter the design to avoid the risk, or where this is not reasonably practical, reduce it."

The Occupational Safety and Health Administration (OSHA) standards relate to the safety of the construction site, the implementation of safe work practices, and the safety of temporary structures, such as fall protection, ladders, scaffolding, and excavations, all of which are typically part of the constructor's responsibilities on a project. The engineer's scope of work, namely the design of the permanent structure, is not directly addressed in the OSHA standards. Nonetheless, engineers are required to be involved, as stipulated in some regulations (Gambatese et al. 2003).

Toole and Gambatese (2002) brought to attention some of the OSHA construction regulations that specifically refer to engineers' input on temporary construction structures and engineer involvement during the design phase.

Before having the aforementioned concerns, it is necessary to ensure that design can affect construction worker's safety. Many studies have been done and data are collected to prove the link between design and worker's safety. Gambatese et al. (2008) believe that the relationship between project characteristics and safety performance is complex with many impacting variables. While the methodologies selected for the research studies differ, all of the studies indicate that a link exists. Jeffrey and Douglas (1994), for example, conducted a review of the safety performance of the United Kingdom's construction industry and conclude that in terms of causation there is a definite link between design decisions and safe construction. Trethewy and Atkinson (2003) maintain that design professionals influence construction worker safety and health outcomes both directly and indirectly. Hecker et al. (2005) and Weinstein et al. (2005) reached the same results.

Outside US, the European Foundation (1991) claimed that 60% of the accidents it surveyed could have been eliminated, reduced, or avoided with more thought during the design stage. Gibb et al. (2004) and Haslam et al. (2003) analyzed accident data in the UK to examine the possible contribution of design in each incident. Gibb et al. (2004) reviewed 100 construction accidents and announced their results as "in 47% of the cases, changes in the permanent design would have reduced the likelihood of the accidents."

In a study of an intervention to prevent musculoskeletal injuries to construction workers, antecedents in design, planning, scheduling, and material specifications were likewise identified as probable contributors to working conditions that pose risks of such injuries during the actual construction process (Hecker et al. 2001).

Behm (2004) conducted a study aiming at linking the design for safety concept to construction site injuries and fatalities. This study claimed that design was linked to the accidents in approximately 22% of 226 injury incidents that occurred from 2000 to 2002 in Oregon, Washington, and California, and in 42% of 224 fatality incidents in the United States from 1990 to 2003. Another expert panel's responses that reviewed a sample of these cases, were in agreement for 71% of the cases reviewed (Gambatese et al., 2008).

Half of the 71 general contractors responding to a survey of the construction community in South Africa identified the design as an aspect or factor that negatively affects health and safety (Smallwood 1996). The contractors surveyed also ranked design as the highest out of all components identified that negatively affect safety (Gambatese 2005).

While the merits of designing for construction safety are evident, implementation in practice throughout the United States is minimal to nonexistent. Lacking regulatory mandate, as is the case in the United States, 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 (Gambatese et al. 2005). Hinze (1992) revealed that "less than one-third of the design firms address construction worker safety in their designs, and less than one-half of the independent constructability reviews conducted address construction worker safety." In addition, the study concluded that the designers who addressed construction worker safety during the design phase tended to work in design-build firms. Constructability, quality, economy of design, and safety of end user are designer's main concerns. Having all the aforementioned reasonings, it proofs the links between the design and safety.

Current Tools for DfS

DfS tools can be categorized in four groups (Taiebat and Ku 2011):

1. Checklist based
2. Risk Mitigation forms
3. 3D/4D visualization
4. Design Review Tools (CHAIR)

The four groups are explained here and an example of each is presented.

Checklist Based Tools

The basis of this approach is to identify a specific condition as "hazardous" based on the past experiences, and look for similar conditions in other projects. In other words, "hazards" happened in specific conditions in the past. As a result, those conditions are considered hazardous for the future. They will be collected together. This collection will act as a plan of records. For designing a new project, the designer uses this plan of record to see if the similar conditions there exist in the project.

Checklists usually target building elements. The way they deal with the hazards is by keeping the same geometry but either adding some temporary/permanent safety elements or constructing it by different means and methods. The other way they help, is by changing the geometry of the element. Their general trend is illustrated in Figure 4.

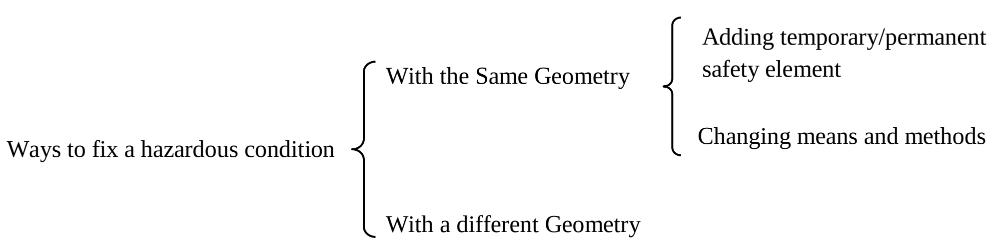


Figure 4. Different methods for fixing a hazardous condition in the DfS concept

Figure 4 visualizes the following methods that checklists use for addressing hazards:

1. They recommend to keep the geometry, but either by adding some temporary / permanent safety elements, or
2. The alternative way is to recommend a change in the geometry of the element.

The main shortcoming of checklist based tools is how they look at the building. Checklist based tools target the elements of the building discretely, and study them to identify their probable hazards. This look prohibits them from identifying the hazards related to interactions between the activities for constructing different building elements. The second noticeable shortcoming in such tools is their poor plan of record (hazard database) when they are being used in hazard identification of state of the art high tech buildings. Since the hazards specific to state of the art high tech buildings are not recorded in their plan of record, they cannot comprehensively cover the probable hazards in such buildings.

Toolbox™ is a checklist based software developed by Gambatese et al. (1997). It is composed of about 430 design alternatives. They are categorized by design discipline, project component, construction site hazard, and project systems.

Risk Mitigation Forms

These forms are made up of factors or criteria to evaluate each design option/component. They are option/component based but general enough that could be used in different projects. They are used to find the risk and give a comprehensive assessment of the design option regarding a couple of criteria (not just safety criteria). It is claimed that the way they find and assess risks can help finding mitigation strategies. These risk assessment forms are developed in the paper or software formats (Duffy 2004, Gambatese 2004, Hecker et al. 2004b). An example is the ToolSHeD (Cooke 2008). This tool provides interactive risk assessment via an online survey interface that generates the risk level of specific activities or materials. A few case studies illustrate that standard simple forms offer a systematic way to evaluate and compare between different design alternatives (Duffy 2004, Hecker et al. 2004b).

Design Review Tools

The other method to remind the analyst of hazards is through structuring the analyst's mind by specific prompt words. These prompt words are more general in nature than checklists' line items. The goal of the prompt words, as implied by their name, is to prompt the discussion about the intended topic. CHAIR (Workcover, 2001) is developed based on the idea of prompt words. Each prompt word in the CHAIR is brought to the session's discussion, and the "facilitator" of the session conducts the discussion based on each word on every single "unit" of the project. "height/depth", "position/location", and "movement/direction" are the examples of the CHAIR's prompt words.

3D/4D Visualizing Tools

This category is capable of covering a variety of visualization / CAD / BIM / VDC tools for hazard identification. Current tools and practices for implementing these tools mainly model and visualize permanent components of the project, and rarely temporary components. Product modeling and process modeling are the basic modeling concepts used in these tools. These tools usually neither give alternative, nor the criteria to help finding/assessing risks.

Table 2. Comparative analysis of the current DfS tools

	Supports state of the art facilities	Targets the risk directly	Be able to target all the risks	Whatever targets, makes it clear
Checklist based tools	☒	☑	☒	☑
Design Review Tools	☑	☒	☑	☒
Risk Mitigation Forms	☒	☒/☑	☒	☑
3D/4D Visualization Tools	☑	☒	☑	☒

Table 2 implies that although checklist based tools are not as comprehensive as the other tools, they address their target much clearer than the other tools. Therefore, checklists have this capacity to get expanded and being made more comprehensive to address more issues. Although the other tools are comprehensive enough, they do not have the ability to address the hazard directly and most of the work depends on the evaluator/designer's familiarity with safety hazards.

Shortcomings of current IT Tools for DfS in Detail

Studying the tools more in detail shows that the fourth category, which is named "Visualization", focused on visualizing the building for the user, designer, constructor, and safety-expert but it does not address specifically safety analyses. Using 3D in safety-constructability started with modeling a static mock-up of building components. This is less effective for safety analysis since safety of the workers is considered through their activities and the construction process rather than building components.

Adding time to the building model for illustrating how building components are put together was another approach taken. Placing roofing slabs in a precast building is an example which contains more unprotected edges rather than the edges of the surrounding slabs. Although this 4D approach does not simulate the processes, it shows how the elements of the building are being put together throughout the project duration. Hadikusumo and Rowlinson (2002) proposed a DFSP tool to identify inherited safety hazards during the construction utilizing virtual reality functions and a safety database. This tool removed the variations in sequence interpretation in safety planning by using 4D CAD and virtual reality for hazards identifications. 4D CAD facilitates 3D visualization of construction processes on a computer screen. Users do not need to interpret sequence in their minds. In these studies construction process visualization was found useful in the identification of potential hazardous situations prior to the construction (Hadikusumo and Rowlinson 2002). One of the shortcomings of this method is that it does not show the methods and processes of constructing the building. Not showing temporary works and equipment is another shortage of this method. Although temporary equipment can be modeled theoretically (Benjaoran and Bhokha 2009), it usually does not happen in practice. The reasons are:

1. It is too time consuming and informal to model all the temporary equipment, and
2. Those applications make it too complicated and impractical to simulate all the temporary equipment.

The other shortcoming of this 4D approach is its time consuming procedure that makes simulation of the different alternative scenarios impractical. This approach was practiced in a high-rise building in Hong Kong by Huang et al. (2007).

Other virtual reality tools are introduced which include the construction equipment within them. They help visualize the construction processes more in detail, and show how equipment and procedures cross over each other. Illustrating a scaffold for working on top of a group and showing how probable the falling objects are is an example of how this type of tools can help DfS. But such applications do not have the equipment in the form of the smart objects within them. This is the shortage of such models, which makes them a place for playing with geometries of the building components and equipment without any intellectuality in them. Most of the shortages of previous approaches still exist, e.g. not showing the actual process of the construction.

The next generation applications invested on adding movement paths of the objects in the model. One strategy they took is to define some points in the objects' movement paths for auto-illustrating their paths. The alternative way is by moving the objects through the paths (manually) and making an animation out of it. Interaction of a concrete group that is working on a level over a masonry worker group, and how material movement affects each subcontractor is the application of this type of tools. Those auto-illustrated paths which are generated based on discrete points on the path are not precise and those manually defined are hard and time consuming to define.

Another type of such applications is the one that adds historical hazard information associated with each object to its geometry. This enables the analyst to walk through the model, get a feeling of the space, guess on hazardous areas, and click on each/suspicious object to find possible hazards associated with that object. Although this method does not simulate anything except the static geometry of the building, it helps the analyst be exposed to the probable hazards by walking through the model. Actually, this type of the application is a checklist that implements computer graphics (CG) for better illustration of the issue (Hadikusumo and Rowlinson 2002).

Another approach was taken to add information of the equipment to their geometrical model in order to help the designer analyze the model in a virtual reality environment (Waly and Thabet 2002). That helps the designer analyze the discrete events of construction processes with the objects and equipment. The modeled equipment has the real data of the actual equipment in the jobsite. The researchers claimed to have a better mock-up of the sensitive processes of the project.

Some other efforts were made to have the software automatically identify and handle some specific hazards of jobsite, and alert the designer or constructor of their existence. A prototype was developed in Israel (Navon and Kolton 2006) aimed at finding some sources of fall hazards, and alert the analyst to take care of them in the design, scheduling, or construction phase. Some of the fall sources defined in that prototype are edges of the slabs, openings in the slabs, and openings in the exterior walls. Table 3 compares all these types of the tools.

Table 3. 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		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		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		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		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		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.

Despite extensive research in 4D CAD technologies, their use is not very common in the construction industry (Bansal 2011). These technologies are somewhat difficult to use and the visualisation provided by them is not easily customisable (Issa et al., 2003). Existing 4D CAD systems are unable to aggregate and distribute the information between spatial and non-spatial databases. These tools are based upon the object-oriented concepts and are used primarily for planning, design phase and appraisal types of analysis (Bansal 2011). Furthermore, 4D CAD models have a single level of detail which hinders the collaboration among general contractors and sub-contractors (Poku and Arditi, 2006).

Koo and Fischer (2000) suggested that the construction industry requires a tool that can generate, manipulate, and link the execution schedule and 3D components in a single environment. Therefore, after 4D CAD there is a major revolution of BIM that provides strong premises to overcome the fragmented nature of the construction industry (Bansal 2011). The main idea behind BIM is a single repository where every item is described only once (Aouald et al., 2007). The invention of BIM facilitates 3D modeling, scheduling, and linking them together to visualize the execution sequence in generating safe construction alternatives (Bansal 2011).

Defining Design and Planning for Safety (DPfS)

As explained in the "Definition of Design for Safety and Similar Terms," there are different terms within the same concept. The definition and scope of each of these terms varies in the references. Having said that, some of the concepts can be extracted from the different definitions.

Talking about DfS, it covers the notion that constructors help each other through construction planning phase. It is clear that when designers assist each other through geometric design of the project, it falls under the realm of DfS. Finally, when designers and constructors collaborate and assist each other through geometric design, they are practicing DfS as well. However, none of the definitions makes it clear whether collaboration of designers and constructors through construction planning and means and methods falls under the definition of DfS or not. Table 4 makes this issue more clear.

Table 4. Design for Safety and the Parties' Interactions

For safety of	Offers help	Receives help	Through	Falls under DfS?
Construction Worker	Constructor	Constructor	Construction Planning	✓
	Designer	Designer	Geometric Design	✓
	Constructor	Designer	Geometric Design	✓
	Designer	Constructor	Construction Planning	Not Clear

This research will be undertaken within the realm of Design and Planning for Safety (DPfS). Although there is not a consensus among the practitioners on whether DfS covers anything except geometrical design of the project, DPfS covers a more diverse range. As implied by its name, DPfS covers collaboration of the designers and constructors for geometrical design as well as construction planning. DPfS has an advantage over “safety through design” (in the architectural design, which deals with safety of the construction product) and “safety through construction planning” (in the construction phase, which deals with safety of the construction process). This method is able to see the effect of process and product over each other, and the mutual synergy of the product design and process planning on the safety of construction workers. This makes the decision of selecting hazard responses optimum and more practical.

Chapter Three

Falls Hazards Classification and Abstraction

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*

  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 list of the memos taken from each three aforementioned hazard databases is presented in Table 5, Table 6 and Table 7.

Table 5. 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	

Table 6. Memos Taken from ToolBox

Store / Docking areas	Concrete forms	Wood temporary connections	Overhead work -> pipe (restraint cable along them)
Pipe/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-Cast in Place 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 Mechanical
Heavy Equipment Entering the Building / Placement	Column splice connection	Minimize roof pitch	Ladder length extend top of edge
Prefab on Ground and Erection Process -> edges	Perimeter Beam and lifeline support	Window installation process / maintenance	Ramp
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

Table 7. Memos Taken from CDC

Scaffold and window installation/maintenance.	When designing skylight see how strong something/somebody may fall on it (when it is in place) not to broken when somebody/something 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 people transportation in height? It might hit things and cause fall of who is 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, mechanical 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	

Grouping the scenarios based on their similarities was the next step taken for turning the scenarios into impact factors. The scenarios were summarized and grouped based on how they satisfy the product modeling, process modeling, and geometric reasoning bases.

Data categorization: Product Modeling / Process Modeling

The hazard summaries, presented in the past section, should be categorized into groups regarding the intended modeling strategies. The intended modeling strategies in this research are product modeling and process modeling. The closer these strategies are to 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 8. 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 9. 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 10. 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 (Mechanical equipment, openings, etc.)	Proximity of mass work to the edges (Mechanical equipment, 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 11. Installation and Movement Path (INS/MP)

Study column / roofing process in detail	Study column / roofing process in detail
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

The following seven subgroups further narrow down the impact factors and present them in relation to the 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 were discarded from the scope of the proposed framework. They are marked as "cmplx" in the previous tables.

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 (Mechanical equipment, openings, etc.)-Proximity of mass work to the edges (Mechanical equipment, 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 in 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)
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
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

Scope Delimitation

Why include Sp, Su, MP, GR, and exclude cmplx and MC

The summarized fall scenarios where categorized based on how they can be modeled under the concepts of Object Modeling and Geometric Reasoning. Analyzing MC (Model Checking Codes) is already undertaken in similar studies, and its commercial software is already developed. These requirements can be checked with the current model checkers such as Solibri™. These model checking codes are mostly concerned with the stair / steps, what geographical side of the building theyare located, and their proximity to a specific space. The other examples are column splice in the floor or exposure to weather either by a window or an unsheltered area. Since the current ICT/BIM tools cover this topic, the proposed tool will not discuss this functionality.

Analysis of Cmplx (complex process of thinking) needs more factors to be studied than Object Modeling and Geometric Reasoning. These two latter are excluded from the research scope because they do not follow the modeling approaches of the research.

Chapter Four

Falls Hazard Representation for Identification in BIM Environments

Chapter Mission

This chapter will study each of the pentagonal groups that are presented in chapter three – as the research scope. It studies these groups to identify the elements that are central to allow falls hazard identification in BIM environments. The resulting flowcharts provide the preliminary framework that guides hazard identification functions in BIM environments.

Each of the pentagonal groups will be studied discretely. Chapter three summarized and narrowed down the falls scenarios (in the form of the short notes) for each of the pentagonal groups (Figure 5). Within each pentagonal group, one or more example scenarios will be developed. Those example scenarios should cover the entire realm of each group (Figure 6).

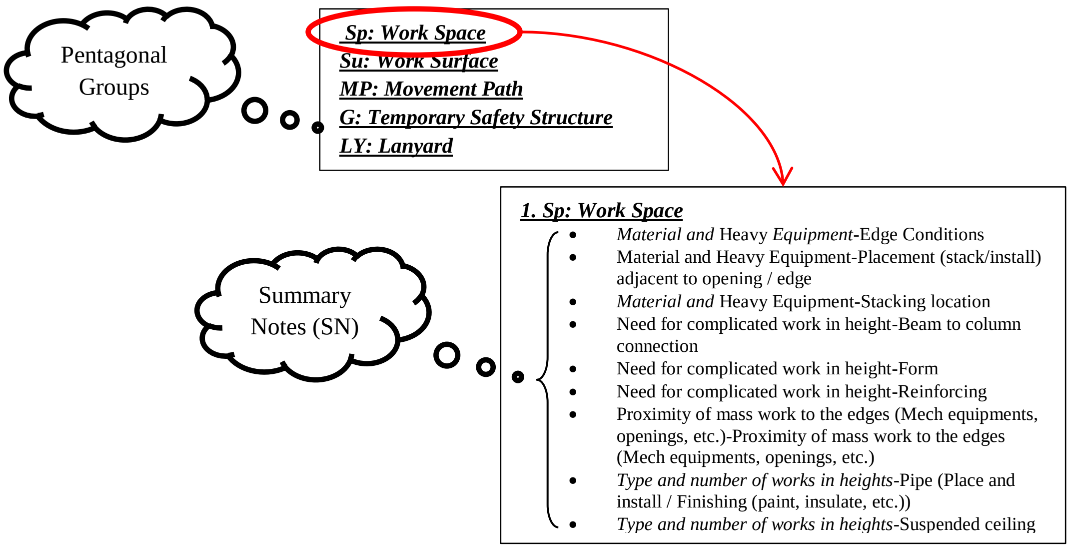


Figure 5. What are pentagonal groups and what are the summary notes (SN)

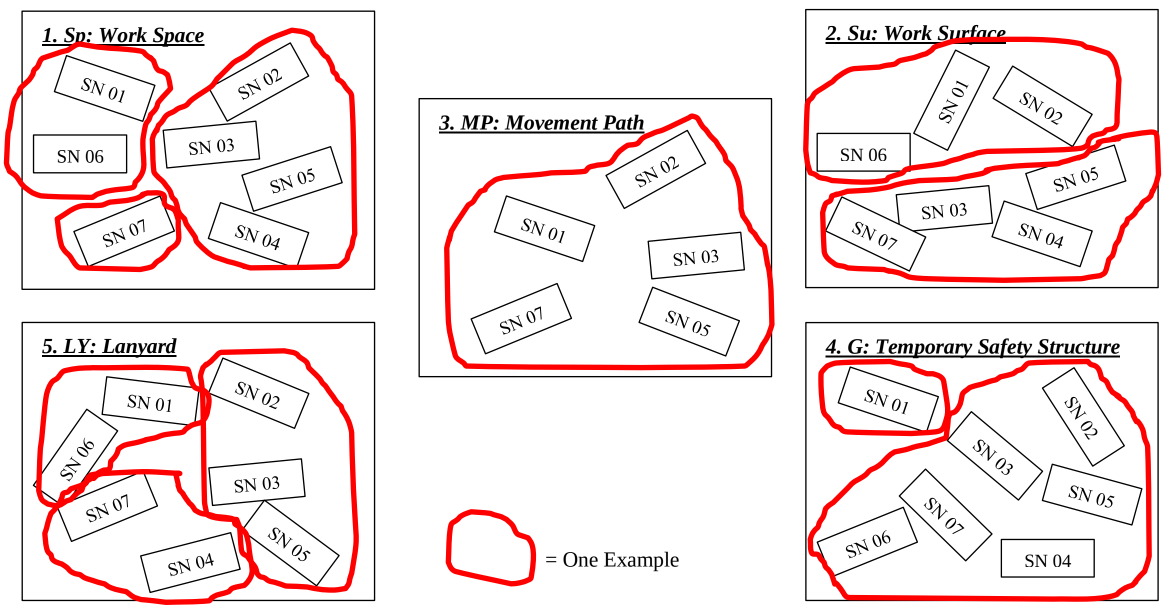


Figure 6. How the examples will cover the answer space

Each example will explain hazardous conditions and the expected information for illustration and simulation of the safety hazard. Hazard elements (impact factors) will be studied in that example and a SketchUp interface-model will illustrate how the future BIM model is envisioned to simulate the impact factors. Based on that example, a flowchart will be presented. This flowchart will guide software developers to develop the BIM model.

Once all the flowcharts of each of pentagonal groups are developed, they are put together and are generalized for that group. The objective is to look 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.

Developing the Pentagonal Groups' Goals

This research envisions future implementation of a BIM-parametric model that incorporates hazard identification properties beyond conventional BIM models. The model's properties will be further explained in this section but the following are some of the preconditions of this model:

A- Shows the work zone around each object (literature exists)
B- Temporary safety utilities are embedded in their relative objects.
C- Temporary safety utilities pop up in their proper time in the 4D simulation
D- Temporary safety utilities are defined based on where the respective building component is located relative to the other objects (parametric modeling).

The next sections will talk about how to turn the pentagonal groups into a flowchart. This flowchart is intended to allow development of a BIM application in future research. In other words, deliverables of this research work as the inputs for future research that will develop BIM applications for facilitating falls analysis in building construction projects.

The next sections use a consistent process to reach a flowchart from the examples in each of the pentagonal groups. The process has four steps with the resulting flowchart:

1. Information analysis
2. Goal
3. Illustration of an example
4. Analysis Procedure

and

5. Flowchart

While each flowchart – developed in each of the pentagonal groups – deals with just one aspect of the falls hazards, they will interact in the BIM model all at the same time. Their simultaneous effects on the model will consider all the aspects of falls from height. The model adopts and complies with mandatory OSHA rules .

Work Space

- *Information Analysis*

The general idea of this section is to embed the required work space associated with each building component or object as part of its accompanying information. The procedures taken in this section are:

1. Identification of the work place:
    1.1. Identify the work in height (where there is no flat ground under 6ft. of the work)
    1.2. Register duration of the work
    1.3. Register type of the work
    1.4. Register where the workers need to stand and the area needed to work around the working zone.
2. Check protection
    2.1. Check proximity of the work to the edge
    2.2. Check status of the edge and the duration it is not protected
    2.3. Check lanyard status when it is needed

- *Goal*

This group's goal is to identify where/when the worker is exposed to unprotected edges.

One of the basic steps in this process is to define "work in height". "Work zone" is embedded in the objects. "Work in height" – for constructing each specific building component – can be detected in the model as follows:

> *Workers' relative working location with the respective permanent surface of the building determines the "work in height." The aforementioned "respective permanent surface" is the one that is already built immediately below that specific building component at the operation time.*

- *Illustration of an example*

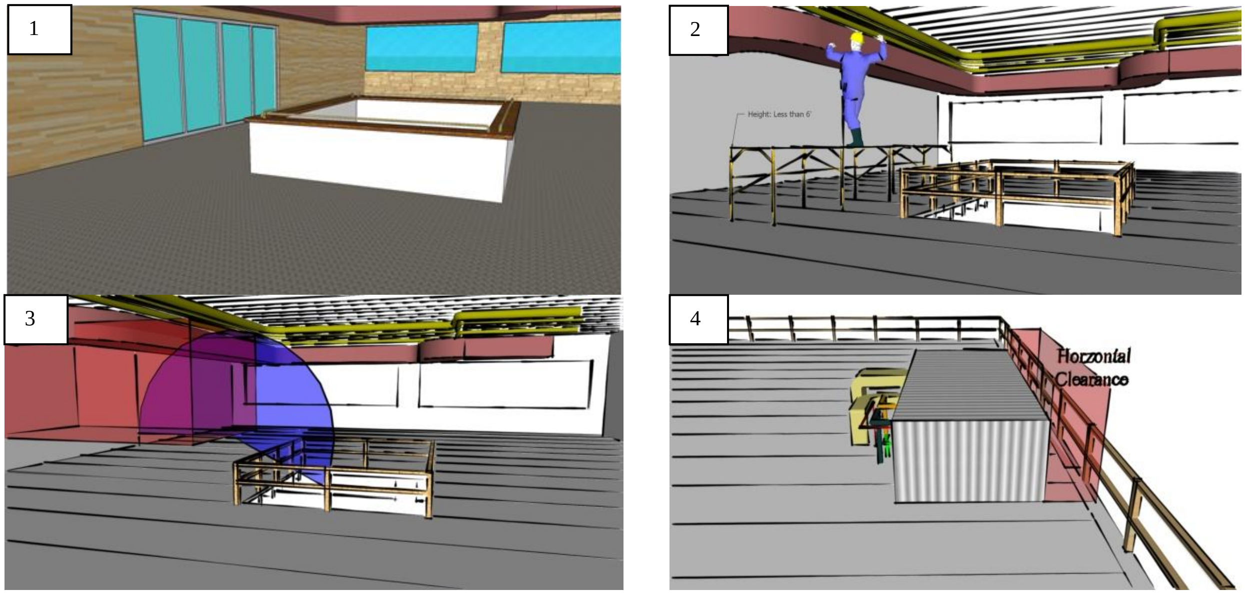


Figure 7. Check the workplace and proximity of the work to edge
1. Current visualization tools only represent building components and fail to represent hazards – 2. Falls hazards exist during the construction process – 3&4. The proposed tool identifies and reports the "work in height" hazardif there is a fall possibility around it.

- *Analysis Procedure*

For this procedure, each building component (permanent object) is considered as the subject of study at the time. When the 4D simulation reaches the time of operating on that specific object, the work zone around it pops up. This working zone is already embedded in the object family by the software programmer. At that time, the working zone is considered as the subject of the study. The workers might stand wherever in the specified working zone. The "ground" where the workers stand will be identified as well. The ground is either a permanent surface that is already constructed by the time of the subject's construction, or a temporary safety utility (e.g. scaffold) that is embedded in the object family (e.g. in the duct). This temporary surface shows up in the 4D simulation when the time frame passes over the construction of the subject.

The parametric model adjusts the temporary safety utility when it recognizes the environment surrounding the subject component. If the "ground" is a temporary safety utility, the model checks edges of the ground for protection. Following OSHA regulations, if the scaffold height is over 6', it automatically is imported with guardrails in a parametric model. Otherwise, it does not pop up with protected edges, and needs to be followed up. In this case, the permanent ground, where the scaffold stands on, is identified. Through "terrain moving" the ground outward the scaffold and the closest edges will be detected. The term "close" should be defined in future research (out of the scope of this research). Status of the open edges should be checked during the operation time of the building component. The model will be able to report the unprotected times.

For every work zone, the chance of worker's fall-over from heights should be checked geometrically. Height of the work zone over the protected/unprotected edges (whether temporary or permanent) should be checked for fall-overs. The model checks this chance when the clearance between the work zone's top point and guardrails' top point is close to the height of a worker (Figure 8).

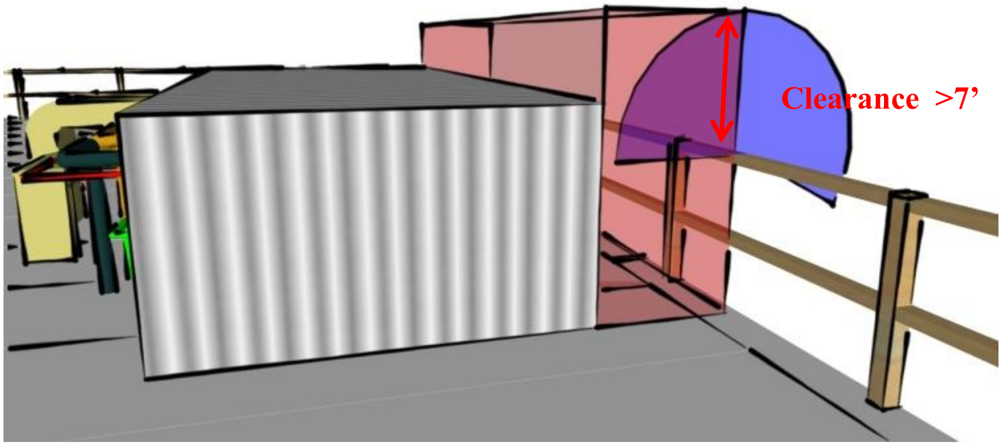


Figure 8. Probability of the workers' fall-over when work zone is higher than the protection system

Whether the temporary component (scaffold) is over or below 6', the work zone for setting up the temporary components (scaffold) should be investigated as well. This can get done through passing the same steps that were passed for a permanent ground.

When the worker is standing on a permanent ground, the model "terrain moves" outward the work zone to detect nearby openings on the "ground," checks potential protection, and investigates the status of workers' fall-over chance during work on the building component.

For all the cases, the system can alert the designer about the proximity of workers close to edges (either protected or unprotected). The designer may decide to move the work farther away from the opening for more security, such as moving the AHU from the building edge, or moving a duct away from a floor opening..

Where the edge is not protected, the model will be referred to "Lanyard Analysis" to investigate how the building supports the workers' harness system.

- *Flowchart*

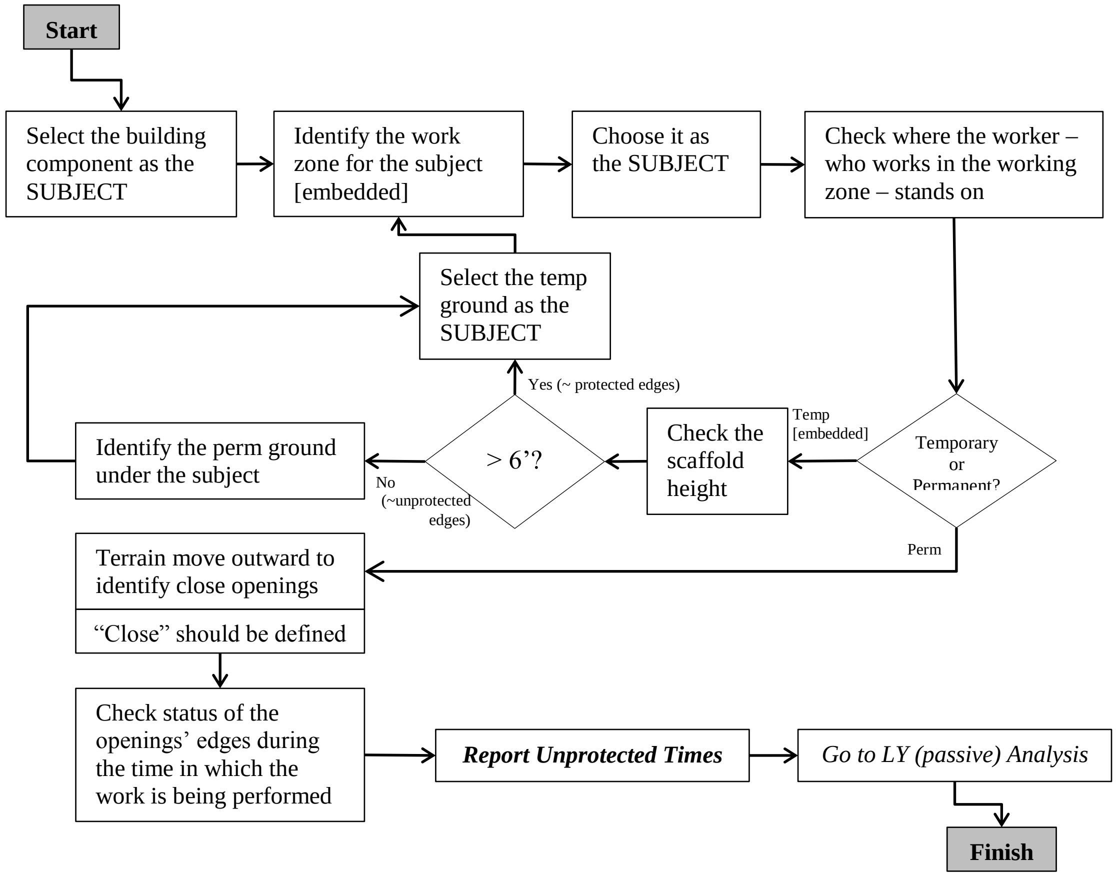


Figure 9 . Preliminary Work Space Flowchart

Work Surface

- *Information Analysis*

This section deals with the installation of prefabricated panels. The panels are studied in two specific groups: sloped/horizontal panels and vertical panels. The procedure of this section involve identifying the hazards and guiding the safety analysis to the relevant sections such as lanyard, work space, etc.

Sloped/flat flooring

1. Embed layers of the paneling and the sequence in which they are put together
2. Where the workers stand (input from past section)
3. Study the tie-off points to make sure they are properly designed (refer to lanyard analysis)
4. Identify, report, and analyze the lanyard for the duration the tie-off is required (up to the point in time that when the panel is in place and is fixed and strong enough to be stepped on).

Side of the building

1. Embed layers of the paneling, and the sequence they are put together
2. Where the workers stand (input from past section)
5. Study the tie-off points to make sure they are properly designed (refer to lanyard analysis)

Future study: locations where the worker comes and leaves the work zone.

- *Goal*

The fall records studied for this section converged to one concern for workers' safety:

> *When working with surfaces, how long the working area is not safe and workers need active fall protection systems.*

This section should identify the unprotected time periods when the workers work at the unprotected edges. These time periods will be reported to Lanyard Analysis, and active protection of the workers will be ensured.

- *Illustration of an example*

The idea behind the example presented here is based on precedents of past fatalities in construction not limited to but including: FACE 88-07; FACE 88-08; FACE 88-38; FACE 89-22.

> *FACE 88-08 – 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.*

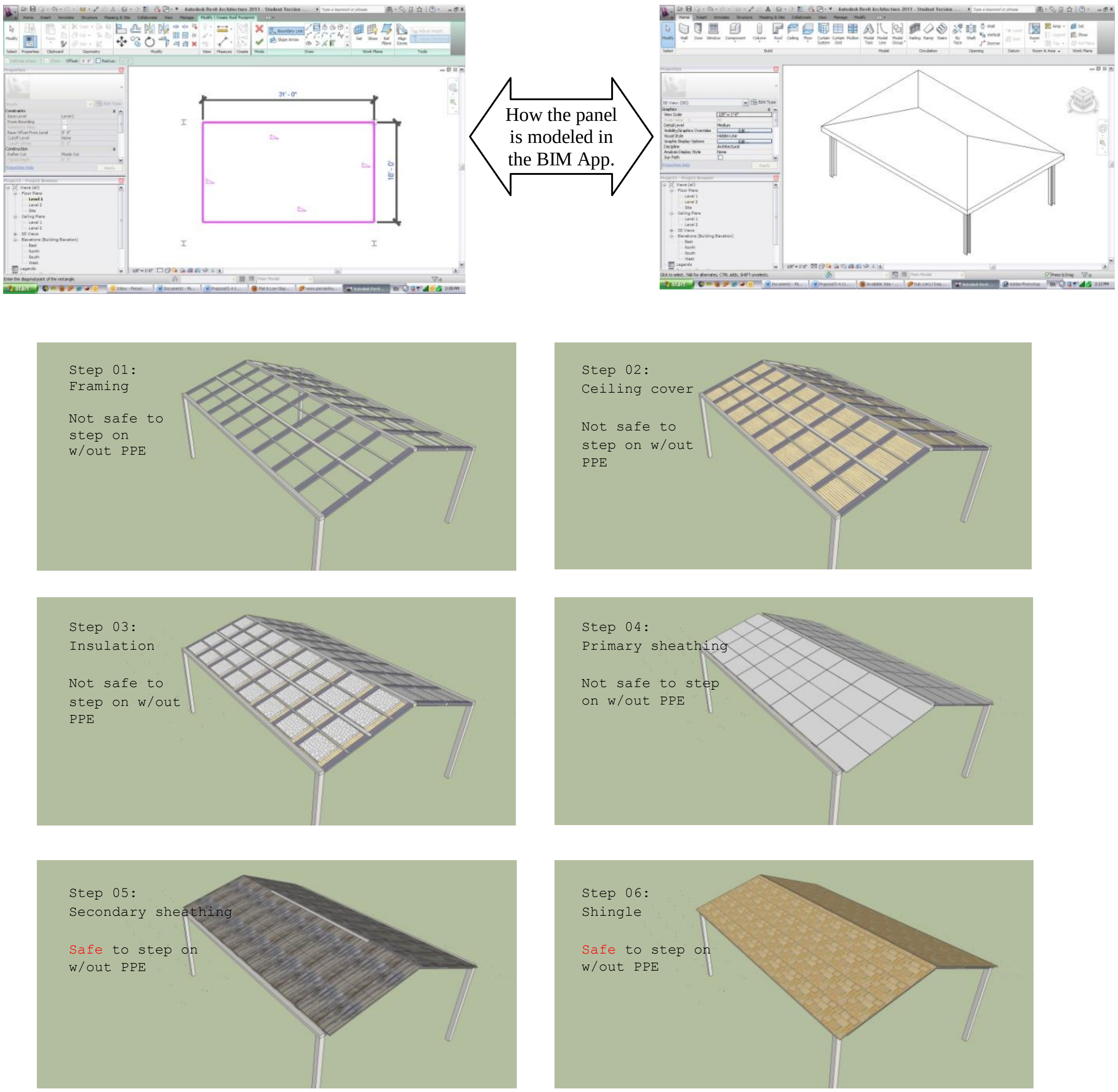


Figure 10. While modeling in a BIM application does not provide enough information about the safety during the construction process, embedding layer information in the panel's object family will determine when the panel is safe.

- *Analysis Procedure*

BIM and parametric modeling play a major role in fulfilling this section’s mission. In other words, the information embedded in the building components and their relation to their surrounding conditions present the information that is crucial to the hazard analysis.

The panels’ object families in the model embed their layers’ information and the sequence of putting the layers together. When the scheduled time for installing a panel (e.g. drywall) is allocated, it distributes the scheduled time to its layers properly at the lowest levels of detail. As mentioned in the Work Space section, the building component defines where the worker stands. Parametric modeling detects the surrounding conditions and defines whether a temporary safety utility (e.g. scaffold) is required or not (Figure 11).

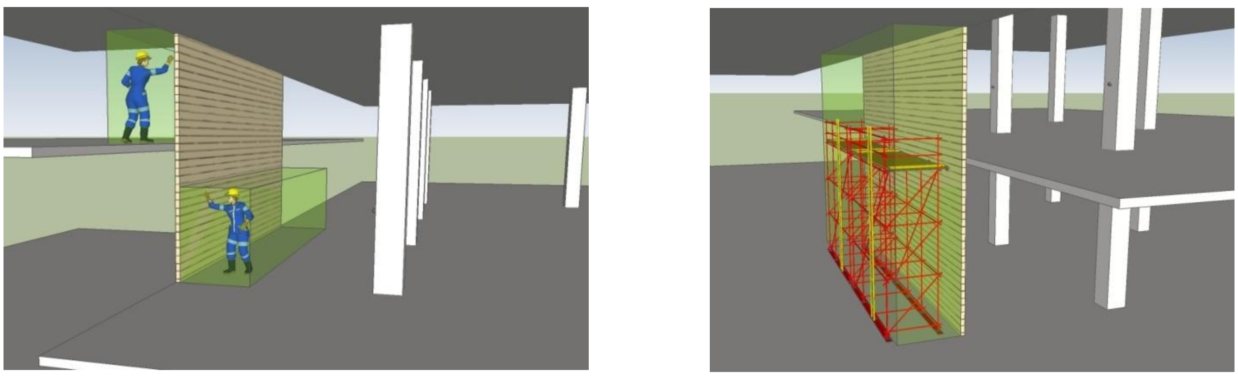


Figure 11. Parametric model can identify whether the scaffold is required or not. The panel’s work space can check the working height and the related “ground”, and determine if the scaffold is required.

The panels in the intended model are grouped into two groups: Stepping Panels and None-Stepping Panels. This grouping comes from whether the worker steps on the panels when installing them. Non-stepping panels are such as building envelope panels or curtain walls. The model will check the proximity of the panel installation with the “lower ground”. If the lower ground – at the time of the installation – is over 6ft. the edge needs protection during the panel installation. A passive fall protection system will be automatically placed adjacent to the panel installation.

A piece of information that is embedded in the panels’ object families is the “safe” message. This message is generated when the panel by itself can protect the edges, and guardrail and other passive fall protection systems are no longer required. Figure 12 shows when the safe messages progresses as the panel installation progresses: when the studs keep the edge safe and guardrail is no longer required.

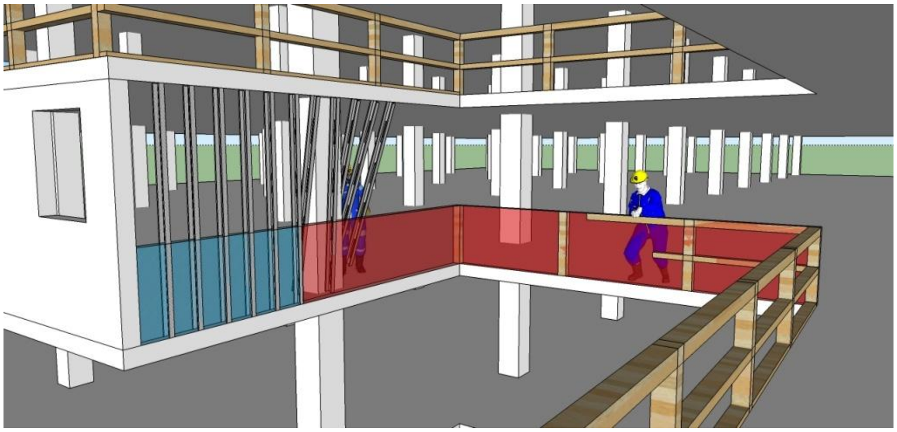


Figure 12. Blue surface illustrated the “safe” message when the studs keep the edge safe and guardrail is no longer required.

As mentioned before, the model is intended to report the unsafe duration along with the location to the active fall protection systems analysis. This time for each panel “at the edge” will be counted from the removal of the passive fall protection systems (e.g. guardrail). Counting will be continued until the “Pass” message is generated by the panel. If the time of removing the safety protection system is after the safe message, this time will be counted zero, and no “unsafe condition” will be reported. The process for studying stepping panel is the same as the non-stepping one. The difference is the “Pass” message. The “Pass” message is generated when the non-stepping panel has two conditions:

1. the layer that is strong enough is placed
2. that layer is set and secured (fixed) in place

- *Flowchart*

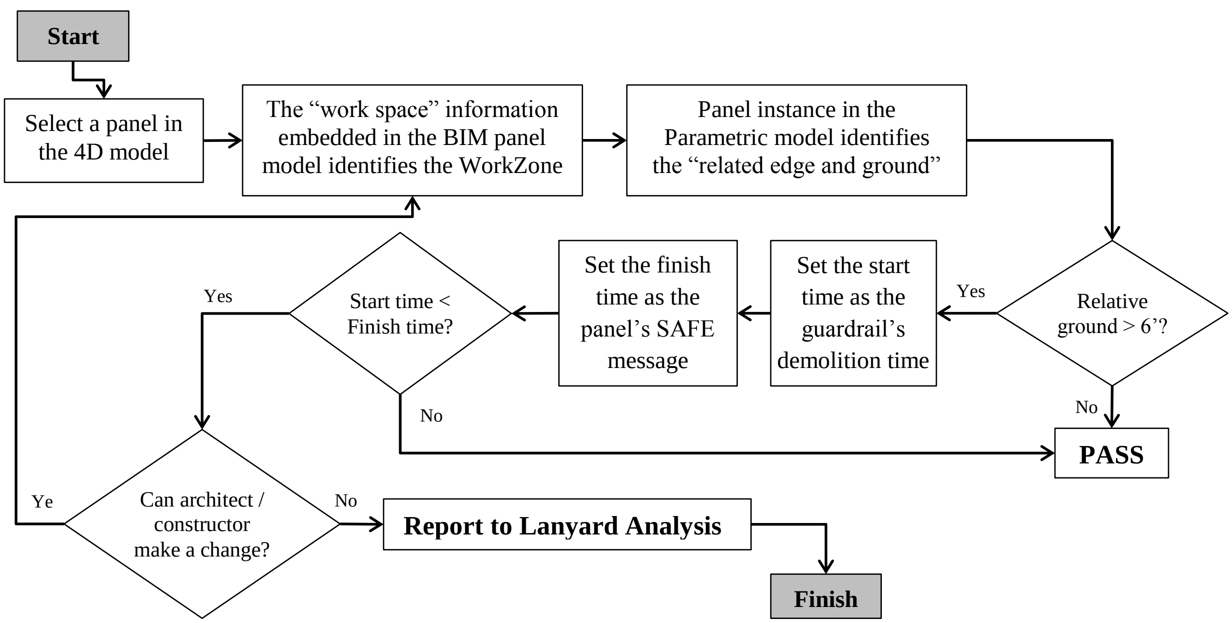


Figure 13 . Preliminary Work Surface Flowchart

Movement Path

- *Information Analysis*

In each step of the schedule, the model will illustrate the building and its safety utilities as they are in place. It identifies the hazards that arise when materials are moved around and safety tools need to be temporarily removed. Temporary removal of safety utilities will present temporary hazards that do not show up in the general safety reviews in current tools.

- *Goal*

This section investigates clashes between safety utilities and materials when they are being delivered in place. The goal is to study clearance of material delivery paths. This study might avoid temporary removal of guardrails and other safety utilities when they block material delivery.

- *Illustration of an example*

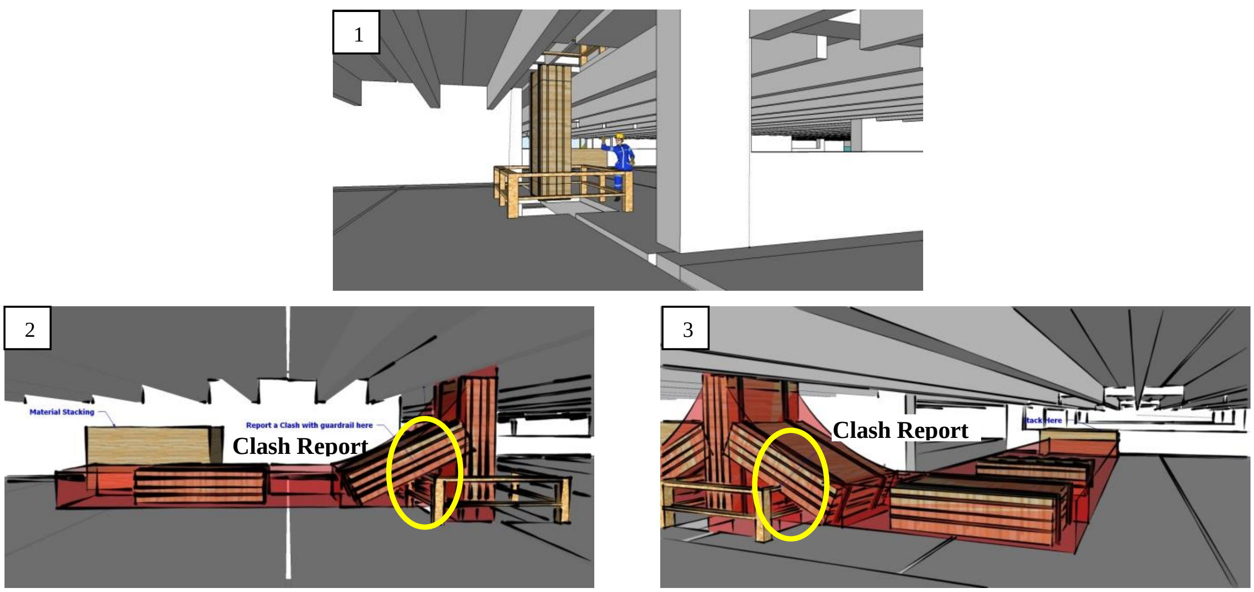


Figure 14. Illustrating movement paths for identifying clear path to avoid hazards - 1- material delivery requires the guardrail to be removed, but it does not show up in the current hazard identifier tools 2&3 – the proposed framework considers the movement path and presents and identifies where it clashes with temporary safety utilities

- *Analysis Procedure*

Building components and temporary safety utilities are composed of materials. Materials movements will be tracked from its unloading on site to stacking for installation. Their location will be checked at specific points along the movement path in the model. Their movement paths will be specified by multiple points that define straight moving lines. Height and width of material packages need to be defined. This height and width considers material size as well as the worker location.

The other important factor to consider in this section is proximity of material with adjacent surfaces. These surfaces are "ground" in horizontal movement, and "walls/façade" in vertical movements. When the movement direction changes, the corner's dimension will be defined based on the method of transmission. Dimensions of the height and width for different materials as well as corners' geometries and dimensions are the subject of a future research which will incorporate experimental data (out of scope of the current research).

As mentioned before, materials' movement paths will be studied from stacking points on site to the stacking points or installation in place. Movement Path Zones (MPZones) are defined in the model through the collaboration of designers, constructors, and subcontractors. What the model needs from designers, constructors, and subcontractors are:

- Location and start/end points of the directions
- Material package sizes

This information should be inserted at their planned time in the construction schedule. Movement path zones' sizes and corners' geometry and dimensions will be generated by the model.

In the 4D simulation, the MPZones will be clash-detected by the model and its permanent / temporary components within the schedule. A clash with the safety utilities requires removing the safety utilities temporarily. In such situations, the designer / constructor might change the model / means and methods, or refer the case to the harness system analysis (LY Analysis).

- *Flowchart*

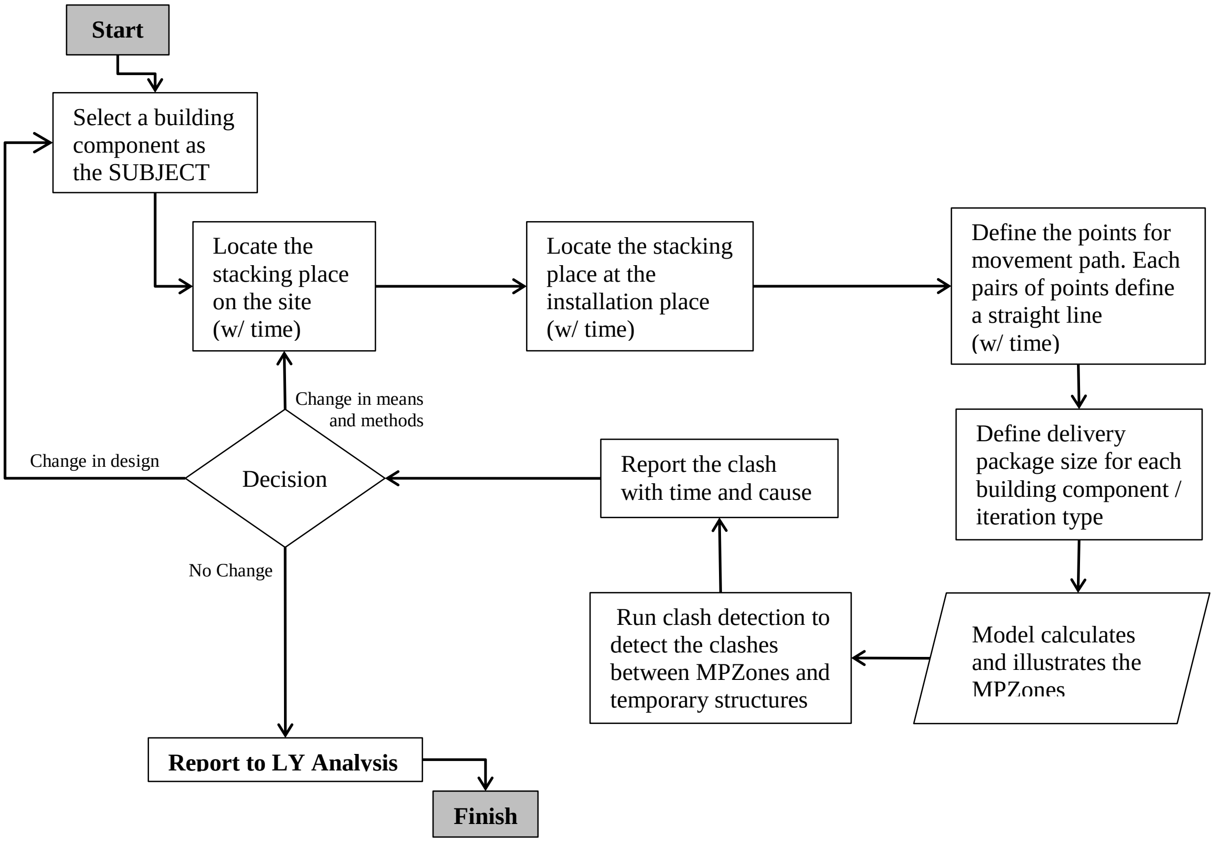


Figure 15 . Preliminary Movement Path Flowchart

Temporary Safety Structure

- *Information Analysis*

The mindset of designers, safety analysts, and construction planners is that when an edge exists in the building, a guardrail or a protective lid can make it safe. This is when the edges are not protected for a huge amount of time. During this time, the use of personal protective equipment (PPE) is not studied for those locations. The examples of these conditions are when the edge is just constructed and is planned to be guarded, when the guard is temporarily taken off to pass the material from the edge, when the guard is permanently taken off to construct the surrounding wall. None of these conditions are studied in the construction document to evaluate how supportive the building is for the use of PPE i.e. if lanyard can be used appropriately.

The first step to overcome this problem is to study where and when it is not safe, and what the reason is for the unsafe conditions of the edge. The designer's decision to design the building properly for use of PPE, to change the type of the guardrail for keeping it permanent or for keeping it for a longer time etc. will not be covered in the proposed tool. This tool will identify where and when it is not safe, and the reason it is not safe.

- *Goal*

1. To embed guardrail and other openings protective tools such as temporary protective lid or structured net in the horizontal surface components.

2. To have openings' protective tools pop up at the right time and disappear at the right time. This appear / disappear transition needs to be simulated in schedule fractions close to a coefficient of an hour.

- *Illustration of an example*

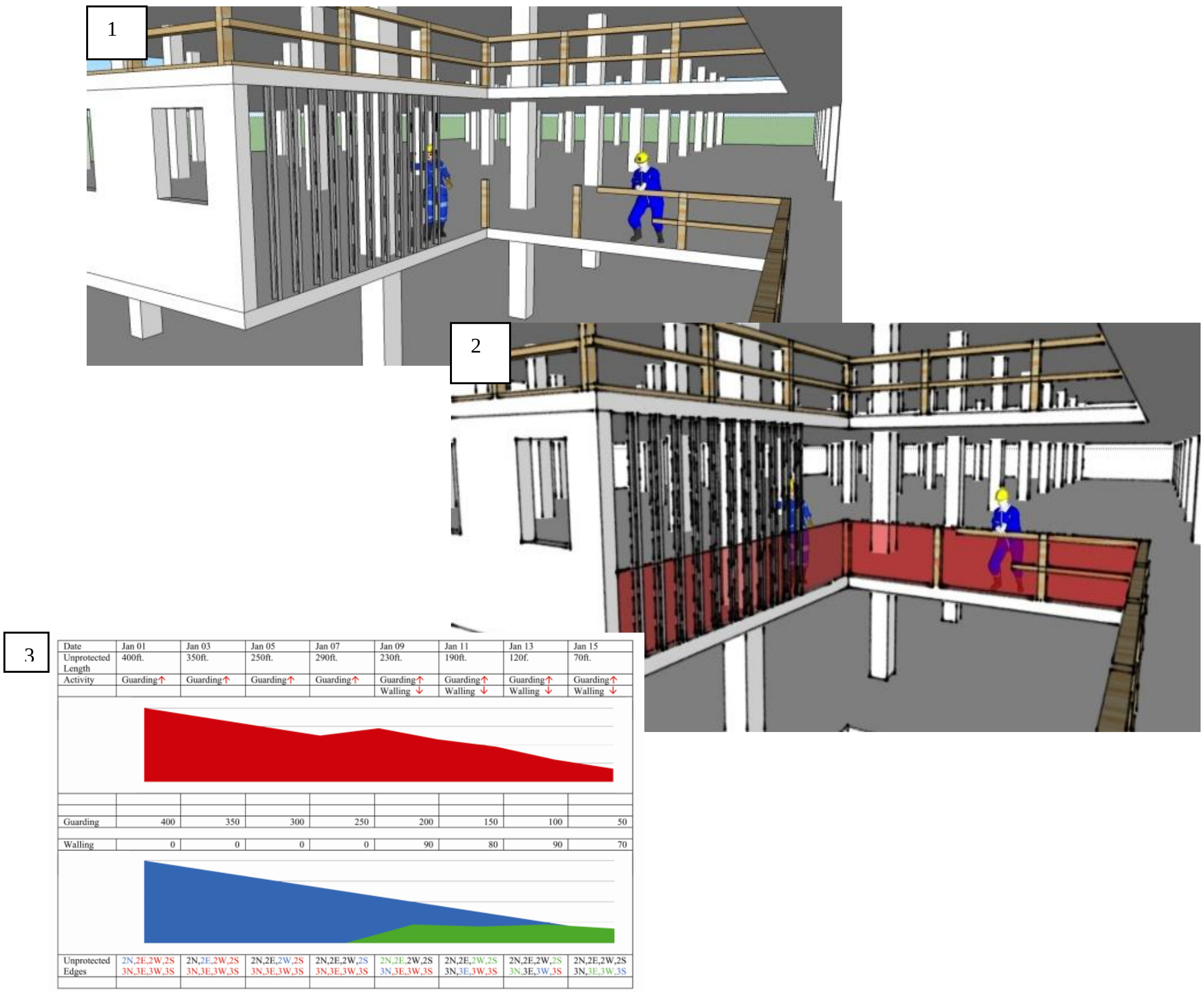


Figure 16. Check status of the edge and the duration it is not protected (2.2.) - 1. When the edges are not protected in the building – 2. The proposed tool identifies and visualizes the unprotected edges – 3. The proposed tool shows how the long edge is not protected during each period of time, what the reason for unprotected edges is, and how the protection pace is.

- *Analysis Procedure*

In order to fulfill this section's goal, logic needs to be defined for embedding temporary safety utilities in the permanent horizontal surfaces. All the following procedures are written assuming the 3D geometry is connected to the schedule and a 4D model is already developed. Level of detail is assumed to be the level required for making on-site daily decisions.
The application will identify boundaries of the building components in their level of detail construction progress. Based on the company policy, a length will be defined that can be covered by a flat temporary surface, e.g., a protective lid. This length is called "λ" hereafter.

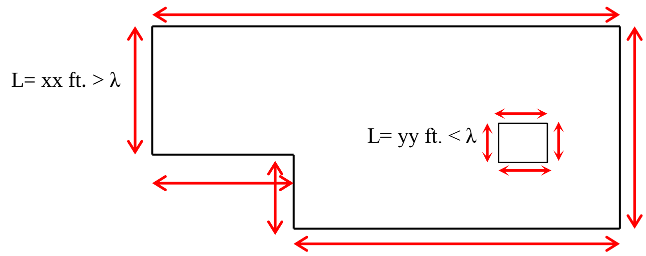


Figure 17. How the opening length (λ) is defined

The default of the application will be set to suggest guardrails for the openings, and will keep a temporary protective lid and structured net for the openings with the length less than λ. These options can be chosen by the modeler – when the object-family is loaded from the object library and being placed in the model – or can be modified by the constructor later on. The "catch platform" can be defined manually and will follow the rules of other fall protection systems.

The geometric location of the start point(s) to set up guardrails is added by the constructor, as well as geometric location of their end point. The start points and end points of setting up the guardrails are identified with the time frame specified for them. The duration is automatically distributed linearly (unless otherwise specified) for guardrail setup. This will show guardrails' setup in their smallest time fraction. The application will set up guardrails (3D geometry) in the right time (4D) and right place. The same procedure takes place for removing guardrails i.e. start points, finish points, start time, and finish time.

It is imperative for the walls (partition wall, curtain wall, etc.) to be defined at the same level of detail in order to crosscheck the accuracy of the removal time of the guardrails. In this model, "clash detection" is active to report clashes between guardrail and walls.

Having such assemblies, it is feasible to report unprotected times or unplanned times of passive fall protection systems. With such a report, the designer might change the geometry of the wall and opening, or the constructor might change the guardrail type or means and methods of construction. If none of these decisions are made, the case will be referred to Lanyard Analysis for evaluating feasibility of active fall protection.

The report can be in different forms. It can be a moving-camera recorded time elapsed animation of the unprotected locations in their unprotected times, or it can be a series of 3D maps (2D + time) or 4D highlighted visualization of unsafe zones with annotated visual cues to describe the cause on the screen.

- *Flowchart*

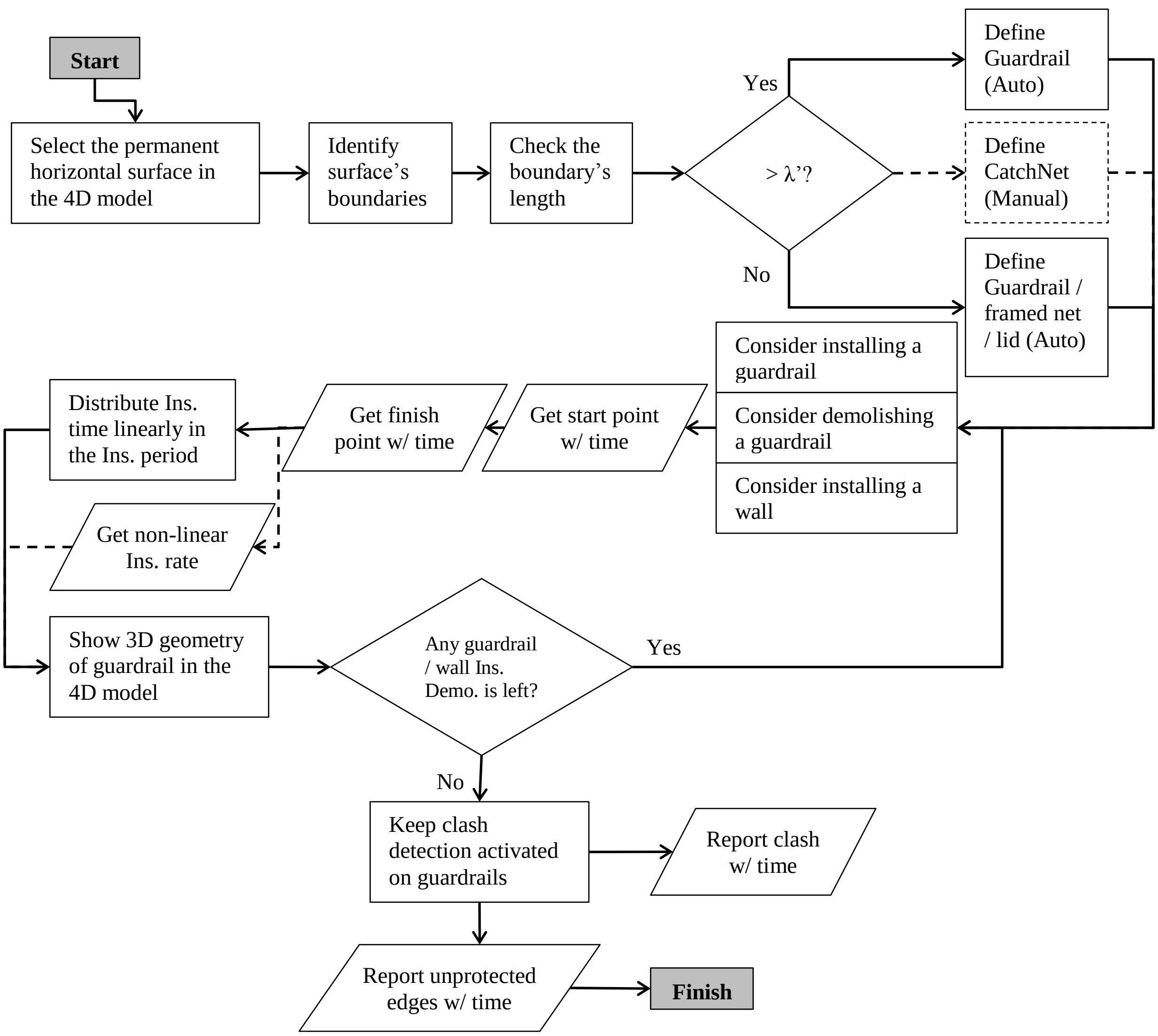


Figure 18. Preliminary Temporary Safety Structure Flowchart

Lanyard Analysis

- *Information Analysis*

The current practice for using lanyard is that it is not usually designed in the model, and the construction planner does not plan for it specifically. They place it in some random places based on the discretion of the construction safety engineer on site. This means that the lanyard is not engineered and/or analyzed. Since the proposed tool can identify the working zones, it can analyze if the lanyard reaches all the required points while not losing its functionality as a result of using a long cord.

The extension of this function is incorporated into the architectural design phase (DD / CD). It can work in a way that for each designed tie back, the model presents a transparent box that shows how far the lanyard is effective. The next tie back hook up should be placed in a position where it does not leave an unsecured working space unprotected, and the relationship between the hook up points (attach/detach) is considered as well.

- *Goal*

Define the Lanyard length to:

1. reach every single point in the unprotected work zone
2. does not let the worker fall on the ground lower than 6'

- *Illustration of an example*

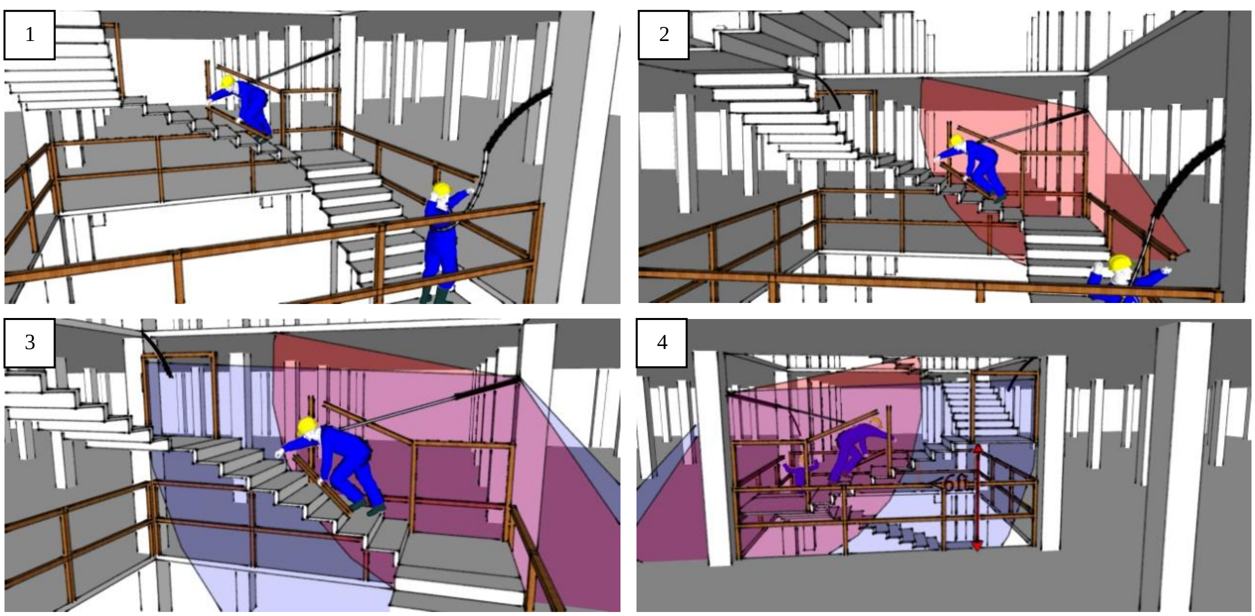


Figure 19. Check lanyard status when it is needed - 1. Where the lanyard is needed – 2. If it reaches the required areas – 3. If the length of the lanyard satisfies this need – 4. If the length of the lanyard creates a side hazard (does not protect from hitting the ground)

- *Analysis Procedure*

As shown in the other four sections, they report the unprotected edges to the Lanyard Analysis section. The underlying concept of this section is: when there is no passive fall protection system, active fall protection systems should be studied and implemented. This section aims at engineering and designing active fall protection systems – which is usually not seriously taken into account during design in the current practices of the construction industry.

The open edges are referred to this section from the other four sections. It is the designer's / constructor's responsibility to define some hookup points tentatively. These points are defined at the designer's and/or constructor's discretion when they view a 4D model of the building at the time periods when the edges are not protected (these times periods are identified and reported in the other four sections). The existing surrounding building components of the edges (at the unprotected time) are the available options for the designer / constructor to choose them as the base for hook up points. Alternatively, the designer can "design" a new base for the hookup point.

The designer's / constructor's construction knowledge is the primary factor in the decision of defining a tentative hookup point. Once the hookup points are defined, the system will suggest the lanyard length (as the system default) that fulfills the aforementioned goals (explained above). The system allows to study feasibility of defining tiebacks to reach over the unprotected work zones while they protect the worker.

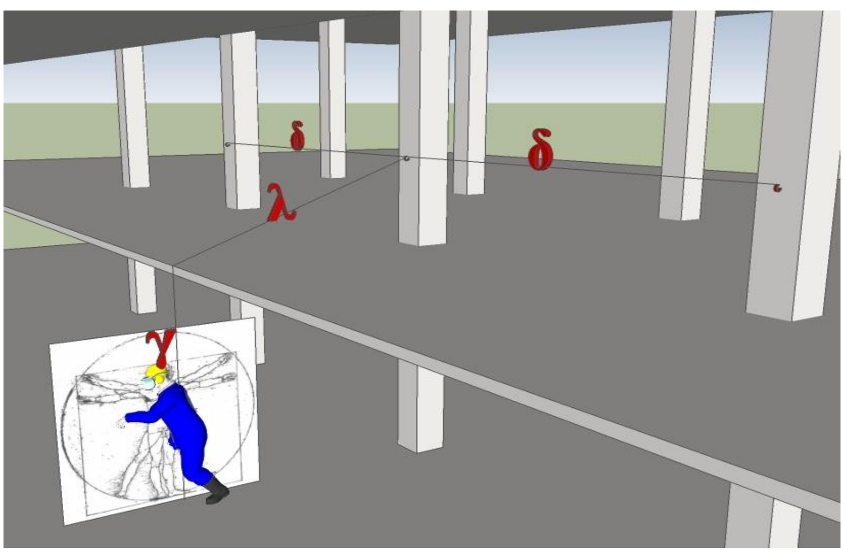


Figure 20. The model detects δ (distance between two adjacent hookup point), λ (shortest lanyard that lets the worker reach the working zone = lower limit), and γ (distance between the edge and the lower surface). Upper limit = λ + γ – (anthropometry of worker's body)

The first step the system takes is to identify the lower surface of the understudy edge. Upon defining the lower surface, the upper limit and lower limit of the lanyard can be defined. The upper limit is the longest lanyard that does not let the worker fall on the lower surface. The lower limit is the shortest lanyard that lets the worker reach the working zone as well as reach the adjacent hookup point (in order to let the worker attach to the adjacent hookup point before detach from the current one). Any length between these two limits is an acceptable length at this step.

The next step is to define each lanyard’s share of the work zone. This means if multiple lanyards are defined, what portion of the work zone should be served by each specific lanyard.

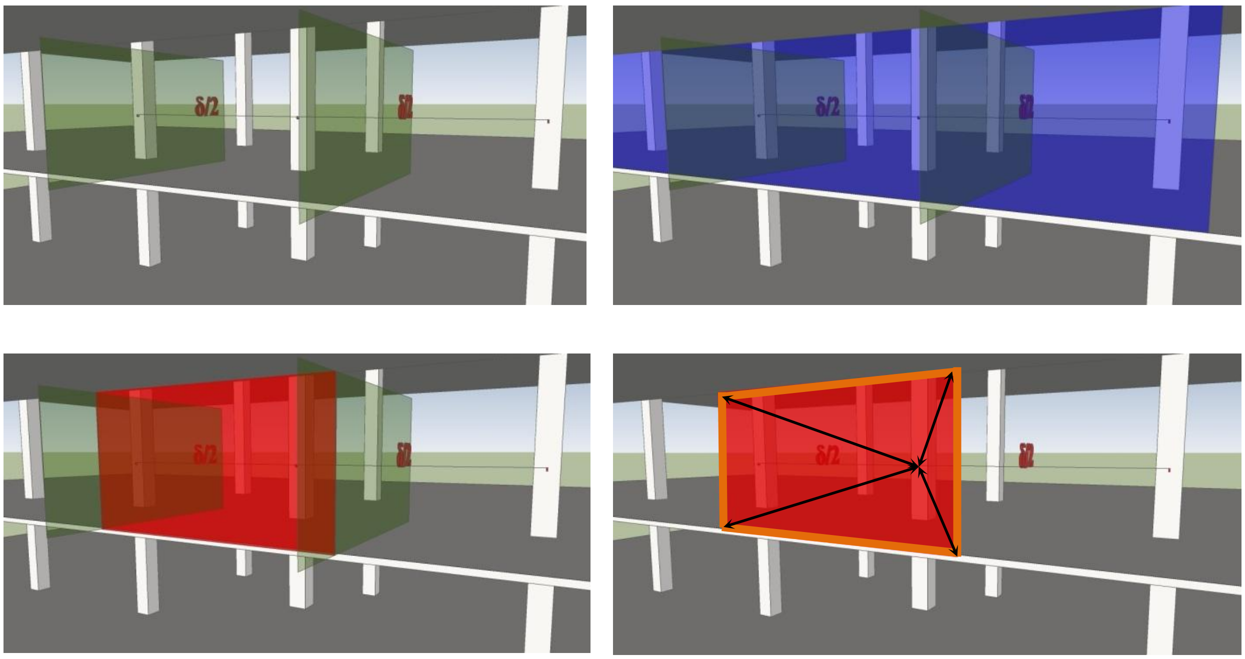


Figure 21. δ/2 surfaces (top left) and their intersections with the work zone (top right) defines the work zone share (bottom left). θ = farthest point of δ/2 and work zone with the tieback (bottom right)

δ/2 surface is defined for this purpose. δ is the distance between the two adjacent hookup points, and δ/2 surface is the surface passing from δ/2 point perpendicular to the working zone face. Each lanyard’s work zone shares the work zone surrounded by the two adjacent δ/2 surfaces. The system calculates the distance between each hookup point and the borders of its work zone share (defined by intersections of δ/2 surfaces and the work zone face). The longest distance is set as the default lanyard’s lower limit. This length should be less than the lanyard’s upper limit. Otherwise, one of the δ/2 surfaces (the farthest to the hookup point) will move closer and the calculations will be re-done. This process will repeat over and over until all the lanyards are properly suggested by the system.

It is preferred that the longest lower limit of all the lanyards in a row, and preferably in the building, do not exceed any of the upper limits. This means one lanyard with a constant length can serve that row (or the whole project) without any re-adjustment when the worker moves.

If the system cannot fulfill the mission for all the lanyards, it will show the error message and human intelligence (designer/constructor) will modify the hookup points by changing their number (frequency) and/or location.

- *Flowchart*

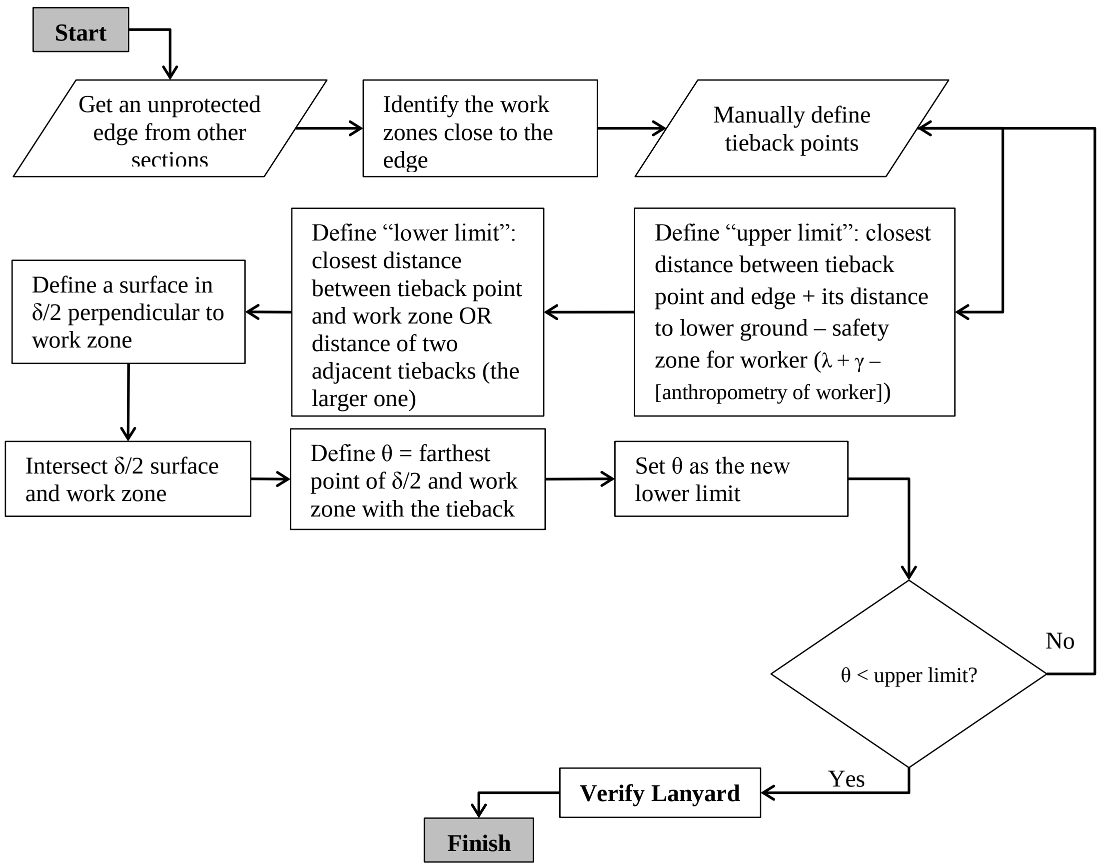


Figure 22 . Preliminary Lanyard Analysis Flowchart

Chapter Five

Falls Hazard Identification Framework for BIM Environments

Chapter Mission

The preliminary framework was developed in the past chapter. Chapter 1 explained that this framework needed an expert panel to add to it, expand it, and cover its gaps. Chapter five introduces the panel members and explains why/how they were selected. It explains how the panel was set up and presents the panel discussions. After a critical analysis of the panel discussions, this chapter categorizes the comments and concerns of the panel members, how they wanted to see the results of this research, and where the panel saw gaps in this research.

After presenting its objectives and making them clear, this chapter sheds light on the dark spot of the framework, and reflects the panel members' comments on the preliminary framework. It explains how the five flowcharts of the Pentagonal groups can be merged together and create an integrated flowchart to meet all the concerns of the research scope. Standardization, unification, and developing shared blocks in the flowcharts are explained here, and updates to the five flowcharts have been incorporated. Following sections of this chapter explain the changes to the individual flowcharts of chapter four, and discuss their improvements.

Procedures for choosing the second panel members and verification of the results are described in the last parts of this chapter.

Setting Up the Panel

Panel Set Up

Chapter 1 explained requirements of the expert panel, knowledge needed, and expertise required for fulfilling the panel mission. It explained that the first panel requires five members from five different disciplines in the construction industry. Having a position in a required discipline is not the only criteria for qualification of an industry expert to participate in the panel. In other words, when the panel requires participation of a general contractor representative, the individual for this position should not be selected from the most available general contractor around the researcher. Required knowledge and skills are discussed in detail at Chapter 1. Considering these guidelines, this research chose the panel members for the mission of adding to the preliminary framework and further developing it towards the final framework, which is the deliverable of this research. The procedures taken for choosing each of the panel members are explained in detail.

BIM Software Developer Representative

Buddy Cleveland

Senior Vice President of Applied Research, Bentley

A review of the existing commercial BIM software packages identified five software developer companies that are the pioneers of developing BIM tools. Autodesk, Bentley, Graphisoft, Vico, and Solibri are the well-known software developers in the field of BIM especially for the Building Construction sector. Graphisoft, Vico, and Solibri are the European based companies and their products are not well implemented in the U.S. Autodesk and Bentley are the two U.S.

based software developers and their products are predominantly being used in the U.S. construction industry. Both companies have large R&D labs and association with schools.

Senior vice president of applied research at Bentley is in close collaboration with Myers-Lawson School of Construction. Mr. Cleveland agreed to participate in this research as a panel member. A short bio of Mr. Cleveland is presented from the Bentley website:

> *Alton B. (Buddy) Cleveland, Jr. is Bentley's senior vice president of Applied Research. From 2000 through 2006, Mr. Cleveland held the role of senior vice president of Bentley Software. Prior to that role, he was the senior vice president of Bentley's Model Engineering Business Group. Mr. Cleveland joined Bentley in December 1997 when Bentley acquired Jacobus Technology, which he founded and served as president from its inception in 1991 until 1999. Before founding Jacobus Technology, he enjoyed a 20-year career with Bechtel Corporation, where he last served as the manager of Automation Technology. Mr. Cleveland holds a bachelor's degree in Engineering from Johns Hopkins University and currently serves on the advisory board for Hopkins' Department of Civil Engineering.*

General Contractor Representative
Melanie Parks
Environment Health and Safety (EHS) Director, Skanska

The industry based survey (refer to chapter two) made the researcher and the dissertation committee board familiar with the activists of BIM & DfS in the U.S. construction industry. One of the most specific expertise that the research is looking for in the panel is "hazard identification" skill. Skanska is an international general contractor with the headquarter in Sweden. Dr. Ku, one of the two co-advisors of this research, introduced the researcher to Melanie Parks. Her resume showed that she has experiences in Hazard Identification in some of the Scandinavian projects. Ms. Parks is currently working in Durham office of SkanskaUSA. She agreed to serve as a general contractor representative in the dissertation panel. A short bio of Ms. Parks is presented here from Skanska website:

> *Following a two-year assignment in Stockholm, Sweden, at Skanska headquarters, she has relocated to Durham, N.C., for the position of Environment Health and Safety (EHS) Director.*
>
> *In her new role, Parks is responsible for developing and implementing project specific safety and environmental impact plans. She is currently overseeing workplace safety initiatives for all Skanska projects in the Carolinas and Virginia, including the Duke University Keohane Quad and Chiller Plant projects. Parks was identified early as a rising star at Skanska. In just five years in the construction industry, she has worked on high-profile projects such as the Nissan*

Americas Office Facility in Franklin, T.N., a $109 million, 530,000-square-foot, 10-story building, as well as healthcare projects in Texas and Kentucky. Most recently, she coordinated safety personnel and policy work with Skanska employees in three countries: Sweden, Norway and Finland.

Architectural Designer Representative
Jesse Oak
Vice President / Design Support Manager, Parsons Brinckerhoff

The researcher had an internship experience with Balfour Beatty on summer 2010. He researched implementation of DfS in Balfour Beatty at their Fairfax office at the Technology and Process Development (TPD) department. Balfour Beatty is recently awarded a project with DfS as a requirement on it. Balfour Beatty's collaboration on industry baseline survey showed their familiarity and interest with the research area. In order to find a designer familiar with BIM and DfS concepts, senior manager of the TPD department at Balfour Beatty was contacted. His appreciable collaboration with the researcher put the researcher in contact with a sister company of Balfour Beatty, Parsons Brinckerhoff.

Jesse Oak, Vice President and Design Support Manager of Parsons Brinckerhoff agreed to participate in the dissertation panel. A brief summary of Parsons Brinckerhoff is presented here from their website:

> *Parsons Brinckerhoff is a leader in developing and operating infrastructure around the world, with approximately 14,000 employees dedicated to meeting the needs of clients and communities in the Americas, Europe, Africa, the Middle East, Asia and Australia-Pacific regions.*
>
> *Parsons Brinckerhoff is a global consulting firm assisting public and private clients to plan, develop, design, construct, operate and maintain hundreds of critical infrastructure projects around the world. We know very well that the projects our clients entrust to us significantly impact the lives of those who live and work in their communities because we live and work in those same communities. It is this fact that motivates the Parsons Brinckerhoff professionals who partner with our clients to design solutions to a broad range of technical, logistical and managerial challenges.*

Sub-Contractor Representative
Robert Zahner
Robert Zahner, Senior Vice-President of Zahner

Subcontractor was the trickiest panelist to choose. It is very important that the panelist self-performs the jobs. The subcontractor should not only use BIM software, but also know basics of the BIM concept. Subcontractor should know concept of DfS and practice it in the shop drawings. It will be great if the subcontractor design its share of the project, and does not just perform drawings that are already designed by the others. From this perspective, a painting subcontractor might not be a good choice since its share in the design of the project is very negligible. Zahner is an international subcontractor for the building cladding. Zahner has an architectural design team for designing their project share. As Robert Zahner, Senior Vice-President of Zahner, said, they consider safety factor in their designs and shop drawings. He said that they change the draft design to make it safer for construction. A short introduction to Zahner is presented here from their website:

> *For over 115 years Zahner has advanced the architectural metal by applying aircraft-grade engineering technologies to its high level of craftsmenship. Zahner is known throughout the world for its precision craftsmanship in the production of designs by bold architects. The museum level craft and engineering that Zahner consistently provides can be found in both North & South America, Europe, Asia & the Middle East. Zahner provides consultation and design assist services, fabrication, and installation for art and architecture.*

Safety Representative
Thomas Mills
Associate Director of Construction Industry, Center for Innovation in Construction Safety and Health

There is a safety research center at Virginia Tech named: Center for Innovation in Construction Safety and Health. A short summary of this institute is presented here from its website:

> *In support of the Institute for Critical Technology and Applied Science (ICTAS) mission, the faculty associated with the Center for Innovation in Construction Safety and Health are available for projects in other industrial sectors. Many, if not most, hazards and respective interventions are non-specific in terms of industry. Similar issues are seen across industries and many of our researchers have considerable experience across industries. In addition, there are efficiencies to be realized by benchmarking what works in one industry and adopting or adapting best practices in the targeted industry. In the coming months and years, looks for cross-sector impacts, lessons learned, and success stories.*

The leadership team of the institute is composed of:

- Dr. Maury Nussbaum, Director
- Prof. Thomas Mills, Associate Director, Construction Industry
- Dr. Brian Kleiner, Associate Director, Research
- Dr. Tonya Smith-Jackson, Associate Director, Safety Intervention and R2P

Since it is preferred to choose the panelists out of the dissertation committee, Dr. Kleiner was not chosen for the panel. Dr. Nussbaum and Dr. Smith-Jackson are not in the construction trade though. Prof. Mills was the best choice for this panel. He agreed to serve as the panel moderator in the session date. The following short bio of Prof. Mills is presented from the institute website:

> *Professor Mills is an associate professor of Building Construction at Virginia Tech and is an Associate Director of the Center for Innovation in Construction Safety and Health Research and adjunct faculty in the Department of Civil and Environmental Engineering at Virginia Tech. Prior to entering academia, Professor Mills was a small business owner practicing commercial architectural design and construction management with single projects upward to $50 million. His academic research work has spanned several disciplines but the dominant theme is the translation of research-to-practice. His research work has crossed the design, construction, and educational aspects including pre-engineered modular facilities for aging populations, informational transformations, exchanges, and decision-making among owners, designers and construction personnel, safety systems for accelerated construction activities, and construction industry recruitment and retention. Well-grounded in the building trades prior to academia, Professor Mills keeps a constant involvement with the industry through his involvement with the Associated General Contractors, and the Associated Builders and Contractors. He recently completed a faculty fellowship with Hensel-Phelps Construction Company, a $1B self-performing general contractor, that allowed him to actively engage in projects as diverse as the Pentagon reconstruction that utilizes a short interval progress schedule system for a 24/7 project work program, a $400M design-manage project where HPCC is the lead and incorporating aspects of Building Information Modeling (BIM), and to experience and be mentored in quality management and the Hensel-Phelps Safety Management System, including receiving STOP training. Professor Mills has authored of over 30 refereed publications involved in various aspects of construction information exchanges and work processes and has served as faculty advisor to numerous PhD and MS students.*

Contacting the Panel Members

Once the panel members were identified, an introductory email was sent to them. The panel members were introduced to each other and a general procedure of the two panels was explained to them. A link to a doodle file was copied in the introductory email and the recipients were asked to fill the doodle file with their preferred time to schedule the panel session.

One of the challenges of the research was to avoid panel members' bias towards a specific idea. The first step was choosing the panel from a variety of construction sectors to balance each other's bias. The other step was to have everybody on the panel think about applications of BIM in the DfS concept, and express his/her vision on it before they read the current research. This would avoid everybody starting with the specific vision of the research and have their mind structured. Last but the most effective; a facilitator was chosen for the panel to avoid the researcher's bias in the panel as well as to balance the panel members' bias. It was imperative to keep the panel members as neutral as possible when they evaluated the preliminary framework. The question they were asked was:

> *"Regarding my research definition, scope, and goal how do you see the application of BIM in DfS? In other words, if you want to give a big picture of "how BIM – as a tool – can be used for DfS", what picture of the premise do you envision?"*

The question was sent to them with a two-page summary of research characteristics, including research question, research scope, research goal, etc. This was intended to help them get a general understanding of what the research was looking for and how far they needed to expand their thoughts.

The panel members were given a three-day timespan to answer the question. Once the researcher received the answers to the question, he shared a summary version of the research in less than 20 pages with the panel members. It was sent to them along with an appendix with more detailed explanation of the research.

The panel members were given four days to review the research summary. The summary was sent to them along with two sets of questions. "General Questions" were composed of two questions to be answered by everybody in the panel. General Questions investigated the general view of the members on the research approach and the preliminary framework as a whole. The General Questions are:

1. *One way to integrate these five flowcharts is to put them in one flowchart with a 5-ways decision node and unite them in one big flowchart. Is this the best method based on the current flow of the research up to this point? If not, other than this method, what other method do you suggest for combining and uniting the pentagonal flowcharts?*

2. *Do you validate the general approach and the preliminary structure of the framework?*

Answers to these questions are copied here from their email:

<u>*Robert Zahner*</u>

The model helps us to resolve the areas of concern where we need to utilize different equipment to safely access a work area. Further, it allows us to modularize our fabricated product so we can avoid having to put people in hazardous areas wherever possible. DFS really goes hand in hand with quality and cost as the difficult work areas also usually translate into the areas where quality can become less important (to the person physically working in the hazardous environment) and more specifically they are the areas that it costs more to install a given unit.

<u>*Melanie Parks*</u>

The majority of accidents on our sites happen for two reasons: lack of training and poor planning. The first item needs to be addressed from a "people" point of view. However, the second item of poor planning is where BIM applies. Primarily, BIM would allow the industry to truly plan for safety in the exact same way that they plan for other activities on the site (deliveries, production, logistics). We also know that our ability to influence safety is at its greatest in the design phase, decreasing in an exponential way to the end of the project. If a team has a BIM model with "smart" BIM components (components having weight, volume, carbon footprint, assembly time, specifications, etc), then they can plan for safety early as though it really were a part of the overall project. Using a model, they can estimate how much of a safety supply is needed, like scaffolding. The model would help the team order planking, couplers, and sill plates. It would also allow a team to see how long it would take to erect this scaffold, helping them put this activity into the schedule. Previously, this kind of thing would not have been included on a schedule. Applying BIM to DfS would also help a team visualize which equipment will be needed and situations will arise later in the construction – the interior finish phase. A BIM model with smart safety components helps a team plan for safety like it is part of the work. This is how it should be managed to maximize productivity and minimize loss.

<u>*Jesse Oak*</u>

BIM is a tool we currently use in the development of the design for a full wide range of projects for our clients. As the industry adopts BIM and

> *VDC practices collaboration among the design and construction teams is starting earlier in the process and allows for working out potential pitfalls prior to construction. This includes how things fit, how they are to be connected and attached and allows everyone to understand any conflicts that can be corrected in virtual space saving time and money. Safety is always a major concern on any construction site and working in a virtual world from the start allows everyone to study how a structure will go together and identify any potential danger situations. This includes staging locations, crane placement, deliver points and separation of truck traffic from work crews, potential fall areas just to name a few.*

The second set of questions (Individual Questions) contained four individual questions – one for each panel members to answer. This set investigated expectation of bringing everybody on the panel. It generally questioned how they think the outcome of this research can benefit their expertise. The Individual Questions are:

> <u>*BIM expert (Buddy Cleveland)*</u>
> Is there any missing property in the framework that prevents the intended BIM application to function as expected? This can be a property that is not clearly explained or a property that is completely missing in the framework.
>
> <u>*Designer (Jesse Oak)*</u>
> Regarding the determined scope of the research, what info you see missing in the framework, and what other types of analysis you feel important to add to the framework's processes and outputs?
>
> <u>*General Contractor and Sub-Contractor (Melanie Parks & Robert Zahner)*</u>
> How can this framework be improved in order to better contribute to the designer and/or safety analyst in hazard identification and analysis?
>
> <u>*Safety Expert (Thom Mills)*</u>
> Beside the described impact factors and the processes explained for analyzing them, what other impact factors and analysis processes do you see missing (if any) in this framework? If not, is there a better way to analyze any of the pentagonal groups?

Answers to these questions were not required before the panel session. The questions asked the panel members to contemplate about the research goals and how the developed framework can fulfill its goals as well as to give the panel members a sense of what they are expected to do in the panel.

Session Structure

As mentioned before, Professor Mills agreed to be the facilitator of the session. Melanie Parks from Skanska physically attended the session on the Blacksburg campus along with Prof. Mills and the researcher. Buddy Cleveland from Bentley, Jesse Oak from Parsons Brinckerhoff, Robert Zahner from Zahner, and Dr. Ku (co-advisor of this research) were called from Blacksburg campus.

Prof. Mills introduced the panel members to each other. He gave everybody a brief summary of the submitted documents. Prof. Mills suggested allocating 15-20 min to each panel member, and everybody to answer the three questions (two general questions, and one individual question) at the same time. The panel members agreed with the agenda, and the talks started. After everybody answered his/her questions in the allocated time, Dr. Ku started challenging the answers, and had the panel members continue the discussion until their ideas and comments on this research merge together.

Panel Members' Discussions on the Dissertation

1. Architectural Designer Representative
Jesse oak – Vice President –Parsons Brinckerhoff

Jesse started with introduction of his company. He continued with the fact that safety in the job site can root in many aspects such as

- Staging location
- Crane placement
- Delivery points
- Separation of vehicular and human traffics, etc.

Then he talked about their company's practices of BIM and Safety. Jesse explained his concerns with the framework as well as his positive insights with the research. He suggested to define more interrelationships between the flowcharts and to make them more interconnected. He appreciated the breakdown of the research scope to a digestible chunk and thinking through it in detail. Jesse explained how developing consistent standards in the flowcharts can help the final framework to digest the existing five flowcharts. He was interested in seeing more interconnected flowcharts with rules and standards repeating consistently through them.

1.1.Recommendations

1. Flowcharts to be interconnected
2. Rules to be created for the flowcharts and they follow consistent standards

1.2.Note

1. Safety is too broad of an issue to bring to the design phase.

2. ***BIM Software Developer Representative***
   Alton B. (Buddy) Cleveland – Senior Vice President, Applied Research – Bentley

Buddy's talk switched the discussion to the concept of BIM and how the BIM concept is being broadly expanded with different definitions. He required more clarification on the concept of BIM in this research and how BIM is defined here. He needed to know what type of information is required in this framework, and what information is assumed to be in the future model. He talked about the multi-faceted aspect of safety and the need to consider safety with looking at different aspects of construction. He was interested to hear more about the critical factors in safety, and their importance in the construction projects.

2.1.<u>Recommendations</u>

1. Define information requirements for the proposed framework (future software) to be able to analyze safety
2. Safety is a multi-faceted concept. Design is one of the elements, and the other elements such as means and method, delivery points, etc. contribute in safety. What are the critical factors in safety of the construction workers?

3. ***General Contractor Representative***
   Melanie Parks – EHS Director – Skanska

Melanie's talk shifted the discussion towards the responsible party for the safety of construction workers. She expressed her company's concern on "Who" is in charge more than "How" to perform it. She talked about tradeoffs between time, budget, and safety. She explained the multi-faceted nature of safety in construction, and the interactions of the impact factors on each other. She pointed to administrative decisions and different preferences of different companies regarding their safety policies. Melanie was expecting a software application in the future that considers differences in different companies. She added to the previous discussions of multi-faceted nature of safety, and explained her interest in seeing interconnections of impact factors rather than seeing them in isolated analysis silos. For the movement paths, she suggested to include material storage considerations and connect the existing research with the study of hazardous materials. She explained how crane movement analysis is important in the study of construction workers. Melanie talked about a link to connect this research to a research that studies site congestions and site clashes by moving vehicles and lorries. She suggested to introduce different types of lanyards including retractables for the future software.

2.1.<u>Recommendations</u>

1. See the multi-faceted nature of safety in the results
2. Reflect the administrative company-specific decisions to the safety analysis, e.g. scaffold's handrails requirements and height of the scaffold.
3. Consider transition points such as moving in and out of scaffolds to the building

4. Distinguish the storage of hazardous materials
5. Model crane movement (as a temporary safety structure) and site clashes
6. Make it possible for the model to know retractables

2.2.<u>Note</u>

1. Who is in charge is more important to us rather than How to perform it.

4. Sub-Contractor Representative

Robert Zahner – Senior Vice President – Zahner

Robert started his talk with introduction of his company, and what they do in it. He talked about application of BIM/VDC in their company and sample practices they performed to make construction safer by changes in the design. He introduced his company as the one with more work on the exterior side of the building. He wanted to see a separate section parallel to this developed one for the exterior side of the building and analyzing its hazards. When he was asked about an example of an exterior safety concern, he suggested to see the sloped surfaces in the model, transitions zones e.g. from scaffold to building, and positioning zones e.g. ladder as well as rescue plan in the design phase. He said that his company looks at Movement Path safety via material storage, material movements, and crane movements.

2.3.<u>Recommendations</u>

1. A five node decision at the beginning of the flowcharts does not reflect the interconnection of the impact factors.
2. Nodes should be more complicated
3. To incorporate clear zones and positioning zones such as ladder clearance zones in the model
4. This model investigates interior fall hazards

2.4.<u>Note</u>

1. 4^{th} dimension is a critical factor for the effectiveness of safety analysis

5. Safety Representative

Thomas Mills – Virginia Safety Center

Thom explained a summary of the research to make the scope more clear for the panel members. He talked about hierarchies of control, and suggested to see hierarchies of control as a standard of the flowcharts. He emphasized on interconnection of the flowcharts and feedback loops that make the analysis more interrelated. Thom said that at this time, default of the flowcharts seems to be set on Lanyard analysis, and a more clear illustration of the hierarchies of controls is necessary to see.

2.5. Recommendations

1. Define hierarchies of control as a backbone of the flowcharts
2. Define standardization for the terms and rules
3. Define interconnection between the flowcharts
4. See the human-machine interface in your final framework

Analysis and Grouping the Panel Members' Comments

The researcher found feedbacks of the panel members very helpful for further developing the preliminary framework. When the panel discussion finished by the end of the session, the panel members' ideas on the progress path of the research converged to four specific topics. These topics were considered in developing the final framework. Some of the comments and questions were either out of the scope of this research or already considered in developing the preliminary framework and need to be clarified more. Since most of the comments from different panel members overlap each other, a compiled summary of them is presented here:

1. Converged recommendations to be used for further developing the preliminary framework

1.1. To Interconnect the flowcharts in different points and define cyclic loops (1.1.1 – 4.1.1 – 5.1.3)
1.2. To create consistent standards and rules for the flowcharts (1.1.2 – 5.1.2)
1.3. To make the nodes more complicated (4.1.2)
1.4. To clarify the Human-Machine interface in the framework (5.1.4)

2. Recommendations to be used for extension of this research

2.1. To consider transition points from building to temporary safety structures (3.1.3)
2.2. To distinguish storage of construction materials based on their hazardous conditions (3.1.4)
2.3. To model cranes and their movement paths (3.1.5)
2.4. To make the framework open for defining new safety utilities e.g. retractable lanyards (3.1.6)
2.5. To incorporate clear zones and positioning zones such as ladder clearance zones in the model (4.1.3)

3. Areas need to be explained more clearly for the reader – Misconceptions about this research

3.1. Safety is too broad of an issue to bring to design phase (1.1.3)
3.2. Safety is a multi-faceted concept and cannot be viewed as a result of one cause (3.1.1 – 2.1.3)
3.3. What are the critical factors in safety? Material delivery, movement paths, congestion, etc. (2.1.3)
3.4. What information from the BIM model is being used and shared in the model (2.1.2)
3.5. Who is in charge of safety rather than how to perform safety analysis (3.2.1)
3.6. Incorporation of administrative and company-specific decisions in the model (3.1.2)
3.7. Incorporation of hierarchies of control (5.1.1)
3.8. This model investigates interior fall hazards (4.1.4)

The first group which is the subject of the following sections of this chapter (developing the Final framework) was reflected on in the preliminary framework, and turned into to the final framework. The second group is out of the scope of this research and is presented as the "future steps" of this research. The third group covers the areas needed to be explained more. They were explained more in detail in the next section.

To Clarify Misconceptions in the Research

3.1. Safety is too broad of an issue to bring to design phase

The concept of Design for Safety (DfS) stands on the contribution of designers in the safety of construction workers. The rich literature of this area of study (refer to the Literature Review chapter) indicates that a noticeable number of construction hazards root in the design phases. This concept does not transfer the whole responsibility of the construction safety to the design phase, but it rather takes advantage of collaboration of designers with constructors in making construction safer.

3.2.Safety is a multi-faceted concept and cannot be viewed as a result of one cause

This is an absolutely true statement and the researcher agrees with it. The unsaid side of this statement is that "this research considers one cause for safety, and tackles with one cause for providing a safe construction site." Although the researcher agrees with the said-side of the statement, he disagrees with this unsaid-side of the statement. The counter-dispute the researcher brings for this unsaid-side is that "falls" are the consequences of the interaction of multiple factors. Actually this was the trigger for starting this research. Otherwise, the existing simple checklists would be the best tool for identifying safety. The reason this research proposes the flowcharts in Chapter 4 is because it acknowledges the fact that interaction of multiple factors causes the hazards, and "identifying the hazards" is not enough for providing safety of construction workers. The researcher believes that analyzing the hazards (rather than simply identifying them) is the best solution to the multi-faceted nature of construction hazards. The proposed framework takes a noticeable step in directing the safety researchers towards analyzing multi-faceted nature of hazards. This is when the current practices of safety simply identify the hazards.

3.3. What are the critical factors in safety? Material delivery, movement paths, congestion, etc?

As it is said before, there are multiple factors – named impact factors in this research – contributing in each hazard. The nature of the hazards, the circumstance under which the hazard happens, type of the project, and many other factors determine the importance of each factor compared to the other impact factors. The researcher cannot determine – and has no intent to determine one factor as the “Critical Factor” for construction hazards for the following reasons::

1. Not all the hazards root in the same causes (factors). As a result, no one factor can be shared among all the hazards to be determined as the main cause of construction hazards.
2. There is no measure other than subjective judgments of each individual to let analysts compare the contributing share of each factor in a hazard event. This is when the subjective judgments vary person to person.

3.4. What information from the BIM model is being used and shared in the model?

Chapter four (BIM-based Falls Hazard Identification Framework) defined some basic properties (characteristics) for the future intended BIM model. It explained that the mission of the framework is to further explain the properties of the final model. Characteristics (properties) of the final model are the information embedded in the BIM model, and how/when they show up and interact in the model (parametric aspects of the model). Readers are referred to Chapter 4, sections “Work Space” through “Lanyard Analysis” for reviewing the basic properties of the model. These properties along with the parameters that have them interact with each other are further explained in the extended explanation of the pentagonal groups in Chapter 4.

3.5. Who is in charge of safety rather than how to perform safety analysis?

The concept of Design for Safety in this research stands on the collaboration of designers and constructors in the design and planning phases. Although their share of collaboration is not consistent in different phases of design and planning, none of the parties will be disregarded in any of the stages. This explanation clarifies that everybody is involved and the question of “WHO” cannot target any specific person.

3.6. Incorporation of administrative and company-specific decisions in the model

The thinking logic behind the research kept this premise in mind that different users in different companies have different preferences. The preferences are in the selection of utility tools, risk thresholds, etc. The general idea for dealing with personal preferences in the intended BIM software is to have a default preference selection in the model. When an object is called from the library, the object's parameters recognize the surrounding condition parameters. The coded parameters of the called object determine the default required safety utilities for the called object in the existing surrounding conditions. The modeler / designer / constructor can manually change the default of the specific object in the model. The intended BIM software will have the ability to change the default of the software (vs. one object) for specific items. This means each company can tweak the software and customize it based on its preferences.

3.7.Incorporation of hierarchies of control

Manuele (1997) defines Designing for Construction Safety as an intervention supported by the hierarchy of controls common to the safety and health professions which identifies designing to eliminate or avoid hazards as the preferable means for reducing risk. Based on the hierarchies of control, safety analyses always result in responses that follow different criteria. The agreed Hierarchies of Control in the construction safety is the most comprehensive hierarchy preference that aims at eliminating and then decreasing the effects of hazards with regards to company / personal preferences. There are five levels in the Hierarchies of Control:

- Elimination
- Substitution
- Engineering controls
- Administrative controls
- Personal Protective Equipment (PPE)

There is a misconception about the default of the proposed framework. Lanyard Analysis that analyzes the PPE is the last choice of the system. In other words, when no other solution terminates the safety analysis loops in the proposed flowcharts, it ends up in Lanyard Analysis. The flowcharts are designed completely in-line with hierarchies of control. PPE is not the default of the system. It is the last choice of the system when no other better solution satisfies safety requirements of the system.

3.8.This model investigates interior fall hazards

The processes that the Research Methodology undertook and the limits that the Research Scope defined were to study three sources in order to compile the "Summary Notes." The final scenarios that resulted in developing the flowcharts and consequently the final framework are limited in the determined scope of this research. Any scenario that falls out of this scope is not planned to be considered in this research. Having said that, there is at least one example of exterior hazard analysis in each of the pentagonal groups in Chapter 4 . This statement clearly explains that this research is not limited to interior hazards.

On the other hand, this research does not intend to develop a comprehensive framework for developing a software application. This research planned to study a small pie of construction hazards. It studied the processes for developing a flowchart for the specified pie of hazards. As a result, this research is intended to present a generic sample of the processes. The goal of the research is to develop the processes leading to a generic enough frameworks to be able to generalize and apply those processes to the rest of the construction workers hazards. The main focus of this research is on the proposed “processes leading to the output framework” rather than “a developed framework as a product.” In other words, the main focus of the final product of this research is on a series of processes rather than a piece of product.

Developing Final Framework

Changes in the Current Pentagonal Flowcharts

Discussion between the panel members converged their applicable comments into four points:

1. To interconnect the flowcharts at different points and define cyclic loops
2. To create consistent standards and rules for the flowcharts
3. To make the nodes more complicated
4. To clarify the Human-Machine interface in the framework

Line items two and three are reflected on the five flowcharts of Chapter 4, and the updated versions are presented here in Chapter 5 of this dissertation. Line item two suggests developing consistent rules and standards in the flowcharts. This makes the flowcharts more compatible with the bases of “procedural programming”, and optimizes coding of the future software. To fulfill this objective, the researcher broke the flowcharts down and created “consistent blocks” in the five flowcharts. These consistent blocks can be coded as “procedures” in the coding of the future software, and optimize the software code. Developing these blocks or procedures helped unifying the existing five flowcharts and shrinking the final flowcharts. Some of the examples of these consistent flowcharts are as follows:

1. User interface for making decision on machine outputs

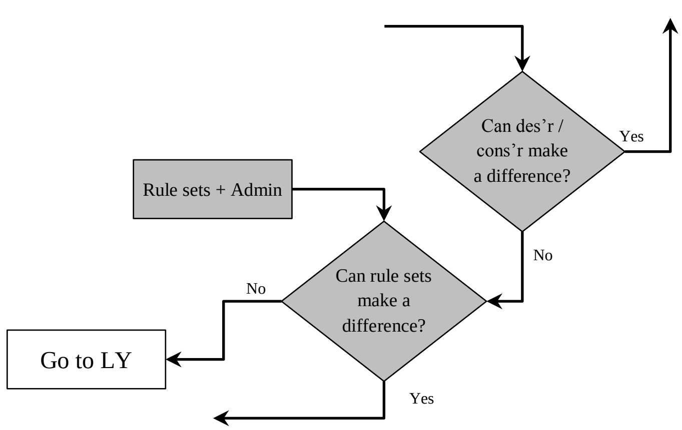


Figure 23. Decision maker the Hierarchies of Control

2. Machine report

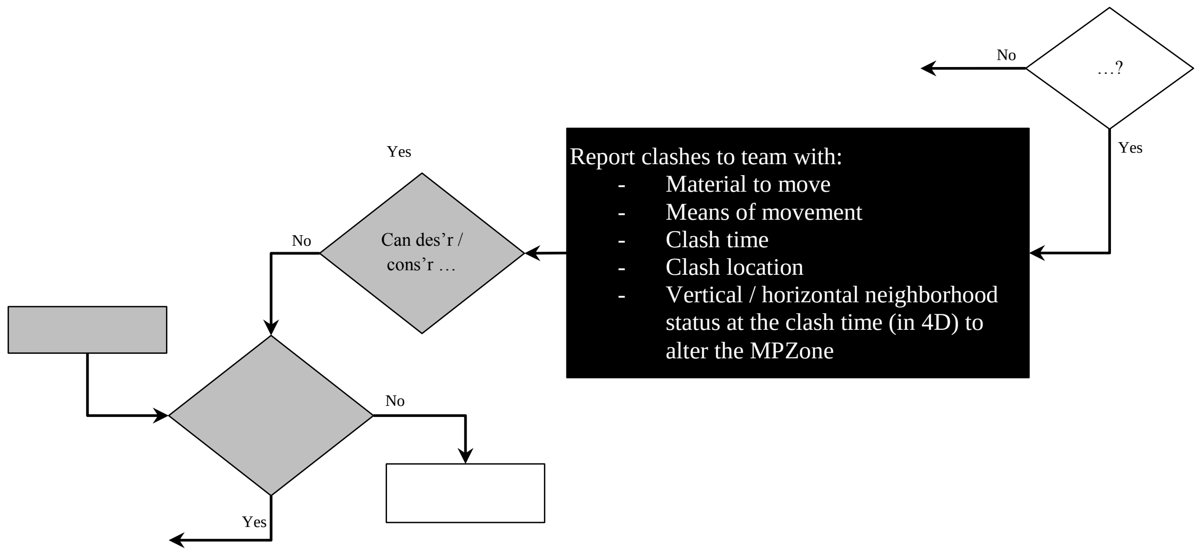


Figure 24. Machine report to the human interface

3. Ground mover and opening / edge finder

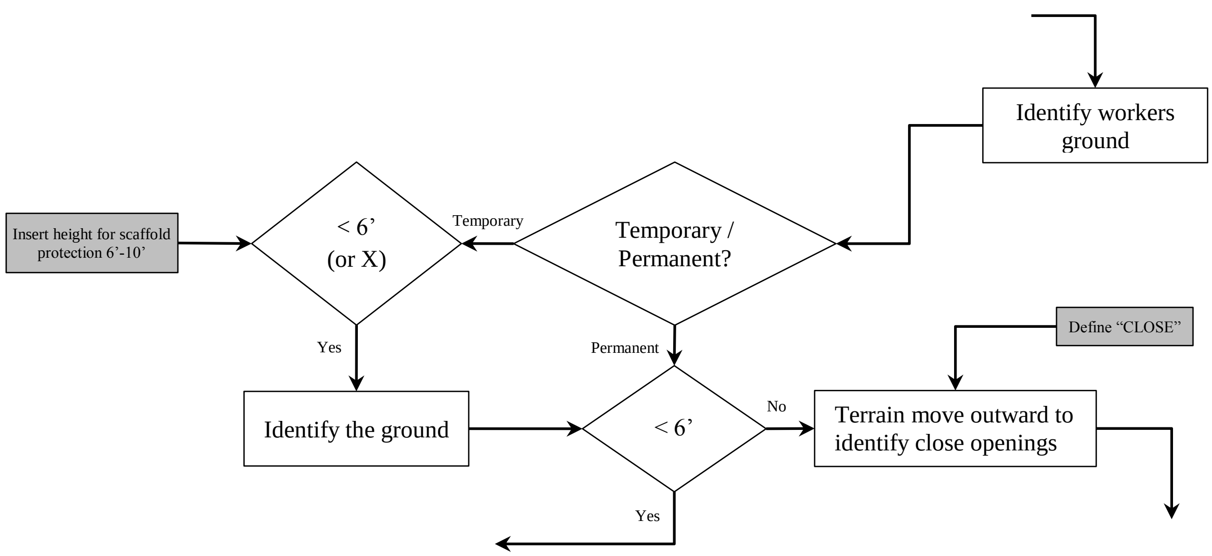


Figure 25. Ground mover / edge detector

The fourth point concerns clarifying the human-machine interface in the flowcharts. This concern is reflected on both the final flowcharts and the preliminary flowcharts in Chapter 4. The idea to apply this suggestion on the research is to color code the shapes in the flowcharts. The internal procedures of the software are represented by blank shapes. Human inputs and machine outputs of the flowcharts (human-machine interface) are represented by dark-filled shapes.

Where a human (designer / constructor) inputs are required by the system, the relative shape is presented in gray with black fonts, whereas machine outputs of the interactions are represented in black shapes with white fonts.

Following, the updated versions of the flowcharts are presented. A bulleted description explains the functionality of the flowchart, as well as their improvements.

Work Space

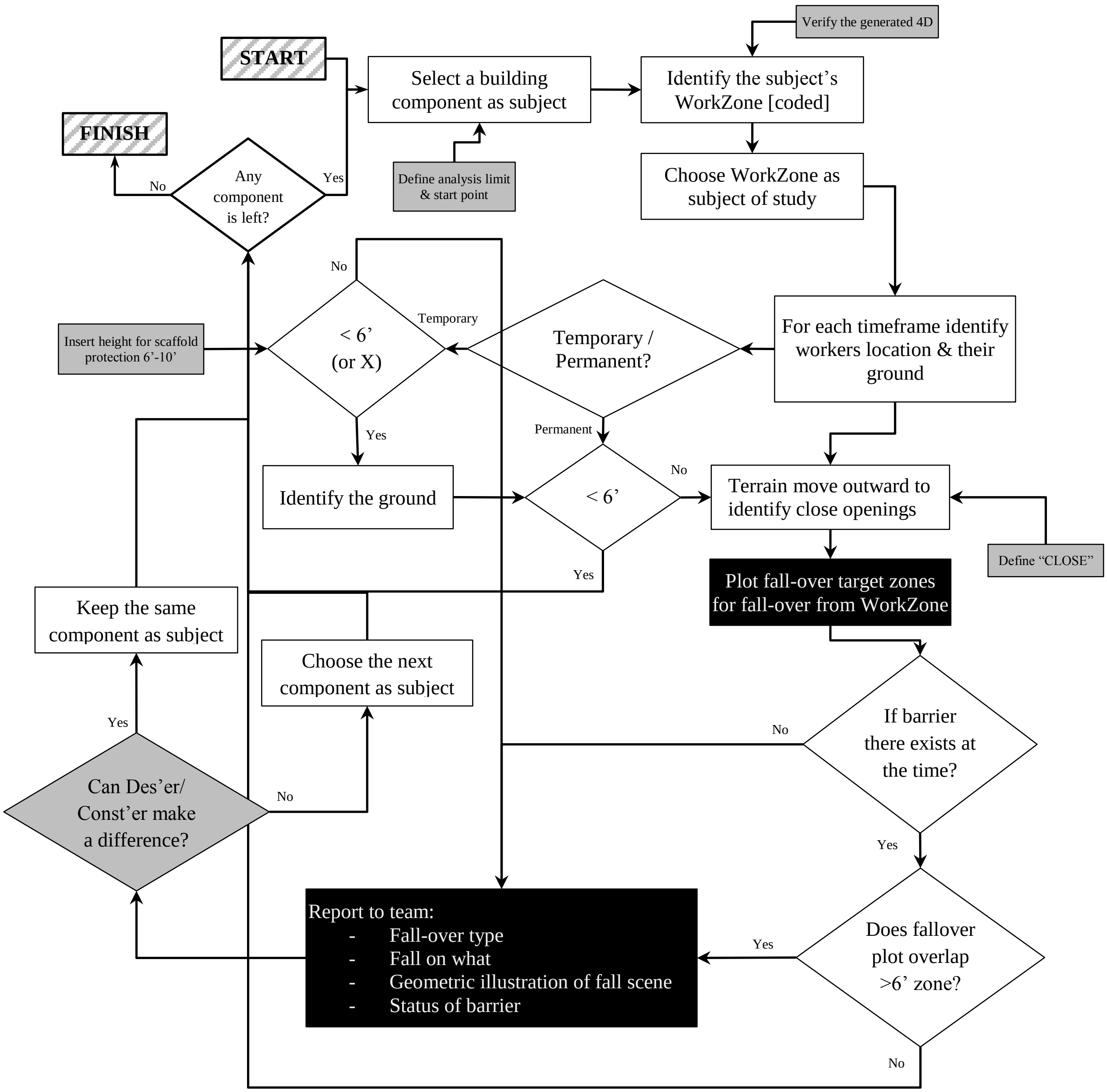


Figure 26. Final Work Space Flowchart

What it does:

- Identifies workers locations
- Identifies works in heights
- Identifies fall-over target zones
- Interconnects with GR (Guard Rails) to study barriers' status
- Plots the status of workers safety at heights

Improvements

- Explicitly show of Work Space status
- Improved representation of hierarchies of control
- Improving the repeating loops
- Using consistent blocks for the operations
- Clarifying human-machine interface

Work Surface

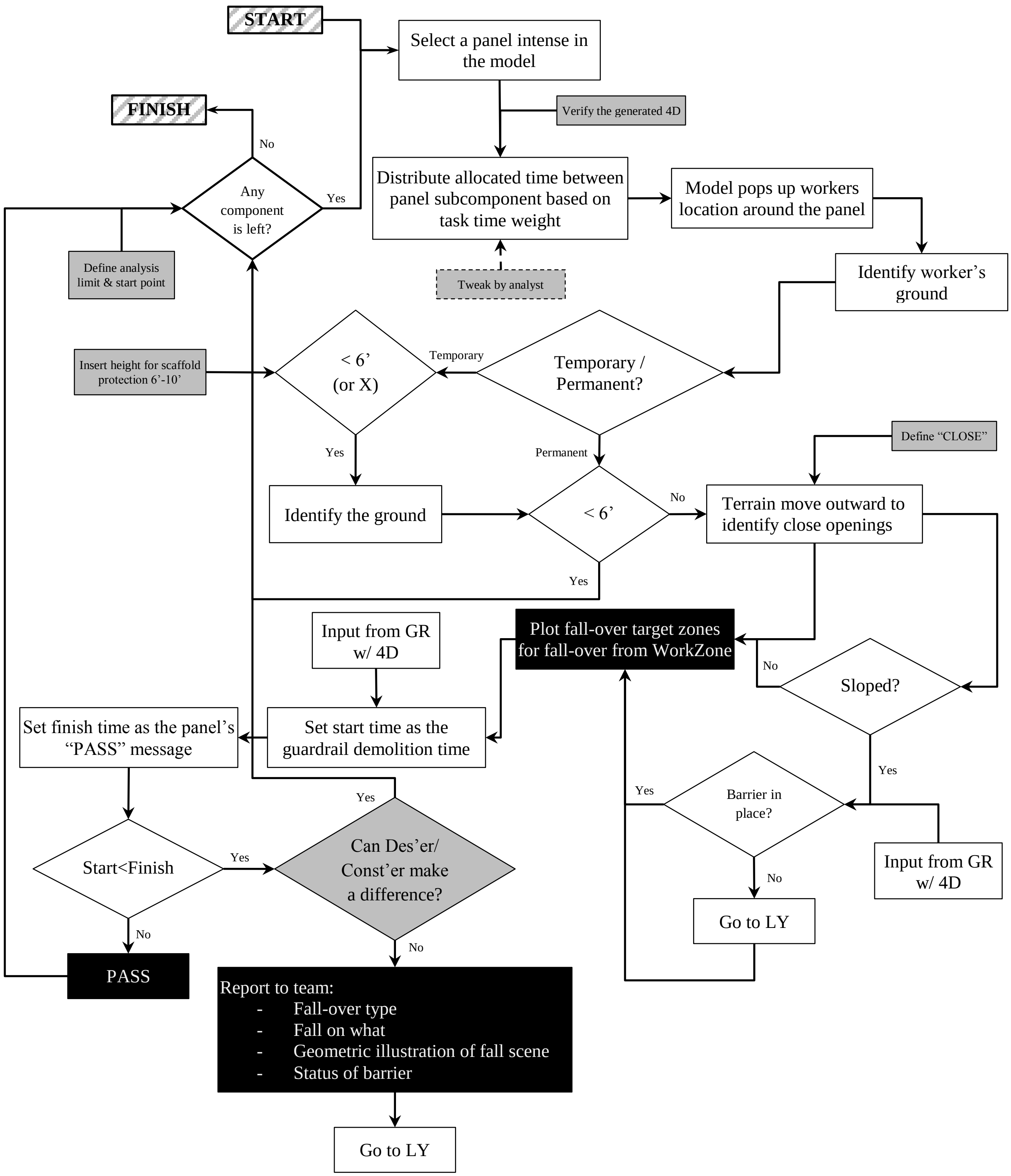


Figure 27. Final Work Surface Flowchart

What it does:

- Studies panel safety
- Breaks down the allocated time in panel construction
- Highlights workzones around the panel
- Identifies works in heights
- Plots fall-over zones and checks their status
- Checks sloped surfaces
- Reports sloped surfaces for side guarding
- Reports sloped surfaces for PPE
- Investigates continuous protection of temporary removals, and when a non-secure panel is in place
- Reports panel works' safety status

Improvements

- Improving the repeating loops
- Using consistent blocks for the operations
- Clarifying human-machine interface
- Improving extra-loop interconnections

Movement Paths

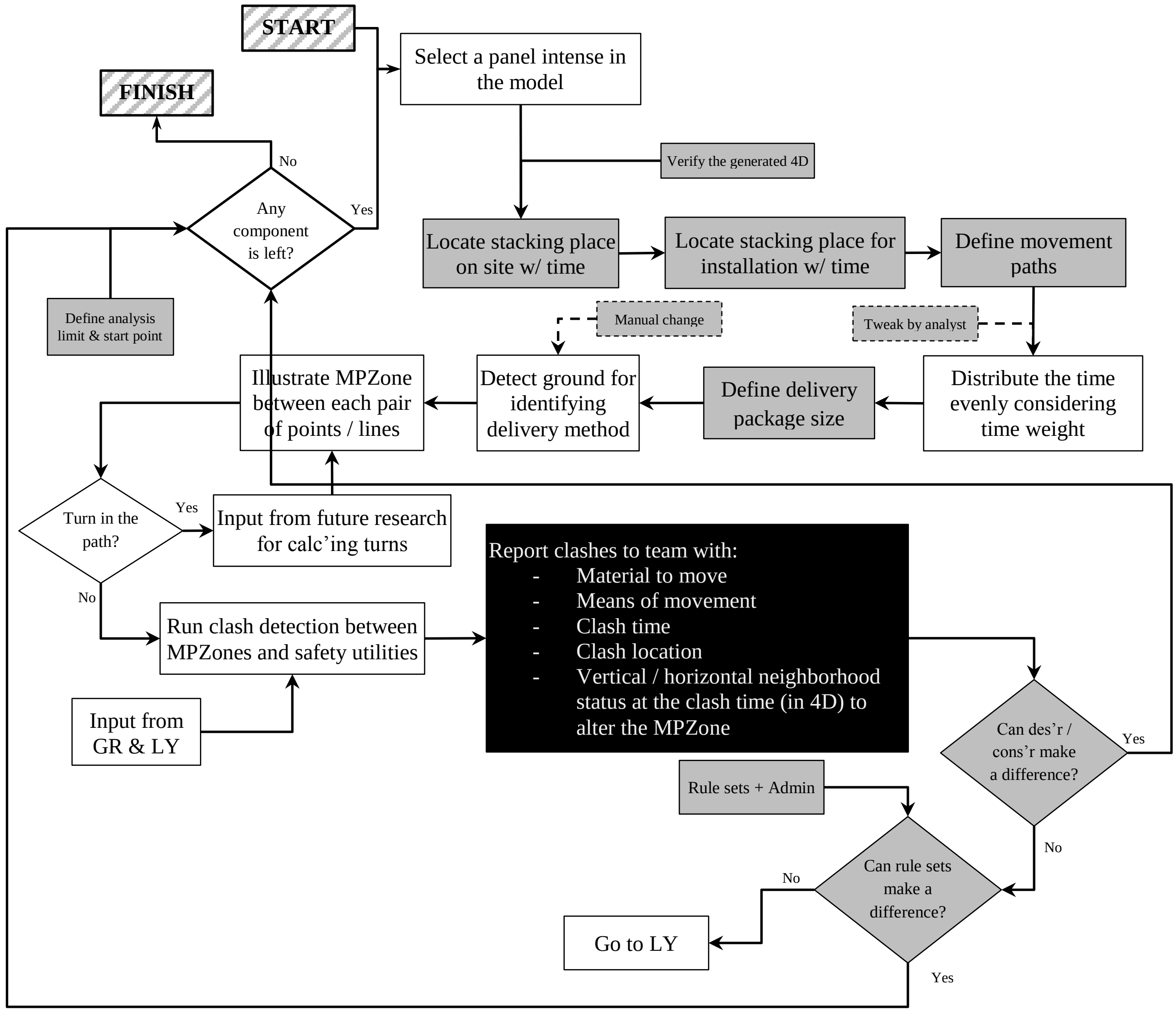


Figure 28 . Final Movement Paths Flowchart

What it does:

- Studies material stacking locations
- Studies material movement paths
- Studies material movement means and methods
- Detects clashes with temporary safety utilities
- Reports temporary removal of temporary safety utilities

Improvements

- Improving the repeating loops
- Using consistent blocks for the operations
- Clarifying human-machine interface

Temporary Safety Utility

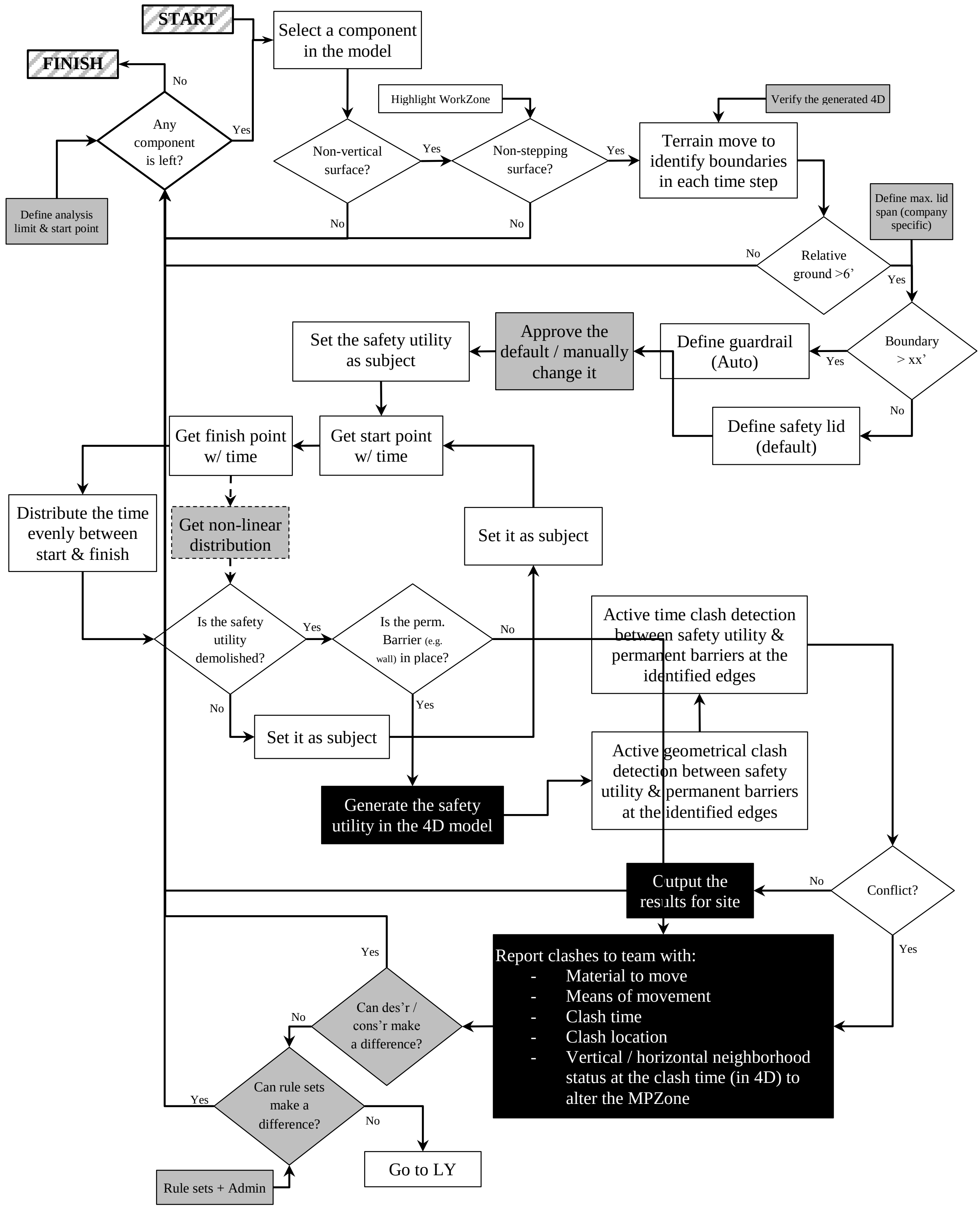


Figure 29. Final Temporary Safety Utility Flowchart

What it does:

- Identifies stepping surfaces
- Identifies working zones in heights
- Identifies passive fall protect systems
- Studies barriers in place
- Highlights safety utilities in the right time/place
- Checks crossing of temporary / permanent building components
- Reports safety of edges

Improvements

- Clear representation of hierarchies of control
- Improving the repeating loops
- Using consistent blocks for the operations
- Clarifying human-machine interface

Lanyard Analysis

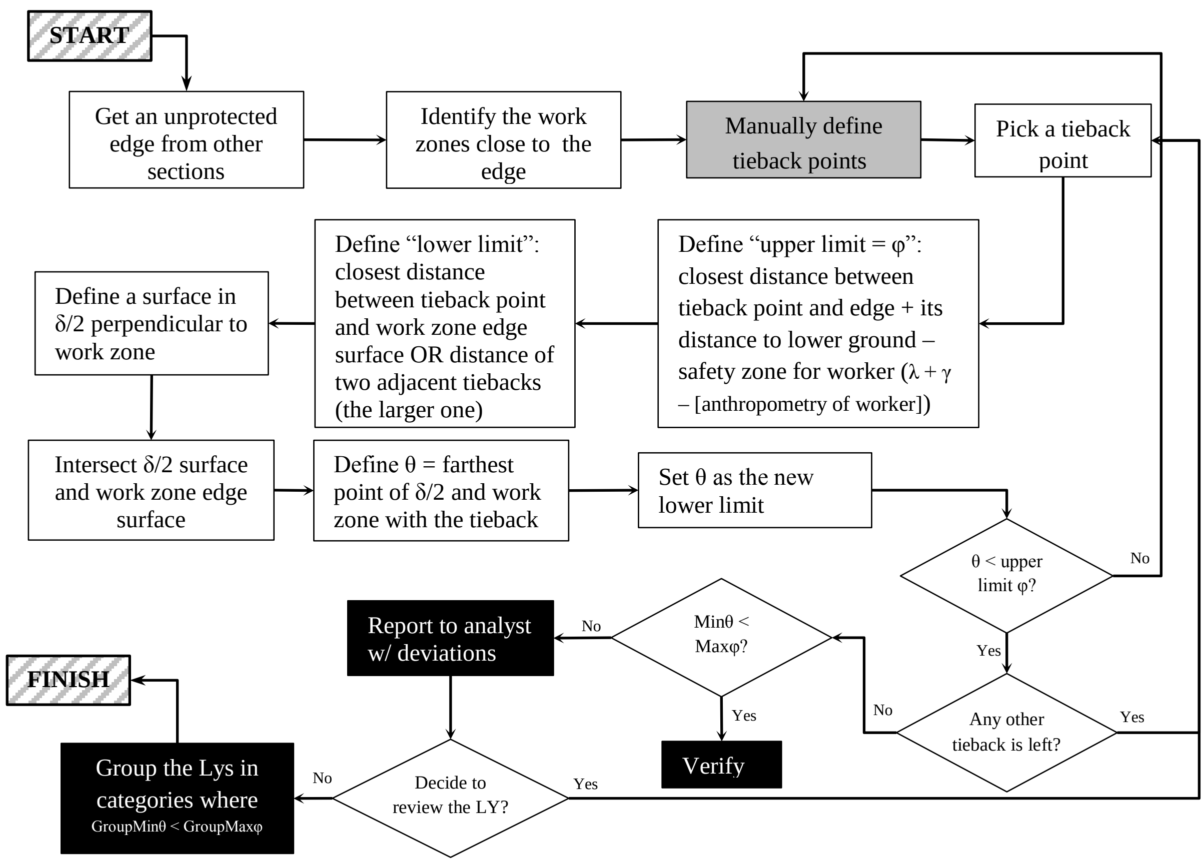


Figure 30 . Final Lanyard Analysis Flowchart

What it does:

- Gets input from the other parts
- Identifies areas requiring lanyards
- Analyzes length and effectiveness of lanyards
- Analyzes trust-ability of lanyards
- Interconnects with operator for customizing lanyards

Improvements

- Better connection with other analysis loops
- Identifies human-machine interface
- Clears hierarchies of control

Integrated (Final) Flowchart

One of the feedbacks, made by most of the panel members, was the technique of merging the five flowcharts and creating the integrated flowchart. This feedback is the result of the discussions on the first general question. The panel members disagreed to place a five-node decision maker point at the beginning of the five flowcharts and simply siting them together. They expected the final framework to have more interactive relations between the flowcharts as well as inside the flowcharts. Use of the consistent blocks developed common points between the flowcharts and increased the interconnection of the flowcharts. This technique will decrease the length of the future software code.

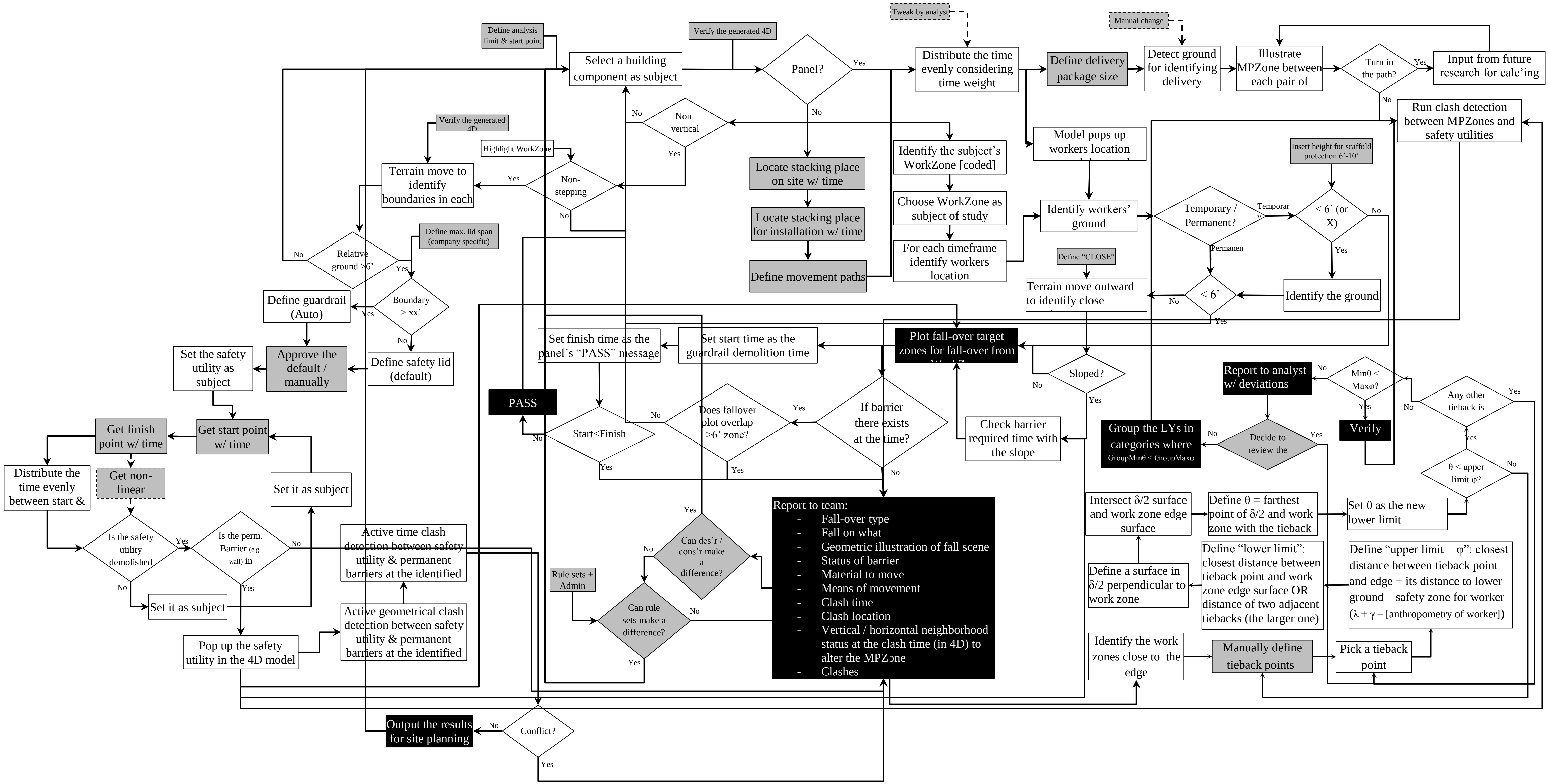


Figure 31 . Final Flowchart

Second Panel and Results Validation

The second panel was scheduled for November 16, 2011. The attendees of the panel were:

- Jesse Oak from Parsons Brinckerhoff, Architectural Designer representative
- Jason Reece from Balfour Beatty, BIM Expert representative
- Melanie Parks from Skanska, General Contractor representative
- Thomas Mills from Virginia Tech Safety Center, Safety Expert representative

Two members from the first panel could not attend the session due to their booked schedule:

- Buddy Cleveland from Bentley, BIM Expert representative
- Robert Zahner from Zahner Construction, SubContractor representative

The researcher decided to proceed with the available members, and set up another session with the two non-attendees.

Four documents were shared with the panel members one week prior to the scheduled session date. The shared documents are:

- *Main files*
    1. A summary of the comments from the previous panel, changes to the preliminary results, responses to some of the questions.
    2. The final flowchart. The final flowchart represents the final framework's interface in an 11x17 page.

- *Appendix*
    3. The two page appendix is the same file shared in the first panel, and explains research characteristics e.g. goal, scope, methodology, etc.
    4. The first panel summary files as a reference for cross-checking the improvements to the pentagonal flowcharts.

The second panel was coordinated by prof. Mills. Jesse Oak, Jason Reece, and Melanie Parks were contacted through a conference call. Dr. Ku joined the session by phone to supervise it. Prof. Mills introduced the panel members together and read the session agenda for them. He explained them that the panel goal is to answer three questions:

1. Are the questions from the first panel responded to in the updated documents, and are the recommendations properly reflected in the final flowcharts?
2. Is there any other modification that is missing in the final results?
3. Do you see this framework fulfills the goal of the research within its scope?

In order to avoid miscommunications in understanding of the updated results, the researcher gave an oral summary of the research results, and the final changes. Panel members started their discussions after the introductory talks.

Jesse Oak

Mr. Oak started his talk by appreciating the interconnection of the activities in the final flowcharts. He talked about the capabilities of designer in considering safety of the construction workers. Jesse compared designers' capabilities with constructors capabilities in controlling safety of construction workers. He emphasized again that he can see a lot of the recommendations reflected on the final flowchart. He was satisfied with the improvements of the final framework. Color-coding of the human-machine interface is a positive step from his stand point. He said that he did not look at the final flowchart in detail, but he sees it very complete in a short look. He suggested checking the flowchart with sample scenarios to see if it works. Jesse saw the flowchart to come extend over-whelming to understand in a short look.

Melanie Parks

Ms. Parks was the second panelist to talk about the results. She generally talked about how the industry prefers prevention over protection. Melanie referred back to her previous comment on considering retractables in the lanyard analysis. Ms. Parks said that she is totally thrown by the flowcharts. She saw the final flowchart complicated to read.

Melanie's comments continued with a question by Prof. Mills. He explained systems (FPS) and fall arrest systems (FAS). Thom believed that fixed tie backs will fall under FPS, and retractables will fall under FAS. He concluded that FPS systems are preferred over FAS. Prof. Mills defended this concept that FAS has the last priority, and FPS systems are preferred over them. This is when Melanie replied him with a different terminology from Skanska. She distinguished between the different terminologies in different places.

Jason Reece

Mr. Reece from Balfour Beatty Construction started his comments with a new vision on the research. He believed that the best idea for a hazard analysis tool is a tool that provides safety analysts with a decision tree. He continued that the software developers do not have the knowledge of construction safety. Knowledge of safety in construction should be obtained through industry connections. From this point of view, Jason believed that this research helps software developers with the knowledge of safety to incorporate in the backbone of the BIM software applications. The other positive point Jason pointed at was the ability of the intended BIM model for bringing the erroneous conditions to the attention of the safety analysts. He saw the whole framework as a positive step for the process Design for Safety. Jason brought a point on the table about the nature of hazards in construction industry. He referred to the 30hr. OSHA safety training, and said that identifying a situation as a hazardous is a very subjective opinion, while the rules and regulations are black and white. Jason's conclusion was the importance of the human-machine interface of this research.

Thom Mills

Prof. Mills started his share with acknowledging the integrated final framework. His recommendations were mainly about formatting and presentation of the flowchart. He recommended use of legend for the flowcharts, and better sorting of arrows and boxes. He liked the interconnection between the pentagonal flowcharts and how they merged together. He endorsed the human-machine representation and the rules and standards set up in the flowcharts. He needed more time to investigate and verify representation of hierarchies of control in the final flowchart. Prof. Mill's criticism on the final results was mostly on the following items:

- Difficult to understand the chart
- Lines overlap each other
- Boxes can be sorted better
- Distinguish between the five pentagonal flowcharts in the final flowchart

Jason Reece suggested using Visio for the flowcharts for better representation of the charts.

So far, all the panelists talked about the first two questions i.e. whether the recommendations from the past panel are properly reflected on the new results, and whether they recommend any other modification for the final framework. Prof. Mills withheld the third question for the end of the session. The third question asked the panelists if they verify that the research fulfills its predetermined goal. Jason Reece was the first one to answer this question. He believed that this research can support a broad-based BIM tool. Jason said that the methodology is sound, and the final results just need cleanup and a more clear presentation. Mr. Reece liked to see a practical implementation of the tool. He emphasized that the human-machine interface of the future BIM tool should be strong enough to help collaboration of a safety group. Mr. Oak acknowledged the work and suggested some examples to be checked by tracing the flowchart. He believed that this can help identifying the probable errors in the flowchart.

Researcher's note: at least one example for each of the pentagonal groups was studied through its relative flowchart.

Two members of the first panel were traveling on the week of November 14th, and could not attend the second panel. Buddy Cleveland and Robert Zahner were contacted via another conference call the week after. On November 22nd, Dr. Beliveau and the researcher set up a conference call with Buddy and Robert and discussed the changes on the prelim results. Mr. Zahner and Mr. Cleveland were asked the same three questions and discussed them with the researcher and Dr. Beliveau.

The panel was mostly concerned with formatting and presentation of the results. They saw the flowcharts complicated the understanding. They preferred to see it more clear and simple. Mr. Cleveland suggested highlighting the input/output data of the system. He suggested illustrating how automation in this system works. Another concern was the Micro / Macro level of schedule generation in the model and how it is observed. The panelists suggested presenting the results at different levels of detail.

Presenting the Final Flowchart

Comments by the panelists, and the exchanged ideas in the second panels (November 16th and November 22nd) helped the researcher present the results more clearly for the readers. The final flowchart is presented in different formats in Figure 33 through Figure 49. These figures help convey the message of the flowchart better to the audiences of this research.

Figure 33 presents the final flowchart with a clearer layout. Lines and boxes are not crossing each other, and lines and boxes are color coded. Arrows are presented in solid and dashed lines. It helped distinguish between the arrows inside each individual flowchart, arrows that connect two individual flowcharts, arrows that take each individual flowchart to the model output, and arrows that take each individual flowchart to the start / finish zone of the diagram.

The dark boxes are distinguished by their surrounding lines (dashed vs. solid) as well as their inside patterns. Dashed lines around the boxes show optional inputs by the user, while solid lines require inputs. Colored boxes need input of the data, while hatched boxes need revision of the generated / processed information.

Figure 34 spot-maps each individual flowchart in the final flowchart. It represents how each individual flowchart is located in the final flowchart. Although the individual flowcharts overlap with each other, the spot-map (Figure 34) ignores the overlap areas and illustrates how roughly each individual flowchart is seated adjacent to the other flowcharts. Work Space and Work Surface have a lot of the processes in common. They share a noticeable portion of each other. The researcher decided to merge these two individual flowcharts together and represent them with one WSp/WSu spot in Figure 34. There are two distinguishable areas in the final flowchart; 1. Start / Finish zone, and 2. Final Output zone. These two are the share points between all the individual flowcharts. Arrows going to these two spots are distinguished in Figure 40 and Figure 42 with specific dash types.

Figure 35 through Figure 39 show clearly each individual flowchart within the final flowchart. they explain what each individual flowchart does in the final flowchart, what types of inputs it requires, and some examples of how that flowchart implements BIM for automation. Each of these figures explains how the individual flowchart is seated in the final flowchart. Each diagram explains its role in accomplishing the research mission.

Since the purposes of the inputs in this research are different, three different types of the input representations are presented in Figure 32. The three inputs are:

1. Regular Manual Input – this type needs manual data to be entered by the user. These data are inserted by collaboration of designers and constructors. This flowchart uses a very limited number of manual regular inputs of data.

2. Revision / Verification of Information – this group covers most of the inputs. This user-interface group asks to revise or verify the information generated and processed by the system. Here is where the system assists users with processed information.
3. Company Policy – Although hazard and safety are driven by the project and the local regulations, company policies play an important role in analyzing the hazards and determining responses to the hazards. Company policies do not need to add to the system in every run of the flowchart. They can be added once, and the user can set the software based on them for each company. They can be defined as a plugin to the final software.

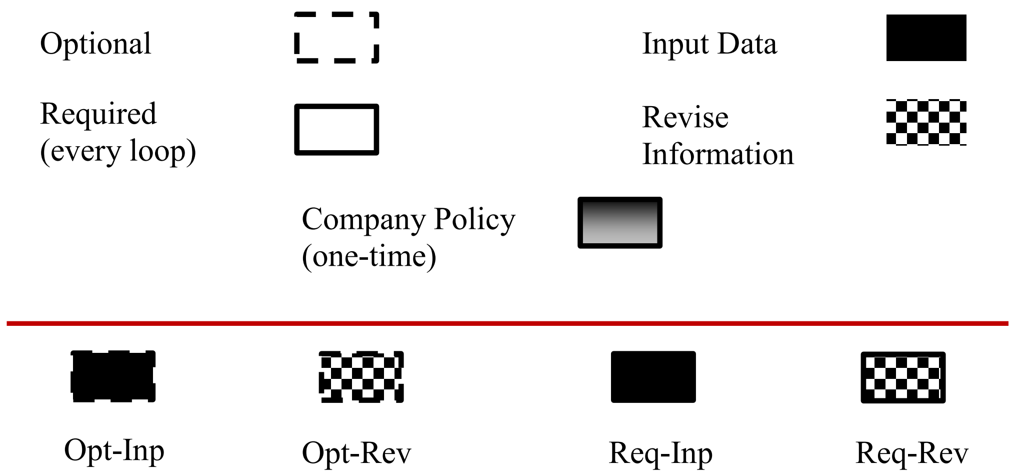


Figure 32. Different types of inputs in the flowcharts

The main purpose of implementing BIM in this research is to automate generation and process of information. Each flowchart plays a role in the whole automation of the final flowchart. The annotations on Figure 35 through Figure 39 bring some examples of automation in that specific flowchart.

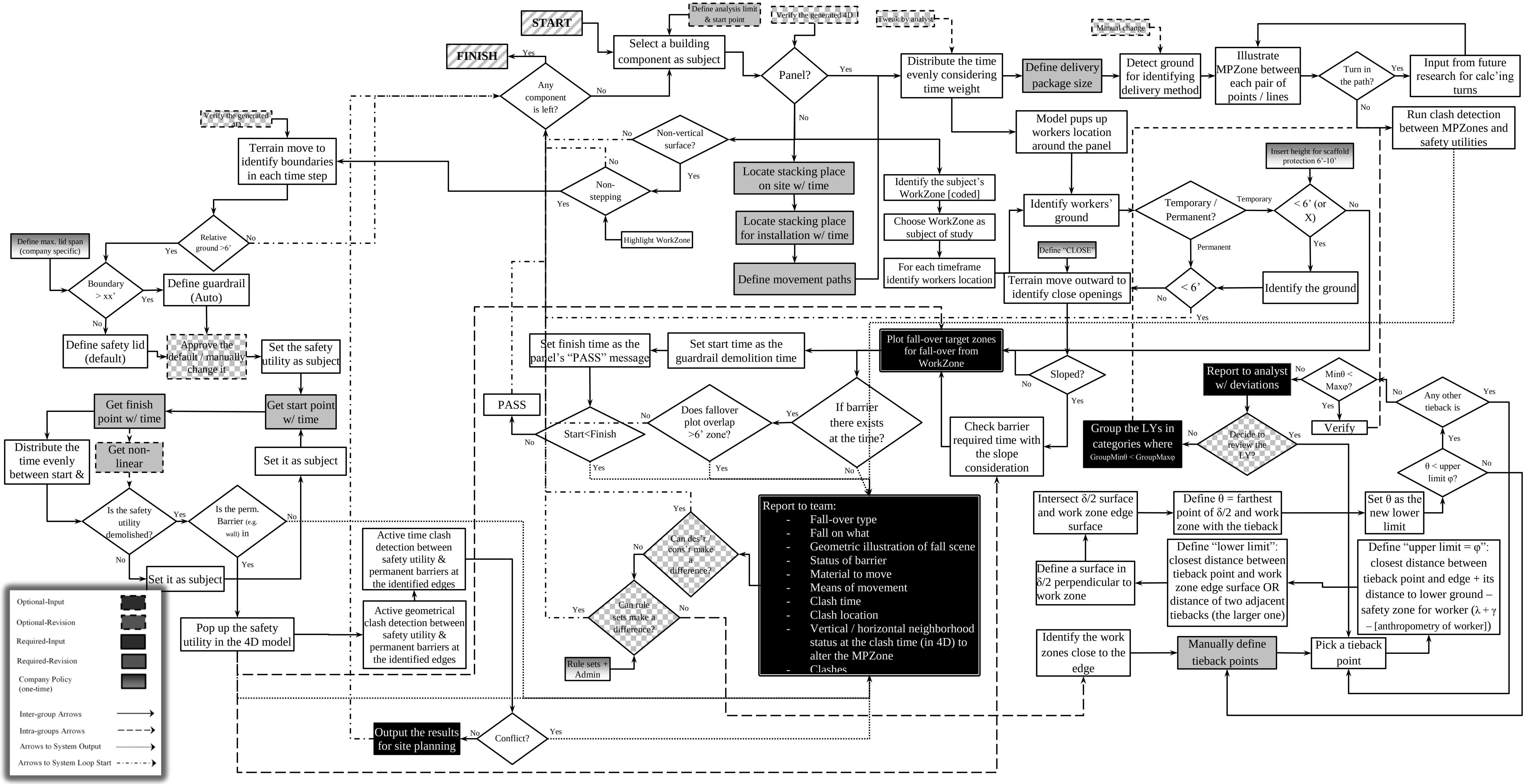


Figure 33. The Final Flowchart

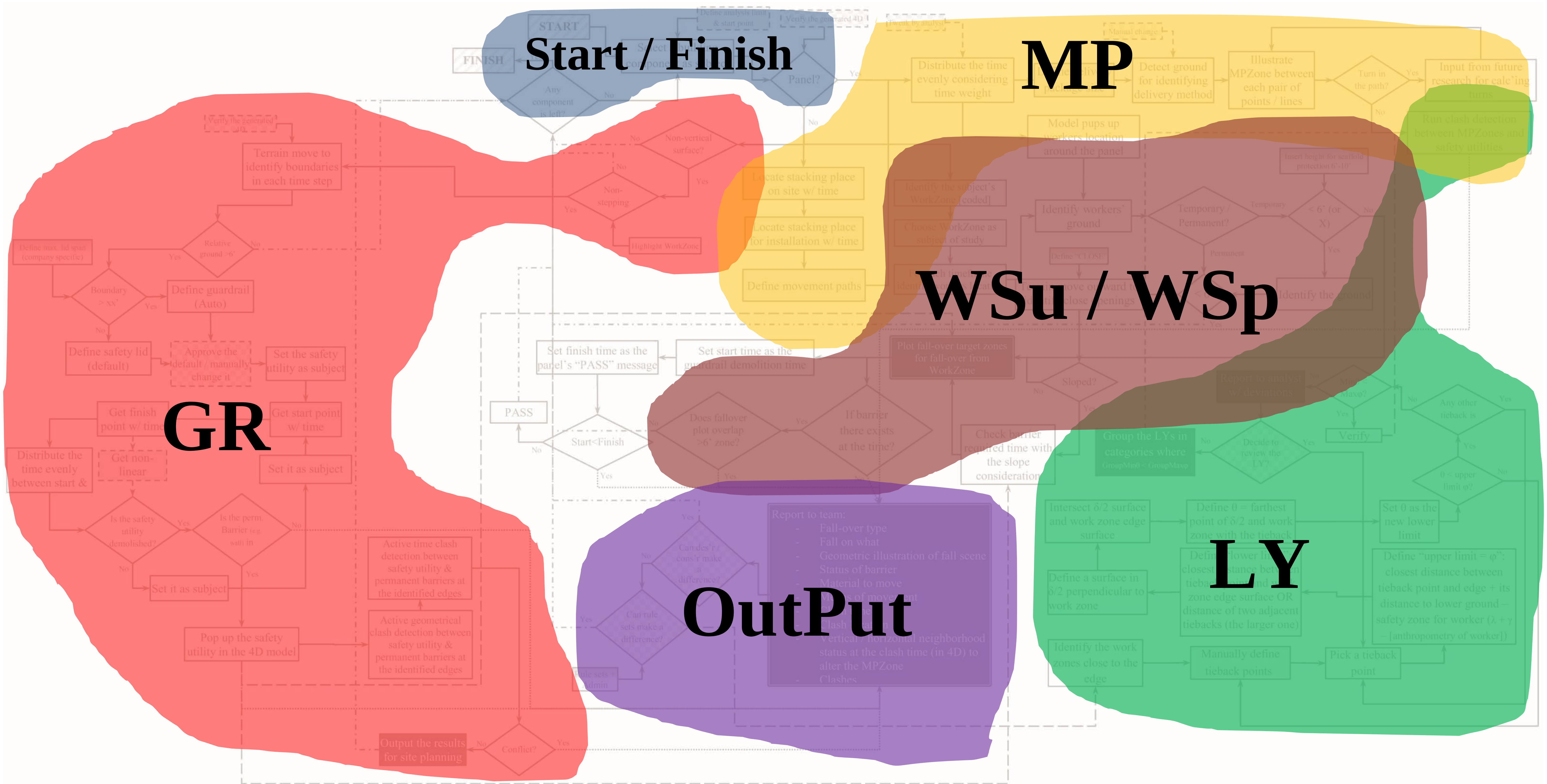


Figure 34 . Spotting Map of Individual Flowcharts

Figure 35 fulfills the goals of Work Space that are explained in Chapter four. It maps Work Space flowchart, Figure 26, on the final flowchart, Figure 33. As explained there, the procedures taken in this section are:

1. Identification of the work place:
    1.1. Identify the work in height (where there is no flat ground under 6ft. of the work)
    1.2. Register duration of the work
    1.3. Register type of the work
    1.4. Register where the workers need to stand and the area needed to work around the working zone.
2. Check protection
    2.1. Check proximity of the work to the edge
    2.2. Check status of the edge and the duration it is not protected
    2.3. Check lanyard status when it is needed

Figure 35 does not require any manual input. It needs verification of the generated 4D schedule by the system. This verification is common to all the flowcharts. The company policies that this section allows to be considered are the clear zone radius and the Height for scaffold protection.

The Work Space flowchart automates some aspects of safety analyses. They are including but not limited to:

- Identifying and highlighting building components' work-zone
- Detecting workers' location around the study subject
- Suggesting temporary safety utilities

Figure 36 distinguishes Work Surface, Figure 27, in the final flowchart, Figure 33. It explains how this section accomplishes its share in fulfilling the mission of the flowchart. As mentioned in Chapter 4, this flowchart considers horizontal and sloped surfaces (stepping / non-stepping) in the building. It analyzes them to check the following items:

Sloped/flat flooring

1. Embed layers of the paneling and the sequence they are put together
2. Where the workers stand (input from past section)
3. Study the tie-off points to make sure they are properly designed (refer to lanyard analysis)
4. Identify, report, and analyze the lanyard for the duration the tie-off is required (up to the point in time that the strong panel is in place and is fixed and can be stepped on).

Side of the building

1. Embed layers of the paneling, and the sequence they are put together
2. Where the workers stand (input from past section)

3. Study the tie-off points to make sure they are properly designed (refer to lanyard analysis)

It also checks the vertical surfaces that are non-stepping but they surround the workers' space and protect the openings and edges permanently. The mission of the flowchart is explained as follows:

- Studies panel safety
- Breaks down the allocated time in panel construction
- Highlights work-zones around the panel
- Identifies works in heights
- Plots fall-over zones and checks their status
- Checks sloped surfaces
- Reports sloped surfaces for side guarding
- Reports sloped surfaces for PPE
- Investigates continuous protection of temporary removals, and when a non-secure panel is in place
- Reports panel works' safety status

This part of the final flowchart does not need any manual input from the user. Similar to other flowcharts, it gives this option to the analysts to revise and verify the 4D schedule generated by the model. It also allows the user to revise macro-level schedule generated by the model. It allows the users to revise micro-level schedule in the panels set up. As explained in chapter four, the model parameters weight the schedule breakdown based on the panel sub-components, and distribute the macro-level schedule to this micro-level schedule. This flowchart gives the users this option to revise and verify the micro-level auto-generated schedule. Clear zone radius, and height for scaffold rail are the company policies that can be set for the flowchart.
Two examples are presented in the Figure 36 to show how this flowchart contributes in automation of the final flowchart. As explained before, the model's parameters distribute the allocated time to the micro-level panel installation. It also identifies workers locations and detects workers' grounds.

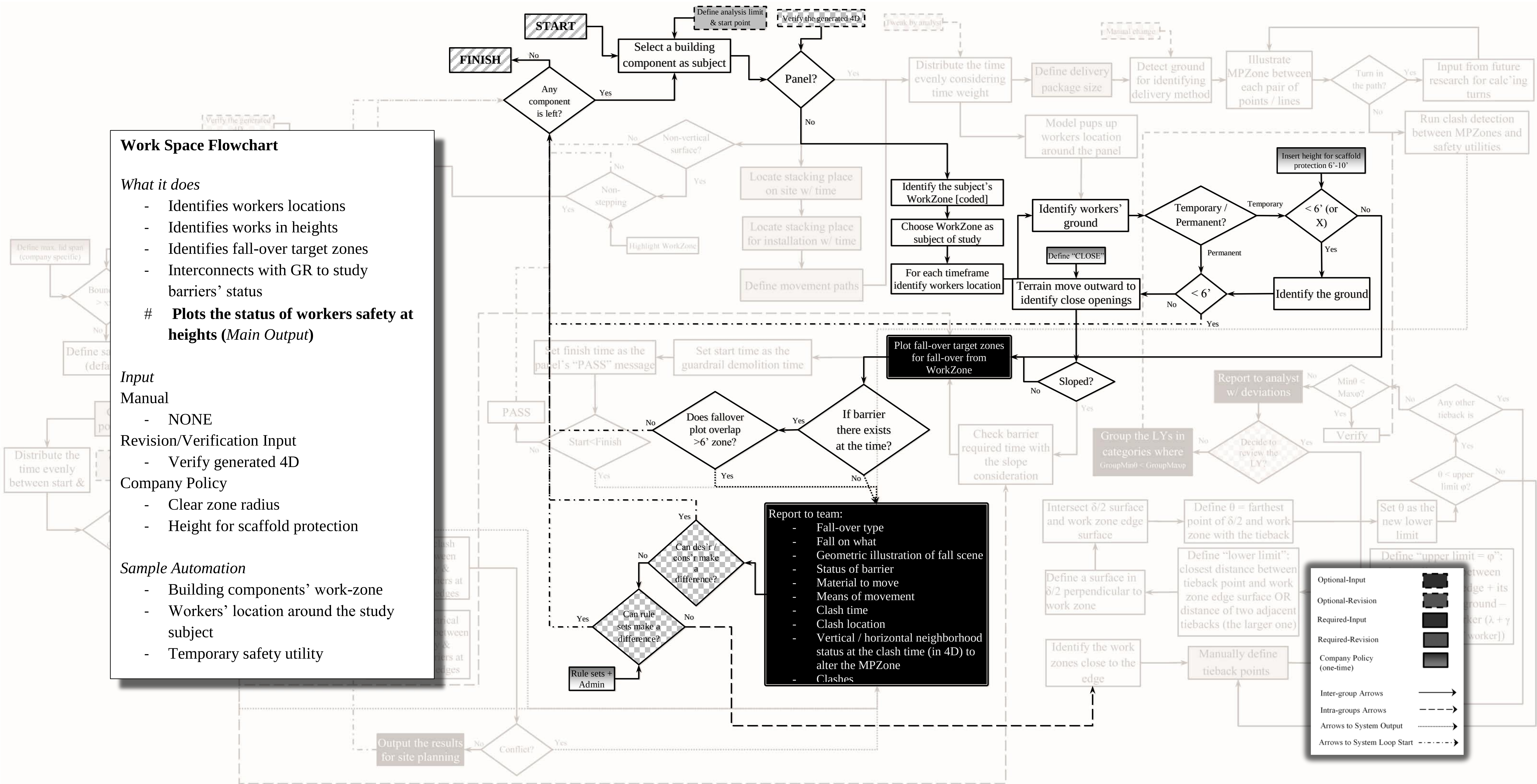


Figure 35. Illustration of Work Space in the Final Flowchart

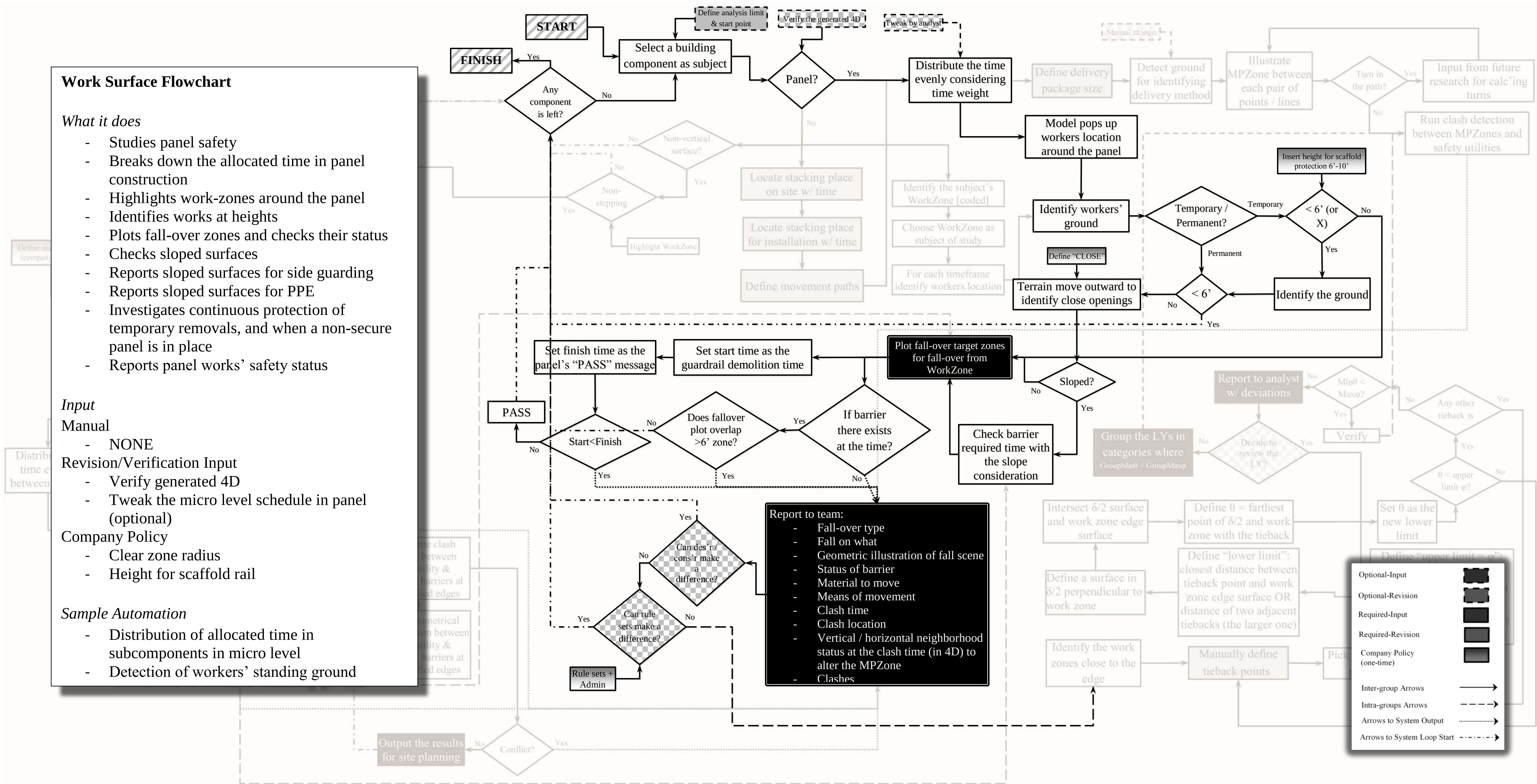


Figure 36 . Illustration of Work Surface in the Final Flowchart

Figure 37 illustrates how movement paths are studied in the final flowchart. It studies how materials move from site stacking locations to the installation locations. It studies whether materials are clashing with the temporary safety utilities, and might cause a hazard to workers.

The goal of this section is to study clearance of material delivery paths. This study might avoid temporary removal of guardrails and other safety utilities when they block the material delivery path.

This section has the most manual input comparing to the other sections. It highly requires collaborations of designers and constructors for the required manual data inputs. Four groups of data are required for this flowchart.

- Locate stacking place on site with time
- Locate stacking place for installation with time
- Define movement paths
- Define delivery package size

Although the materials are defined manually, the stored materials on site are the same as the material installed in the building. They know each other and their parameters speak to each other. Two out of three information verifications are the same as Work Surface, i.e. Verify generated 4D, and Tweak the micro level schedule in movement path (optional). It also gives this option to the users to verify the conveying means. General company-policies for means and methods are the input for the hierarchies of control at the decision making level. They are presented as the company policy inputs in the flowchart.

As explained before, the parameters set between the materials from the time they are stored on the site up to the time they are installed in the building are one example of how this flowchart can contribute to automating hazard identification and analysis. Movement Paths that are auto-illustrated by “start / finish points” and “package sizes” are another example of how this flowchart contributes to the hazard identification and analysis. As mentioned in chapter four, path change geometries should be embedded in the Movement Path parameters. Although its detail studies are out of scope of this research, their results are part of this flowchart, and contribute to the automation of the final flowchart.

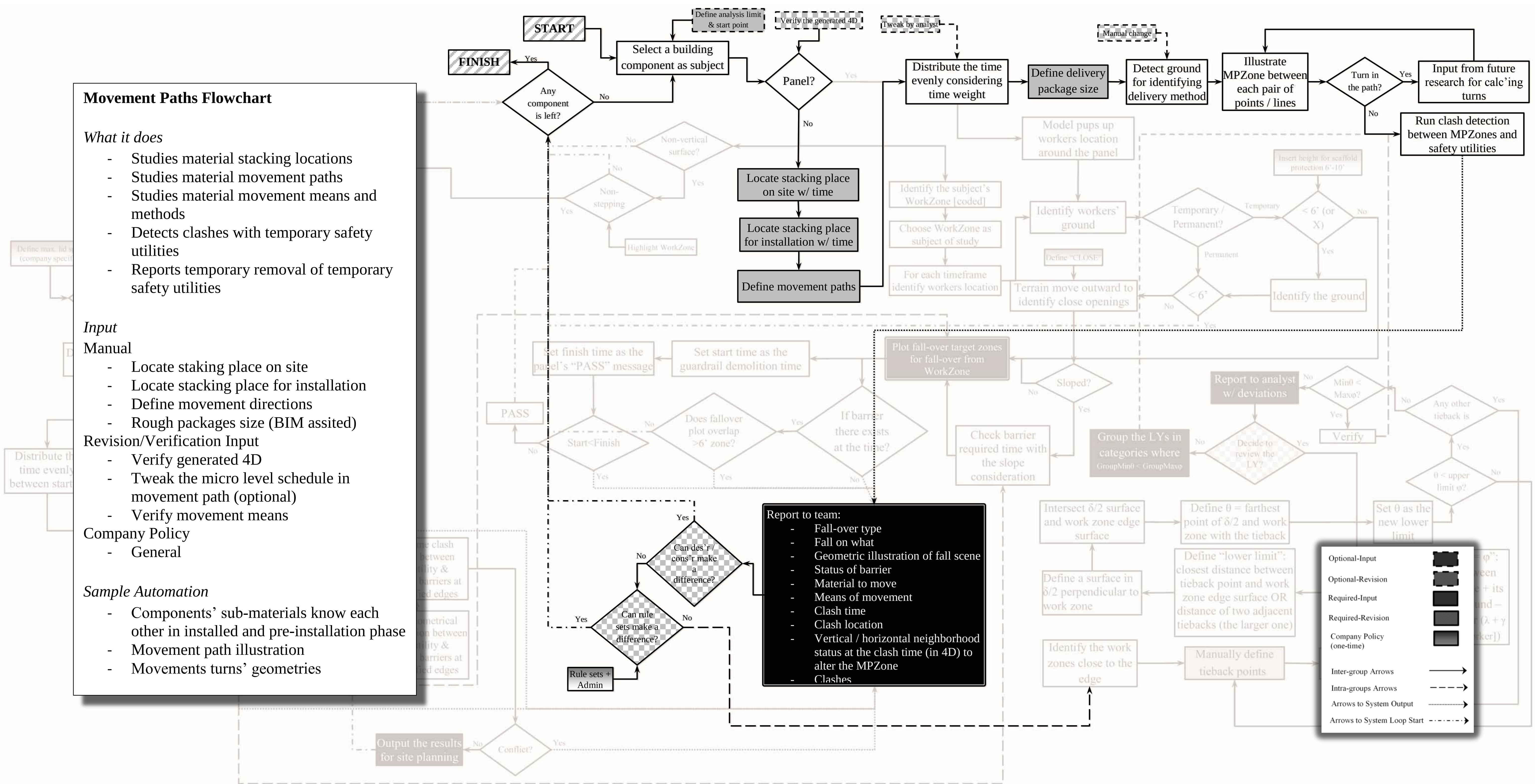


Figure 37 . Illustration of Movement Paths in the Final Flowchart

Figure 38 maps Figure 29 on the final flowchart. It analyzes temporary safety structure during the construction phase. The first step to accomplish this mission is to study where and when it is not safe, and what the reason is for the unsafe conditions of the edge. Chapter 4 explained the goals this flowchart is seeking. They are:

- To embed guardrail and other openings protective tools such as temporary protective lid or structured net in the horizontal surface components.
- To have openings' protective tools pop up at the right time and disappear at the right time. This appear / disappear transition needs to be simulated in schedule fractions close to a coefficient of an hour.

Figure 38 takes following steps to accomplish these goals:

- Studies material stacking locations
- Studies material movement paths
- Studies material movement means and methods
- Detects clashes with temporary safety utilities
- Reports temporary removal of temporary safety utilities

This flowchart requires collaboration of constructors with designers on the micro-level planning of safety utility installation / demolition. The model distributes the safety utility setup / demolition time based on a weighted breakdown for the entire safety utility e.g. guardrail. It allows the option of non-linear distribution of time on the subcomponents. Figure 38 gives the option of verifying and proving the generated 4D, the generated safety utilities, the micro level schedule in placing/replacing the safety utility. The maximum span that the company allows for a safety lid is a company specific policy that can be entered to this system.

This model automatically suggests temporary safety utility, and the safety utility can be changed by the company policies. The model identifies slopes in the panels. It can measure the panel stiffness for support of lateral load or weights. The model has panel installation processes defined in the panel parameters.

Figure 39 maps Figure 30 on the final flowchart, Figure 33, and illustrates how lanyards are allocated and assigned in the final flowchart. As appears, it does not get inputs from the start / finish point of the flowchart. It gets input from the safety report of the flowchart output section. Chapter four introduced this flowchart's mission as:

To define the Lanyard length to:

- Reach every single point in the unprotected work zone
- Does not let the worker fall on the ground lower than 6'

It performs the following tasks to fulfill its mission:

- Gets input from the other parts
- Identifies areas requiring lanyards
- Analyzes length and effectiveness of lanyards
- Analyzes trust-ability of lanyards
- Interconnects with operator for customizing lanyards

Users are required to manually define tentative lanyards' locations. The system will calculate their length and adjust their positions. The system does not add to the number of the lanyards. In other words, the system assists the user to verify the tentative lanyards and reports their deviations from their required functions.

Determining the lanyard length and verifying the reach of the work zones while protecting the worker are the sample contributions of the flowchart in the automation.

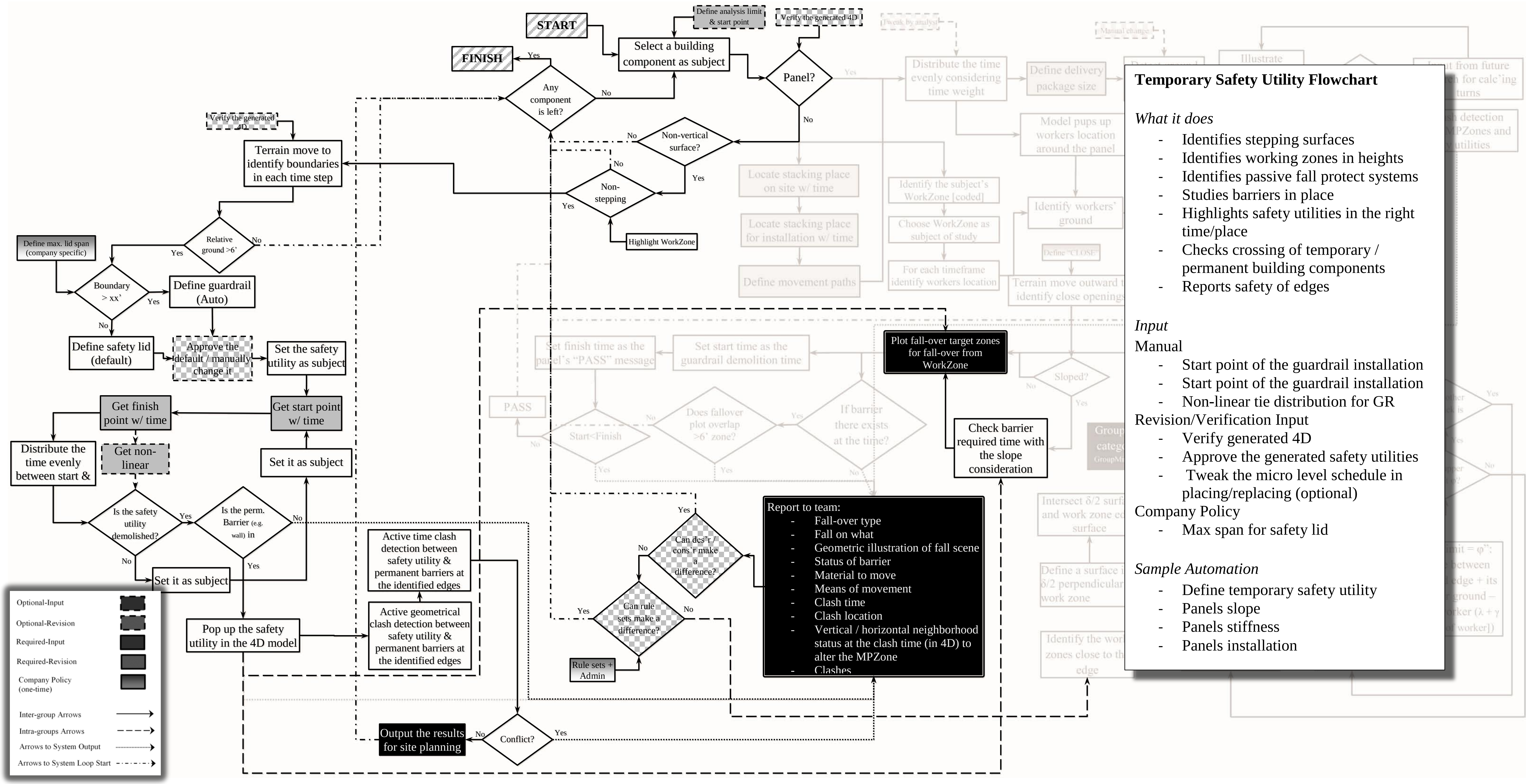


Figure 38 . Illustration of Temporary Safety Utility in the Final Flowchart

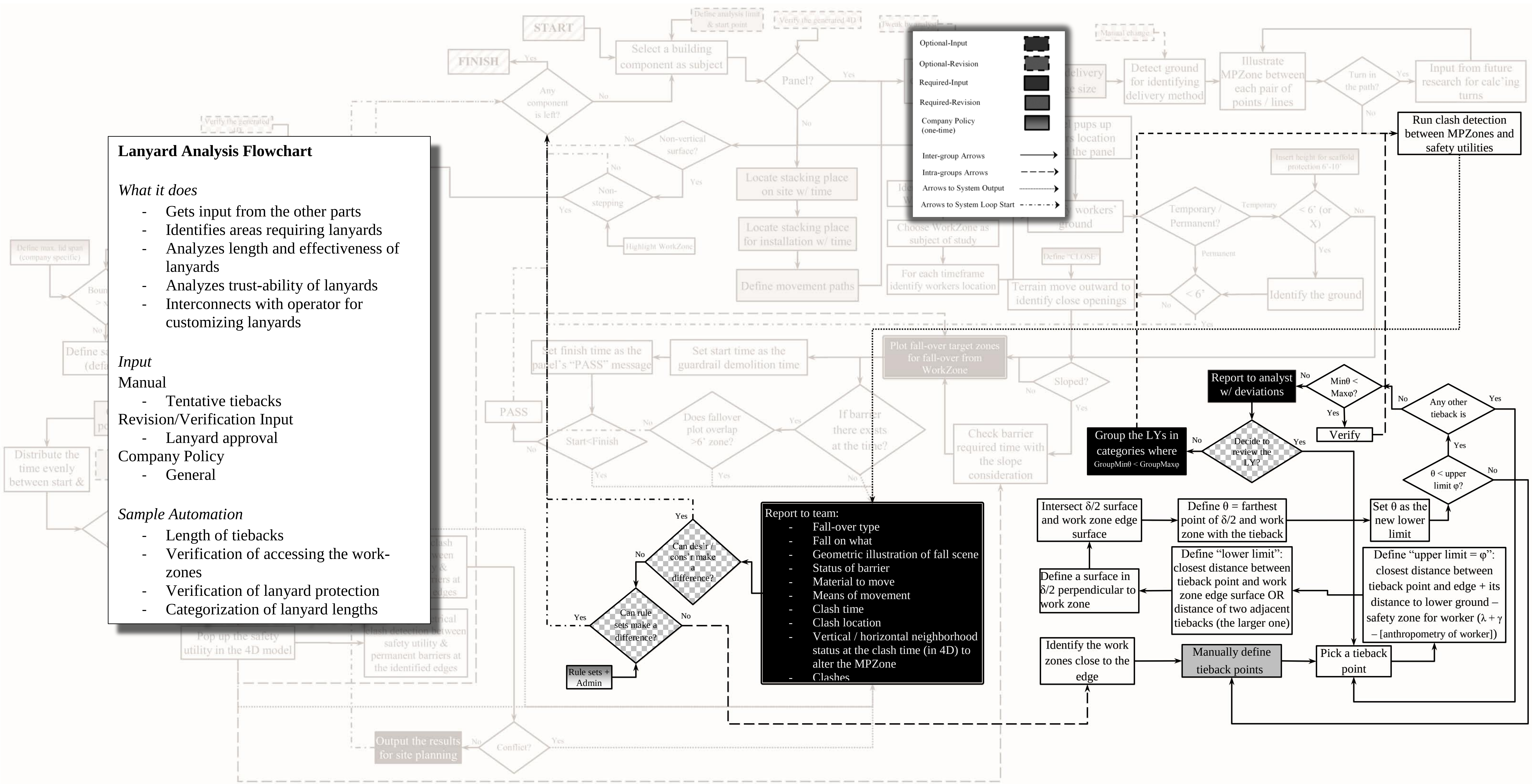


Figure 39 . Illustration of Lanyard Analysis in the Final Flowchart

One of the steps that made the final flowchart more reliable was distinguishing between different arrows. The arrows inside the individual flowcharts are illustrated with solid lines. However, the arrows that connect the individual flowcharts are illustrated with different dashes. Figure 40 shows the arrows connecting each individual flowchart to the Output spot. The arrows are shown on the Spot Map of the flowchart to avoid disruption of the internal arrows in the flowcharts. As Figure 40 shows, all the individual flowcharts go to the Output spot except the Lanyard flowchart that gets input from the Output spot (Figure 41).

Figure 41 shows how/why individual flowcharts connect to each other. It shows that the Temporary Safety Utility spot inputs to Work Space and Work Surface in order to illustrate the guardrails in the 4D for analyses in WSp/WSu. It represents that the last step of the hierarchies of control are to enter the Lanyard location. Figure 40 shows that all other flowcharts provide input to the hierarchies of control. Lanyard Analysis node feeds the Movement Path node to feed the clash detection between MP & LY.

Figure 42 illustrates how individual flowcharts attend the big loop of the final flowchart and/or terminate the loop.

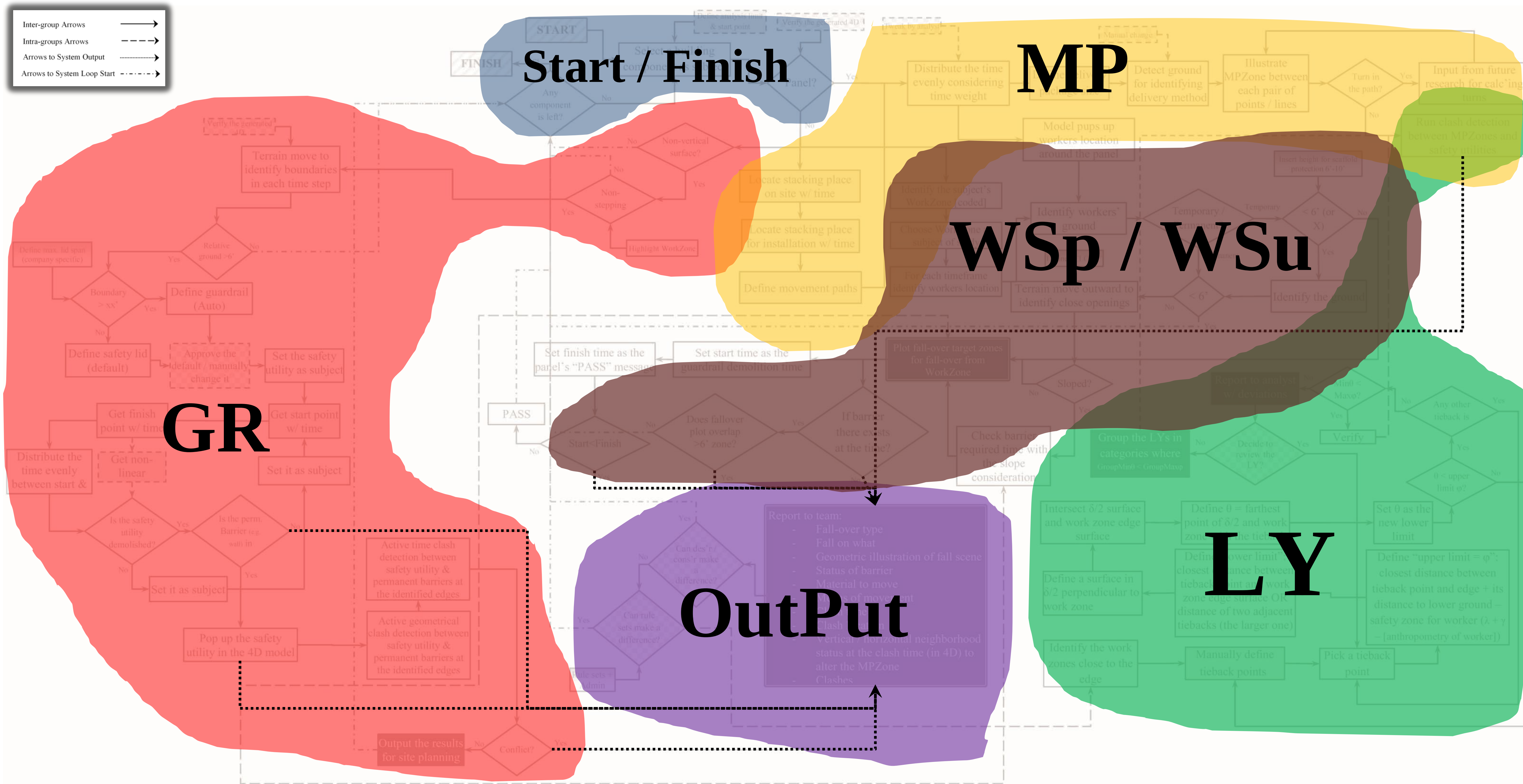


Figure 40 . Connections from each Individual Flowchart to the Outputs.

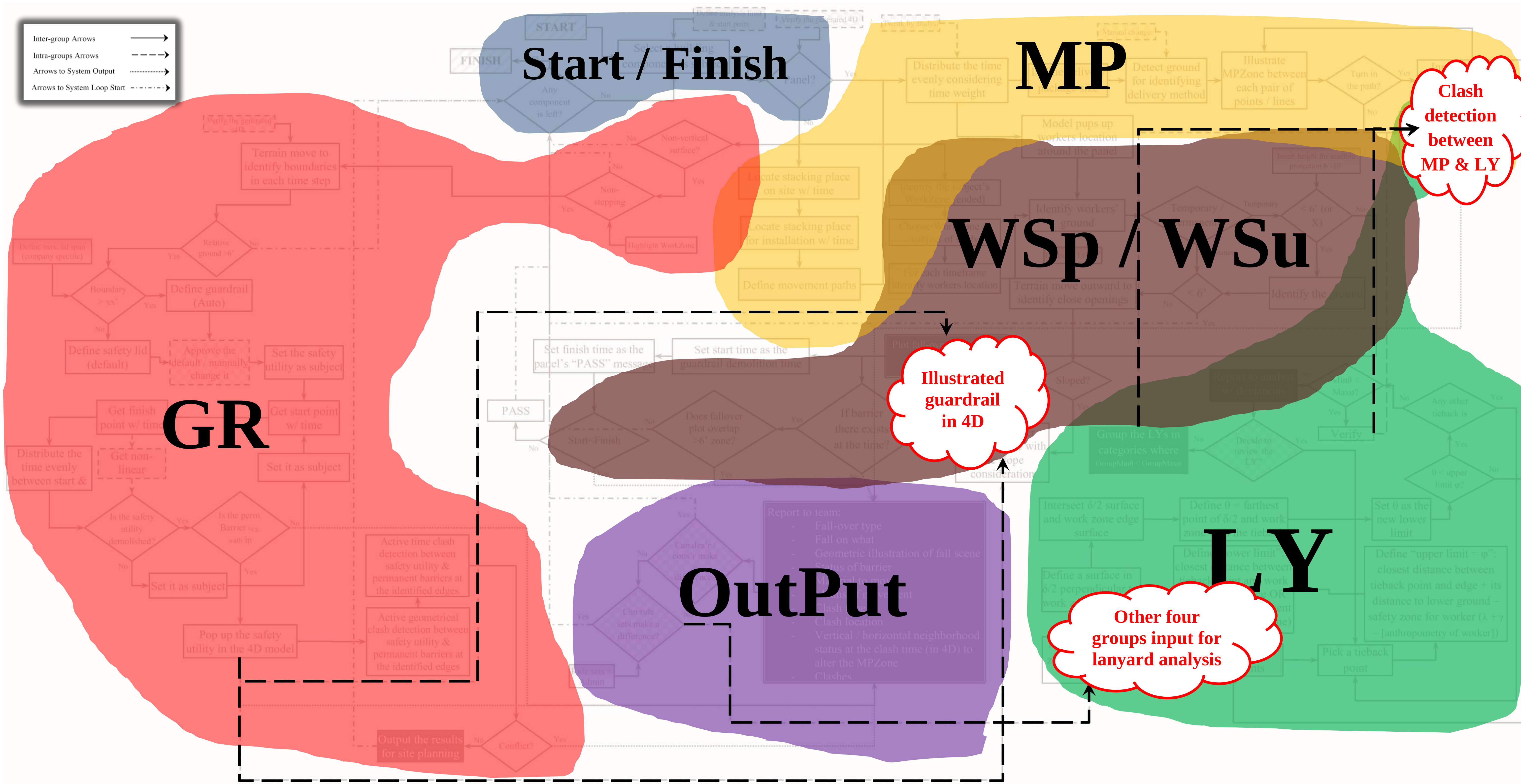


Figure 41 . External Connections between the Individual Flowcharts

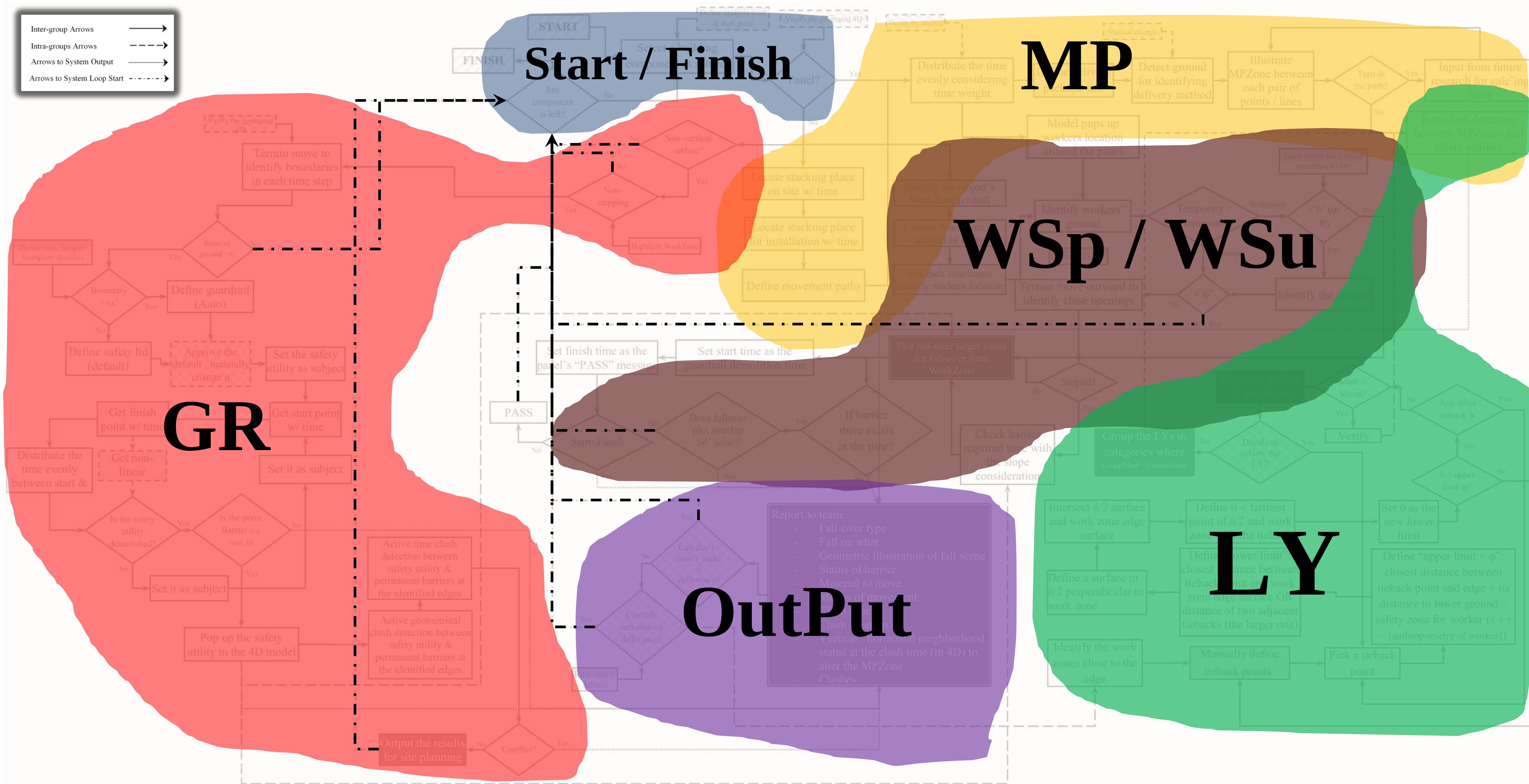


Figure 42. Connections of the Individual Flowcharts to the Start / Finish Spot of the Diagram

Figure 32 showed different types of input in the final flowchart. Figure 43 through Figure 47illustrates how / why those inputs are required. Figure 43 shows the required revision for the generated information. A patterned shape with a solid strip around represents this type of input. The system requires revision of information in two places:

1. In the LY analysis section where the lanyards' sizes for the project vary. This is an interim revision of the information.
2. In the system Output node where the system needs to follow hierarchies of control. This is the final revision of information in the system.

Figure 44 shows the required manual data inputs in the system. This type of input takes place in three locations in the flowchart. In the Temporary Safety Utility section the flowchart requires input for guardrail placement at the micro-level scheduling. This point requires collaboration of designers and constructors. The Movement Path section requires collaboration of designers and constructors one more time for inputting material movements. The last place for manual input of data is the lanyard analysis section where the user should propose some tentative lanyards to be analyzed by the system automatically.

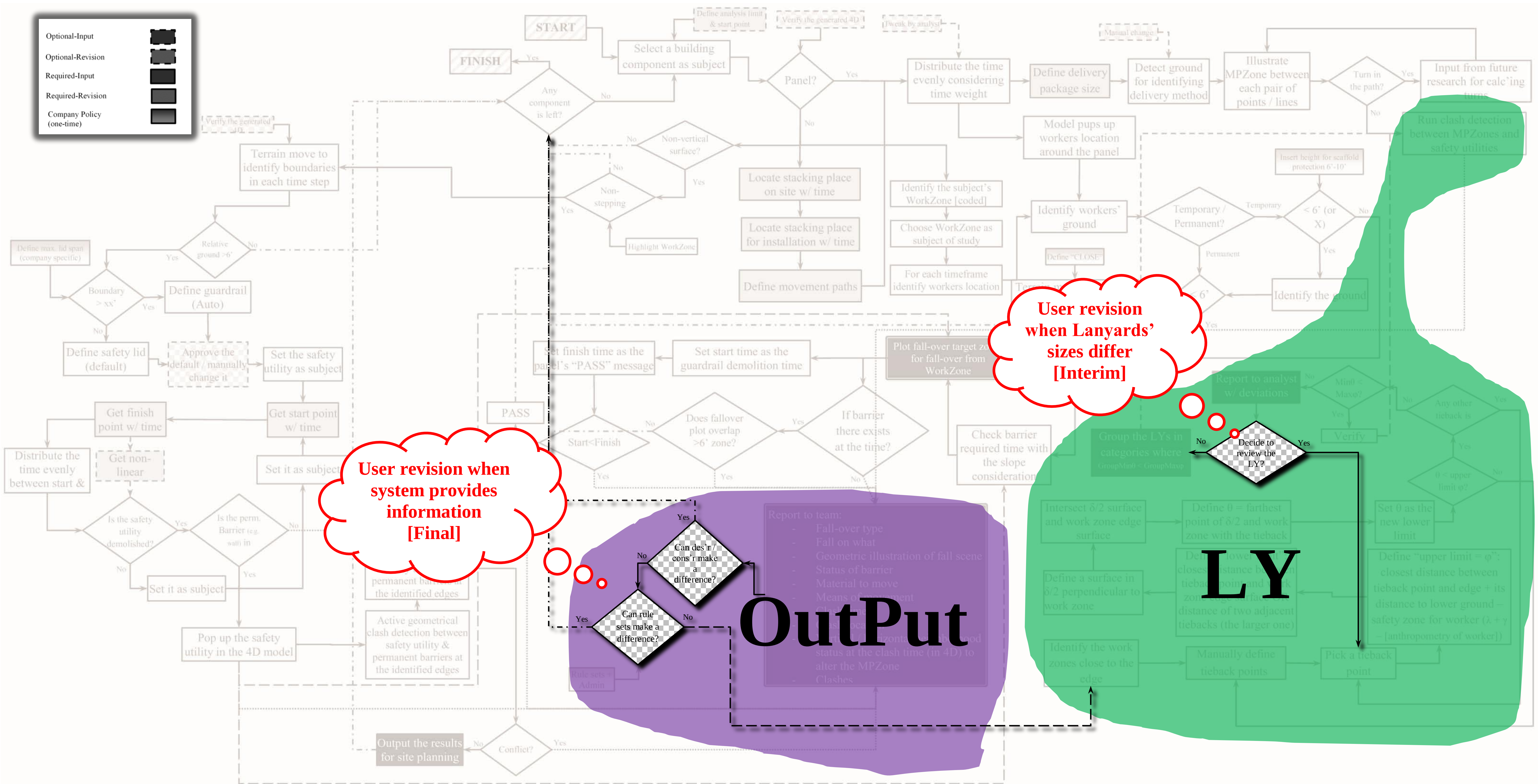
Figure 45 illustrates optional revision of the generated information by the user. This happens mostly in the beginning of the flowcharts when the user has the option to revise the generated 4D schedule. Users can review and verify the suggested safety utility for the edge/opening. MP flowchart suggests the delivery methods for materials based on the parameters of the model. The system allows users to revise the suggested delivery method.

Figure 46 represents the optional manual inputs of data. This type of input happens in GR and Start/Finish nodes. The system distributes the time linearly based on a weighted scale to the guardrails subsections. The user has the option to fine tune the time and distribute it non-linearly. Start/Finish section offers an option to users to define a limited scope of the model to be analyzed by the system.

Figure 47 shows the organizational policy inputs to the system. Company policies should input the system in:

GR	→	for safety lid
WSp/WSu	→	for defining clear zones and change in OSHA standards
Output	→	for general construction rules.

Figure 48 and Figure 49 differentiate between the intermediate and final outputs. Intermediate outputs are shown in solid black boxes with a single strip around them (Figure 49). Final outputs are shown in the same black boxes but a double strip around them (Figure 48). These two figures show the outputs on the figure annotations.



Optional-Input
Optional-Revision
Required-Input
Required-Revision
Company Policy (one-time)
START
FINISH
Select a building component as subject
Any component is left?
Panel?
Distribute the time evenly considering time weight
Define delivery package size
Detect ground for identifying delivery method
Illustrate MPZone between each pair of points / lines
Turn in the path?
Input from future research for calc'ing
Model pups up workers location around the panel
Terrain move to identify boundaries in each time step
Non-vertical surface?
Non-stepping
Locate stacking place on site w/ time
Locate stacking place for installation w/ time
Define movement paths
Identify the subject's WorkZone [coded]
Choose WorkZone as subject of study
For each timeframe identify workers location
Identify workers' ground
Temporary / Permanent?
Relative ground >6'
Boundary > xx'
Define guardrail (Auto)
Define safety lid (default)
Approve the default / manually change it
Set the safety utility as subject
Set finish time as the panel's "PASS" message
Set start time as the guardrail demolition time
Plot fall-over target zone for fall-over from WorkZone
Get finish point w/ time
Get start point w/ time
Distribute the time evenly between start &
Get non-linear
Set it as subject
PASS
Start<Finish
Does fallover plot overlap >6' zone?
If barrier there exists at the time?
Check barrier required time with the slope consideration
Is the safety utility demolished?
Is the perm. Barrier
Set it as subject
Pop up the safety utility in the 4D model
Active geometrical clash detection between safety utility & permanent barriers at the identified edges
Output the results for site planning
Conflict?
User revision when system provides information [Final]
User revision when Lanyards' sizes differ [Interim]
Can des'r cons'r make a difference?
Can rule sets make a difference?
Decide to review the LY?
Yes
No
OutPut
LY
Report to team:
Verify
Pick a tieback point
Manually define tieback points
Identify the work zones close to the edge

Figure 43 . Required-Revision of the Generated Data

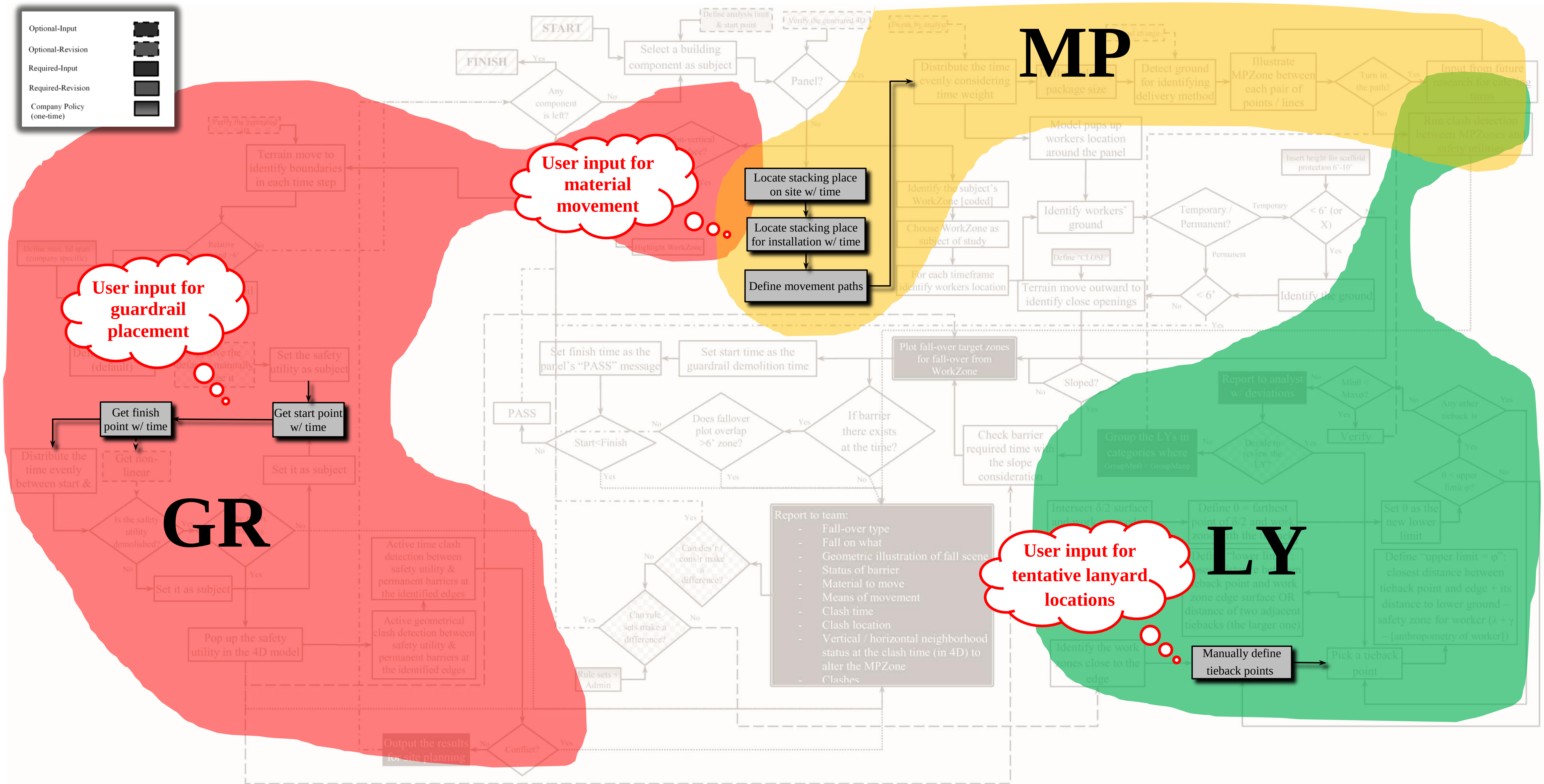


Figure 44 . Required-Input of Data Manually

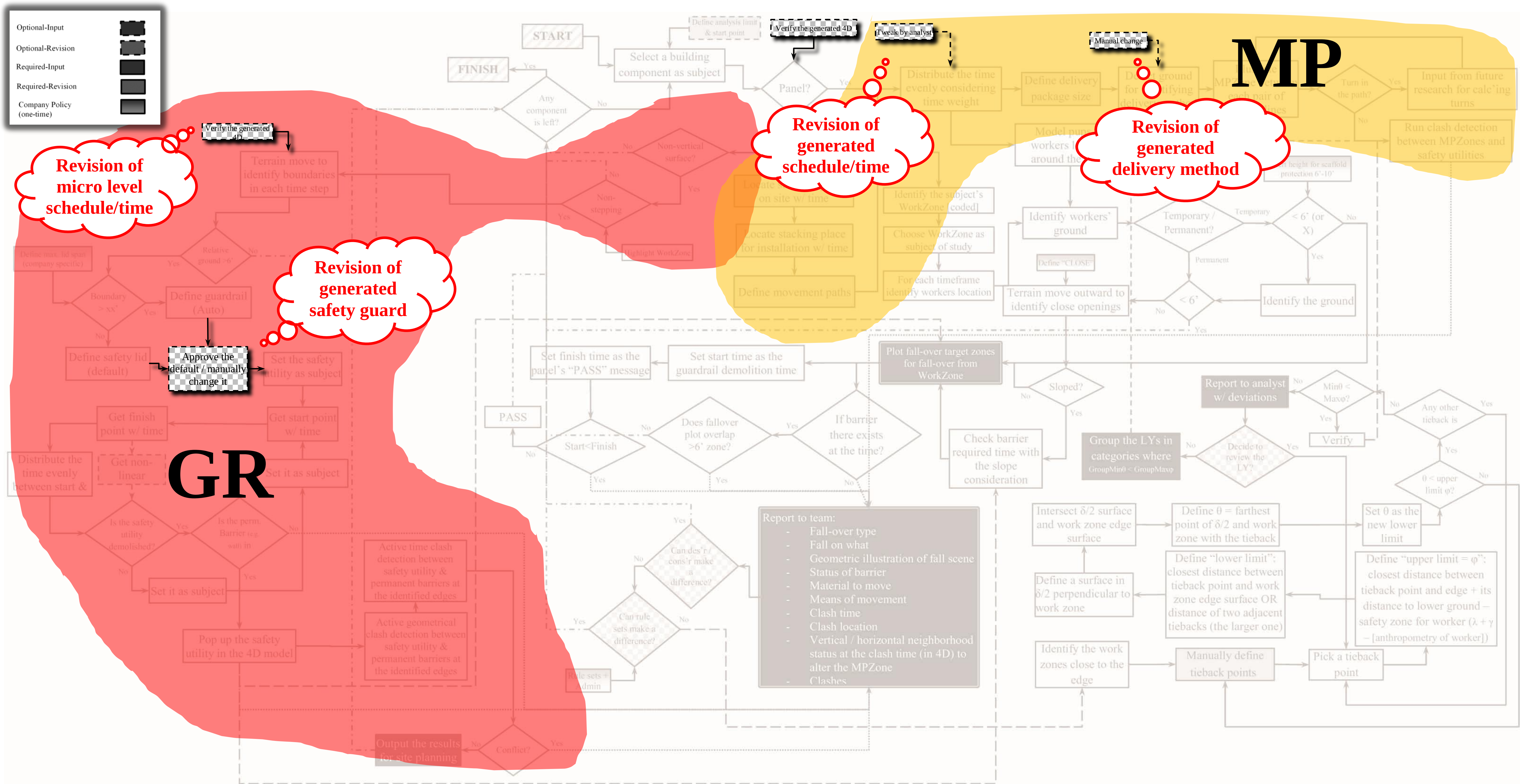


Figure 45 . Optional-Revision of the Generated Information

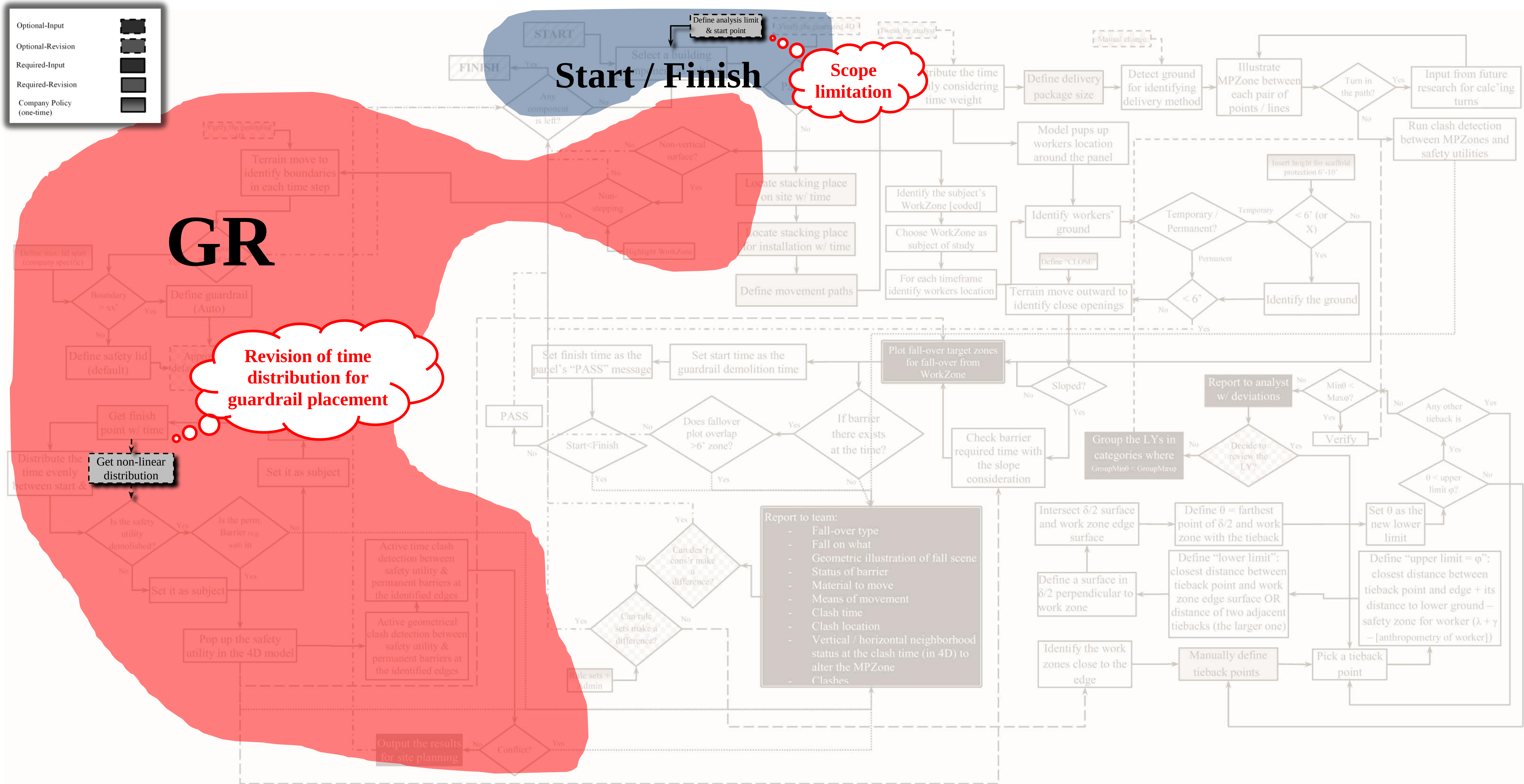


Figure 46 . Optional-Input of Data Manually

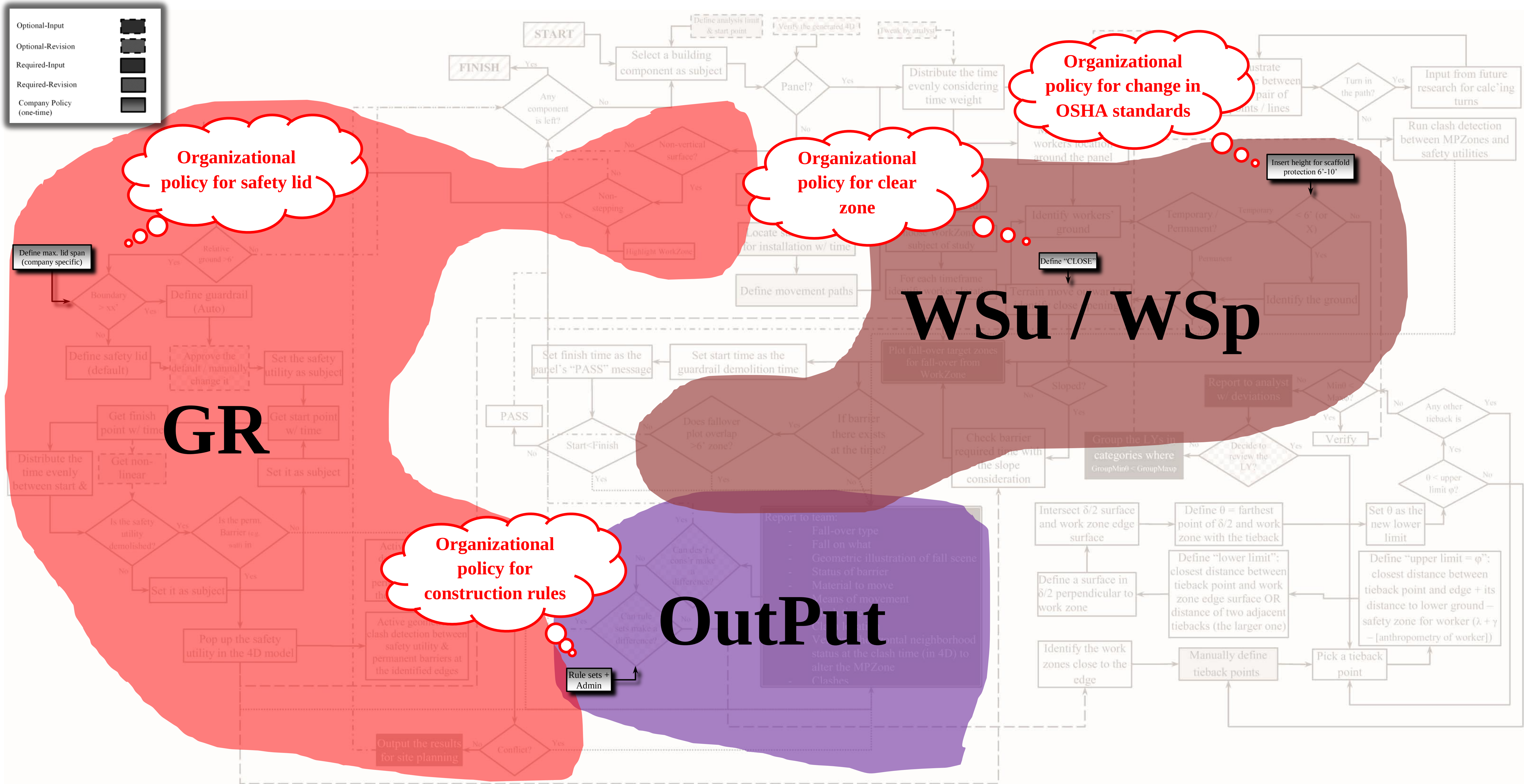


Figure 47 . Organizational Policy Inputs

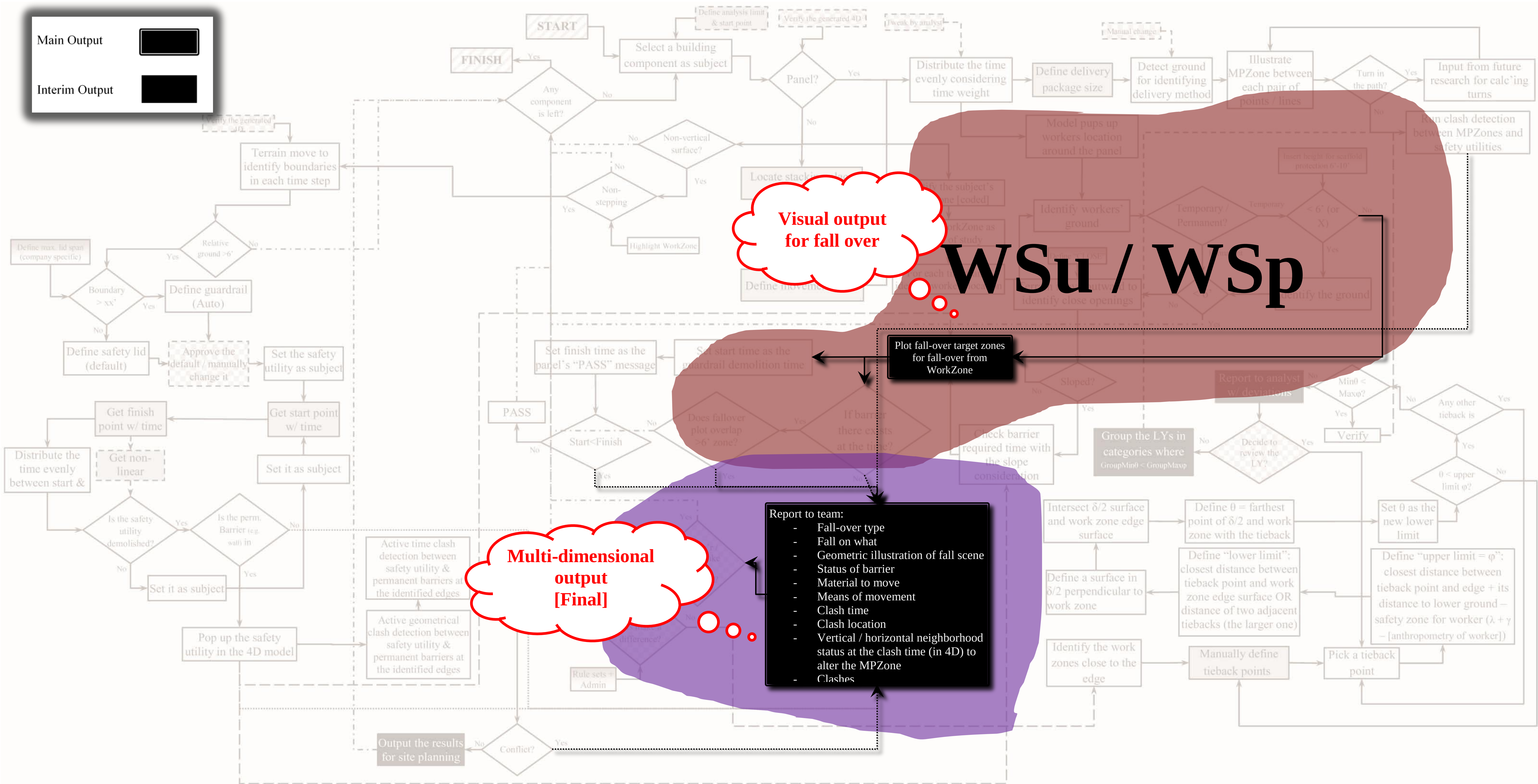


Figure 48 . Main Output of the System

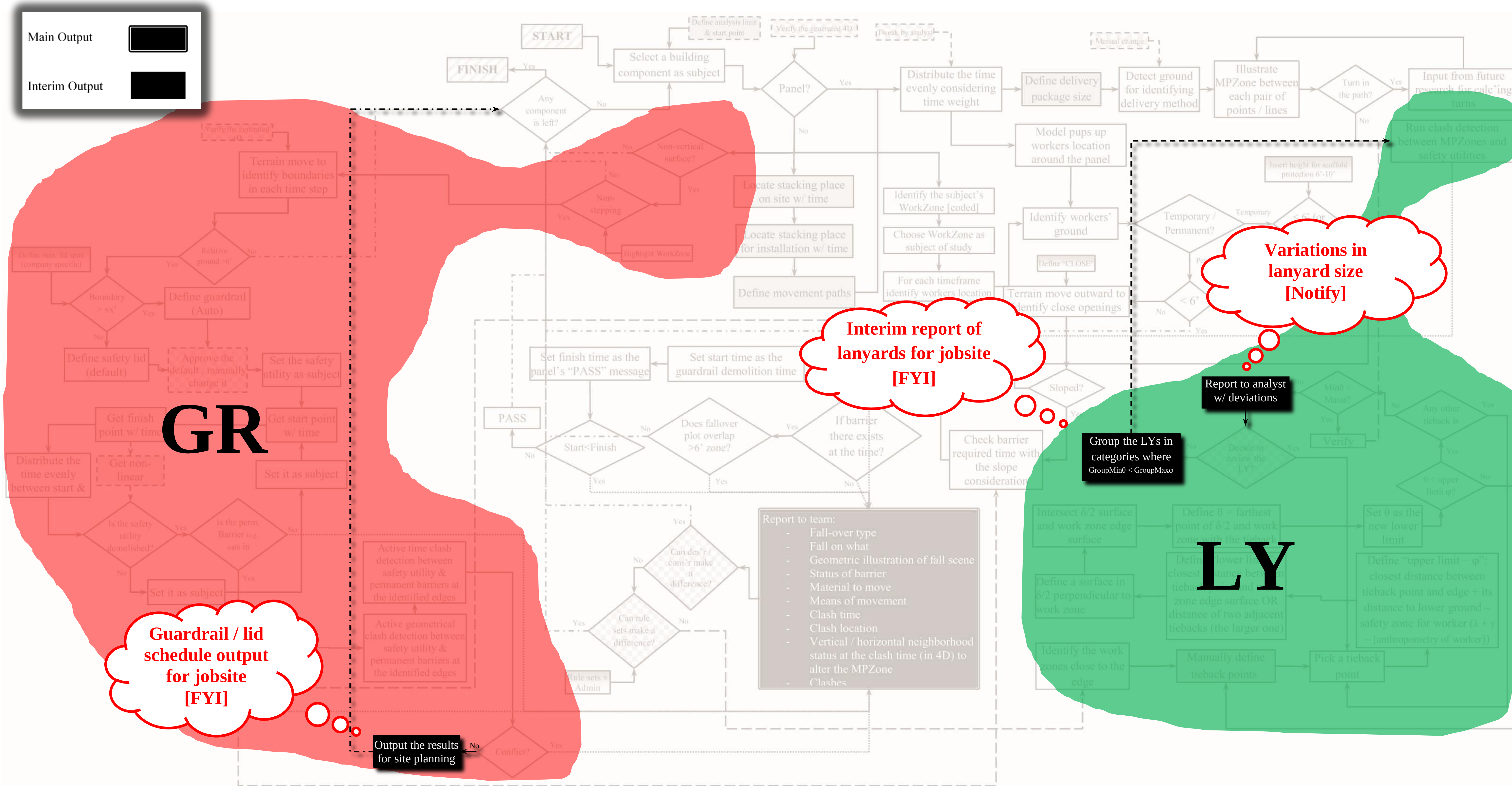


Figure 49 . Interim Output of the System

The illustrated final flowchart is the main interface and representation of the developed framework for the research scope. The research applied its methodology to the determined scope and developed the final flowchart. The generic research methodology can be applied to the whole research target. Figure 50 shows how this research customized the generic research methodology for the falls from heights.

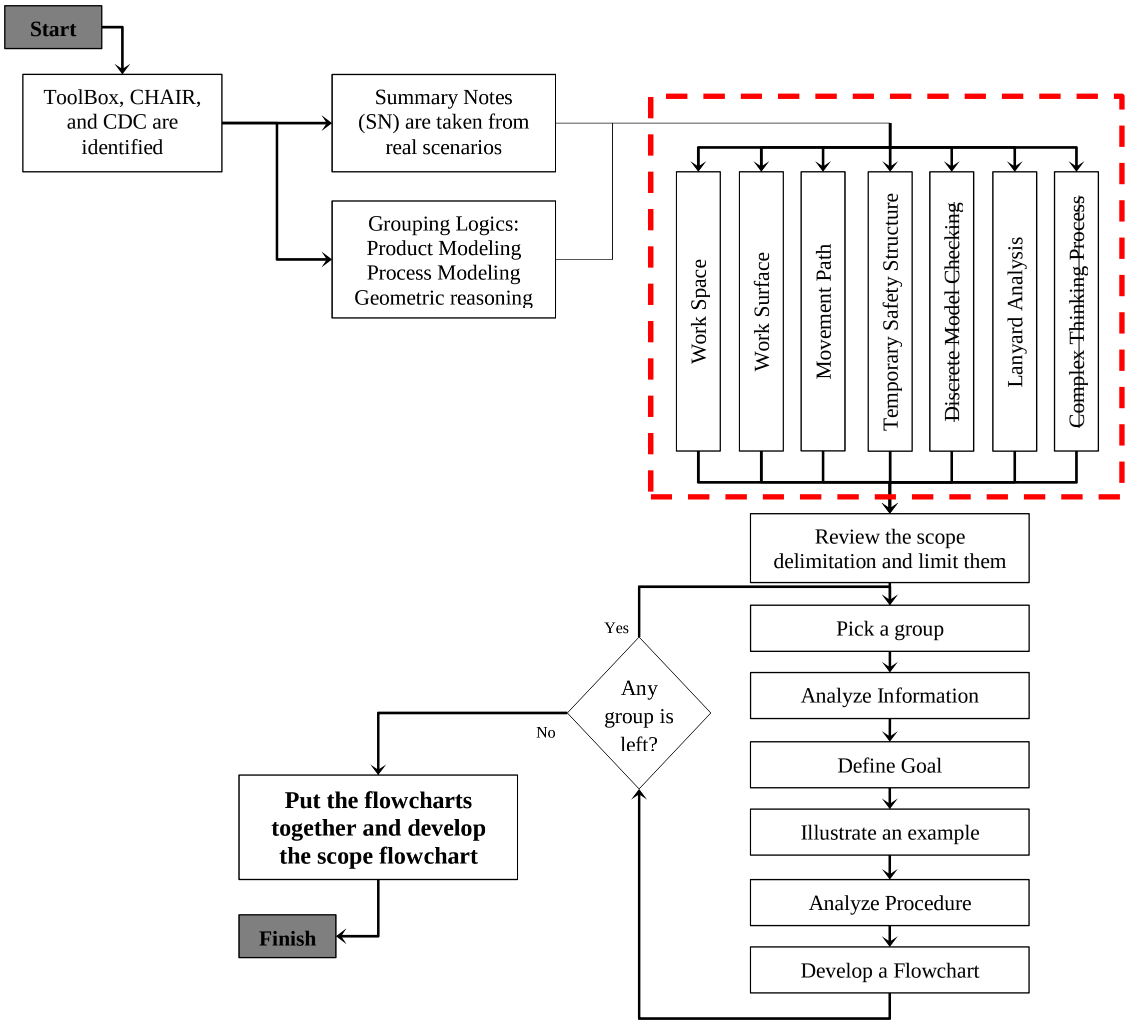


Figure 50. Research framework applied on the research methodology

The dashed section in Figure 50 shows the framework that this research developed for study of falls from heights through openings and unprotected edges. This framework helped the research develop the appropriate flowchart for its scope. The developed flowchart is the main output and representative of the framework in this research. As it is explained before, the flowchart is approved in two industry panels and by the research committee.

Chapter Six

Conclusion

Research Summary

This research was inspired by work experiences of the author in different construction companies in the U.S. as well as studies at Myers-Lawson School of Construction. The researcher had various experiences with BIM in three leading construction companies: Clark Construction (2008), Balfour Beatty Construction (2010), and Turner Construction (2011). He worked in BIM/VDC teams in those three companies, and researched Design for Safety (DfS) for Balfour Beatty Construction. The Myers-Lawson School of Construction at Virginia Tech had a strong focus on safety, and BIM was taught in this school with noticeable consideration. This environment led the researcher towards safety and thinking on how BIM can contribute to safety.

The conventional practice of safety in the construction industry does not involve designers in the safety of construction workers. Recent research by Gambatese, Behm, Hinze, Toole, etc. showed that a noticeable portion of hazards are rooted in the design phase. Those studies showed that designers can contribute to the safety of construction workers. The studies did not claim that designers should be taking responsibility for safety of construction workers, nor did they claim that designers can provide a safe working environment through a safer design. However, the studies emphasized the role of safer design in a safer working environment. The studies considered collaboration of designers with constructors through safety planning. The concept of DfS does not intend to transfer the whole construction safety responsibilities to designers. Rather it can provide an environment for improvement of designers' and constructors' collaborations. Integrated Project Delivery (IPD) methods provide a collaborative environment for synergistic efforts of designers and constructors. This research is developed for the IPD projects in which designers are in close contact with the constructors. Having such an environment, the research sought a medium for facilitating collaboration of designers and constructors in providing a safer construction environment.

The research started with a seed-project funded by the Myers-Lawson School of Construction Research Affiliates Program in 2009. This research introduced the concept of DfS and its similar concepts to the researcher. The researcher studied different practices and tools that help DfS concept. These studies revealed a gap in the recent Design-for-Safety tools and practices.

BIM is one of the most appealing new concepts in the construction industry. The power of BIM is in its information structure and exchange aspects. The researcher saw information as the missing part of safety analyses in the current practices of safety. This research claimed that current tools and practices of DfS do not provide appropriate information for safety analysts. The current practices help analysts with the following information:

- Walking the safety analyst through the building model as it is designed to have him/her guess on the probable hazards of the construction phase based on their personal knowledge.

- Walking the safety analyst through a 4D model of the construction phase to have him/her guess on the probable hazards of the same phase. This model only illustrates the permanent components of the building but no safety utilities or temporary structures
- Connecting the model components (in their final mode) with a depository of relevant hazards. This model enables the safety analyst to walk through the building as it is designed and to review a list of probable hazards associated with individual building components by clicking on it.
- Manually modeling each part of the building in the expected level of detail with its required temporary components. The model visualizes a snapshot (or a series of snapshots) to the safety analyst (discrete event simulation).

One of the first steps in a research is to define a digestible scope. This helps the research to go through the scope deeply and study in detail. This scope can be a small slice of the whole research target. The research methodology should be generalizable and expandable to the broader research target. This methodology will develop a generic framework that can be used on other sections of the broader research target. Following this policy, the research chose one of the primary hazard sources in the construction industry; i.e. falls. The literature categorizes falls into three groups:

- Falls of objects and materials from heights
- Falls of construction workers from heights
- Falls of construction workers in the same level

This research picked the second group and justified this selection in Chapter 2. The research narrowed down its scope to falls of construction workers from heights through edges and slab openings. In addition to the justifications out of library studies, the first expert panel acknowledged the selection of the scope and policy of studying a digestible chunk in detail.

The step this research takes beyond the state of the art tools is to change the passive visualization and presentation of the generic data of hazards to an active (vs. passive) visualization and analysis (vs. presentation) of hazards' information (vs. generic data).

The research developed an intermediate product to be further developed in the future and to be used in a BIM tool. The future intended BIM tool will provide a medium for collaboration of designers and constructors in addressing safety of construction workers during the design and construction phases.

The research proposes a framework to identify and analyze falls hazards in construction. The components of the intended future BIM model embed their own spatial-temporal data as well as their relevant temporary safety utilities. This model visualizes a 4D simulation that simulates the building in the construction phase with the temporary and permanent components. The model analyzes how the impact factors of falls interact with each other. It is important to emphasize that temporary safety utilities and safety factors are embedded in the "object families" by the software programmer. The modeler/analyst does not need to manually model them. Once a permanent object is “called” from the “library”, its relevant features – such as the safety utilities, the impact factors, and how they should be represented – are already called into the model. As a result, the 4D simulation presents them together in their proper time, and illustrates the results to the safety analyst through visualization and/or exported reports.

This research neither claims to identify all the impact factors of falls from height, nor claims to develop a framework that analyzes all the identified impact factors in the literature. The scopes of the impact factors and the framework are described in Chapters 1 and 3.

Examples of the analyses of the impact factors are: auto analyzing when, how, and why the edges are safe/unsafe; clearance of material delivery paths; adjacency of the work with the edges; efficiency and applicability of the PPE; etc.

The library study of current practices in DfS identified four sources for collecting information about construction workers safety:

- *CHAIR*

  CHAIR is developed based on the idea of prompt words. Each prompt word in the CHAIR is brought to the session’s discussion, and the “facilitator” of the session conducts the discussion based on each word on every single “unit” of the project. This tools is developed in Australia.

- *ToolBox database*

  The Design for Construction Safety ToolBox is a checklist based hazard identification tool developed in the U.S. It is composed of 17 hazard categories.

- *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.

- *Construction (Design and Management) known as CDM*

  Construction (Design and Management), CDM, is a standard developed in the UK at 1994, and revised in 2007. This can help as what a client expects in Design for Safety concept.

Chapter two (literature review) explained how activists look at CDM and how beneficial they see it. That chapter explained that safety activists believe that CDM does not go beyond setting up rules to be used for punishment of designers. Safety activists believe that CDM’s contribution in offering design alternatives or safety guidelines is very limited. As a result, the researcher focused on the three other safety data sources i.e. CHAIR, ToolBox, and CDC. These three sources are studied more in detail in the research body. The researcher took short notes about probable hazard scenarios from the three sources. These notes were about the hazard scenarios that directly or indirectly relate to the research scope i.e. falls from heights through openings and unprotected edges. Once the summary notes were already developed, the next step was to categorize them in appropriate groups. This categorization facilitated study of the hazard scenarios. Since the final purpose of this research was to implement a parametric BIM model for safety evaluation, it looked at the scenarios from modeling point of view. The research categorized the summary notes and scenarios, and narrowed the groups down gradually in order to reach the five major groups. Those five groups are called Pentagonal Groups. The Pentagonal Groups are:

- Work Space (Sp)
- Work Surface (Su)
- Movement Path (MP)
- Temporary Safety Structure (GR)
- Lanyard Analysis (LY)

The research put forth some basic characteristics of the intended BIM model that goes beyond the current BIM applications. The products of the Pentagonal Groups will add to these characteristics as the research goes forward and as the Pentagonal Groups develop.

A consistent format explained each of the groups, illustrated an almost-comprehensive example of the group, analyzed the example from different angles, and finally created a flowchart for that group. The flowchart showed how the future BIM software will investigate the model and interact with the analysts.

Once the Pentagonal Groups were formed, and their outputs (i.e. flowcharts) were developed, they were presented to an industry panel. The purpose of presenting the preliminary results to the industry panel was to have the preliminary results criticized and challenged by the external judges. This helped viewing the preliminary results from new points of view other than the researcher's mind structure. It was very important to prevent introducing a bias to the panelists' evaluations. This helped the research get more neutral comments, and avoided focusing too much on one idea while ignoring some other ideas. The panelists' neutral evaluations helped criticizing the preliminary results from a wide variety of angles. In addition to finding the right panelists for the required knowledge and skills, diversifying the panel helped reducing the bias of the panel. The researcher had the panelists think about how BIM can help DfS before they study the research summary. This was intended to avoid influencing the panelists with the specific research method

The five panelists represented architectural designers, general contractors, sub-contractors, BIM software developers, and safety experts. They commented on the preliminary framework and suggested some improvements on it. Some of the comments made by panelists were out of the scope of this research and are suggested for future improvements. Since the panelists read a summary of the research, and furthermore, limited time had them skim through the summary, there were some ambiguities and gaps for them in the research. These questions and concerns were addressed in the research body. The final flowchart is the main external interface of the framework. This flowchart as well as the pentagonal flowcharts benefited from the panel's feedback. Once the preliminary flowchart was updated, the final flowchart was created. The same panelists along with a new member verified the final flowchart results. The new BIM specialist was added to the second panel for two reasons:

1. To view the results from a new perspective
2. To have the idea of a person who implements BIM (Jason Reece) in addition to the idea of a person who supervises BIM development from a vice-president perspective (Buddy Cleveland).

The second panel verified the research process and believed that it can support a broad based BIM tool for the DfS concept.

Figure 51 shows how this research scope (falls from heights through openings and unprotected edges) is sliced in the whole research target (construction workers safety). The purpose of undertaking this research was to develop a generalizable process that would be applicable to the broader area of construction safety design in order to fulfill the research goal.

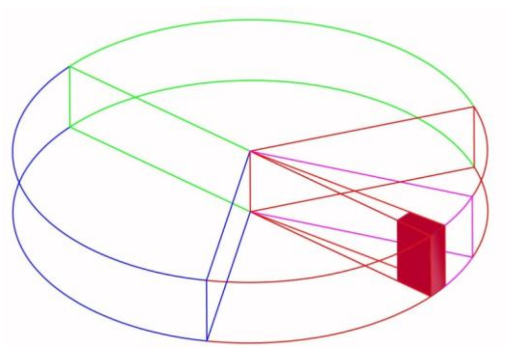


Figure 51. The Research Scope Slice in the Whole Research Target Pie

The limited proposed scope allows the researcher to experience a small slice of the research field in detail. Experiencing the Generalizable Master Process in a small slice of the target pie helped the research prove that the Master Process works and it is generalizable to the whole research target pie. Figure 52 illustrates the Master Process that is used in this research.

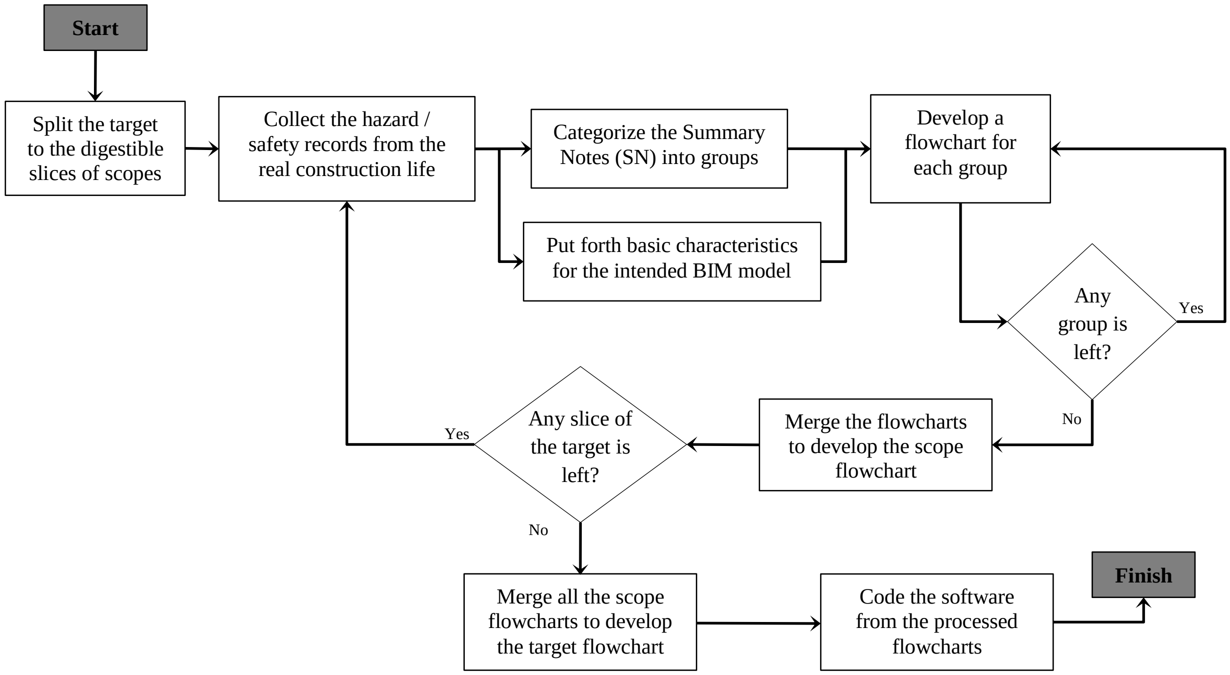


Figure 52. Generalizable Master Process of the research

This research proposed the Generalizable Master Process and applied it to a critical section of construction safety i.e. falls from heights through openings and unprotected edges. The framework that this research developed is presented in chapter five, Figure 50. The developed framework is the main contribution of the research. The developed final flowchart (Figure 33) is the main interface of the framework. The flowchart represents the framework for the example of falls of construction workers from heights through openings and unprotected edges.

The main limitation of this research is its required project delivery method. Inputs of the developed flowchart require collaboration of designers and constructors in the design phase of the project. The required information is beyond the knowledge and authority of designers. When this model runs in the design phase of the traditional project delivery environment, it lacks the inputs of constructors. When it runs in preconstruction phase of traditional bids, it lacks the inputs of designers. Since the product of this research provides a medium for collaboration of designers and constructors, it requires an environment for collaboration of these two groups as the prerequisite.

The researcher’s opinion is that identifying, analyzing, and minimizing construction hazards cannot get done without collaboration of designers and constructors. In other words, designers will not be able to have an effective impact on the construction workers’ safety without being in a collaborative environment with the constructors in the design phase.

Research Conclusion

A study of the literature shows there are a lot of discussions on the Design for Safety concept. A variety of tools are developed to support this concept. However, the literature study showed a gap in the current developed tools. This research was mostly about the “process” of developing a tool rather than developing a tool as the “product” of the research. Having said that, this final section explains what is the tangible meaning of this research to the real life of construction.

This research suggested and experienced a small slice of a concept. This concept can develop a resource/schedule-loaded BIM model that can be used in the design and preconstruction phases of the construction industry. This section explains meaning of the research in two sub-sections:

1. The research process
2. The research product

These two concepts are discussed in the following.

The Research Process

This research suggested and experienced a process in which a reasonable scope of hazards is determined. The research suggests this experienced process to be repeated for the remaining parts of safety hazard recognition. The safety databases and hazard records for each determined scope should be identified in the research. This research framework suggests extracting summary notes of the hazard scenarios and prompt-words for safety considerations. The next step is to categorize these summary notes based on the concepts of Product Modeling, Process Modeling, and Geometric Reasoning. Categorization should be narrowed down to a limited number of groups that address a same concern in each. The developed framework suggests investigating and analyzing each group. Illustrating a comprehensive and clear example can smooth the road for understanding the hazards and the required information for analyzing those hazards.

The explained procedure and analysis can be converted to the form of flowcharts. These flowcharts should merge together and develop a larger flowchart for that specific slice of the research target pie. Once all the slices of the construction hazards are turned to flowcharts, a final comprehensive flowchart can be developed by merging them together. The final flowchart should eventually turn into structured concepts to help develop the intended BIM software.

The Research Product

The ultimate purpose of the research is to help develop a BIM application. Although this goal is out of the determined scope of the undertaken research, it is set as the ultimate horizon of this research. The intended BIM software develops a resources/schedule-loaded model. This future model will illustrate and analyze safety impact factors of construction workers during the construction phase. Opposite to the current tools that are either too generic (and cannot clearly focus on specific hazards of a specific project) or are too specific (and cannot apply to a wide range of the projects), this application considers impact factors of hazards rather than the hazard scenarios. The concept of analyzing impact factors rather than analyzing scenarios applies the software to a wider range of construction projects.

Future Work to Implement From This Research

The future intended BIM tool will develop a parametric BIM model for an example building. The "objects" in the model know each other through the parameters. These parameters are beyond the parameters in conventional BIM tools. The developed flowchart in Chapter 5 explained those parameters in more detail. The objects' parameters can propose a project schedule through their embedded information.

Another step this intended model takes beyond the conventional BIM models is proposing temporary safety utilities for the building components. The model can also identify and highlight temporary locations of workers when installing building components.

When the software identifies a probable hazardous condition, it reports them to the user of the software and presents it via multi-media interfaces. The software not only flags hazards for the analysts, but provides the analysts with the information needed to better understand hazard conditions and respond to them. Hazard representation is through visual and multi-media representation of the hazards and the surrounding conditions of the hazards. The impact factors of the surrounding conditions will be presented in the software results.

The future intended BIM model will analyze safety impact factors and interactively communicate with the safety analyst. This interaction helps studying and identifying construction hazards in the design and preconstruction phases. Construction data can be augmented to the software from the design phase through the construction phase. A better identification of the construction hazards leads to more proper and in in-time response to them.

Future Research Directions

The past section discussed the research from two points of view. The main concern of the research was to develop processes and to generalize them to the broader research target. The developed framework demonstrates these sample processes, and eventually is illustrated in the form of the final flowchart. This final flowchart is the sample product of this research. Future recommendations for this research are offered in both areas i.e. the processes and the sample product.

Future research that continues the mission of this research can expand upon input knowledge database for identifying hazard scenarios and prompt words. Although this research identified a group of the hazard scenarios and safety sources, future research should expand the database to the identified hazard scenarios and safety repositories. It further suggests including experts opinions and field studies to the input sources.

Since the sample product, i.e., the flowchart, was not the main purpose of this research, a lot of changes and improvements can apply to the product of the future research. These changes are including but not limited to the second category of the first panel's recommendations. Those recommendations are discussed in Chapter 5 in detail. The following presents a short summary of them:

- To consider transition points from building to temporary safety structures
- To distinguish storage of construction materials based on their hazardous conditions
- To model cranes and their movement paths
- To make the framework open for defining new safety utilities e.g. retractable lanyards
- To incorporate clear zones and positioning zones such as ladder clearance zones in the model

Since this research product is an intermediate product, it is recommended that future research develop their products to a more detailed level. The research product needs to be presented closer to the coding details. It needs to specifically include objects parameters, and to explain characteristics of the building components.

The research needs to interconnect with the research that propose project schedule from building components. It needs to be interconnected with the research on resource-loaded models. Developing geometric reasoning as the analysis food of the research is the other step that can be taken for this research.

It is discussed that this research developed a sample slice of an interim product. The first step to fulfill the mission of further developing this interim product is to generalize the Generalizable Master Process, GMP, (Figure 52) to the other slices of the research (Figure 51). This requires identifying the whole research target (Figure 51) and split it into digestible research slices. Once the research target is split to different research scopes, the GMP (Figure 52) should be applied to each scope. This process analyzes each slice to a flowchart such as the research output in Figure 33. The final flowchart from all the research should merge together to develop the flowchart for a comprehensive hazard identification model.. This final flowchart will work as the interim product for developing the intended BIM tool.

Design and construction companies have a very important role to ensure that the developed flowchart covers the research target and does not leave a gap. They also should discuss their different policies in facing hazards. This will end up in a system that allows customizable settings in the future software based on each company's policies.

While the construction and design companies will watch the future research to fulfill the research target, they should observe the proposed processes in order to keep them within the acceptable framework of their routine daily processes. These companies should keep the proposed processes in their comfort zones. If the proposed processes are out of the comfort zones of the construction and design companies, the final product loses its applicability in the construction industry, and construction and design companies will not be willing to implement it.

BIM software developer companies have a different role in this research. They have two distinguishable roles during the phase of developing the flowcharts and after the flowcharts are already developed and they need to be programmed. During the period of developing flowcharts, the BIM software developer representatives should monitor the proposed processes in order to be programmable in a BIM application. They are expected to check if the developed flowchart is in line with the concept of Product Modeling, Process Modeling, Parametric Modeling, and Geometric Reasoning. The software companies should ensure that the inputs of the system can be inserted by the user-interface, or alternatively the embedded information of the object families can provide such information. The User Graphic Interface (UGI) of the system and how the system outputs the user should be shared between designers, constructors, and software developers. Designers and constructors should confirm the usability of the UGI while the software developer companies approve the UGI programmability.

After the flowcharts are developed and before the final flowchart is coded, the role of the software companies is very unique. The software companies should further develop the intermediate product (the flowchart) to a more detailed product. These companies should develop the flowchart to make it codeable. To do that, the software companies should conduct a follow up research and develop the parameters and information to embed in the object families. Level and type of information in the objects should be defined in detail. Once all these supportive researches are done, the software can be developed and used by the design and construction companies.

The intended BIM model – that is expected to be developed in the future researches – can be improved by considering the recommended changes.

Research Topic for a Future Researcher

The author has a recommendation for another PhD student who is seeking a hot topic for application of BIM in DfS. Although this research undertook one slice of the whole research pie, and other slices of the pie are not studied, the author does not recommend undertaking the other slices of the research pie. The reason is that the author believes undertaking the other slices is a redundant work. Previous researches have identified all the slices of the research pie. The current research has developed a Generalizable Master Process that is applicable to the whole pie. It means that undertaking the other slices of the pie is redundant work with little innovation and creation by the future researchers.

The author's recommendation for another PhD researcher is to assume the research pie completed and the comprehensive flowchart already developed. The recommended question for that future PhD researches is "how to make the comprehensive flowchart ready for writing the software code?” The author expects that research to clearly identify and investigate the steps the comprehensive flowchart needs to take on order to get ready for coding.

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Appendix A

	Section	No.	Title	Hazardous Condition	Suggested Response
1	**Project Component: General Conditions, Special Provicions**	1	**Schedule / Sequence A**	the work schedule and construction sequence can lead to safety hazards if they do not allow for adequate lighting, rest, or safety and health requirements	
2			1		To prevent accidents resulting from tired construction workers, do not allow schedules which contain sustained overtime
3			2		Minimize the amount of night work
4			3		Do not allowe work to be performed on Friday or Saturday nights
5			4		Design and schedule different projects that occure at the same location to be performed simultaneously
6			5		When estimating the length of time for completion of individual work satges and the overal work project, take into account the safety and health requirements of the construction worker
7		2	**Schedule / Sequence B**	Road construction, maintenance, and excavation operations can be hazardous for construction workers when working around existing utilities and ongoing public traffic.	
8			1		Require hand excavation around existing underground utilities
9			2		Design new utilities under roadways and sidwalks to be placed using trenchless technologies or tuneling instead of trenching
10			3		Require public traffic to be detoured around the project site
11			4		Require ongoing public traffic to be slowed down as much as possible by using flagcars, flagpeople, or by closing adjacent traffic lanes
12			5		Impose a ceiling on the number of workers on site or in a particular area
13		3	**Schedule / Sequence C**	Complicated or unique designs and improper materials handling can lead to safety hazards for construction workers	
14			1		Provide or require the constructor to submit a construction sequence for complicated or unique designes
15			2		Require requlatory scheduled site housekeeping
16			3		Rquire unused or unsecured materials to be stored in designated areas only, and not in areas of construction activity
17			4		Prohibit metal decking or forming work by hand if wind speed exceeds 30 mph
18			5		Require the construtor to locate and mark existing reinforcing steel prior to cutting into existing reinforced concrete structures
19		4	**Site hazards**	working with existing utilities and toxic substances, and renovating an existing structure creat potential safety hazards for construction workers	
20			1		Require the subcontractor to "pothole" underground utilities before excavation operations
21			2		Do not locate constructor material storage areas next to, over, or under electrical power lines.
22			3		Provide the constructor with a list and the location of toxic sunstances and other hazardous materials, which may be located on the site

23			4		Confirm that the constructor knows of the potential hazards of all construction materials, and their proper storage and disposal
24			5		Provide the constructor with original erection drawings of the existing structure on renovation projects
25	**5**	**Safety Plans**		An absence of safety plans during construction can compromise the safety of construction workers in emergency situations	
26			1		Require the submittal of a fire control plan, or that the fire department be contacted to discuss plans for fire protection services during construction. Consider a fire watch system
27			2		Require the submittal of a job-site safety survey and plan, and an emergency action plan.
28			3		Require the submittal of an erosion control plan
29			4		Require a pre-construction meeting between the general contractor and all subcontractors to discuss safety issues
30			5		Consider involving OSHA in planning safety measures prior to starting construction, or prior to performing complicated or unique construction efforts
31	6	**Public Interaction**		Public access on or adjacent to the project site can distract the construction the construction workers and create safety hazards for the workers and public	
32			1		Minimize construction visitation and public access through or adjacent to the project site
33 change here					Contact the local police department to set up police officer patrols during road construction and maintenance work
34					Provide for evacuation drills, egress routes, and expedite installation, testing, and turnover of fire systems
35	7	**Materials**		Construction materials can be hazardous to construction workers if the materials are flammable, contain toxic substances, or do not meet their specified use requirements	
36			1		Ensure that specified materials of construction are appropriate for flammability hazards which may be encountered on the work site
37			2		Do not specify materials which contain asbestos or other known hazardous substances
38			3		Ensure that all materials meet the expected environmental and work site conditions
39	8	**Concrete**		Concrete placement and post tensioning operations can be hazardous for construction workers if adequate design-related safety plans are not developed and followed	
40				A lack of knowledge of the contents of underground concrete structures can lead to safety hazards for construction workers during excavation operations	
41			1		Limit the lift height of concrete pours to minimize the load on formwork and the risk of collaps of fresh concrete during poring operations
42			2		Provide a procedure for placing and holding initial loads on post-tensioned concrete members
43			3		Use red concrete to encase underground utility lines
44	9	**Masonry**		Construction worker safety and health can be affected by continual exposure to masonry materials and cleaning agents which contain toxic substances	
45			1		Do not specify the use of masonry materials or liquids which contain toxic substances
46			2		Investigate the hazards associated with the specified construction

Project Component: Tec

					materials and alert the constructor of the necessary safety precautions
47	hnical Specifications	10	**Steel**	Tall steel structures can easily collapse during the erection process if the steel is not adequately supported before it is permanently bolted or welded into place	
48			1		Limit the lift heights of steel erection
49		11	**Wood**	Construction worker safety and health can be affected by continual exposure to wood treated with chemicals containing toxic substances	
50			1		Avoid using creosote to treat piles, railroad ties, or other ground contact members
51		12	**Roadways**	Repeated work on or adjacent to autombile traffic facilities increases the safety hazard risks for construction and maintenance workers	
52			1		Increase the project maintenance life cycle by increasing or upgrading the project specification standards
53		13	**Testing**	Timely testing of materials, structural members, and project systems is essential to prevent collapse of the structure or injury during construction	
54			1		Require concrete test results to be verified before form stripping and removal of shoring
55			2		Specify the use of testing devices which are embedded in concrete members in order to test the strength of the concrete before form removal
56			3		Specify testing procedures for complicated designs or specialized mechanical, electrical, or piping systems
57	Project Componenet: Contract drawings	14	**Utilities**	A lack of access to or knowledge of existing utilities can affect the safety of construction workers in emergency situations and during excavation operations	
58			1		Indicate on the contract drawings the locations of shut-off valves and switches for existing utilities . Provide the constructor with access to these locations
59			2		Indicate on the contract drawings the locations of existing underground utilities and mark a clear zone around the utilities
60			3		Include the name, address, and phone number of local utility companies on the drawings
61			4		Note on the drawings the source of information and level of certainty on the location of underground utilities
62		15	**Existing Structure**	Working with an existing structure can lead to collapse hazards if the constructor lacks knowledge of the existing structure's loading conditions and structural integrity	
63			1		Note on the contract drawings the location of existing vertical load bearing walls
64			2		Indicate on the contract dawings the locations where shoring of the existing structure is required during construction
65			3		Review the condition and integrity of the existing structure and indicate any known hazards or deficiencies on the contract drawings
66		16	**Design Loads**	Adequate support for construction workers, equipment, and metrials is essential for preventing collapse of the existing or new structure	
67			1		Provide the constructor with floor and roof design loads for use in determining material stockpile locations and heavy equipment maneuverability
68		17	**Hazardous Substances**	Hazardous and toxic substances existing on the project site can creat safety and health hazards during construction	
69			1		Research the history of the project site and alert the constructor of the

					type and location of any hazardous and toxic substances existing on the site
70		18	**Stairways**	Timely erection of pemanent stairwyas and handrails can help eliminate falls and other hazards associated with temporary stairs and scaffolding	
71		1			Schedule a permanent stairway to be constructed at the beginning, or as close as possible to the start, of construction
72		2			Schedule permanent handrails to be erected along with the structural steel as one assembly
73		19	**Fire hazards**	The scheduled construction or demolition of fire prevention devices can lead to fire hazards for construction workers	
74		1			schedule an underground firewater system to be constructed at the beginning of the project
75		2			For multi-story buildings, schedule a fire water protection system to be installed and in use as early as possible during construction
76		3			Schedule permanent emergency exit and egress signs to be erected early in construction
77		4			Schedule fire walls and fire doors to be constructed or placed early in the construction phase
78		5			During demolition operations, schedule fire walls and fire doors to be kept in place as long as possible
79		20	**Electrical**	The scheduled construction of the electrical lines equipment can lead to safety hazards for construction workers	
80		1			Schedule permanent telephone lines to be installed early in the construction phase. Locate the lines in remote buildings, process areas, and on the site perimeter
81		2			Schedule the permanent electrical system to be installed early in the construction phase and available for constructor's use
82		3			Schedule permanent lighting systems to be installed early in the construction phase and available for constructor's use
83		4			if possible, where existing electrical lines need to be in service during construction, consider scheduling the voltage or current to be decreased before construction begins
84		21	**Mechanical / HVAC**	The scheduled construction of mechanical and HVAC equipment can lead to safety hazards for construction workers	
85		1			Schedule air conditioning, heating and ventilating systems to be available for use by the constructor at close-in
86		2			Design and schedule vantilating systems to be in place in areas where coating will be applied prior to applying the coatings
87		22	**Materials**	Construction materials and debris scattered around the project site can lead to onstructions, tripping hazards, and fire hazards for construction workers	
88				Painting, installing, or other similar work on materials, piping or equipment in place can lead to falls if the work is performed at elevated levels	
89		1			Require regulatory scheduled site housekeeping to ensure a neat and clean work area
90		2			Schedule materials, piping and equipment to be painted and/or insulated prior to erection or installation
91		23	**Workers**	Construction schdules can affect worker safety and health if the schedules do not allow for sufficient safety planning and recognize worker health requirements	
92	Linked	1			In order to prevent hazards due to fatigue, do not allow schedules with

						sustained overime
93	Project Component: Work Schedule / Sequence	Linked	2			To minimize a work crew's exposure to hazards, design and schedule projects which occure at the same location to be completed simultaneously
94			3			Account for incompatible activities in the schedule, e.g. no welding during painting operations
95			4			Schedule the release of engineering drawings such that sufficient time is allowed for materials to be purchased, delivered, and installed
96		Simillar to	5			Require a pre-construction safety meeting between all workers on the site, and require a jobsite safety survey and plan to be submitted before construction begins
97		24 Should be l		**Designs**	Without adequate knowledge of the project design concept, complicated or unique designs can lead to construction site hazards	
98			1			Provide or require the constructor to submit directions for a construction sequence in complicated or unique designs
99			2			Conduct constructability reviews early in the design phase. Include the constructor and maintenance personnel in the reviews
100		Linked to 2	3			In estimating the periods for completion of work stages and the overall project, take into account worker safety and health requirements
101		25		**Elevated work**	The work schedule and construction sequence for work performed at elevated levels can affect the safety of construction workers	
102		Linked to 1	1			Limit the lift heights of steel erection and concrete pours
103			2			Prefabricate building components in the shop on on the ground and erect them as one assembly
104		Simillar to	3			Erect permanent lighting systems along with the structural framing as one assembly
105			4			Schdule sidewalks, slabs, and roadways around elevated work areas to be constructed as aerly as possible to provide a stable base for scaffolding and ladders
106			5			In multi-story buildings, schedule the exterior walls structure and/or finish to go up with the framework or soon therafter
107		26		**Testing**	Timely testing of new construction materials and work in place can eliminate safety hazards for construction workers	
108			1			Require concrete test results to be verified before removal of the forms and shoring
109			2			Provide a shedule for removing concrete forms and shores
110		Linked to 1	3			provide a procedure for placing and holding initial loads on post-tensioned concrete
111		27		**Roadways**	The work schedule and construction sequence for road construction and maintenance can affect the safety of construction workers	
112		Linked to 1	1			Do not perform road work on Friday and Saturday nights
113			2			Avoid road work during peak traffic volume times of the day
114		Linked to 1	3			Minimize the amount of night work
115			4			Prior to the start of the project, erect informational signs near the project site and annouce the media about construction work and schedule

116		5			Schedule the project to minimize the amount of time that excavations are open
117		28	**Existing Structure**	The work schedule and sequence for projects which require work with an existing structure or utilities can lead to safety hazards for construction workers	
118		1			Minimize existing automatic sprinkler systems in operation as long as possible in the construction phase
119		2			Provide a work sequence for safe tie-ins to existing utilities
120		29	**Power Lines**	Power lines which are in service during construction present an electrical shock hazard. Below-grade lines present a hazard when operating excavation, pile driving equipment. Overhead lines are hazardous when operating cranes and other tall equipment	
121		1			Maintain a minimum clearance between the project and overhead powerlines as outlined in Section 1926-950 of the Code of Federal Regulations
122		2			Disconnect the powerlines before construction begins
123		3			Bury overhead powerlines below grade before construction begins
124		4			Re-rout the power lines around the project site before construction begins
125		5			Clearly mark the power lines with warning flags, tape, paint, chalk, etc. and note their location on the contract drawings
126		30	**Ememrgency Access**	Emergency access to all parts of the project site is essential to provide prompt and adquate reponse to accidents and injuries	
127		1			Allow for at least two formal controlled intersections at access points to the site
128		2			Orient the project to allow for the construction of temporary roads, fire lines, and approach roads during construction
129	**Project Component: Project Layout**	31	**Excavations**	Inadequate clearance or congestion during excavation work can create cave-in and obstruction hazards for construction workers	
130		1			Allow adequate clearance for shoring, forms, quipment, and workers to perform below-grade work
131		2			Locate underground utilities and other below grade features in areas easily accessible for excavation. Allow sufficient area around excavations for stockpiling the soil
132		3			Avoid locating utilities which cross under other pipelines, run directly adjacent to existing piplines, intersect previously backfield, distributed, or fissured soil, intersect manhole excavations or cross different types or conditions of soil
133		4			Consider area drainage of excavations during construction when developing the plot plan
134		32	**Masonry**	Crowded and confined areas below elevated masonry work increases the risk of workers being struck by falling bricks, mansonry tools, and other materials	
135		1			Allow for large, unobstructed, open area (limited access zone) below elevated masonry work to minimize the risk of workers being struck by falling objects objects. See Section 1926.750 of the Code of Federal Regulations
136		33	**Vehicular Traffic**	Confined, congested, or sloped areas for constructor parking, material storage, and pedestrian access can lead to safety hazards for construction workers	
137		1			Do not locate constructor material lay-down areas next to or under electrical power lines
138		2			Allow adequate room for constructor parking, temporary buildings, shops, material storage areas, and unobstructed access to and from the project site

139	Project Componenet: Structural Plan/Elevation	3			On sloped sites, orient the project layout or grade the site according to minimize the amount of work on steep slopes
140		4			Allow for pedestrian traffic to be isolated from construction vehicular traffic
141		34	**Floor Plan**	A building floor plan can lead to fall hazards if there are noumerous offsets of varying size, floor levels varying in size or shape, or if the size and layout does not meet local building codes	
142		1			To minimize the risk of falling, minimize the number of offsets, and make the offsets a consistent size and as large as possible
143		2			In multi-story buildings, design each floor plan to have a smaller area than the story blow to prevent objects and workers from falling more than one story
144		3			Ensure that the building height and area per floor meet all local building code requirements for the type of construction used
145		35	**Space layout**	Rooms, walkways, platforms, etc. within a building which do not allow adequate egress or provide protection against hazardous material can create safety hazards for construction workers	
146		1			Isolate from adjoining areas the storage areas for combustible and toxic materials such as paper, explosivs, tires, celluloid, excelsior, petroleum, plastics, etc.
147		2			Provide at least two means of egress on large maintenance platforms or walkways
148		3			Minimize the number of confined spaces. Design access points to confined spaces as large as possible. Provide at least two access points to confined spaces
149		4			Provide access by means of a ladder or stairway when there is a change in elevation of grater than 19 inches
150		36	**Mechanical**	The location and layout of mechanical rooms, and the position of control valves and panels can create obstruction and other safety hazards for construction workers	
151		1			Provide a clear, unobstructed, spacious work area around all permanent mechanical equipment. See Section 1926.403 of the Code of Federal Regulations
152		2			Do not locate permanent mechanical equipment in or directly adjacent to passageways
153		3			Position control valves and panels away from passageways and work areas
154		4			Prevent access near hoist or crane electrification points and travel clearnaces
155		37	**Electrical**	The location and layout of electrical rooms, and the positioning of electrical controls can create electrical shock and other safety hazards for construction workers	
156		1			Provide adequate passageways and access areas around all equipment in control, electrical, and electronic rooms
157		2			Locate electrical circuit breaker boxes in sight of the equipment it affects
158		3			Do not locate electrical rooms under pipes carrying liquids
159		38	**Windows**	Prior to installation of upper story windows, low sill heights add to the chance of falling through the window openings	
160		1			Design window sills to be 42 inches minimum above the floor level. Window sills at this height will act as guardrails during construction
161		2			Keep dimensions similar from story to story to facilitate the reuse of concrete forms

Project Component: Foundation

162		39	**Stairways, Ramps**	Stairways and ramps which are exposed to the weather and isolated can lead to fall hazards for construction workers	
163		1			Locate exterior stairways and ramps on the sheltered side of the structure to protect them from rain, snow, and ice
164		2			Locate exterior stairways and ramps away from the north side of the structure to minimize the buildup of moss and ice
165		3			Design stairways and ramps to run parallel and imediately adjacent to the structure, rather than perpendicular to the structure
166		40	**Excavations**	Foundation excavations which are congested, excessively deep, of varying depth within the work site, or which are required to be open for long periods of time can be cave-in hazards	
167		1			Consider using a pile or caisson foundation system which does not require excessively deep excavation, and allows construcion work to be performed above grade
168		2			Minimize the amount of excavation work and maintain a constant foundation depth throughout the project
169	Linked to 4	3			Design and schedule the project to minimize the amoutn of time excavations are open
170	****	4			Keep detailed work above grade, simplify all below grade work
171		5			Allow adequate clearance for shoring, forms, and workers within the excavation
172		41	**Footings**	Footing location and reinforcing steel can create collapse, tripping, and all fall hazards for construction workers during the construction of the foundation	
173		1			On spread and continuous footing, and mat foundations design the top layer of the reinforcing steel to be spaced at no more than 6 inches on center, each way, to provide a continuous, stable walking surface before the concrete is poured
174		2			When developing a plot plan, group footings in a way that permits proper drainage of mass excavation
175		3			Locate new footings away from existing foundations
176		42	**Piles**	Pile foundation systems which are not designed with consideration of soil conditions and pile driving equipment can lead to cave-in and other hazards for construction workers	
177		1			TO prevent cave-ins due to vibration of loose soil, do not use driven piles in deep excavations in areas of loose or backfilled soil
178		2			Avoid designing piles at angels flatter than 4:12 (horizontal:vertical)
179		3			Design wood piles such that they are below the water table, and do not specify creosote for protection of piles from environmental deterioration
180		4			Design the foundation for the soil variations within the site. Consider the soil classifications outlined in Section 1926.650 of the Code of Federal Regulations
181		5			Take heave into account when location the piles
182		43	**Landings**	Stairway and ladder landings should be designed to prevent falls and obstructions during ascent and descent	
183		1			Design and schedule the layout of stairway and ladder landings to be constructed as part of structure's foundation system
184		44	**Structural Members**	All structural members should be designed to withstand construction loading, and to minimize the safety hazards associated with erecting and working around the members	
185		1			Design the structural members to withsatand all anticipated construction

				loading during fabrication, storage erection, and final connection
186	2			Design member depth to allow adequate head room clearance around stairs, platforms, valves, and all areas of egress
187	3			Minimize the amount of overhead work
188	4			Design members which are of consistent size, light weight, and easy to handle
189	45	**Column**	Connection points for lifeline and guardrail attachment which are welded or connected to columns by the constructor can break off, and also protrude into working areas	
190			Column splice connections which are located at or just below the floor level can present safety hazards for construction workers	
191	1			Design columns with holes at 21 & 42 inches above the floor level to provide support locations for lifelines and guardrails
192	2			Locate column splices between 2 & 3 feet above the finished floor level, and at two stories intervals
193	46	**Beam**	Traditional beam to column horizontal framing requires manipulating numerous components that can easily be dropped, provide minimal support for workers, or collapse	
194	1			In order to allow sufficient walking surface use a minimum beam widthof 6 inches
195	2			Consider alternative steel framing systems which reduce the number of elements and where beams are landed on supports rather than suspended between them
196	3			Minimize the use of contilevers
197	4			Design premeter beams and beams above floor openings to support lifelines (minimum dead load of 5400 lbs). Design connection points along the beams for the life lines. Note on the contract drawings which beams are designed to support life lines, how many life lines, and at what locations along the beams
198	50	**Wall**	Wall surrounding elevated automobile traffic surfaces which only rise to the height of the traffic surface can be hazardous for construction workers operating motor vehicles	
199			Confined and congested work areas below masonry walls can lead to workers being struck by falling bricks or masonry tools	
200	1			Design perimeter walls to rise above the automobile traffic surface in order to provide a curb before permanent wheelstops and guardrails are placed
201	2			Allow for a large, unobstructed, open area (limited access zone) below masonry walls to minimize the risk of workers being struck by falling objects. See Section 1926.750 of the Code of Federal Regulations
202	51	**Connection A**	The design of structural steel framing connections can greatly affect the fall hazards associated with constructing the connections	
203	1			Consider the erection process when designing and locating member connections
204	2			Design beam-to-column double-connections to have full support for the beams during the connection process
205	3			Avoid steel beams of common depth connecting into the column web at the same location
206	4			Avoid pin-hole or bolted connections on beams and columns to creat proper alignment and stability immediately after placement of the members
207	5			For bolted beam connections, provide an extra "dummy" hole in which a spud wrench or other object can be inserted to provide continual support for the beam during installation of the bolts.
208	52	**Connection A**	Complicated or non-standard connections can lead to confusion and mis-installation of bolts, screws, or nails, and collapse of the structural members	

Connection A

Project Component: Structural Framing

209			1		Use a single size, or a minimum number of sizes possible, of bolts, nails, and screws. If more than one size is required, specify sizes which vary greatly and are easily distinguishable
210			2		Use a minimum of two bolts, nails, or screws per connection
211	53	**Concrete**		The manipulation and erection of reinforcing steel and formwork for reinforced concrete structural members can be hazardous to construction workers	
212			1		Prohibit forming work by hand if wind speed exceeds 30 mph
213			2		Design concrete members to be of similar size and regularly spaced to facilitate the use, and re-use of pre-fabricated forms. Consider using shotcrete instead of poured concrete
214			3		Use a metal deck and concrete fill rather than a slab that requires temporary formwork
215			4		Use small sized rebar for framing members at elevated floor levels. Design the rebar such that it can be assembeled on the ground and erected in large sections
216			5		Use a single or multiple curtain(s) of welded wire mesh for reinforced concrete walls and columns to allow placement of the reinforcing in large sections rather than many small pieces
217	54	**Masonry**		Construction workers can sustain injuries due to repeated lifting of masonry blocks which are heavy, odd-sizad, or irrgularly shaped	
218			1		Minimize the size and weight of mansonry blocks
219			2		Use manosnry blocks of consistent size and shape
220			3		On large masonry blocks provide cast-in handles or handholds for easy lifting
221			4		Consider other materials such as precast concrete or light weight, stick or modular components
222	55	Steel		Structural steel erection operations can lead to collapse if adequate support is not provided for the members before permanent connection	
223				Welding operations can creat fire hazards due to excessive slag or sparks, and also expose construcion workers to toxic fumes	
224	Linked to 1		1		Limit lift heights of steel erection
225			2		Design connections to be welded in the shop rather than in the field
226			3		Eliminate field welding of steel with a galvanized coating
227			4		Ensure that the welding procedures specified are compatible with the materials being welded
228			5		Consider alternative steel framing systems which reduce the number of elements and where beams are landed on supports rather than suspended between them
229	56	**Wood**		Complicated or non-standard wood connections can lead to confusion and mis-installation of member bollets, screws, or nails, and colapse of the structural members	
230			1		Consider using prefabricated metal timber fasterners for wood connections instead of end nailing or toe nailing
231	57	**Post-tensioning**		Concrete post-tensioning operations can be hazardous to construction workers if a jack, cable, or fitting fails during tensioning	

232		1		Align or locate post-tensioning cables such that if failure of a jack, or fitting occures during tensioning, the cable is not directed towards an active work area
233	58	**Pre-fabricated**	Prefabricated members which are similar in size and shape can be easily mixed up and incorrectly placed, leeding to collapse hazards	
234			Without adequate connection locations for lifeline, construction workers are at risk of falling during elevatd work	
235		1		Design prefabricated members to be of one size and shape, or easily distinguishable different sizes
236		2		For precast concrete members, provide inserts or other devices to attach fall protection lines
237	59	**Elevated Work**	Work at elevated levels or on the exterior of a structure puts construction workers at risk of falling and being struck by falling objects	
238		1		Design special attachments or holes in members at elevated work areas to provide permanent stable connections for supports, life lines, guardrails, and scaffolding
239		2		Design holes in the webs of beams above piping for attachments of supports and lifelines
240		3		Use light precast materials and attachments for elevated exterior work areas
241		4		use prefabricated members for work over water, railways, roads, etc.
242	60	**Existing Structure**	When welding near or cutting into existing structures, connection workers are at risk of injury due to fire or collapse of the existing structure	
243		1		When working on or near existing structures, consider using bolted rather than welded connections to minimize the fire hazards
244	Linked to 7	2		Require the constructor to locate and mark the existing reinforcing steel prior to cutting into existing reinforced concrete members
245	61	**Fire Hazards**	Structure which contain or are constructed of combustible materials can be fire hazards during the construction phase	
246		1		Provide adequate fire protection on all structural framing
247		2		Limit the spread of fire by the use of fire walls, parapets, fire stops, deluge systems, etc.
248	62	**Slab on Grade**	A stable base around the structure must be provided to prevent overturning or collapse of temporary scaffolding and ladders	
249		1		Design and schedule slab-on-grade, side walks, roadways, and other flatwork around elevated structures to be constructed as early as possible and available for use by construction workers
250	63	**Floors A**	Many floor features can present trippling and obstruction hazards for construction workers during the construction phase	
251		1		Design the finished floor around mechanical equipment to be at one level (no steps, block outs, slab depressions, etc.)
252		2		Keep steps, curbs, blockouts, slab depressions, and other tripping hazards away from window opennings, exterior edges, and floor openings
253		3		Design the covers over stumps, outlet boxes, drains, etc. to be flush with the finished floor
254		4		Route pipes at least 30 inches above the finished floor level

Projet Component: Slan-on-Grade, Floor, Roof

255		5			keep all equipment and related hardware on a pad above the finished floor
256	64		**Floor B**	Inadequate floor finishes, coverings, or drainage can put construction workers at risk of slipping	
257		1			Provide non-slip walking surfaces on floor adjacent to open weather or exposed to the weather
258		2			Route piping drains and overflow outlets to trench drains
259		3			Route pump seal water in a manner to avoid wet surfaces around the equipment
260		4			Locate drains away from walkways, work areas, and the structure perimeter
261	65		**Floors C**	Floor openings can be hazardous to construction workers if they are numerous, in or adjacent to passageways, or not adequately guarded	
262		1			Group floor openings together to create one larger opening rather than many smaller openings
263		2			For access doors through floor, use doors which immediately provide guarded entry around the hole perimeter when the door is open
264		3			Locate floor openings away from passageways, work areas, and the structure perimeter
265		4			Provide permanent guardrails around floor openings
266		5			Eliminate tripping hazards around floor openings
267	66		**Floors D**	Construction materials, equipment, and formwork can overload existing and new floors, and lead to collapse of the structure or fall hazards during their manipulation and installation	
268	Linked to 7	1			Prohibit metal decking or formwork by hand if wind speed exceeds 30 mph
269		2			Note on the contract drawings the existing and new floor design loads to aid the constructor in determining material stockpile locations and heavy equipment maneuverability
270		3			For elevated floors, use permanent metal formed deck with concrete fill rather than a concrete slab which requires temporary formwork
271		4			Do not design Split-level floors
272	67		**Floors E**	The design of post-tensioned and conventional steel reinforcement for floor slabs can create hazards for construction workers	
273		1			Align post-tensioning cables such that if failure of a jack, cable, or fitting occures during tensioning, the cable is not directed towards an active work area
274	Linked to 8	2			Use welded wire mesh for slab reinforcing to allow placement of the steel in large sections rather than many small pieces
275	Linked to 6	3			Design the top layer of floor slabreinforcing to be spaced at no more than 6 inches on center each way to provide a stable, continuous walking surface before placement of the concrete
276	68		**Roof A**	Roof openings can create fall hazards for construction workers if they are numerous or not adequately guarded	
277		1			Locate roof openings away from the edge of the structure
278	Linked to 1	2			Group roof openings together to create one larger opening rather than

				many smaller openings
279	Linked to 1	3		Provide permanent guardrails around roof openings
280	Linked to 1	4		Eliminate tripping hazards around roof openings
281		5		Locate rooftop mechanical/HVAC equipment away from roof openings
282	69 **Roof B**		Short parapets and steep roofs increase the chance of construction worker falling off of the roof during construction and future roof maintenance	
283		1		Design the parapet to be 42 inches tall. A parapet of this height will provide immediate guardrail protection and eliminate the need to construct a guardrail during construction or future roof maintenance
284		2		Minimize the roof pitch to reduce the chance of workers slipping off of the roof
285		3		Provide a guardrail around roof accesses and roof work areas
286	70 **Roof C**		Inadequate or no connection points for fall restraint systems on the roof increases the chance construction workers falling off of the roof	
287			Stairways, ramps, and walkways which are uncovered and exposed to the weather can create fall hazards due to the buildup of moss or ice	
288		1		Install belaying bolts on pitched roofs for workers to connect fall restraint systems.
289		2		Design-in a means of attaching a railing and safety lines for roofing operations
290		3		Design and schedule eye-bolts or othr connections used for window maintenance so that they can be constructed as early as possible and used during construction
291		4		Provide a covering or extend the roof line over exterior stairs, ramps, and walkways
292	71 **Skylights**		Unprotected or poorly located skylights can present fall hazards for workers during construction and during future roof maintenance	
293		1		Provide permanent guarrails around skylights
294		2		Design domed, rathr than flat skylights with shatterproof glass or odd strengthening wires
295		3		Locate skylights on flat areas of the roof and away from the roof edges
296		4		Locate rooftop mechanical/HVAC equipment away from skylights
297		5		place skylights on a raised curb
298	72 **Controls**		Mechanical/HVAC controls can creat safety hazards for construction workers if they protrude into passageways, or are head to operate, hidden, or inaccessible	
299	Linked to 6	1		Position equipment controls and control panels away from passageways and work areas
300		2		Indicate on the contract drawings the location of equipment shut-off valves and switched for existing utilities. Allow the constructor access to these locations for emergency situations
301	Linked to 6	3		Place electrical circuit breaker boxes in sight of the equipment which they affect

302			4		Provide early marked and identified emergency controls and displays
303			5		Allow adequate access to equipment controls for ease of operation
304	73	**Valves**		Valve location and operation can lead to safety hazards for construction workers during the construction and initial startup phases	
305			1		Locate valves such that they can be operated easily, or so that a standard type of operating device can be installed. Consider using remote valve operators
306			2		Provide remotly operated valves or valves with extension handles when valves are located near hazardous materials or in confined spaces
307			3		Provide a safety valve on the discharge of positive displacement type air compressors and multi-stage centrifugal compressors to avoid over-pressurization in case the discharge valves is closed
308			4		Provide reliefe valves for heat exchangers and chiller refrigerant
309	74	**Piping**		Piping element which are not designed with consideration of the connecting mechanical and HVAC units can lead to safety hazards during construction and initial startup phases	
310			1		Provide purging cycles and special interlocks for all gas and oil-fired equipment
311			2		Ensure that the shut-off head on all pumps is compatible with the associated piping
312			3		Design piping systems which feed tanks, chests, and large walk-in type equipment to prevent inadvertant system activation (LO/TO procedures)
313			4		Ensure that safety relief valves exhaust and drain away from passageways and work areas
314	75	**Equipment Cooling**		Inadequate cooling and ventilation of electrical equipment can lead to fire hazards during the construction phase	
315			1		Ensure that all electrical equipment is adequately cooled and ventilated
316	76	**Electrical/ Grounding**		Adequate electrical protection and grounding of equipment is essential to prevent electrical shock hazard	
317			1		Ensure that all equipment is grounded and protected against lighting
318			2		Isolate all live conductors and equipment from accidental contact
319			3		Ensure an adequate interrupting rating to protect all equipment
320	77	**Equipment Supports**		Mechanical and HVAC systems and their support which are not designed to withstand all anticipated construction loading present collapse and fall hazards to construction workers	
321			1		Design overhead equipment and their supports to hold up the weight of a construction worker
322			2		Specify the material hoist or crane loading capacity to be clearly stenciled onto the hoist or crane beams or rails
323	78	**Equipment Location**		The location of mechanical and HVAC systems within a project can lead to fall, ergonomic, and other safety hazards for construction workers	
324	Linked to 7		1		Minimize the amount of overhead work

Project Component: Mechanical/HVAC

325		2			Locate underground equipment in an area easily accessible for excavation. Allow sufficient area around the excavation for stockpiling the soil
326	Linked to 1	3			Locate rooftop mechanical/HVAC equipment away from the structure's edge and skylights
327		4			Ensure that equipment located in a hazardous area meets the requirements for the area's hazard classification
328		79	**Work Area A**	An enclosed or congested work area surronding mechanical and HVAC equipment can affect the safety of workers during installation and maintenance of the equipment	
329		1			Do not locate mechanical equipment in or directly adjacent to passageways
330		2			Provide a clear, unobstructed, spacious, area around all permanent equipment. See Section 1926.403 of the Code of Federal Regulations for working clearances
331		3			Ensure that all equipment enclosures meet hazardous location classification requirements
332		4			Do not place machinery breathing equipment, oxygen sensor, refrigerant sensor, or refrigerant/fuel burning equipment in the same space unless a clean air source is povided.
333	replication	80	**Work Area B**	The floor area and support structure surronding mechanical and HVAC systems can create safety hazard during placement of the equipment and work around the equipment	
334		1			Keep the finished floor around mechanical and HVAC aquipment free of steps, blockouts, etc.
335		2			Place all equipment and related hardware on an elevated housekeeping pad above the finished floor level
336		3			Locate lifting eyes, hoist, or crane above quipment to aid the installation and maintenance of the equipment
337		4			Minimize the number of wires, cables, and hoses laid on walking surfaces. Use elevated cable trays or hose supports
338		81	**Work Area C**	Work areas without adequate protection from equipment noise, electrical shock, or moving parts are hazardous for construction workers	
339		1			Specify mechanical and HVAC equipment which does not reduce high noise levels while operating. See Section 1926.52 of the Code of Federal Regulations for acceptable noise levels
340		2			Provide guards around equipment to protect workers from moving parts
341		3			Provide guards around fan inlets/outlets and exhaust parts
342		4			Provide signs, lights, alarms, etc. as necessary to ensure safety near exposed equipment
343		5			Provide smoke detectors or insulation around equipment susceptible to fire
344		82	**Equipment Materials**	Mechanical and HVAC systems which are not constructed of matrials adequate for the expected construction environment and loading create safety hazards for construction workers	
345		1			Design all mechanical equipment and HVAC components to meet the anticipated material, corrosion, and loading requirements of the construction site
346		83	**Ventilating Equipment**	Adequate ventilation for construction workers during the construction phase is essential for a safe work environment	
347		1			Design ventilating and lighting fixtures in a mechanical room and confined space to be operated by the same switch

348				2		Provide ventilation systems in mechanical rooms and confined spaces which are temprature, oxygen depletion, or refrigerant controlled
349				3		Design and schedule ventilation and illumination in stair shafts to be operable during construction
350				4		Provide ventilation systems around fueled equipment operating indoors
351		84	**Erection**		The erection or placement operations required for mechanical and HVAC systems can create safety hazards for construction workers	
352				1		Design and schedule new air conditioning and ventilating systems to be in use as early as possible in the construction phase
353				2		Minimize the need for special or complicated equipment installation operations
354				3		Design and schedule equipment to be painted and/or insulated prior to erection or installation
355				4		Schedule new ventilating systems to be in use in areas in which painting or other coating will be applied, prior to their application
356		85	**Testing**		Sufficient testing of mechanical and HVAC systems is essential to eliminate safetyhazards due to failure of the systems	
357				1		Require systems, components, and welds to be tested to ensure they meet minimum requirements. Types of testing to consider: hydrostatic, rediographic, ultrasonic, magnaflux, weld sectioning, dye penetrant, halogen mass spectrometer, etc.
358				2		Design for safety against possible equipment failures, such as desuperheated, control valve, or component failure
359		86	**Existing Structure**		Working with and connecting to existing mechanical and HVAC systems present safety hazards for construction workers	
360				1		Design and schedule safe tie-ins to existing utilities
361		87	**Controls A**		Electrical instrumrntation controls can create safety hazards for construction workers if they protrude into passageways, or are hard to operate, hidden, or inaccessible	
362	Linked to 6			1		Position controls and control panels away from passageways and work areas
363				2		Indicate on the contract drawings the location of existing equipment and electrical shut-off switches. Allow the constructor access to these locations for emergency situations.
364				3		Include the name, address, and tlephone number of the local electrical power supply company on the contract drawings for quick refrence in emergency situations
365		88	**Controls B**		A lack of safety alarms, switches and component identification can lead to safety hazards for construction worker in emergency situation	
366				1		Provide safety switches, pull cords, alarm, etc. which are clearly displayed standardized, and easily identifiable
367				2		Provide disconnection switches which are readily accessible
368				3		Review from a safety aspect the possible misuse of the electrical/ instrumentation control systems
369				4		Ensure that all electrical circuits are sufficiently identified throughout their length
370		89	**Grounding**		Electrical systems must be adequately grounded to prevent electrical shock of construction workers	
371				1		Ensure that all equipment is adequately grounded and protected against

					lighting
372		2			Provide grounding circuits to all 480 volt lighting fixtures
373		3			Ensure that all the withstand rating is adequate for the avilable fault current
374		4			Ensure that the interrupting rating is adequate to protect all equipment
375		90	**Location A**	Locating electrical/instrumentation systems overhead can creat fall, electrical shock, and other safety hazards for construction workers	
376		1			Route cable trays above pipe lines to minimize the chance of electrical shock due to leacking pipes
377		2			Minimize the amount of overhead work
378		3			Do not place overhead wiring close to windows or equipment. Locate overhead lines to minimize contact
379		91	**Location B**	Electrical and instrumentation system enclosures and surroundings can affect the safety of construction workers	
380		1			Provide electrical/instrumentation system enclosures which are adequate for the expected environmental/ climate conditions
381		2			Ensure that electrical/ instrumentation systems located in hazardous areas meet the hazard classification requirement
382		3			Isolate live conductors from accidental contact
383		4			Prohibit access near hoist and crane electrification components
384		92	**Location C**	Inadequate design of electrical and instrumentation system cooling and fire protection can affect the safety of construction workers	
385		1			Ensure that electrical/instrumentation componenets are adequately cooled
386		2			Design electronic, electrical, and control rooms which are designated to be fire protected by Halon systems to be interlocked with their respective HVAC system
387		3			Route main cable runs to avoid potential fire hazard areas
388		93	**Location D**	The location of electrical/instrumentation components throughout a project can affect the safety of construction workers	
389		1			Design and schedule lighting systems to be provided in enclosed stair shafts as early as possible in the construction phase
390		2			Provide adequate access to all electrical/ instrumentation components in control, electrical, and electronic rooms
391	Linked to 1	3			Do not locate electrical/ instrumentation components under pipes carrying liquids or in other areas where water is present
392		4			Minimize the number of wires, cables, and hoses laid on walking surfaces. Use elevated cable trays or hose supports
393		94	**Electrical Materials**	Without knowledge of the nature of each existing electrical wire, construction workers are at risk of electrical shock	
394		1			Specify that all electrical and instrumentation wiring is to be color coded to comply with N.E.C design requirements

Project Component: El

ectrical/Instrumentation

395		95 **Erection**	The erection schedule and sequence can affect the safety of construction workers	
396		1		In structures with tall stories, design and schedule the lighting systems to be erected with the structural steel
397		2		Schedule telephone lines to be installed and in-use early in the design phase. Locate telephones in remote buildings, process areas, and on the site perimeter
398		3		Design and schedule the electrical systems to be constructed early and allow the constructor to tie into it for use during construction
399		4		Provide permanent electrical outlets on the roof to allow for easy tie-in during construction and future roof maintenance
400		96 **Underground Lines A**	new and existing below-grade power lines present hazards for excavation, pile driving, and drilling operations	
401		1		Locate underground lines in areas easily accesible for excavation. Allow sufficient area around the excavations for stockpiling the soil
402	Linked to 3	2		When new electrical lines are to be placed below existing concrete surfaces, roads, or other traffic areas, design the lines to be placed using trenchless technologies
403	Linked to 2	3		Note on the contract drawings the level of certainty and source of information on the location of existing underground powerlines
404	Linked to 2	4		Mark on the contract drawings a clear zone around existing underground power lines
405		97 **Underground Lines B**	Underground power lines which are in service during construction present an electrical shock hazard to construction workers	
406	Linked to 8	1		Require the constructor to locate, or 'pothole', for underground lines before work begins
407	Linked to 3	2		Specify hand excavation when near existing underground lines
408		3		Encase new underground lines in concrete which is colored red
409		4		Require a brightly colored warning tape to be placed along underground lines approximately 12 inches above the lines
410	Linked to 4	5		Disconnect the power lines before construction begins
411		98 **Overhead Power Lines**	Overhead power lines which are in service during construction are hazardous when operating cranes and other tall equipment	
412	Linked to 4	1		Disconnec the power lines, or decrease the voltage before the construction begins
413		2		Bury the powerlines below grade, or re-route the lines around the project site, before construction begins
414	Linked to 5	3		Clearly mark the power lines with warning flags, and note their location on the drawings
415		4		Allow adequate clearance between the power lines and the structure. See Section 1926.950 of the Code of Federal Regulation for minimum clearance
416		5		Do not locate power lines adjacent to constructor material storage areas
417		99 **Equipment**	The design of electrical systems for mechanical rooms and equipment can lead to safety hazards for construction workers	

418	Linked to 1	1			Design the ventilation systems and lighting fixtures in a mechanical room to be operated by the same switch
419	Linked to 1	2			Place the electrical circuit breaker boxes in sight of the mechanical equipment they affect
420		3			Provide fire stops where cable trays penetrate floors and walls
421		100	**Testing**	Sufficient testing of electrical and instrumentation systems is essential to eliminate safety hazards due to failure of the systems	
422		1			Require systems, components, and welds to be tested to ensure they meet minimum requirements. Types of testing to consider: hydrostatic, rediographic, ultrasonic, magnaflux, weld sectioning, dye penetrant, halogen mass spectrometer, etc.
423	Linked to 1	2			Design for safety against possible equipment failures, such as desuperheated, control valve, or component failure
424		3			Design all systems components to prevent inadvertent system activation
425		4			Ensure that the electrical system design meets all N.E.C. requirements and the requirements of N.F.P.A. for the protection of electronic computer/ data processing equipment
426		101	**Existing Structure**	Working with and connecting to existing electrical and instrumentation systems present safety hazards for construction workers	
427		1			Design and schedule safe tie-ins to existing utilities
428		102	**Pipes A**	The design of piping materials and welds, and the identification of piping contents, can affect the safety of construction workers	
429		1			Check that foreign piping materials and welds, and the identification of piping contents, can affect the safety of construction workers
430		2			Color code the pipes to easily identify their contents
431		3			Show the pipe content flow dirction on the contract drawings so that the first valve upstream of an emergency can be easily located
432		4			Avoid interior welds in large pipes and tanks, and ensure that welding conditions are appropriate for the type of pipe material, e.g. alloy piping systems requiring PWHT/ preheat
433		5			Specify the use of hose racks for all areas requiring hoses
434		103	**Pipes B**	Piping systems which do not meet design code regulations and which are not designed for the appropriate construction conditions create safety hazards for construction workers	
435		1			Design piping system components to meet all national, state, and local building code requirements
436		2			Do not make direct cross connections between drinking water or utility systems and plant or process streams
437		3			Design trap discharge piping for the pressure of the piping system being trapped unless protected by vents or reliefe valves
438		4			Minimize pockets in piping systems. Trap all pockets
439		5			Minimize flanges in piping under high pressure, or which contain explosive or lethal gases
440		104	**Pipes C**	Inadequate consideration of the entire piping system design can lead to safety hazards for construction workers	

441			1		Provide adequate safety measures in the event of possible equipment failure.
442			2		Design adequate protection against over-pressure for all piping equipment
443			3		Locate explosive or lethal gas lines outside of buildings, or in areas properly ventilated. Use all-welded construction to reduce chances of a leak
444			4		Design all impoundments for liquids to provide a means or facility to accommodate emergancy bypass conditions
445			5		Design pipe materials to be chamically resistant to the fluids the system is designed to carry
446	105	**Controls/ Valves A**		The design of piping controls and valves can lead to safety hazards for construction workers	
447			1		A bypass around a reducing valve should not have greater capacity than the reducing valve unless the piping is adequately protected by reliefe valves or meets the requirements of the higher pressure system
448			2		Provide proper protection to prevent injury or damage caused by escaping fluid from relief or safety valves if vented to the atmosphere
449			3		Prevent "water hammer" by providing air vents, surge valves, surge chambers, or delayed or timed valves operation
450	Linked to 6		4		Position controls away from passageways and work areas
451	106 Linked to 1	**Controls/ Valves B**		The design of piping controls and valves can lead to safety hazards for construction workers	
452			1		Locate valve controls so that handles can be reached easily, or so that a standard type operating device can be installed
453			2		Indicate on the control drawings the location of shut-off valves and switches for existing systems. Allow and provide access by the constructor to the locations
454			3		Ensure that control valve specifications meet the piping specifications for body rating, body material (corrosion and hazardous services), and flange type
455			4		Size control valveswith consideration of noise level
456			5		Provide a tag or other positive ID for the appropriate pressure, temperature, etc. on all valves
457	107 Linked to 1	**Controls/ Valves C**		The desin of piping controls and valves can lead to safety hazards for construction workers	
458			1		Direct safety relief valve exhausts away from passageways and work areas
459			2		Consider rupture disks as a safety device either in conjunction with or as a substitute for safety valves, or to act as an explosion door on vessels and piping subject to explosions
460			3		Check safety relief valves against the piping process to determine if the valves are required to be A.S.M.E. code stamped
461			4		Provide relief valves between each pair of sectionalizing valves on lines containing liquids and subject to being both isolated and heated, such as heat exchangers, liquefied gas piping, etc.
462			5		Use a globe or throttle valve on a bypass
463	108 Linked to 1	**Piping Location**		The location of piping components throughout a project can affect the safety of construction workers	
464	Linked to 1		1		Route piping lines below electrical/ instrumentation cable trays to

Project Component: Piping

					prevent the chance of electrical shock due to leaking pipes
465	Linked to 7	2			Minimize the amount of overhad work
466	Linked to 1	3			Locate piping lines which are under very high presuure or contain explosive or lethal gases on the outside of buildings or in areas properly ventilated and guarded
467		4			Do not locate piping in rooms containing high voltage equipment, bare wires, or bus bars
468		5			Route piping to avoid "head knockers" (6'-6" min above grade) and tripping hazards
469		109	**Piping Supports**	A lack of sufficient support for piping systems can create collapse and fall hazards for construction workers	
470		1			Provide fall restraint cables along the length of overhead piping runs
471	Linked to 1	2			Design overhead piping and supports to hold up a worker
472		3			Provide for thermal expansion of the piping by adding pipe bends, offsets, etc.
473		4			Design steam lines with drips or freeblows to prevent "steam hammer" or "slugging"
474		5			Design cross connections between low and high pressure systems with one or more of the following valves: double valves (both to have high pressure rating), high pressure chack valve, normally open vent valve between double valves, or a relief valve on low pressure system
475		110	**Drains**	Drains can create tripping and slipping hazards for construction workers	
476		1			Design covers over sumps and drains to be flush with the floor level
477		2			Design area drains to be trapped or valved shut to avoid the spread of fire in case of a raptured pipe
478		3			Route piping drains and overflows to trench drains so that floors remain dry
479		4			Route pump seal water in a manner to avoid slipping, e.g. case drains/ base plates to hubs
480		111	**Underground Lines A**	New and existing below-grade piping lines present hazard during excavation, pile driving, and drilling operations	
481		1			Locate underground lines in areas easily accessible for excavation. Allow sufficient area around the excavations for stockpiling and transporting soil
482		2			When new piping lines are to be placed below existing concrete surfaces, roads, or other traffic areas, design the lines so that they may be placed using trenchless technologies
483		3			Note on the contract drawings the level of certainty and source of information on the location and size of existing underground lines
484		4			On the contract drawings, mark a clear zone around existing underground lines
485		5			Require hand excavation when near existing underground utilities
486		112	**Underground Lines B**	Existing underground lines which are in service during construction present safety hazards for construction workers	
487		1			Protect underground lines from crushing by use of sleeves or slabs, or by providing guard posts to prevent travel over them

488	2			Provide over-sized pipe sleeves around lines under railroad tracks and highways to avoid damage to the tracks or roadbed in case of leak
489	3			Encase new underground lines in red concrete
490	4			Require a brightly colored warning tape to be placed along underground lines approximately 12 inches above the lines
491	5			Provide anchor or tie-downs for piping with push-type joints or other mechanical joints
492	113	**Fire Hazards**	The schedules construction of new fire water systems, or demolition of existing systems, can lead to fire hazards on the construction project	
493	1			For taller buildings, design and schedule the fire water systems to be installed early in the construction phase
494	2			Design and schedule an underground fire water systems to be constructed throughout the project site before construction begins
495	3			Minimize downtime periods of existing automatic sprinkler systems
496	114	**Hazardous Fluilds**	Piping system which contain hazardous fluids can present safety hazards for construction workers	
497	1			Design piping which carries hazardous fluids to have a double lock-nut capacity. Allow for a pressure bleed on trapped hazardous fluids, especially steam and condensate bypasses
498	2			Eliminate drainage of slippery and dangerous chemicals into passageways and work areas
499	3			Avoid routing dangerous fluids over equipment, control boards, aisles, and operator areas to avoid injury in case of a pipe leak
500	115	**Erection**	Applying paint or insulation to elevated piping systems can lead to fall hazards for construction workers	
501			Large pipe sections which lack adequate connection points for lifting, and lack restraint from rolling, can create safety hazards for workers during lifting and placing operations	
502	1			Design and schedule piping materials to be painted and/ or insulated prior to erection or installation
503	2			Design large pipe sections to be ovel or have one flatten portion to prevent rolling
504	3			Design in connection points on piping sections for lifting operations. Consider designing the connection points such that after pipe installation they can be used to connect the pipe sections
505	116	**Testing**	Piping material and system performance testing is essential to eliminate construction site safety hazards	
506	1			Require performance testing of the piping system, components, and welds using such tests as hydrostatic, radiographic, ultrasonic, magnaflux, weld sectioning, dye penetrant, etc.
507	2			Require a stress analysis to be perfprmed on applicable systems
508	3			Ensure that the shut-off head on all pumps is consistent with the associated piping
509	4			Design piping systems which feed tanks, chests, and large walk-in type equipment to prevent inadvertent system activation
510	117	**Existing Structure**	Working with and connecting to existing piping systems present safety hazards for construction workers	

511	Project Component: Tank, Vessel	1			Design and schedule safe tie-ins to existing utilities. Ensure that the tie-ins is appropriate for the piping contents and system. (stopple/hot top/cold cut, rubber plug and weld flange/unbolt)
512		2			Use bolted rather than welded connections when working around existing flammable structures
513		3			Minimize the need for "hot work" permits by providing adequate buffer from existing piping systems
514		118	**Hazardous Conditions**	Tanks can present confined space, toxic substance, fire, and explosion hazards for construction workers	
515		1			Avoid interior welds in tanks. Provide ventilation in the tank if interior welds are required
516		2			Provide vents and overflow or reliefe devices to avoid over-pressurization, and to avoid creating sufficient vacuum to cause the tank to collapse
517		3			Provide dikes around storage tanks which contain hazardous substances. Use a slab rather than HDPE liner for the leak detection (LD) system on the bottom of large storage tanks
518		4			Provide traps or valves on process sewers and area drains to avoid the spread of fire in case of raptured tank
519		5			Ensure that tanks and vessels meet all local, state, and federal design code requirements
520		119	**Tank Stairs**	The design of stairs for large tanks and vessels can lead to fall hazards for construction workers	
521		1			Coordinate the layout of tank stair landings with tank foundation design to prevent tripping hazards
522		2			Design circumferential stairs around tanks to ascend clockwise
523		120	**Tank Entrances**	Without adequate entrances and ventilation, tanks and vessels can create confined space hazards	
524		1			Locate permanent atmosphere testing devices and forced air ventilation equipment at entrances to tanks and vessels
525		2			provide connection points adjacent tank and vessel entrances for attachment of a lifeline or safety harness
526		3			Provide at least two access ports for tanks and vessels to aid access/ egress and ventilation
527		4			Provide for a door to be installed in floating roofs for large vessels. Design and schdule the door to be installed prior to erection of the roof
528		121	**Underground Tanks**	Underground tanks and vessels which are not adequtely protected can be safety hazards for construction workers	
529		1			Protect underground tanks and vessels against crushing by use of sleeves, concrete slabs, or by providing guard posts to prevent travel over them
530		122	**Tank Erection**	The erection and/or placement process used for tanks and vessels can lead to safety hazards for construction workers	
531		1			Fabricate tank roofs at grade and lift them into place as one assembly
532		2			Complete interior welds on tank walls before erecting the roof
533		3			Provide a guadrail along the perimeter of the tank roof

Project Component: Door, Window

534		4			Provide connection points for lifelines at center of the tank roof
535		123	**Doors**	Doors which open into passageways and work areas can strike other workers, and also limit the width of the passage or work area when open	
536		1			Design doors to swing away from passageways and platforms when opened
537		2			Design doors to swing open in the direction of exit travel
538		3			Instead of regular swinging doors, use sliding or bi-folddoors, or doors with window panels
539		4			Clearly mark interior glass doors to prevent workers from mistakenly trying to walk through the doors when closed
540		5			Design and schedule doors to be installed late in the construction phase
541		124	**Doors B**	The design of door hardware and the structure surrounding doors can lead to safety hazards for construction workers	
542		1			Select door hardware that can keep doors in an open position without props or blocking
543		2			Eliminate tripping hazards around doors
544	Linked to 3	3			Design and schedule new fire doors to be hung as early as possible in the construction phase. In demolition projects, keep existing fire doors in place as long as possible
545		4			Provide door protection such that natural elements (snow, wind, lightning) will not cause unsafe conditions
546		125	**Windows**	Prior to installation of upper story windows, low sill heights add to the chance of falling through the window openings	
547		1			Design window sills to be 42 inches minimum above the floor level. Window sills at this height will act as guardrails during construction
548		2			Design window sills at a consistent level throughout the project
549		3			provide inserts in window jambs for guardrail attachment
550	Linked to 2	4			Clearly mark interior glass windows to prevent workers from mistakenly trying to walk through the windows
551		126	**Skylights**	Skylights present falling hazards during roof construction and future maintenance operations	
552	Linked to 1	1			Design a permanent guardrail that surrounds each skylight
553	Linkedto 1	2			Design domed rather than flat, shylights with shatterproof glass or add strengthening wire
554	Linked to 1	3			Locate skylights away from rooftop mechanical/HVAC equipment
555	Linked to 1	4			Place skylights on a raised curb
556		127	**Access Doors**	Access doors in floors and roofs present fall hazards when no guardrails are used around the doors when they are opened	
557		1			Use access doors which automatically provide a guarded opening when

Project Component: Walkway, Platform

					the doors are opened
558		128	**Environment/ Climate**	Environmental/climate conditions can create slipping hazards for construction workers walking or working on exterior walkways and platforms	
559		1			Protect exterior walkways and platforms from the weather by providing a covering, extending the roofline, or locating them on the sheltered side of the structure
560	Linked to 6	2			Locate exterior walkways and platforms away from the north side of the structure to prevent the buildup of moss and ice due to lack of sun
561		3			Provide a minimum amount of slope on exterior walkways and platforms to prevent puddling
562		4			Provide a non-slip walking surface on walkways and platforms adjacent open water or exposed to the weather
563		129	**Access**	Limited access to elevated walkways and platforms can prohibit timely response and efficient maneuverability into and out of the areas in emergency situations	
564		1			Provide multiple means of access to elevated walkways and platforms which can be used during emergency situations
565		130	**Materials**	Walkways and platforms of steel construction can lead to electrical shock hazards and slipping hazards for construction workers	
566		1			Design walkways and platforms to be constructed of non-conductive materials, such as concrete, wood, or plastic
567		2			Use serrated grating, instead of checkered steel plate for walking surfaces to prevent slipping hazards
568		131	**Stairs A**	A lack of consistent stairway slopes and stair dimensions throughout a project can lead to construction workers tripping or falling due to unanticipated stairway layouts	
569		1			Maintain a uniform stair slope throughout the project
570		2			Use consistent tread and riser dimensions throughout the stairway run and the project
571		132	**Stairs B**	Inadequate, misplaced, or obstructed stairway landings can lead to falls when stepping onto or off of a stairway	
572	Linked to 2	1			Coordinate the layout of exterior stair landings with the foundation design to provide a smooth, clear landing area free of tripping hazards
573		2			Avoid stair landings constructed separate from the stairs
574		3			Provide a minimum 2'-6" x 2'-6" landing area
575		4			Build stair landings up above an uneven grade
576		133	**Stair C**	Stairway materials should be selected with consideration of the anticipated construction work area and surrounding environmental conditions to minimize deterioration of the stairways and the possibility of falling	
577	Linked to 2	1			Use perforated steel or steel grating for stair treads on exterior stairways to prevent slipping when there is a need to "see through" the stairs in tight, congested work area
578		2			Consider using prefabricated stairways which can be erected as one assembly
579		3			Use steel or concrete instead of wood for stairways in areas where welding or other potntial fire sources are present
580	Linked to 2	4			Use wood, concrete, or other nonconductive materials instead of steel for stairways in areas where electrical work will be performed

581		134	**Stair D**	Exposed or tightly compacted stairways can create climbing problems for construction workers carrying materials or equipment and lead to falls	
582	Linked to 6	1			Design exterior stairs to be directly adjacent and parallel, rather than perpendicular to the structure
583		2			Design circumferential stairways to ascend clockwise
584	Linked to 6	3			In areas which receive snow, place exterior stairways on the sheltered side of the structure, or under a covering, overhang, or extended roofline
585	Linked to 6	4			Place exterior stairs on the sunny side of the structure to prevent the buildup of moss or ice
586		5			Avoid using spiral stairways. If spiral stairways are used, provide a handrail to prevent stepping on areas where the tread is less than 6 inches
587		135	**Stair E**	Stairways with inadequate or non-existent handrails or stairrails can create fall hazards for construction workers	
588		1			Provide a handrail or stairrail along each unprotected edge, and when the gap between the stairway and the structure is greater than 6 inches
589		2			Provide at least one handrail or stairrail along stairways with 4 or more risers, or which rise more than 30 inches in height, whichever is less
590		136	**Stairs F**	To get to elevated work areas prior to erection of permanent stairways, construction workers must use temporary stairs, ladders, or manlifts which are often unusable, inadequately designed, or damaged	
591		1			Design nad schedule permanent stairways to be built as soon as possible in the construction phase and used by the construction workers
592		137	**Ladders A**	The orientation and design of ladders with respect to the structure can create fal hazards for construction workers	
593		1			Design laddrs to be vertical, or not exceeding 15 degrees foreward, and straight throughout their length
594		2			Orient ladders such that the person faces the structure while climbing
595		3			Provide safety gates at the top of walk through and side access ladders
596		4			provide a ladder cage or barrier on the back side of ladders that can be inadvertently climbed on the back side
597		138	**Ladders B**	Inadequate landings and ladder design at the top and bottom of ladders can create fall hazards	
598	Linked to 2	1			Provide a minimum 2'-6" x 2'-6" landing area at the top and bottom of ladders. Coordinate the layout of the landings with the structure design to eliminate tripping hazards
599		2			Design the step-across distance between the center of the step/rung and the nearest edge of a landing to be between 7 & 12 inches. Provide a landing platform if more than 12 inches
600		3			For through-ladder extensions, omit step/rungs within the extension. Flare the extension side rails to provide between 24 and 30 inches clearance between the side rails
601		4			Design the side rials of through or side-step ladders to extend at least 42 inches above the top level or landing platform
602		139	**Ladders C**	Ladder step or rung size, spacing, and materials can make ladders awkward to climb or slippery and create fall hazards for construction workers	
603		1			Design ladder steps/rungs to be spaced between 10 & 12 inches apart, parallel, level, and uniformly spaced throughout the ladder

Project Component: Stairs, Ladder, Ramp

604		2		Locate the first step/rung between 6 and 12 inches above the bottom landing, and the top step/rung at the level of the top landing
605		3		Design ladder steps/rungs to be corrugated, knurled, dimpled, coated with skid-resistant material, ortreated to minimize slipping. Do not coat wood ladders with an opaque material
606		4		Design the ladder steps/rungs of individual step/rung ladders to be shaped to prevent slippig off the end of the steps/rungs
607	140	**Ladders D**	Inadequately designed ladder cages can create obstructions or snag construction worker clothing or equipment while climbing, and lead to construction worker faling	
608		1		Design horzontal bands to be fastened to the side rails of rail ladders, or directly to the structure for individual-rung ladders
609		2		Design vertical bars to be on the inside of the horizontal bands and fastened to them
610		3		Design horizontal bands to be spaced at intervals not more than 4 ft. apart between centrelines
611		4		Design vertical bars to be spaced at intervals not more than 9.5 in. apart between centrelines
612		5		Keep the inside of the cage clear of projections
613	141	**Ladders E**	Ladder cages can create fall hazards for construction workers if they are too small, too large, or do not provide protection along the entire length of the ladder	
614		1		Design cages to extend at least 27 inches, but not more than 30 inches, from the centerline of the step or rung, and not less than 27 inches wide
615		2		Design the botton of the cage to be between 7 and 8 feet above the point of access to the bottom of the ladder. Flare the bottom of the cage not lass than 4 inches between the bottom horizontal band and the next higher band
616	Linked to 2	3		Design the top edge of the cage to be a minimum of 42 inches above the top of the platform, or the point of access at the top of the laddr
617	142	**Laddrs F**	Ladder length can affect a construction worker's risk of falling if the laddeers are long and do not provide a rest area, or if they do not extend above the top landing	
618		1		Provide ladder cages, wells, or other safety devices where the length of climb is less than 24 feet but the top of the ladder is at a distance greater than 24 feet above lower levels
619		2		If the total length of a climb equals or exceeds 24 feet, provide a cage or well, and multiple ladder sections, each section not to exceed 50 feet. Offset each ladder section from adjacent sections, and provide landing platforms at intervals of 50 feet maximum
620		3		Design individual step/rung ladders to extend at least 42 in. above an access level or landing platform either by the continuation of the rung spacing as horizontal grab bars or by providing vertical grab bars that have the same lateral spacing as the vertical legs of the ladder rails
621	143	**Ladders G**	Ladders which have attachments or other objects adjacent to the climbing area can obstruct workers during climbing and create fall hazard	
622		1		Design ladders to prevent injury from punctures or lacerations, and prevent snagging of cloting
623		2		provide a minimum perpendiculare clearance of 7 inches between ladder rungs, cleats, or steps, and any obstruction behind the ladder, except that the clearance for elevator pit ladders may be not less than 4.5 inches
624		3		Provide a minimum perpendiculare clearance of 30 inches between the centerline of ladder rungs, cleats, or steps, and any obstruction on the climbing side of the ladder. If obstructions are unavoidable, clearance may be reduced to 24 inches provided a deflection device is installed to guide workers around the obstruction
625	144	**Ladders H**	Ladder which are not designed to withstand construction loading can collapse and lead to construction workers falling	
626		1		Design ladders to be capable of supporting at least two loads of 250 lbs. each concentrated between any two consecutive attachments

627			2		Design each step or rung to be capable of supporting a laod of at leas 250 lbs. applied in the middle of the step pr rung
628			3		Design ladders for any anticipated loads caused by ice builup, wind, rigging, and impact loads resulting from the use of ladder safety devices
629	145	**Ladders I**		Inadequate spacing of ladders with respect to other ladders and objects can limmit the climbing area and create fall hazards for constructon workers	
630			1		Provide a minimum clear distance of 16 inches between the sides of individual step/rung ladders, and between the side rails of adjacent laddrs
631			2		Provide ladder cages or well around ladders which have greater than 15 inches clear width to the nearest permanent object on each side of the centerline of the ladder
632			3		Avoid designing manhole covers, doors, or other objects which swing into the climber's access space at the foot or head of the ladder
633	146	**Ladders J**		Ladder wells can create fall hazards for construction workers if the wells are too small, too large, or do nto provide unobstructed protection along the entire length of the ladder	
634			1		Design the well to completely encircle to ladder
635			2		Design the inside face of the well on the climbing side of the ladder to extend between 27 and 30 inches from the centerline of the step/rung
636			3		Design the inside width of the well to be at least 30 inches
637			4		Design the bottom of the well above the point of access to the bottom of the ladder to be between 7 and 8 feet
638			5		Keep the inside of the well clear of projections
639	147	**ladders K**		Frequent use of ladders by construction and maintenance workers to move material and equipment increases the possibility of falling from ladders	
640			1		Consider stairs in lieu of ladder when the ladder will be used frequently to move material and equipment
641	148	**Ramps**		Ramps which do not contain any slip resistance measure or are subject to water, snow, or ice can be falling hazards for construction workers	
642			1		provide a non-slip surface treatment on ramps to help prevent slipping
643			2		Prevent cleats on steel or wood ramps, or create grooves on concrete ramps, to help prevent slipping
644	Linked to 2		3		In areas which receive snow, provide a covering, overhang, or extend the roofline over exterior ramps
645			4		Use a maximum ramp slope of 7 degrees
646	149	**Railing Dimensions**		Handrail, guardrail, and stairrail dimensions can affect the safety of construction workers	
647			1		When the top edge of a stairrail system also serve as a handrail, the height of the top edge should be between 36 & 37 in from the upper surface of the stairrail to the surface of the stair
648			2		Design the height of handrails to be between 30 & 37 inches from the upper surface of the handrail to the surface of the tread
649			3		Design intermediate vertical members on stairrails and guardrails to be at most 19 inches apart
650	150			Inadequately designed handrails, quardrails, and stairrails can lead to obstruction	

Project Component: Handrail, Guardrail

		Railing Design A	and fall hazards for construction workers	
651		1		Mount the toprail on top of the posts, rather than on side of the posts
652		2		Provide a minimum clearance of 1-1/2 inches along the top and sides of the toprail
653		3		Do not attach equipment of other objects to the toprails
654		4		Connect railing members by welding rather than bolts
655		5		Design joints and railing ends to be rounded and smooth
656	151	**Railig Design B**	Handrails, guardrails, and stairrails which are not designed for construction loading and work site conditions can create safety hazards for construction workers	
657		1		Design handrails and top rails of a stairrail system to withstand at least 200 lbs. applied within 2 in. of the top edge of the top edge in any downward or outward direction, at any point along the top edge
658		2		Provide continuous toeboards along the length of guardrails
659		3		Use a uniform railing height throughout the project
660	152	**Materials**	The selection of handrail, guardrail, and stairrail materials can affect the safety of construction workers	
661		1		Use steel instead of wood for railings in areas where welding or other potential fire sources are present
662		2		Use wood, concrete or other non-conductive material instead of steel for railings in areas where electrical work will be performed
663	153	**Erection**	Stairs and elevated walkways and platforms can lead to falls during construction before handrails, guardrails, and stairrails are erected	
664		1		Design and schedule handrails, guardrails, and stairrails to be erected as part of the structural steel erection
665	154	**Cabinets**	Cabinet, cupboard, and locker handles which project into work areas and passageways create obstruction hazards for construction workers	
666		1		Provide recessed handles and other cabinet, cupboard, and locker hardware which do not project into work areas and passageways
667	155	**Lighting**	The design and erection sequence of lighting systems can affect the safety of construction workers	
668		1		Design and schedule lighting systems to be erected with structural framing
669	156	**Ceilings**	Inadequate design of ceiling systems and their supports can lead to safety hazards for construction workers	
670		1		Design ceiling hangers and connections to support anticipated construction live loads including the weight of a worker
671		2		Minimize the complexity of construction of ceiling systems
672		3		Provide permanent catwalks or work platforms for ceiling installation and maintenance on tall, long span structures
673	157		The design and erection sequence of permanent signs can create obstruction and	

Row	Project Component	No.	Topic	Hazard	Item	Design Suggestion
			Signs	other safety hazards for construction workers		
674					1	Design signs with rounded or blunt corners, free of sharp edges, burrs, splinters, and other sharp projections. Orient fasteners so that they do not constitute a safety hazard
675					2	Design and schedule traffic and emergency signs for erection early in the construction phase
676	**Project Component: Furnishings, Finishes**				3	Design signs to be integral parts of walls and floors using color, tiles, or floor coverings
677					4	Ensure proper position and location of warning signs to clearly alert workers of hazards
678		158	**Warning Devices**	Inadequate safety warning devices and signs can lead to safety hazards for construction workers		
679					1	Ensure that warning signs, controls and alarms are standardized throughout the project
680					2	Ensure that hazardous areas are identified, classified, and provided with adequate boundaries
681					3	provide signs, lights, alarms, etc. to ensure safety near dangerous equipment or areas
682					4	Provide warning signs which describe the allowable floor loading
683					5	Provide emergency showers and eye-wash basins in areas where personnel might come in contact with highly toxic or poisonous materials
684		159	**Coatings**	The selection of coating materials can affect the safety and health of construction workers		
685					1	Specify high solids, and no, or low, V.O.C. coating systems
686		160	**Elevated Work**	Work performed overhead and at elevated levels presents fall, ergonomic and other safety hazards for construction workers		
687					1	Minimize the amount of overhead work
688					2	Use smaller, light weight, materials and equipment for elevated work
689		161	**Erection**	The erection sequence or placement procedures for furnishings and finishes can affect the safety of construction workers		
690					1	Design and schedule materials and equipment to be painted and/or insulated prior to erection or placement
701		164	**Project Layout**	The layout of a project can lead to safety hazards for construction workers by crearting congestion and limiting access to the site		
702					1	Locate project control points away from areas of high construction and public traffic
703					2	Allow room for temporary roadways to be constructed for use by emergency vehicles
704					3	Require at least two formal, controlled intersections at access points to the site
705					4	Provide road access into large, deep excavation such as wastewater treatment ponds and underground garages
706						

Project Component: Earthwork, Sewer, Etc.

707		170 **Embarkments**		Embarkments which are unstable or very close to the work area can lead the congestion and falling object hazards for construction workers	
708			1		Require rock fences to be erected on embarkements early in the construction phase to amother any falling rocks
709			2		Provide an initial earthwork bench at the level of the work area to allow sufficient room for construction equipment and materials
710			3		Design-in regularly spaced benches on embarkments to stop loose rock from falling down to the work site
711		171 **Excavation A**		Excavaion can present cave-in hazards for construction workers	
712			1		Design the project such that the cut and cover method can be used for excavation rather than tunneling
713			2		Minimize the amount of excavations required in backfilled or other loose soil, and where there are variations from railroads, highway traffic, or large machines
714	Linked to 2		3		Provide road access into large, deep axcavations such as wastewater treatment ponds or underground garages
715			4		Provide a seal slab or walls in excavations where the soil is saturated or likely to flood the excavation before backfilling
716		172 **Excavation B**		Trench excavation for underground utilities can lead to cave-in hazards for construction workers	
717	Linked to 3		1		Allow for the placement of underground utilities using trenchless technologies rather than the cut and cover
718			2		Avoid requiring trenchless in previously backfilled or disturbed soil, or which cross between different types or condition of soil
719			3		Avoid designing utilities which cross under existing pipelines, run parallel to immediately adjacent existing pipelines, or intersect manhole excavations
720		173 **Sewers A**		Inadequate sewer coverings and bypasses can create safety hazards for construction workers	
721			1		Design open drainage pipes from storm sewer to allow for easy access to and removal of debris
722			2		Design sewer gratings such that the openings are not easily plugged by debris, but not too large that a worker's foot will go through
723			3		Cover open drainage routes in high foot traffic areas to prevent tripping hazards
724			4		Design all equipments or holding ponds with emergency bypass capabilities
725			5		Ensure that all accessways and amnholes are provided with venting or non-venting lids appropriate to the service and traffic location
726		174 **Sewers B**		Sewer systems which are not designed for the surrounding conditions and the liquids they will carry, can be safety hazards for construction workers	
727			1		Ensure that all open sewer embarkments are designed for adequate stability under anticipated worksite conditions
728			2		Provide sewers with adequate accessways to allow for inspection and maintenance operations
729			3		Ensure that sewer lines are suitable for the maximum temprature service conditions

730		4		Provide adequate clearance between process/sanitary sewers and any adjacent or crossing portable waterlines
731		5		Design process/effluent sewer systems to vent any gases to the outside of all buildings or other project work areas
732	175	**Underground Utilities**	Existing underground utilities create safety hazards for construction workers during excavation and pile driving operations	
733		1		Require the constructor to locate, or "pothole", existing underground utilities before excavation operations begin
734	Linked to 3	2		Require hand excavation when near existing underground utilities
735	176	**Slopes**	Earthwork performance on sites which are steeply sloped can be hazardous for construction workers operating heavy equipment	
736		1		Orient the project layout or grade the site accordingly to minimize the amount of work on steep slopes
737		**Safety Plans**	A lack of safety planning for the construction phase can lead to increased risk for construction workers	
738		1		Prepare, or require submittal of an erosion control plan

Appendix B

CHAIR 1 - STUDY GUIDEWORDS - GENERIC

CARD NUMBER	GUIDEWORD	SUB-PROMPTS	CARD NUMBER	GUIDEWORD	SUB-PROMPTS
Chair 1. Generic 2	SIZE	Too large Too small Too long Too short Too wide Too narrow	Chair 1. Generic 7	LOAD / FORCE	High / Excess Low insufficient Additional loads (construction) Dynamics Temporary Weakness
Chair 1. Generic 3	HEIGHTS / DEPTHS	Working at heights Falls / struck by falling objects Scaffolding (shape, space to fit) Confined space Access / egress	Chair 1. Generic 8	ENERGY	Low / high energy Tension / compression Potential / kinetic Inertia / moment
Chair 1. Generic 4	POSITION / LOCATION	Too high Too low Too far Misaligned Wrong position	Chair 1. Generic 9	TIMING	Too late, too early Too short, too long Incorrect sequence Extended delays
Chair 1. Generic 5	POOR ERGONOMICS	Posture / manual handling RSI / discomfort / fatigue / stress Entry / exit points Effect on PPE Visibility (lighting slightlines) Slips, trips, falls	Chair 1. Generic 10	EGRESS / ACCESS	No. of exit points, Emergency egress, size Obstructions, lighting External Impacts Maintenance People and Equipment Movements
Chair 1. Generic 6	MOVEMENT / DIRECTION	Stability Compression Physical damage Vibration Friction / slip Rotation Upwards / Downwards Reverse Expansion / Tension Rollover	Chair 1. Generic 11	MAINTENANCE / REPAIR	Posture / Manual Handling Size / Width Access / Egress Heights / Dropped Objects Weight Discomfort / Stress / PPE Visibility / Slips / Trips Rotating Equipment Other

SUMMARY - CHAIR 1 - STUDY GUIDEWORDS – OVERVIEW

CARD NUMBER	GUIDEWORD	SUB-PROMPTS	CARD NUMBER	GUIDEWORD	SUB-PROMPTS
Chair 1. Overview 2	ENVIRONMENTAL CONDITIONS	Extreme Weather Temperature Ground Noise Water	Chair 1. Overview 9	SAFETY EQUIPMENT	Personnel Protection Safety Showers Barriers / Guards
Chair 1. Overview 3	EXTERNAL SAFETY INTERFACES	Members of the public Traffic Adjacent Property Power / services External fire / plans High Winds Day / night / weekend	Chair 1. Overview 10	NATURAL HAZARDS	Earthquake Flooding Thunderstorm (lightning protection)
Chair 1. Overview 4	TOXICITY	Lead / Asbestos Handling Precautions Ventilation	Chair 1. Overview 11	INSPECTION / TESTING	Eliminating Isolation Access
Chair 1. Overview 5	FIRE / EXPLOSION	Prevention / detection Fire protection Emergency procedures	Chair 1. Overview 12	DEMOLITION	Ease Issues Documentation
Chair 1. Overview 6	ENVIRONMENTAL IMPACT	Vapour / dust Effluent / Noise Seepage / Waste	Chair 1. Overview 13	DOCUMENTATION	Operations Maintenance Inspection /Testing Sequence Emergency Records / Reports
Chair 1. Overview 7	UTILITIES & SERVICES	Lighting Air / Water Fuel / Electricity Oxygen / Water	Chair 1. Overview 14	QUALITY CONTROL	Inspection / Testing Quality Assurance
Chair 1. Overview 8	COMMISSION / STARTUP / SHUTDOWN	Requirements Sequence	Chair 1. Overview 15	CONSTRUCTION EQUIPMENT	Sequence Timing, Access

CHAIR-2 - STUDY GUIDEWORDS
Construction Based Guidewords

CARD NUMBER	GUIDEWORD	SUB-PROMPTS	CARD NUMBER	GUIDEWORD	SUB-PROMPTS
CHAIR 2.2	ELIMINATE	Falls (of people) Falling material / objects Stepping on or striking against objects Caught or trapped Lifting and carrying over exertion Asphyxiation / drowning Machinery Electricity Transport / mobile plant Toxicity, Fires and Explosions	CHAIR 2.5	AVOID	Construction/Lifting Sequence Timing / Locations Temporary Instability Access / Egress Delays / Confined Space Erection / Dismantling Heat / Cold / Noise
CHAIR 2.3	SUBSTITUTE	Falls (of people) Falling material / objects Stepping on or striking against objects Caught or trapped Lifting and carrying over exertion Asphyxiation / drowning Machinery Electricity Transport / mobile plant Toxicity, Fires and Explosions	CHAIR 2.6	OTHER ISSUES?	Modification Isolation / engineering Controls Personnel Protective Equipment Alter / rearrange Increase / reduce Simplify /Improve
CHAIR 2.4	COMBINE	Construction / Lifting Sequence Timing Locations			

CHAIR-3 WORKSHEET

DETAILED MAINTENANCE / REPAIR SAFETY IN DETAILED DESIGN (CHAIR-3) STUDY				**Reference:**
System:	**Sub-System:**	**Item/Component:**		
Maintainability Aspect	**Assessment**	**(Good, Fair, Poor, N/A) and WHY**	**Recommendation/Comment**	**Who/Date**
POSTURE / MANUAL HANDLING				
ACCESS / EGRESS				
HEIGHTS / DROPPED OBJECTS				
WEIGHT				
DISCOMFORT / STRESS				
PERSONNEL PROT. EQUIPMENT				
VISIBILITY				
SLIPS, TRIPS, FALLS				
ROTATING / MOVING EQUIPMENT				
IS REPAIR DIFFERENT?				
OTHERS THAT MAY APPLY (list below)				