Fall hazard prevention system in an early design stage with BIM

A flowchart for implementing IFC

Dustin Bolte

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Author: Dustin Bolte
Student number: 0770539
Email: bolte.dustin@gmail.com
Graduation program: Construction Management and Engineering

Graduation Committee:

Prof.dr.ir. B.(Bauke) de Vries
University supervisor (chairman graduation committee)

Ir. A. (Aant) van der Zee
University first supervisor

Ir. L.I.H. (Luuk) Wijnholts
University second supervisor

Company supervisors (Strukton Worksphere):

Ing. J. (Jeroen) Mackaij
BIM Manager Strukton Worksphere (External Supervisor)

Ir. M. (Michiel) Klep
Project leader Strukton Worksphere

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Preface

It is with great pleasure that I would like to present this thesis as graduation project for the master Construction Management and Engineering. The research in this thesis is conducted in collaboration with the Eindhoven University of Technology and Strukton Worksphere. The results of the thesis is a product of the feedback sessions with my supervisors from the university and from Strukton Worksphere. And I would like to thank them for that. I would like to thank Aant van der Zee for being my first supervisor. The two weekly feedback session helped in giving direction to the project. Also I would like to thank Bauke de Vries and Luuk Wijnholts for participating in the graduation committee. From Strukton Worksphere I would like to thank Jeroen Mackaij for being the supervisor within the company. Feedback sessions with Jeroen gave me more insight in the practical part of BIM. I also would like to thanks Michiel Klep as first point of contact in Son. Doing my research within Strukton was a informative experience. The work environment was good and it made me work more efficient.

As last I would like to thank Maxime and my family for their support throughout my entire study. Under family also falls the friend I made within Meteoor and Senaat 59. Without them I would not have been able to come to this point.

I hope that this research helps making the construction site a saver work environment. Taking on a combination of the topics BIM and safety gave me an interesting view on a sensitive topic in the construction industry. It certainly convinced me that the transition towards the BIM working method is the way to go for the construction industry.

I hope you will enjoy reading this thesis as much as I had conducting the research.

Dustin Bolte

February 2019

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Summary

This thesis is part of the graduation project of the Master program Construction Management and Engineering at the Eindhoven University of Technology. The aim of this thesis is to develop a fall prevention system during the construction phase of a building project. The system uses the Building Information Management (BIM) working method. The research question is:

"How should a BIM related system work to help prevent fall hazards in an early design phase?"

For the research to be structured, the research is divided into four sub-questions. 1) Where in the project lifecycle should the system be implemented? 2) What are the safety rules and regulations towards fall hazards? 3) What are the requirements for the data representation? 4) What are the requirements to the building model? The research is done according to the waterfall development model. This is a well-known methodology within software development.

Firstly, a literature study was conducted. This analyses the status of safety on the construction site and what kind of research has already been done towards safety on the construction site. Construction sites are one of the most dangerous working environments in the world. Fall related accidents are one of the most common accidents worldwide. BIM has a different meaning. In this research the meaning of Building Information Management is taken for BIM. This focuses on building information: the (re) use and management of data through the entire life cycle of the construction project. Within BIM there are different levels of detail. The further in the process, the higher this level of detail. Depending on which information is available per level and what information is required for the system, it is possible to determine at which stage the system can be implemented. For this system, implementation will take place in the 'design development' phase. To work with BIM it is important that we all speak the same language. To accomplish this a designer should use the Dutch Basic Information delivery Manual (ILS or IDM). For a number of years BuildingSmart has been working on an open standard for the entire AEC sector. These Industry Foundation Classes (IFC) can be exported from a CAD program. A Model View Definition is required for this. This is a kind of filter that only extracts the necessary information from the model. IFC4 is the latest version of IFC and therefore used for this research. The combination of BIM and safety has been investigated before. For example, there are applications for VR and AR, but also the possibilities of rule-based-checking have been investigated. This research is used as a basis for this research.

The current research starts with defining four different standard situations that can lead to a fall hazard. Situation 1 is defined as an edge of a roof or floor slab without adjacent floor slabs and without a wall. Situation 2 is defined as a floor slab without adjacent floor slabs with a wall. Situation 3 is defined as an opening in a floor without walls around it. When there are walls around the opening, it is referred to situation 2. Situation 4 is defined as the roof. In the Netherlands, the safety rules are determined by Dutch law and the ARBO. The ARBO says that because every situation in the construction industry is different and construction workers go to work every day in a different situation, it is difficult to make every situation waterproof with safety rules. It is therefore important to think for yourself about what is safe. Different necessary safety ruels are determined for well-defined stand situations If the ARBO or the Dutch law has not included a situation, a solution will be sought with the help of the QHSE department of Strukton Worksphere, based on their experience. Here, rules are set that determine what dimensions building elements may have to be safe.

This makes it known which building elements are important for the system. Within the digital world there are agreements about solid modelling. A geometry can be created in different ways: B-reps, CSG and Sweeping volumes. With a topological and geometric approach, requirements are made on how a building element should be modelled. The requirements are: An opening must be defined as a separate element; A geometry of a building element must be defined as that specific element; A list of coordinates must be available per element; The topological relationship must be defined from a building element; And a building element must be modelled as a B-rep. These requirements are already partially met with the IFC 4. The requirements that are not met will be recommendations for a next version of the IFC. The MVD required for this system is the Design Transfer View (DTV).

Because some of the requirements have not yet been met, there is shown how building elements are now being modelled in the data file. It is possible that there are several walls on the edge of a floor slab. To find all these cases, a poly line is drawn around the edges of a floor slab. Where this meets a wall an extra vertex is placed. The line can now be divided into pieces with and without a wall on it. As the pieces of line run through the system, it acquires a coding based on true-false questions. This coding represents a specific situation to which solutions can be referred.

There are also preconditions for how a building must be modelled in order to use the fall hazard prevention system. 1) the Basic IDM must be used. 2) The export must be performed with the IFC4 DTV. 3) Always model building elements as standard case versions. 4) A building element is always on one building storey. 5) Only use flat roofs.

Then the steps of the flowchart are presented. To prove that the system actually works, a test case is also being carried out. Based on the output generated by the system, a safety manager can do his work more efficiently. It is important to realize that due to the factor of time there is not always one specific solution to the fall hazard. Therefore, it is necessary to offer the user of the system a choice with possible solutions. The coding of the piece of line will therefore refer to a number of solutions and give one preference. Here the user is free to choose which one. From the chosen solutions a list can be made with what has to be ordered for fall prevention material. Which material depends on the company from which the material is ordered.

Samenvatting

Deze thesis is onderdeel van het afstudeertraject van het masterprogramma Construction Management and Engineering van de Technische Universiteit Eindhoven. Het doel van deze thesis is het ontwikkelen van een valpreventie systeem voor tijdens de constructiefase van een bouwproject. Het systeem maakt gebruik van bouw informatie management (BIM) werkmodel. De onderzoeksvraag is:

"Hoe moet een op BIM gebaseerd valpreventie systeem werken om val gevaar te vinden in een vroege ontwerpfase?"

Om het onderzoek gestructureerd te laten verlopen is het onderzoek verdeelt in vier sub vragen. 1) Op welk moment in het project moet het systeem worden geïmplementeerd? 2) Wat zijn de veiligheidsregels omtrent valgevaar? 3) Wat zijn de eisen aan de data representatie? 4) Wat zijn de eisen aan het bouw informatie model? Het onderzoek wordt gedaan volgens de waterval ontwikkelingsmodel. Dit is een bekende methodologie binnen de software ontwikkeling.

Als eerste wordt er een literatuur studie gedaan. Hierin wordt geanalyseerd wat de status is van veiligheid op de bouwplaats en wat voor onderzoek er richting veiligheid op de bouwplaats al is gedaan. De bouwplaats is een van de meeste gevaarlijkste werkomgeving in de wereld. Val gerelateerde ongelukken zijn een van de meest voorkomende ongelukken wereldwijd. BIM heeft voor vele in de bouwsector een verschillende betekenis. In dit onderzoek wordt de betekenis van Building Information Management genomen voor BIM. Hierin staat bouwwerk informatie centraal: het (her)gebruik en beheer van data door de hele levenscyclus van het bouwproject. Binnen BIM zijn er verschillende niveaus van detail, de informatie die het model bevat. Hoe verder in het proces hoe hoger dit niveau van detail. Op basis van welke informatie er beschikbaar is per niveau en welke informatie nodig is voor het systeem, kan er worden bepaald in welke fase het systeem kan worden geïmplementeerd. Voor het systeem ontwikkeld in dit onderzoek is dat tijdens de 'Design Development' fase. Voor het werken met BIM is het belangrijk dat we allemaal dezelfde taal spreken. Daarom moeten ontwerpers zich houden aan de Nederlandse Basis Informatie levering specificaties (ILS of IDM). Sinds een aantal jaren is BuildingSmart bezig met een open standard voor de hele Architecture- Engineering- and Construction (AEC) sector. Deze Industry Foundation Classes (IFC) kunnen worden geëxporteerd vanuit een CAD-programma. Hiervoor is een Model View Definitie (MVD) nodig. Dit is een soort filter die alleen de nodige informatie uit het model haalt. IFC4 is de nieuwste versie van IFC. Voor dit onderzoek wordt deze laatste versie dan ook gebruikt. De combinatie van BIM en veiligheid is al vaker onderzocht. Er zijn toepassingen voor Virtual Reality (VR) en Augumented Reality (AR), rule-based-checking onderzocht. Deze onderzoeken worden als basis gebruik voor deze thesis.

Dit onderzoek begint bij het definiëren van vier verschillende standaard situaties die tot val gevaar kunnen leiden. Situatie 1 is gedefinieerd als een rand van een dak of vloerplaat zonder aanliggende vloerplaten en zonder muur. Situatie 2 is gedefinieerd als een vloerplaat zonder aanliggende vloerplaten met een muur. Situatie 3 is gedefinieerd als een gat in een vloer zonder muren er omheen. Wanneer er muren rondom het gat staan wordt er verwezen naar situatie 2. Situatie 4 is gedefinieerd als het dak. In Nederland worden de veiligheidsregels bepaalt door de Nederlandse Wet en de Arbowet. De Arbowet zegt dat omdat elke situatie in de bouw weer anders is en bouwpersoneel elke dag in een andere situatie aan het werk zijn. Hierdoor is het moeilijk elke situatie waterdicht te maken met veiligheidsregels. Het is daarom

van belang om zelf na te denken over of de situatie veilig is. Vanuit de verschillende standaard situaties worden de benodigde veiligheidsregels bepaald. Wanneer de Arbowet of de Nederlandse Wet een situatie niet heeft opgenomen wordt er met behulp van de QHSE afdeling van Strukton Worksphere, op basis van ervaring, een oplossing gezocht. Hieruit worden regels gesteld die bepalen welke afmetingen gebouwelementen mogen hebben om een situatie veilig te maken.

Hierdoor is het bekent welke bebouwelementen van belang zijn voor het systeem. Binnen de digitale wereld zijn er afspraken over solid modelling gemaakt door de Internationale Organisatie voor Standaardisatie (ISO). Een geometrie kan worden gemaakt op verschillende manieren: B-reps, CSG en Sweeping volumes. Met behulp van een topologische en geometrische benadering, worden eisen gesteld aan hoe een gebouwelement het beste en efficiënts moet worden gemodelleerd voor het systeem. De eisen zijn: Een opening moet worden gedefinieerd als een apart element; Een geometrie van een gebouwelement moet zijn gedefinieerd als dat specifieke element; Er moet een lijst met coördinaten beschikbaar zijn per element; De topologische relatie moet zijn gedefinieerd van een gebouwelement; En een gebouwelement moet worden gemodelleerd als een B-rep. Deze eisen worden al deels voldaan met de IFC 4. De eisen waaraan niet wordt voldaan, worden aanbevelingen voor een volgende versie van de IFC. De MVD welke nodig is voor dit systeem aan de hand van deze eisen is de Design Transfer View (DTV).

Omdat er nog niet aan sommige bovenstaande eisen wordt voldaan, wordt zichtbaar hoe gebouwelementen in de huidige omstandigheden worden gemodelleerd in de data file. Het is mogelijk dat er verschillende muren op de rand van een vloerplaat staan. Om deze muren te herkennen wordt er een poly lijn getekend rondom de randen van een vloerplaat. Wanneer deze poly lijn een muur tegenkomt wordt een extra vertex geplaatst. De lijn kan nu worden onderverdeelt in stukken lijn met en zonder een muur erop. Nadat de stukken lijn door het systeem is gelopen krijgt het een codering op basis van waar-onwaar-vragen. Deze codering staat voor een specifieke situatie waaraan oplossingen kunnen worden gehangen.

Daarnaast zijn er randvoorwaarden aan de modellering van een gebouw om gebruik te kunnen maken van het valpreventie systeem. 1) de Basis ILS moet worden gebruikt. 2) Het exporteren moet worden gedaan met de IFC4 DTV. 3) Modeleer gebouwelementen altijd als standardcase versies. 4) Een gebouwelement staat altijd maar op één verdiepingsvloer. 5) Gebruik alleen maar platte daken.

Vervolgens worden de stappen van de flowchart gepresenteerd. Ter bewijsvoering dat het systeem ook daadwerkelijk werkt wordt er ook nog een testcase uitgevoerd. Op basis van de output die wordt gegenereerd door het systeem kan een veiligheidsmanager zijn werk efficiënter uitvoeren. Het is belangrijk om te beseffen dat door de factortijd er niet altijd één specifieke oplossing is voor het valgevaar. Daarom is het nodig om de gebruiker van het systeem een keuze aan te bieden met mogelijke oplossingen. De codering van het lijn stuk zal dus verwijzen naar een aantal oplossingen en er één de voorkeur geven. Hierin is de gebruiker vrij om te kiezen. Vanuit de gekozen oplossingen kan er een lijst worden gemaakt met de benodigde materialen voor valpreventie. Welk materiaal is afhankelijk van het bedrijf waar het materiaal vandaan wordt gehaald.

Abstract

The construction industry has one of the highest rate of work related injuries worldwide. Fall hazards account for most of these injuries. The objective of this thesis is to develop a flowchart for a fall hazard prevention system that is used in the BIM method to identify fall hazards using IFC. The fall hazard prevention system is designed to be implemented before construction is started. The methodology used in this thesis is the waterfall development model which is a well-known method in software development. The research defines 4 standard situations for fall hazards: an edge of a slab with no walls; an edge with walls; an opening in a slab; and the roof. The safety rules are based on the dimensions of the building elements like slabs and walls. With a topological and geometrical approach requirements to the data representation are given for the most effective method to run such an analysing tool. After the requirements are set, the requirements are compared with the IFC 4 schema. The first requirement: openings used must be modelled as a separate element, is satisfied. The second requirement: a geometry of a building element must be defined as that specific element, is satisfied. The third requirement: a list of coordinates must be available per element, is possible but not how it is currently used. The fourth requirement: the topological relationship must be defined from a building element, is possible but not how it is currently used. The last requirement: a building element must be modelled as a B-rep, is possible but not how it is currently used. With these requirement there is determined that the IFC4 needs to be exported with the Design Tranfer View model view definition. The thesis discusses the different steps in the flowchart and set requirements to the BIModel. A testcase is conducted to prove the flowchart can find fall hazards and give the right prevention method.

The flowchart can be further developed in multiple directions. Such as implementing the flowchart in a programming language. Or implementing more shape representations. The results serve as a step up towards the development of fall prevention systems using IFC.

Keywords: Safety management, Construction site, BIM, Fall prevention

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List of Abbreviations

BIM	Building Information Management
IFC	Industry Foundation Classes
AEC	Architecture, Engineering and Construction
NEA	National Survey Working conditions
CBS	Centraal Bureau voor de Statstieken
WIA	Labour Capacity Act
BIModel	Building Information Model
BIR	Building Information Council
BCF	BIM Collaboration Format
IDM	Information Delivery Manual
MVD	Model View Definition
RV	Reference View
DTV	Design Transfer View
LOD	Level Of Detail
QHSE	Quality, Health & Safety and Environment
VGA	Safety health & environment plan
VR	Virtual Reality
AR	Augmented Reality
GIS	Geographic Information System
PTD	Prevention Through Design
CAD	Computer Aided Design

1. Introduction

1.1. Problem definition / objective of the thesis

When working on a construction site, safety is one of the important issues to consider. Working safely and following the rules makes sure you and your colleagues can return to your families each day. So, it should be the responsibility of management to provide the tools and methods to make sure the construction site is as safe as possible for the construction workers. But, the construction industry suffers from an enormous amount of work related (fatal) injuries. These injuries have negative effects on both workers and construction companies. This includes physical, psychological and financial effects. At the top of the list of these accidents stands fall related accidents, which account for most of these injuries. Fall related accidents can occur when safety measures are not taken, simply forgotten or failing to identify fall hazards in the first place. It is not only in The Netherlands that fall hazards are a problem. Construction companies all over the world struggle with fall related accidents. Despite the size of this problem, construction companies in The Netherlands still fail to resolve this problem.

In the past decade, the technology and the development of a universal data model has increased. This is called Building Information Management (BIM). It is becoming common practice to use BIM as a method for the project lifecycle of a building. As projects become more complex and detailed it is harder to ensure the quality, time schedule and costs of a project within the margins. This is where BIM can be the solution to these problems. As more and more data is uploaded into the BIM, more advanced analyses can be perforemed to make the work more efficient. Despite all the benefits of BIM the transition towards a completely BIM-based method is still a long way off for most construction companies in the Netherlands.

Using the data in the BIM can provide changes for Health & Safety management on the construction site. Before construction starts a Health & Safety analysis can be conducted with a 3-dimensional model. Fall hazards can be detected and prevention methods designed. Although this sounds an ideal situation, there is no successful fall hazard prevention system developed or available in the Dutch construction industry. In other countries several researchers have developed their version of a safety tool for BIM. But no one has yet developed a fall hazard prevention system which uses the industry standards for data exchange, the Industry Foundation Classes (IFC).

The objective of this thesis is to develop a flowchart for a fall hazard prevention system that is used in the BIM method to identify fall hazards using IFC. The fall hazard prevention system is designed to be implemented before construction is started. With this objective it is advisable to make the building site a safer work environment for all construction workers all over the world. And allow them to return safely to their families after a hard days work.

1.2. Research questions

To reach the objective of this thesis research towards safety, BIM and the data representation is needed. Based on the defined problem and the objective there are some questions that need to be answered. The main research question this thesis will answer is:

"How should a BIM related system work to help prevent fall hazards in an early design phase?"

To help answer the main research question some sub questions need to be broken down and to structure the information. The first question will focus on the 'early design phase' part of the research question. The project lifecycle of a building project his different stages. But in which stage is the building model ready for a safety check? Therefore the first sub question is:

(Sub 1) "Where in the project lifecycle should the system be implemented?"

To be able to recognize a fall hazard there first must be a need to research as to what a fall hazard is according to the Dutch safety rules and regulations. A data collection needs to be conducted analysing them. Therefore the second sub question is:

(Sub 2) "What are the safety rules and regulations for fall hazards?"

Safety rules and regulations are based on the dimensions and placement of building elements. But how are these building elements modelled? Or even more important how are they defined in the data representation? Is this the best method to define them? These are all answered in the third sub question:

(Sub 3) "What are the requirements to the data representation?"

After the data representation is analysed and decided what the best method is to define building elements, the next steps are to analyse how a building element should be modelled. It is necessary to ensure that the fall prevention system does not omit an unsafe situation because it is modelled incorrectly. Therefore the last sub question is:

(Sub 4) "What are the requirements to the building model?"

By answering these sub question the flowchart of the fall hazard prevention system is created step by step. The result is the answer to the main research question, a working flowchart.

1.3. The practical / social and/or theoretical / scientific importance of the thesis

It is not so relevant where you work, if it is at a construction site or in an office, an employer is responsible for creating a save working environment for its employees. Working on a construction site requires taking extra measures to reduce the chance of accidents. With new technological developments it is important that management is informed over the latest tools to prevent accidents from taking place. Fall related accidents are the number one type of accident on construction sites all over the world. If this research can help reduce only one fatal accident it will be worth the time and effort. The social consequences of occupational injuries and illnesses, described by Dembe (2001), can have an effect on everyone in society. Physiological, physical and economic costs are not only paid by the injured employee. Costs for rehabilitation, workers compensation, medical care and law suits are enormous. Injuries on the construction site can lead to disabilities or even PTSD. Which can have lifelong effects on the employee and their family and friends. Knowing that you work is a safe work environment can reduce stress and increase productivity.

Reducing the amount of accidents is not the only effect of this thesis. The Architecture-, Engineering- and Construction- (AEC-) sector is transitioning in to a new working method. The digital revolution comes with countless of possibilities and benefits construction companies who readily can take here advantage of. In this new digital world exchanging and analysing data is of the utmost importance. Speaking the same language if it comes to organizing the data and using the same standards is something BuildingSmart is endeavouring to accomplish for over a decade. One of these standards is the IFC. Within the Dutch construction industry, it is still not a standard to use the IFC format. Increasing the number of analysing tools which use IFC will increase the acceptance of the format. Also, investing in analysing tools to increase efficiency can increase the competitive position of a construction company.

This thesis investigates the best method of developing solid models for tools such as a fall hazard prevention system. Instead of looking at what is possible with the current IFC schema, this thesis begins the other way around. What is needed for the analysing tools and how can this be implemented within solid modelling. When this cannot be satisfied, recommendations are given toward new versions of the IFC schema. It is also important towards scientific development that recommendations for future development are given.

1.4. Thesis outline

The thesis is divided in to in to 6 chapters. The first is the Introduction. Here the problem definition, research questions, research design, social and scientific importance are discussed. This chapter is meant to give an understanding of what this thesis involves and how it is organised. The second chapter is the Literature review. The Literature review gives background knowledge about the state-of-the-art research towards safety on the construction site, BIM and the research already done in the combination with BIM and safety. The third chapter is the Methodology. In this chapter the method used for the development of the fall hazard prevention system is discussed. This chapter also contains the scope and limitations of the research. The research in this thesis is compared with existing research and explained where it stands in relation to the existing research. In the fourth chapter the actual research completed. The steps of the flowchart are created and discussed. Chapter 4 contains the data collection and the analysis. This includes setting the rule sets for the flowchart, investigating the requirements to the data representation, comparing the requirements with IFC, obtaining the dimensions of the building elements, splitting up the edges of the slabs, processing the rule sets and creating output. In chapter 5 the results of the research are presented. The results contain the flowchart that is developed and a test case is conducted to prove that the flowchart works. At the end of chapter 5 the results and the process of the research is discussed and reviewed. The last chapter is the Conclusion where the answers to the research questions are given, the scientific and social relevance is discussed and recommendations toward future research is given.

Throughout these chapters the answers to the sub research questions are examined. The first sub question is investigated in chapter 2. The second sub question is investigated in chapter 4.1. The third sub question is investigated in chapter 4.2. The last sub question is investigated in chapter 5.2. The answer to the main research question is given in chapter 6 the Conclusion.

1.3. Research design

In the graduation project, knowledge and data from the construction company and building regulation are processed into identifying fall hazards and are then combined with the correct prevention method. The project can be divided in to 5 phases. 1) Collecting data and knowledge about Safety and BIM, 2) Process the data and knowledge to standardize and categorize it so it can be used in the BIM model, 3) analysing key components in the Model to identify a fall hazard, 4) creating a method to implement the fall prevention into the model. 5) Making sure the output can be used in the building process.

The first phase of the project will consist of a in-dept research of the current safety regulations and the implementation of these regulations within the construction company. This will be done by literature research and interviews with safety managers. The goal of these interviews is to determine why and who these accidents (falling from a height) occur despite of the current actions to prevent workers falling.

The second phase is to analyse the safety regulations. How can these regulations be checked in the BIModel? For example, if a hole in the outside wall needs to have a specific height or otherwise a safety railing needs to be constructed, how is this height determined by the program?

In the third phase key components in the Model will be analysed. In the first part of the project research is undertaken as to how accidents happen. Probably these accidents will happen near the edge of the floor and near holes in floors and walls. There needs to be determined how to recognize these elements in an IFC file.

When the key components can be recognized in an IFC file the next step is to create a method of how to implement the correct fall prevention. A small hole in the floor could be covered by a piece of plywood. But on the edge of the floor or when the hole is too big a safety rail may need to be placed. In this phase a method needs to be created for every type of fall hazard. The program should also be able to combine the different fall hazard preventions in to the model.

In the last phase of the project all aspects will be combined. Now it is important to make sure that the output is created in such a way that it can be used further on in the project. This means that the fall hazard prevention is placed in the model. But also, if the designers /BIM managers / safety managers need an information table with order information, or perhaps the fall hazard prevention needs to be placed in the construction schedule.

2. Literature review

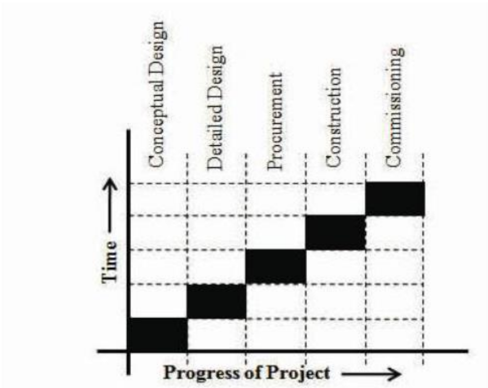
2.1. Accidents on the construction site

The construction site is one of the most dangerous work environments in the world. According to data from the National Survey Working conditions (NEA) 2015 conducted by CBS, construction workers are more often absent from work due to work-related accidents. In 2015 the construction workers were ranked second highest in work-related accident rates in The Netherlands. 4.8% of the construction workers were absent at least one day due to work-related accidents. Compared to 1.4% on average across all occupational groups (CBS, 2016). In the year 2016 7.4% of the employees in the construction sector received payment from the Work and Income according to Labour Capacity Act (WIA) (UWV, 2018). This indicates the high rate of incapacity for this type of work within the construction sector in The Netherlands.

In the first six months of 2016 the number of serious accidents in the construction sector increased with 14% and the number of fatal accidents increased even more, with 56% compared to 2015 (Inspectie SZW, 2016). In the construction industry in Great Britain in 2017 the most common fatal accident is falling from a height. Several studies show that falling from a roof/floor edge and falling through a roof/floor opening on the construction site accounted for 40% -49% of the fatal injuries to construction workers. For non-fatal injuries this was 18% (Coates, 2011; Health and Safety Executive, 2017)(Ale et al., 2008). In half of the fatal accidents there was a failure in the edge protection. This is not a problem from the last few years. Already in 1990 (Culver Glenn Florczak Richard Castell & Constance Connolly Gary Pelton, 1990) noticed that most fatal accidents happened due to falling from a height on the construction site.

Not only in Europe is safety in the construction sector a hot topic. After the financial crisis in 1999 in Thailand an increase in Thailand's construction sector was responsible for an increase in the reported number of accidents within the sector (Taylor & Easter, 2004) (Social Security Office, 2005). The Thai Government has taken significant steps in improving safety in the construction industry by promoting the establishment of safety programs (Aksorn & Hadikusumo, 2008). Studies in Hong Kong show that in 2014 more than 3100 construction workers had an work related accident and 24 workers had died (Performance, 2016).
An accident involves many psychological costs. But besides these phycological cost, accidents have an enormous financial effect on the construction company. In a study done in South Africa investigating the cost of construction accidents, researcher calculated that fall accidents alone cost a construction company an average of 448.609 ZARs. Which is around the 44,800 US dollars at the time of the research (Haupt & Pillay, 2016). According to the Dutch law the employer, the construction company, is responsible for all accidents during or related to the work. In January 2019 the Dutch government introduced a law which demands that the employer compensate also relatives who suffer from accident compensation which is, depending on the situation, between the €12,500 and €20,000 per serious accident (Ondernemersplein, 2018).

The sector is aware off the situation and over the years many researchers have tried to pin point the exact cause of what is creating this unsafe work environment. In the paper by (Evertt, 2000) an accident root causes tracing model was created to determine the root causes of accidents on construction sites. The model proposes that accidents occur due to three root causes: Failing to identify an unsafe condition that existed before an activity was started or that developed after an activity was started; deciding to proceed with a work activity after the worker identifies an existing unsafe condition; and deciding to act unsafe regardless of initial conditions of the work environment. The accident root causes tracing model also determines how the unsafe conditions could have existed before or after an activity had started. Four root causes were identified: Management actions/interaction; unsafe action of worker of co-worker; non-human related events; and an unsafe condition that is a natural part of the initial construction site conditions. Using an automated system in the BIM could mitigate the risk of the first root cause, preventing an unsafe situation from occurring. In the study of (Langford, Rowlinson, & Sawacha, 2000) it states that there are seven factors that affect safety performance on the construction site. These factors are historical; economical; psychological; technical; procedural; organizational and the working environment. The study also shows that the most important relationships between safety performance and these factors are talks on safety by management; issue of safety booklets; using safety equipment and proper safety preparations on site. In (Heinrich, 1959) study towards accident causation theory he defined an accident as followed: An accident is an unplanned an uncontrolled event in which the action or reaction of an object, substance, person or radiation results in personal injury or the probability thereof. The work of Heinrich can be summarized in two points: People are the fundamental reason behind accidents; and management, having the ability, is responsible for the prevention of accidents (Petersen, 1996). What (Evertt, 2000; Heinrich, 1959; Petersen, 1996) found in their research was that management can and should have a huge impact on the safety performance on the construction site. By thinking about safety earlier on in the construction process a great number of the safety hazards could be eliminated. This statement is supported by, (Bhattacharjee, Ghosh, & Young-Corbett, 2011; Gibb, Haslom, Hide, & Gyi, 2004; Zhou, Whyte, & Sacks, 2011). These studies found that 42-71% of these safety incidents can be prevented by safety considerations at the design stages. Examples of these design actions are: permanent anchor points, lifeline systems, and other forms of permanent fall protections that could be designed into the permanent features of the structure (Gambatese, Behm, & Rajendran, 2008). It was found that traditionally the burden of ensuring safety of construction site has been placed solely on the contractor. While the contractor will always bear the responsibility for construction site safety, the novel concept of Prevention through Design (PtD) also allows architects and engineers to contribute in enhancing site safety (Bhattacharjee et al., 2011). The role of the architects and engineers to impact safety in construction projects has not been fully utilized. A major reason behind this can be found in the lack of motivational forces (i.e. legal, contractual, economic, ore regulatory) in the United States that will encourage a designer to consider potential health hazard and risks of the workers during the design phase (Behm, 2005). The article of (Bhattacharjee et al., 2011) puts forward the method of Prevention through Design before the traditional method of construction. When the stakeholders in the different construction phases are listed, it clearly shows that architects and designer can have effective role in recognizing potential unsafe situations (figure 1 and figure 2). Actions that designers can take are: asking contractors how work will be constructed; finding out component sizes for safe installation; coordinating the program for safe sequencing of work and ensuring the contractors have in-depth understanding of the design rationale (Atkinson & Westall, 2010). However, the prevalence of traditional design-bid-build contracting arrangements and the resulting complex hierarchy of subcontracting on any modern building create a significant organizational distance between designers in any domain and the relevant subcontractors who will perform the work. Coupled with designers' aversion to dictating means and methods due to liability concerns, there is still significant reluctance on the part of designers to take an active role in addressing construction safety (Gambatese, Hinze, & Haas, 1997). Recommendations of ILO was supported by the European Foundation for the Improvement of Living and Working Conditions, which concluded that nearly 60% of all fatal accidents in the construction industry was caused due to decisions made prior to actual construction (Bhattacharjee et al., 2011). Figure 2.1 and 2.2 show the involvement of the different stakeholders and their ability to influence safety on the construction site. The best moment to evaluate the construction safety, according to (Szymberki, 1997), is during the conceptual and preliminary design phase. Note that, it is incorrect to assume that a focus on design for safety will automatically eliminate construction



Architect	X	X		X	X
Owner	X	X	X	X	X
Engineer		X		X	X
Contractor			X	X	X

Figure 2.1 | Traditional involvement of stakeholder (Bhattacharjee et al., 2011)

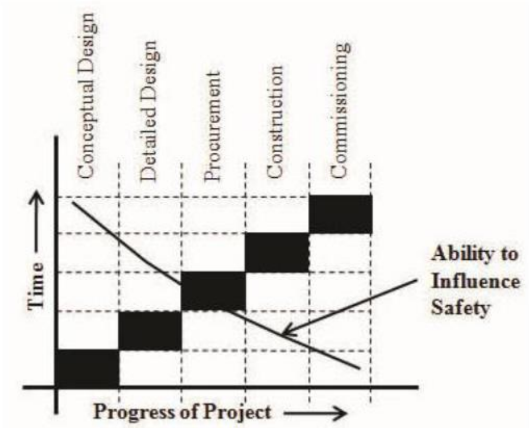


Figure 2.2 | Time vs. safety influence graph (Bhattacharjee et al., 2011)

site fatalities. It is one element within a more holistic approach to minimizing construction project risk and enhancing worker safety, through multi-level risk assessment and hazard prevention mechanisms throughout the delivery of a building project (Gambatese et al., 2008).

2.2. Building Information Management (BIM)

In a building project, many stakeholders from different disciplines exchange important information. Previously, each stakeholder was responsible for their own documents. The exchange took place by paper and the information was interpreted and processed by people. With BIM, construction partners do not essentially exchange documents, but data. Data is entered into the computer only once and then used repeatedly by different parties, in various applications and computer programs. The data is modelled in such a way that not only people but also computers can interpret the information.

BIM is a concept where everyone in the AEC sector has a different explanation for. The letters 'BIM' are used in practice in three coherent meanings: The first meaning is 'Building Information Model'. This is a digital representation of how a building has been designed, realized and / or built. In other words, the BIModel. In the second sense, 'Building Information Modelling', the emphasis is more on the process. This is about working together in construction projects using digital information models. Related concepts are integral design, competitor engineering, lean planning and the sharing of digital information. In the third sense, 'Building Information Management', the information itself is central: the construction, management and (re) use of digital construction information throughout the entire life cycle of the building (Bouw Informatie Raad, 2015). The Building Information Council (Bouw Informatie Raad, BIR) finds all three meanings equally relevant, the term 'BIM' encompasses the whole. For this research report the emphasis will lay on the third meaning of BIM, Building Information Management. It is important to note that BIM is not just software, it is a process and software. BIM means not only using three-dimensional intelligent models but also making significant changes in the workflow and project delivery processes (Azhar, Khalfan, & Maqsood, 2012; Hardin & McCool, 2015). Implementing BIM into the working methods of a construction company can have major benefits for project management. The key benefit of working with the BIModel is its accurate geometrical representation of a building in an integrated data environment (CRC for Construction Innovation, 2007). For these reasons, several construction companies have adopted BIM into their working methods.

BIM can be use in different phases of the building process. In a BIM utilization survey in the UK, BIM is used in the design phase for 55%, preconstruction (Tender) phase 52%, construction stage 35%, feasibility stage 27%, and operation and maintenance stage 9% (Eadie, Browne, Odeyinka, McKeown, & McNiff, 2013). This shows that BIM is used mainly in the first part of the projects. This is also true for Dutch construction companies, where BIM is mainly used in the design phase. Later, in the project lifetime the use of BIM decreases. In the stage of tender BIM is useful as the model holds information about work details and specifications of products. This accelerates and simplifies the process of preparation of the tender documents. More benefits are attained in the construction phase as BIM helps to plan precisely and to regulate the construction process. This resolves errors, decreases construction time and enables to quickly change materials (Doumbouya, Gao, & Guan, 2016). The reason why BIM is not fully adopted in the entire lifetime of a project and all over the construction sector is because the adoption of BIM struggles with different difficulties on each level of the adoption. Construction companies have often complex working methods and organisation. To change these, the benefits must exceed that of the current working methods and organisation. Implementing BIM efficiently requires significant changes in the way construction businesses work at almost every level within the building process (Arayici et al., 2011). Other difficulties in actualizing BIM in construction practice are mastering the imperviousness to change, and inspiring individuals to comprehend the true value and possibilities of BIM, as well as training individuals in BIM (Yan & Damian, 2008). BIM requires an initial investment in the start of the project so later cost can be saved due to better planning. Figure 2.3 shows the investment of working with BIM in comparison with traditional methods. What happens if BIM is only implemented in the first stage of the building process is that the initial investment is done but by not implementing it in the later stages the cost reduction is not made due to processes working in the traditional way. This leads to an increase in costs instead of a decrease what was aimed for.

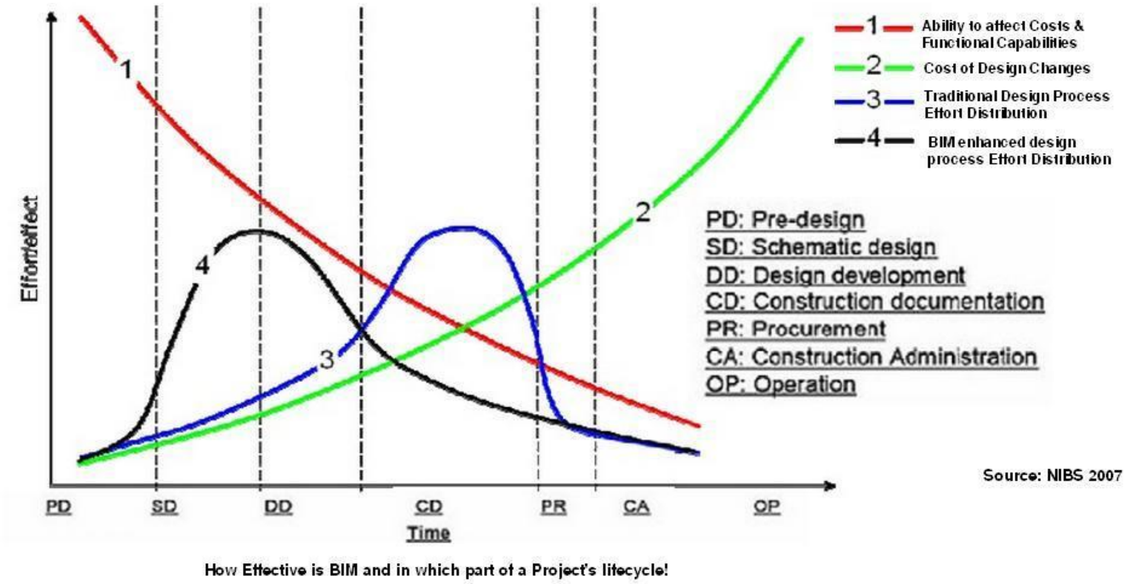


Figure 2.3 | How effective is BIM and in which part of the project's lifecycle (https://pinnacleinfotech.wordpress.com/2014/03/13/how-does-bim-benefit-stakeholders-heres-an-estimate/)

2.2.2. The Industry Foundation Classes (IFC), BIM Collaboration Format (BCF) & Information Delivery Manual (IDM)

The Industry Foundation Classes (IFC) was developed to create a large set of consistent data representations of building information for exchange between AEC software applications. It relies on the ISO - STEP EXPRESS language and concepts for its definition (Eastman, Teicholz, Sacks, & Liston, 2008). Since 1995 BuildingSmart is working on IFC as a sector wide form of information exchange. Although IFC is accepted to become a standard in the construction industry, it is not implemented throughout the entire sector. The lack of automated processes able to support the introduction may hinder the diffusion of correct practices. In fact, the alignment between the competences of the personnel and the requirements of IT is a key aspect for the success of a process of integration of new digital instruments. Therefore, there is a rising need for tools (possibly, automated tools) for simplifying the information flow so that AEC sector can easily adopt IFC within BIMbased processes (Mirarchi, Pasini, Pavan, & Daniotti, 2017). Within the IFC domains, it is important, to avoid any misunderstanding, to note that IFC is neither a software application nor a collection of software components. It is a schema that can be compiled into an executable code or a class library of a programming language that supports information sharing and representation (Namini, Meynagh, & Vahed, 2012).

A BIModel is a representation of a building project. Such a model contains data from various stakeholders. Through clash detection it is possible to find errors in a model. In recent years it has turned out that communicating about these errors is a separate discipline. A specific object can be communicated and shared with partners via IFC, but a specific 'clash' must be described via the phone or with screenshots. That is why BCF (BIM Collaboration Format) has been developed. BCF was developed to communicate 'issues' of a BIModel. BCF is a set of rules about how issues are exchanged. It consists of 3 parts: a picture, a camera angle and a list of objects from the BIModel that the issue is about. Thanks to BCF, 'issues' of a model can also be exchanged simply and unambiguously, which reduces the chance of errors in communication between chain partners. BCF is a relatively young initiative, but the adaptation is growing fast. It is expected that this standard will quickly conquer the market (Berlotti, 2012).

A growing number of parties in the construction industry are joining the initiative to use a basic Information Delivery Manual (IDM). The best practices of recent years have shown that working with open BIM is the only real answer to integral cooperation in the chain. For integral cooperation, speaking the same language is essential and work can be done more efficiently in the chain, eliminate wasteful tasks and prevent errors. The efficiency follows from the fact that everyone knows where information can be found and how information must be provided. The agreements relate to the exchange format, the basic structure to be used and the safeguarding of object information. The simplicity and limited number of agreements must lead to a broad application and support at every link in the chain, from client to maintenance engineer (BIM Loket, n.d.). To get the best results out of the fall hazard prevention system develop in this research it is important to model the BIModel according to the standards of the Basic Dutch IDM. This secures that elements are modelled as the right element. A wall should be modelled as an IfcWall and a floor slab should be modelled as an IfcSlab, so the system can recognize the different elements. Within the IDM Exchange Requirements are defined. To satisfy these Exchange Requirements a subset of the IFC schema is defined. This is called a Model View Definition (MVD). A MVD is a sort of filter to extract specific information for the IFC schema. Currently BuildingSmart developed three MVDs. The IFC2x3, the IFC4 Reference View and the IFC4 Design Transfer View. So, others have also developed their own MVD to make the information exchange more efficient but these MVDs are not available for everyone.

2.2.3. Level of Detail/Development

When working with BIM it is important to realise what the Level Of Development (LOD) is and what LOD is required. The principle of LOD is to specify the information that the model must contain according to its use at the different stages of a project lifecycle (Boton, Kubicki, & Halin, 2015). In the literature the terms Level of Detail and Level of Development are used interchangeably, as they refer to the same definition. In practice the term Level of Detail is often referred to how much detail is needed for a building detail. The term Level of Development is referred to how far building elements are defined. So is it just a mass or already a specific element of even a specific type. For this research report the definition of the literature is used. Which is also the definition of the Level of Development in practice.

Depending on the information that is needed by the analysing tool, the LOD needs to be determined. There are currently six levels of LOD: LOD 100 mainly requires objects in graphical representation, LOD 200 adds approximate quantities, shape, location and orientation with possibly non-graphic information attached, LOD 300 requires more specific systems, objects or assembly in term of quantity, size, shape, location and orientation with possibly non-graphic information attached, LOD 350 adds requirements on interfaces with other building systems, LOD 400 contains more detailed information required for fabrication, assembly and installation, and LOD 500 is a field verified representation. For building models at the design development phase, which is the most typical stage where a building model is complete enough for code compliance submission, LOD 300 or LOD 350 is generally sufficient. (Solihin & Eastman, 2015). Figure 2.4 gives a visual representation of the different LODs. In the BIM approach, the term “level of development” (LOD) is widely used to show that detailing is not only about geometry but also deals with non-graphical information. In 4D models, LOD specification must therefore manage both the graphical level of details and the temporal level of information (Heesom & Mahdjoubi, 2004). The fall hazard prevention system developed in this research report sets requirements to the LOD of the used BIModel. For the system to work properly the model must has at least a LOD of 300 or 350. This also determines when the fall hazard prevention system can be implemented in the design process. If the BIModel is not detailed enough the system cannot retrieve the right information or is the output is not reliable. The goal is to implement the fall hazard prevention system in the design phase. With a LOD of 300 this is possible.

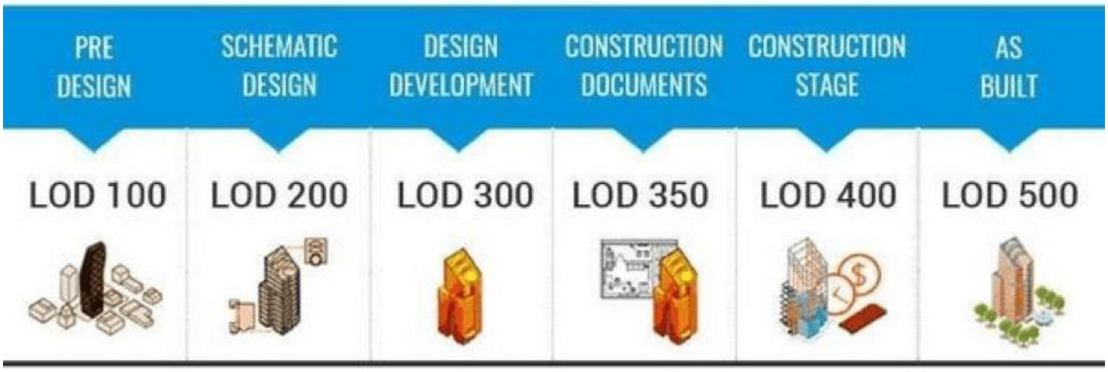


Figure 2.4 | Visualisation of the Level of Development (https://www.kelarpacific.com/construction-design-phases-vs-bim-levels-development-part-2-4/)

2.2.4. 4D BIM

The possibilities of BIM do not end with 3D modelling of construction projects. In the construction industry 4D BIM is often referred to a combination of a 3D BIModel and project scheduling. After adoption of BIM into the workflow, 4D BIM is the next step for gaining all the benefits from the possibilities that BIM has to offer. With the project schedule uploaded in the BIM altering tool, building elements can be assigned to specific parts of the schedule. This way a simulation of the construction phase can be modelled, and errors can be detected at forehand. The simulation is meant to give the construction workers more insight in their tasks and it is a way to support and optimize the communication on the construction site. A disadvantage of 4D BIM is the early investment that the contractor needs to make in modelling the construction phase. Often there is also spoken of 5D and 6D BIM. This refers to, like with 4D BIM and the combination of time, to combine the costs (5D) and the maintenance (6D) in the design phase. As more and more information is put into the model additional domains can be modelled and calculated over the construction project its lifetime and even after.

2.3. BIM and Safety

The combination of BIM and Safety has been researched in various countries around the world, such as Finland, United States, UK and Norway (Arayici, 2008; Khemlani, 2005; Kiviniemi, Tarandi, Karlshøj, Bell, & Karud, 2008; Succar, 2009; Wong, Wong, & Nadeem, 2009). Although all the previous research towards automating the safety process to increase the safety on the construction site, Dutch construction companies use almost no computer aided program to determine where hazard preventions needs to be placed. As mentioned in the literature the responsibility of hazard prevention lies on the contractor and more specific on the responsibility of executor. The Quality, Health, Safety and Environment department (QHSE) only has an advising function within companies like Strukton Worksphere. Randomly a few projects are inspected on site. The QHSE department checks if the executor is aware of the possible risks according to the safety, health & environment plan (VGA) the executor makes for the project. This plan is made by the best practice of the executor. In the next subchapter some promising combinations of BIM technology and Safety are discussed.

2.3.1. Fall hazard prevention

To prevent fall hazards form occurring on the construction site much research has taken place. Most methods implemented by contractors are to educate the employees about risks and unsafe situations. Scientific research describes more than one sort of technology to combine safety and BIM. The article of (Zou, Kiviniemi, & Jones, 2017) mentions different ways of combining safety and BIM for example virtual reality where employees are trained to perform tasks in VR first before preforming the task at the building site, 4D CAD were planning and model are combined to visualize the safety management, rule-based checking like Solibri Model Checker and geographic information systems to track the activities on the construction site. Although there are several options for construction companies to implement safety into the current BIM-activities this still has not been done by most of the Dutch construction companies. The implementation of traditional risk management is still a manual undertaking, the assessment is heavily reliant on experience and mathematical analysis, and the decision making is frequently based on knowledge and experience based intuition, which leads to a decreased efficiency in the real environment (Zou et al., 2017).

With the uprise in BIM more and more data is collected about activities on the construction site. But hence, it is important to investigate more advanced methods to integrate this information. (Zhang et al., 2015). In Finland a fall hazard prevention tool was developed in combination with the software of Tekla structures. This system works by the flowchart given in figure 2.5. How this is visualized in the software is given in figure 2.6. The algorithm searches for the boundary lines of floor elements. After that it searches if there are any wall elements on these boundary lines. In the end it checks if there are holes in the wall that can lead to fall hazards.

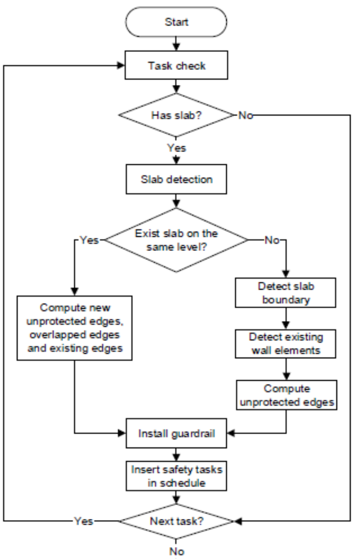


Figure 2.5 | Algorithm automated fall hazard prevention (Zhang et al., 2015)

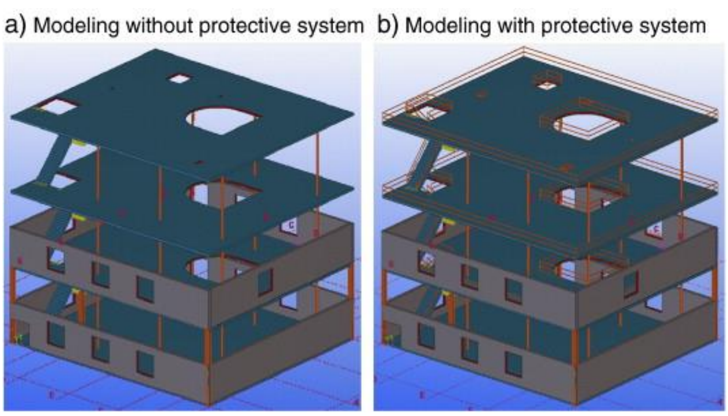


Figure 2.6 | Visualization of fall hazard prevention (Zhang et al., 2015)

The system is based on the principal of rule-based checking. Because safety rules and regulation already exist they can be implemented in to the model. After the developed safety rule checking system has identified the safety issues or hazards in the BIM, Corrective Actions, such as design for safety and safety planning, can be conducted. The goal of the rule checking system is to assist human decision makers in the safety planning and scheduling by proposing realistic solutions to resolve the identified issues (Zhang, Teizer, Lee, Eastman, & Venugopal, 2013). In figure 2.7 the framework for the automated rule-based checking model is represented. Although the tool is promising and useful, (Zhang et al., 2015) it points out that more research is needed to be done towards the use of IFC and safety checking.

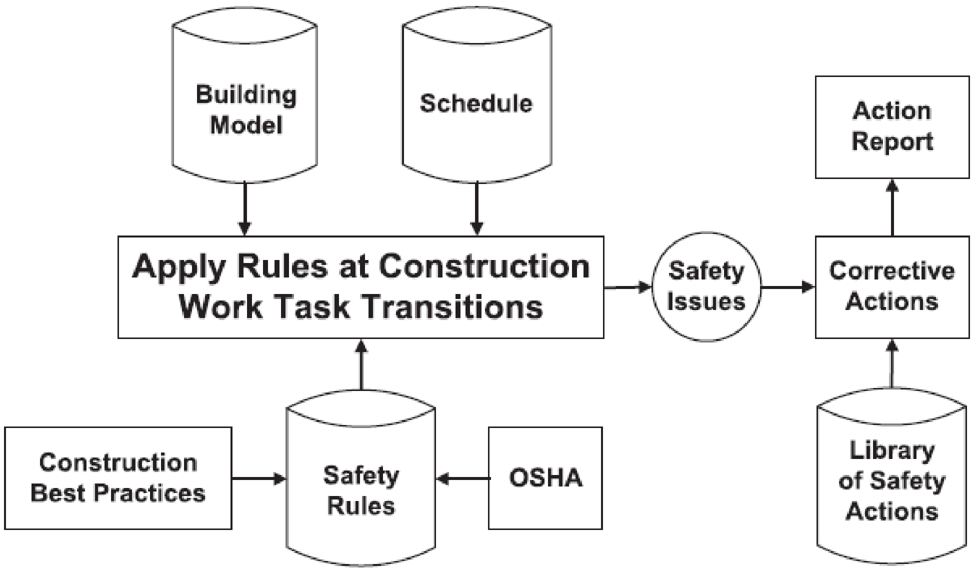


Figure 2.7 | Framework rule-based model checker (Zhang et al., 2015)

2.3.2. VR/AR

One of the uprising and more promising technologies which tries to combine BIM with Safety at the construction site is virtual reality (VR) and augmented reality (AR). VR and AR are implemented in different ways all over the construction industry. For example, hazard identification, safety education and training, safety inspection and instructions, etc. Within these new possibilities safety education and training has the most potential. VR/AR technologies afford new opportunities for effectively training and educating novices or students with higher level of cognition and fewer hazards (X. Li, Yi, Chi, Wang, & Chan, 2018). Workers can easily recognize potential hazards embedded in such a visual environment, thus improving the training (Guo, Yu, & Skitmore, 2017). Visualization technology integrated with game technology provides an interactive approach to safety training. This allows workers to improve their safety consciousness by interacting with a virtual construction environment and checking potential hazards involving unsafe behaviours, lack of necessary safety facilities, etc. (Guo et al., 2017). (Hadikusumo & Rowlinson, 2004) Created a VR-based design-for-safety-process tool which helped to identify safety hazards inherited during the building construction phase that were actually produced during the design phase. The tool created a design-for-safety-process database. It incorporated a theory of accident causation, which lists common unsafe acts and conditions, in the investigation of safety hazards (Zhou, Whyte, & Sacks, 2012). But that is not the only tool developed based on VR. Virtual Construction Laboratory is a knowledge-based VR system, developed to enable the planner to conduct virtual experiments of innovative construction technologies and processes (H. Li, Ma, Shen, & Kong, 2003; Zhou et al., 2012). And the Computer Image Generation for Job Simulation (CIGJS) system supports job safety analysis by applying VR technologies to generate a virtual human. CIGJS seeks to provide realistic simulations of actual work situations, contributing to job safety analyses to improve their effectiveness and usability in routine work situations, including construction work at an operational level, and to make the use of job safety analysis possible also at the design stage (Perrow, 1999; Zhou et al., 2012). Although the combination of safety and VR/AR is promising, and most likely part of the future, this research project will not focus on VR/AR applications. The reason for this is because a lot of research and development has already been done towards this topic and is already implemented by some of the Dutch construction companies. VR/AR applications and the system developed in this report can operate side by side each other. They can even support each other when combined for inspection and instructions.

2.3.3. Geographic Information Systems

Geographic Information Systems (GIS) provides an approach to considering construction safety from the macro perspective as they contain detailed information regarding the environment (Zhou et al., 2012). (Bansal, 2011) applied GIS to safety planning because of environmental issues such as conditions, site topography, thermal comfort, access route planning influence workers safety. These environmental factors cannot be modelled with BIM and 4D CAD because they lack geospatial data by using GIS. GIS was also integrated into a Decision Support System to assist construction engineers in safety monitoring and controlling excavation conditions (Cheng, Ko, & Chang, 2002).

2.3.4. Rule-based checking

The concept of rule-based checking has been successfully implemented within the AEC sector. The definition of automated rule-based checking for this research is defined as ‘software that does not modify a building design, but rather assesses a design based on the configuration of objects, their relations or attributes. Rule-based systems apply rules, constraints or conditions to a proposed design, with results such as “pass”, “fail” or “warning”, or “unknown” for cases where the needed data is incomplete or missing’ (Eastman, Lee, Jeong, & Lee, 2009). The most widely used application in construction might be “clash detection” tools in BIM software (Zhang, Lee, Venugopal, Teizer, & Eastman, 2011). By testing the BIModel against a set of rules, errors within the design can be detected. The rules are written in a query languages. (Solihin & Eastman, 2015) mentioned there are two major parts that a rule checking system must deal with. The first is the building model, and the second is the rule definitions. Building models are large datasets, even for medium-scale buildings. There is no rule or class of rules that applies to the entire set of building model data. Rule sets can be defined by the user itself. This makes it possible to implement best practices into the model. These rules are usually not well-defined. Within the Dutch construction industry, the most common used programs for rule-based checking are Solibri Model Checker and Navisworks. Here Solibri Model Checker is usually preferred because Navisworks can only detect ‘dump’ clashes. Clash detection is

adopted in the working methods of the Dutch construction companies and becoming a standard part of the design. Clash detection has proven to be a correct method to prevent errors and extra costs during the construction phase.
Towards rule-based checking and safety at the construction site much research and development has taken place. This combination relies on the fact that there are already safety rules and regulation. These rules and regulations only need to be translated so the rule-based checking program can understand the rule set. One of the advantages of the use of rule-based checking is that when safety regulation change, the rule set can easily be changed. The disadvantage of the use of rule-based checking is that the program can only detect errors in the design. To resolve the errors a BIM altering tool needs to be used which can be time consuming.

2.3.5 Prevention through design tool

The Prevention Through Design tool (PTD tool) developed by (Qi, Issa, Olbina, & Hinze, 2014) is used to detect fall hazards in the design phase. Using Solibri Model Checker and BIM server to detect fall hazards in a BIModel. In their article they discus that checking for building code compliance through rule-based checking is different from applying Prevention Through Design (PTD) knowledge because the principle of PTD is to protect construction workers during the process of construction. The method works by defining rules in Solibri Model Checker. To define the rules the user needs to be able to read Java script and be familiar with the IFC schema and its hierarchy. In the article a test case is shown were openings in floor slabs are successfully identified. What makes the difference with this research and development project is that when the fall hazard has been identified the user needs to make the alterations in another BIM altering tool. So the PTD tool only identifies the fall hazards.

3. Methodology

3.1. Introduction

This research focusses on the development of a fall hazard prevention system for CAD using BIM. This research provides several steps of the software development process up toward the step of programming. This research presents a flowchart of how a fall hazard prevention system should work. Software development is a complicated process. It requires careful planning and execution to meet the goals (López & Xirgo, 2010). This chapter describes first which research approach is used for the development of the system. Next the scope and limitations of the research are defined, and a comparison is made where this research stands among other research in the same domain of Health & Safety and BIM. The largest part of this chapter is dedicated to the actual research descript in the methodology.

3.2. Method

The methodology of this research is based on the Waterfall development model developed by Winston W. Royce in 1970. The Waterfall development model originates from the manufacturing and construction industry where mistakes and design changes later in the project can involve more expenses. It is also known as the lifecycle development model within software engineering. The waterfall model is a classic approach to the systems development life cycle. It describes a development model that is linear and sequential (Rouse M., n.d.). The development has a clear direction and goal just like a waterfall, downstream. A task is first 100% done before starting the next task. The advantage of the Waterfall development model is its simplicity, it allows developers to schedule and set deadlines. Task can be divided in clear steps. To allow feedback and changes to be made to the development project the steps need to have feedback loops. This creates the modified Waterfall development project. The Waterfall model is often modified with feedback loops to improve the development process (Gao & Hembroff, 2012).

The steps for the traditional Waterfall development model are: Requirements; Design; Implementation; Verification; and Maintenance. As shown in figure 3.1. In the requirement phase the requirements gathered are analysed. In this phase there is defined what the system should do. In the design phase the topics typically are programming language, data layer, etc. Within this research the design phase will focus on how the system should work. In the implementation phase the usually the actual code is made. For this research in this phase the system will be presented which is developed with the design from the previous phase. In the verification phase the developed system is tested. Feedback loops will make sure errors will be resolved. The last phase is the Maintenance phase. Here the system is deployed to a real live environment. Maintenance and support are provided to keep all functions up-to-date. The maintenance phase for the system is out of the scope for this research and will not be discussed.

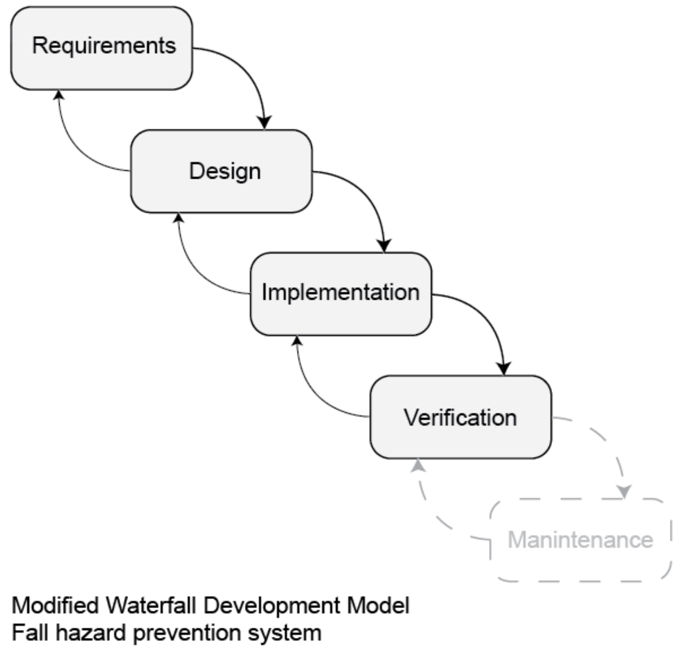


Figure 3.1 | Modified Waterfall Development Model

According to these steps the research is divided in these four steps. In the requirement phase a data collection will be done. Therefore the safety rules and regulations for the construction industry are analysed and the best practice of experienced employees from Strukton Worksphere are combined to define unsafe situations. This includes defining rule sets to check if a situation has a falling hazard. The safety rules and regulations in The Netherlands are recorded in the ARBO and the Dutch law. The best practice will be recorded with interviews. The next step in the requirements phase is analysing the computational environment for solid modelling. What are the key components in the Building Information Model? What is possible within the geometric and topological approach and what is needed in the data representation? In the next phase, the design phase, the answer to how the system should work is given. How can the requirements from the previous phase be met? How should building elements be modelled to let the system work as efficient as possible?, And how should the data represented. In addition to how it should work in the ideal situation this phase also describes how the system should work with the current data representation of IFC4. In the implementation phase a flowchart of system is presented. The individual steps in the flowchart were developed in the previous phase and combined to a working system in the implementation phase. In this phase there is also discussed what is required during the modelling process and export specification, so the data representation contains all the needed information. In the last phase the flowchart is tested against a testcase to prove it works and find any errors in the flowchart.

3.3. Scope and limitations

In the literature review is already mentioned some research is done in the domain of Health & Safety and BIM. This research is state of the art edge in this domain. Although VR related technology and research is promising this research will not focus on this angle of the domain. VR will be part of the future in educating construction workers and some technology is already in use today. The angle of rule-based checking is more in line with this research. Setting up rules and checking them against a BIModel is the basis of the research. This research differentiates itself from rule-based checking research and PTD methods is that rule-based checking is a passive method for resolving fall hazards. An additional BIM altering tools is needed to put the actual prevention method in to place. So, it can only detect safety hazards. The automated fall hazard prevention system of Zhang et al (2015) is an example of a BIM safety tool that can work as a single system. The system is based on Tekla Structure. This research begins with the algorithm and framework developed in their research as a guideline for how to design a fall hazard prevention system of its own. This research is based on the IFC data representation to extract building information to analyse. In the time of the research of Zhang et al. (2015) the IFC had still too many flaws to create a reliable safety tool. This research is one of the steps in creating a fall hazard prevention tool for the sector wide standard data representation. By using the geometric and topological approach towards BIM analysing tools. This research provides new information about what type of data needs to be included in the data representation. The approach has helped research towards energy performers (Khalili, Chua, & Asce, 2015) and the exchange between IFC and GIS to come to an understanding what needs to be improved for an efficient use. The system focuses on the Dutch safety regulations to prove it is possible to create a fall hazard prevention system based on IFC.

Being compatible with other research and developments in the AEC-sector is a one of the best ways of creating a change. That is why this research use the Dutch basis IDM. The modelling and data exchange for this research is limited to only process which use the Dutch basis IDM. The BIM altering tool used is Revit Autodesk 2017. The testcases and the data representation are exported from Revit Autodesk 2017. Building elements are modelled by the standard case entity of the building element. This means that the building elements are constructed of straight lines with a constant height. The processes and best practise of the interviewed are employees of Strukton Worksphere. It is possible that process of decisions based on best practise may be different by other construction companies. Note that the safety regulations are derived from the Dutch regulations at the time of writing the report. These regulations may change over time.

3.4. Data collection and analysis

3.4.1. Setting the constraints

Introduction

In the Dutch construction sector, the safety rules consist of the Dutch law and the ARBO rules. The ARBO rules are made by a partnership between UNETO-VNI, NVKL, VIB, FNV Bondgenoten, CNV Bedrijvenbond en De Unie. The document is aimed at enabling employers, work planners, contractors and employees to quickly take a well-considered decision on what the best solution is to be able to create a safe work location. The composition of the partnership involves representatives from the trade unions and employers. The aim is that the document must be applicable in the daily practice of both small and large companies, in which legal requirements have been incorporated in such a way that it is also possible from a business economical point of view to choose a good measure. The Dutch law sees working at 2,50 meter or higher as working at a height (Arbeidsomstandighedenbesluit art 3.16). From this point on fall prevention must be taken. But for most workers in the construction industry this means that there are only fall hazards form this point on and up. This is not the correct way of thinking. Even working on a height of 0,40 meters from the ground a construction worker can get injured if the appropriate action is not taken. That is why the fall hazard prevention system will search for fall hazards on every level of the construction site. Many construction workers work in different situations every day. Although the Dutch law and the ARBO rules cover a lot of the safety spectrum it is not waterproof. Due to all the different possible situation that can exist on the construction site it is impossible to cover every situation. Therefor the ARBO rules states that it is important for everybody who is working on the construction site to think for themselves if the situation or work might contain risks.

In the next chapter, 4 frequent occurring standard situations are defined. For these situations the risks and appropriate hazard preventions are discussed. The appropriate hazard preventions will be determined by the Dutch law and the ARBO rules. If there is a dimension which is not described between these two the best practices of the Quality, Health & Safety and Environment department of Strukton Worksphere is taken as the dimension. From this, rule sets are defined which will work as the rule set for the fall hazard prevention system. The rule sets can be answered with yes (True) and no (False). The four standard situations are: (1) The edge of a floor slab without a wall element on top of it and no connecting floor slab to the edge; (2) The edge of a floor slab with a wall element on top of it and no connecting floor slab to the edge; (3) The edge of an opening in the floor slab with no wall elements on it; (4) The roof of a building. For the last situation only a flat roof will be discussed. This because the best practice of the QHSE department is of a construction company which mainly focusses on utility buildings. In most cases these buildings have a flat roof.

General rule set

The first set of rules that will be defined is the general rule set. These are the constraints that determine which situation is the case. As said before there are 4 different situations the fall hazard prevention system will check. Three of these situations are related to a floor slab. And the last situation is related to the roof. So, the first check is if the situation is related to the floor slab of to the roof.

0.1 Is there in this situation a floor slab?
0.2 Is there in this situation a roof?

So, in rule 0.1 the system searches for the floor slabs. When the rule is 'True' the first three situation are the case. If the rule is 'False' the system will go to rule 0.2. This rule will search for the roof elements. When this rule is 'True' the last situation is the case. If the rule is 'False' there are no floor slabs or roof elements in the model. So, the system will end. To make sure that every fall risk is found related to the floor slab or roof element the system will loop around these first to rules as long as the rule will answer 'True'. When the answer is 'False' the loop breaks and will go on to the next step in the system.

The next check is to see if there are openings in the floor slab. Therefor is general rule 0.3. This rule determines if situation 3 is the case.

0.3 Is there an opening in the floor slab?

When rule 0.3 answers 'True' situation 3 is the case. The system will go on with the rest of the rules and actions for situation 3. When the rule answers 'False' situation 1 or situation 2 are the case. In this case the system will go on with the next step in the flowchart. Just like in the first two general rules this rule will also contain a loop. As long as rule 0.3 answers 'True' the system will loop over situation 3 till all the openings in the floor slab have come by. When the rule answers 'False' the loop breaks.

The next step in determining if the system is dealing with situation 1 or situation 2, is to make sure the system checks if there are other floor slabs or roof elements connected to the edge of the floor slab that is being analysed. Therefor is rule 0.4.

0.4 Is there another floor slab or roof element connected to the edge of the floor slab?

When rule 0.4 answers with 'True' the edge of the floor slab is not an unsafe situation. In this case the system will go on and loop for the other edges of the floor slab. When rule 0.4 answers 'False' this means there might be an unsafe situation at this edge of the floor slab. The system will move to the last of the general rules.

The last of the general rule set, to determine which of the standard situations is the case, is to check if there is a wall element on the edge of the floor slab.

0.5 Is there a wall element on the edge of the floor element?

When the rule answers with 'True' this indicates that situation 2 is the case. The system will continue with the actions and constraints of situation 2. When rule 0.5 answers 'False' it indicates that situation 1 is the case. The system will continue with the actions and rule set of situation 1. The system will loop the edges over rule 0.5 until it answers 'False'. When all the remaining edges are run through situation 1. The system will return to rule 0.1.

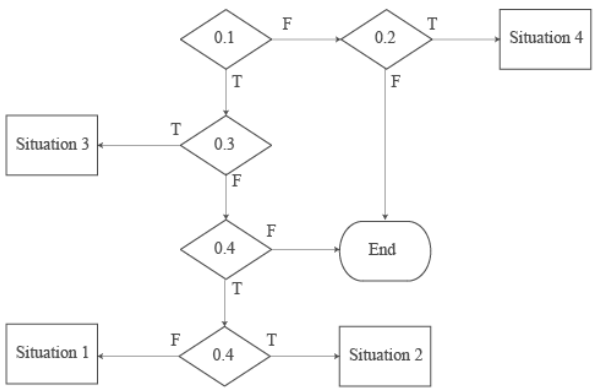


Figure 3.2 | Schema general rule set

In table 3.1 a summary of the rule set is given. In the last two columns the flow for the different answers are shown. Figure 3.2 gives a schema of the general rule set

Number	Description	When 'True'	When 'False'
0.1	Is there in this situation a floor slab?	Situation 1, 2 or 3	Situation 4
0.2	Is there in this situation a roof?	Situation 4	End system
0.3	Is there an opening in the floor slab?	Situation 3	Situation 1 or 2
0.4	Is there another floor slab connected to the edge of the floor slab?	No unsafe situation	Might be unsafe situation
0.5	Is there a wall element on the edge of the floor element?	Situation 2	Situation 1

Table 3.1 | General rule set

Situation 1

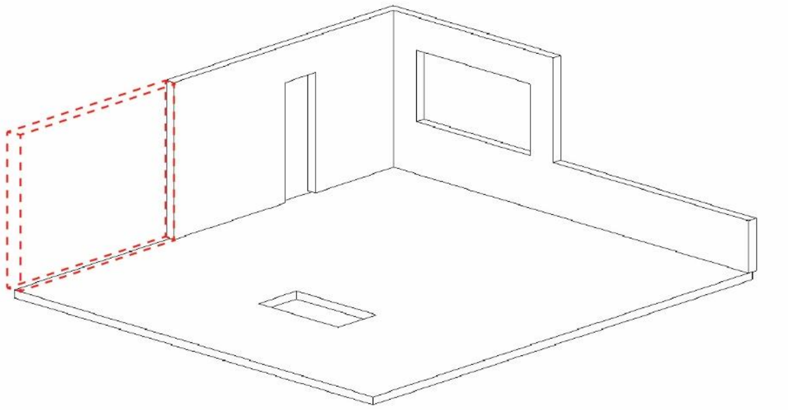


Figure 3.3 | Situation 1

Situation 1 is defined by the edge of a floor slab without a wall element on top of it. There are no other floor slabs connected to the edge of the floor slab. In this situation construction workers risk the change of falling off the edge of the floor slab. Construction workers also risk accidently kicking or dropping items over the edge which might injure colleagues working on a lower level. Figure 3.3 gives an indication of the unsafe situation in situation 1.

To prevent this fall hazard some actions must be taken according to the ARBO rules. The first hazard that needs to be taken care of is preventing items to be dropped or kicked over the edge. This can be done by a baffle kick plate. This obstruction needs a height of minimal 0,15 meter. The length of the obstruction needs to be over the full length of the open edge. This creates the first rule for situation 1:

1.1 Is there a fixed object over the length of the edge of the floor slab reaching from the top of the floor slab to a height of minimal 0,15 meter?

According to the ARBO rules, to prevent a construction worker form falling down a fixed object needs to be placed at a height of 1,00 meter over the full length of the edge of the floor slab to prevent workers from falling down. This creates the second rule for situation 1:

1.2 Is there a fixed object over the length of the edge of the floor slab at a height of 1,00 meter from the top of the floor slab?

Between the height of 0,15 meter from the top of the floor slab and 1,00 meter of the floor slab there is still a space, if not filled, where construction workers can fall through. Because of this an extra obstruction needs to be in placed to prevent construction workers form falling between the upper and lower obstruction. The ARBO does not give an exact number. According to scaffolding construction manuals like (Holland Solar, 2015. Veilig werken op daken) this obstruction needs to be at 0,62 meters from the top of the floor slab. This creates the third rule for situation 1:

1.3 Is there a fixed object over the length of the edge of the floor slab at a height of 0,62 meter from the top of the floor slab?

In situation 1 it is not certain that one rule rules-out one or multiple of the other rules. This means that an obstruction at 1.00 meters does not mean there is an obstruction below. This results in that all the rules need to be checked to make sure all the risks are taken. This is especially the case for kicking items over the edge. In table 3.2 the rule set of situation 1 is summarized. In the last column the reference for the dimensions in the rule set is shown. Figure 3.4 give a schema of situation 1.

Note that: if the model fails at multiple rules it does not mean a separate prevention needs to be made for every rule. There are fall preventions in existence which resolve multiple fall hazards.

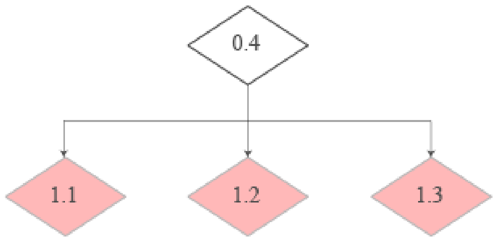


Figure 3.4 | Schema situation 1

Number	Description	Reference
1.1	Is there a fixed object over the length of the edge of the floor slab reaching from the top of the floor slab to a height of minimal 0,15 meter?	'ARBO'
1.2	Is there a fixed object over the length of the edge of the floor slab at a height of 1,00 meter from the top of the floor slab?	'ARBO'
1.3	Is there a fixed object over the length of the edge of the floor slab at a height of 0,62 meter from the top of the floor slab?	(Holland Solar, 2015. Veilig werken op daken)

Table 3.2 | Rule set situation 1

Situation 2

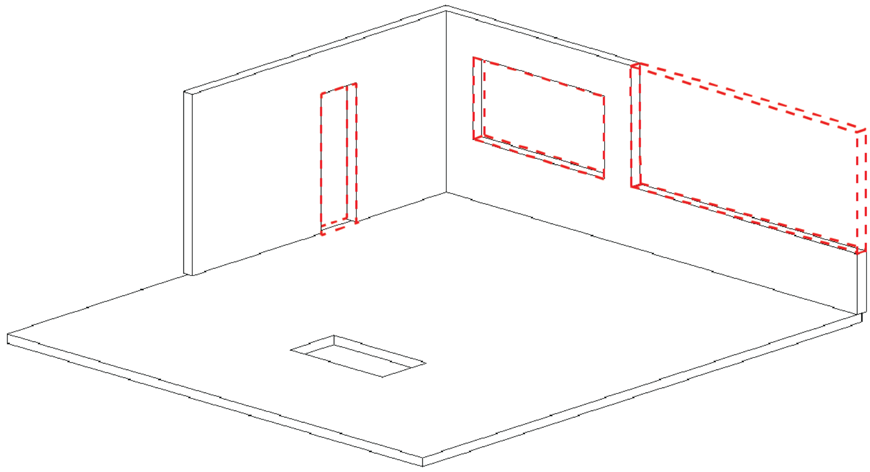


Figure 3.5 | Situation 2

Situation 2 is defined by the edge of the floor slab with a wall element on top of it. The wall element can have one or multiple openings or the wall element might be too low. There are no other floor slabs connected to the edge of the floor slab. In this situation construction workers risk the change of falling through an opening in the wall element or falling over the edge of the wall element. Figure 3.5 gives an indication of a possible unsafe situation that can occur within situation 2.

In this situation the first thing that needs to be checked is if the wall element is high enough to prevent falling over the edge of the wall element. And what type of prevention method needs to be in place if the wall element in not high enough. For this check the same heights are checked for the same reasons as for situation 1. The obstruction in this situation will not be an object but a wall element. The obstruction needs to span over the entire length of the wall element. This creates the following rules for situation 2:

2.1 Has the wall element, over the full length of the element, a height of 1.00 meters from the top of the floor slab?

2.2 Has the wall element, over the full length of the element, a height of 0.62 meters from the top of the floor slab?

2.3 Has the wall element, over the full length of the element, a height of 0.15 meters from the top of the floor slab?

When the first of the rules is answered 'False' it means there is a fall hazard. In combination with rule 2.2 and 2.3 there is determined which fall prevention is needed.

The next thing that needs to be checked is if there is an opening in the wall element. And if this opening is filled. If the opening is filled with for example a window the system will define this as a safe situation. The system assumes that workers cannot fall through a filled opening. This sets the next two rules for situation 2:

2.4 Is there an opening in the wall element?

2.5 Is the opening in the wall element filled?

If rule 2.4 is answered 'True' the system will go on with rule 2.5. If rule 2.5 answers 'True' the system assumes there is no risk of falling through the opening. If 2.4 answers 'False' it will continue with processing the rule sets. When rule 2.5 is answered 'False' this indicates that there might be an unsafe situation where workers can fall.

If rule 2.5 is answered 'False' the width of the opening needs to be checked. If the opening in the wall element is less than 0,3 meter there is no falling hazard because a construction worker cannot accidently fall through such an opening. This sets the third rule for situation 2:

2.6 Has the opening in the wall element a width of less than 0,3 meters?

If the width of the opening in the wall element is more than 0,3 meters, rule 2.6 is answered 'False', this indicates there might be a fall hazard. Just like in the first situation, an obstruction needs to be placed at several height to secure that no construction workers can accidentally fall through the opening in the wall element. The heights of the rules for the obstruction in situation 1 are the same as for the obstruction in situation 2. This leads to the following set of rules:

2.7 Is there a wall element over the length of the opening at a height of 0.15 meter from the top of the floor slab?

2.8 Is there a wall element over the length of the opening at a height of 0.62 meter from the top of the floor slab?

2.9 Is there a wall element over the length of the opening at a height of 1.00 meter from the top of the floor slab?

In table 3.3 the rule set of situation 2 is summarized. In the last column the reference for the dimensions in the rules are shown. Figure 3.6 gives a schema of situation 2.

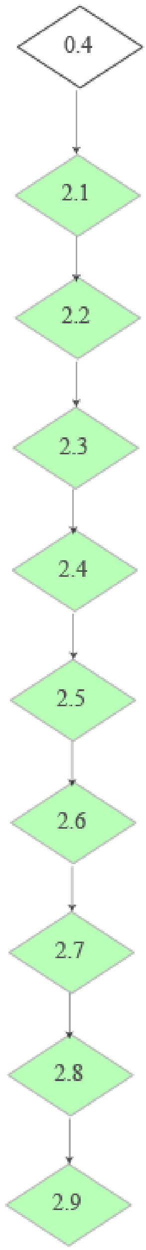


Figure 3.6 | Schema situation 2

Note that: if the model fails at multiple rules it does not mean a separate prevention needs to be made for every constrain. There are fall preventions in existence which resolve multiple fall hazards.

Number	Description	Reference
2.1	Has the wall element, over the full length of the element, a height of 1.00 meters from the top of the floor slab?	'ARBO'
2.2	Has the wall element, over the full length of the element, a height of 0.62 meters from the top of the floor slab?	(Holland Solar, 2015. Veilig werken op daken)
2.3	Has the wall element, over the full length of the element, a height of 0.15 meters from the top of the floor slab?	'ARBO'
2.4	Is there an opening in the wall element?	
2.5	Is the opening in the wall element filled?	

2.6	Has the opening in the wall element a width of less than 0,3 meters?	'QSHE'
2.7	Is there a wall element over the length of the opening at a height of 0.15 meter from the top of the floor slab?	'ARBO'
2.8	Is there a wall element over the length of the opening at a height of 0.62 meter from the top of the floor slab?	(Holland Solar, 2015. Veilig werken op daken)
2.9	Is there a wall element over the length of the opening at a height of 1.00 meter from the top of the floor slab?	'ARBO'

Table 3.3 | Rule set situation 2

Situation 3

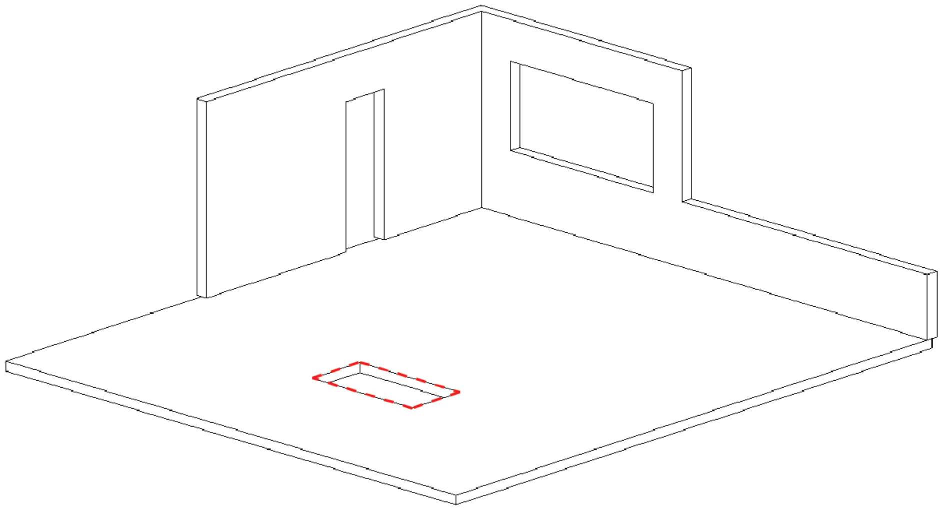


Figure 3.7 | Situation 3

Situation 3 is defined by the edge of an opening in the floor slab. On the inside edges of the floor slab there are no wall elements. If this is the case, the system will flow through to situation 2. It is not possible to have a connecting floor slab to the edge. In this situation construction workers risk falling through the opening in the floor slab and fall several meters down. Figure 3.7 gives a visual example of the situation. A smaller opening, for a duct, will not lead to a construction worker to fall down the opening but may lead the construction worker to trip and injure itself. A bigger opening, for a staircase, can lead to a construction worker to fall down the opening and land several meters below.

Situation 3 begins when rule 0.3 is answered 'True' and rule 0.5 is answered 'False'. This means there is an opening in the floor slab and no wall around. The first thing that needs to be checked within this situation is if the opening is filled. This could be a duct or any other element in the model. If the opening is filled the system will see the situation as save and will continue the with checking for other unsafe situations. This leads to the following rule:

3.1 Is the opening in the floor slab filled?

When rule 3.1 is answered 'False' the system flows on to check the dimensions of the opening. As said earlier, situation 3 can be split up in a large opening and a small opening. The fall prevention for both those situations is different. The larger opening will be resolved by safety railings and the smaller opening will be covered by plywood. The maximum span of the plywood is leading in the decision between safety railings or plywood. Therefor the maximum length of the smaller opening is set at 1,00 meters. This leads to the following constraints:

3.2 Is the length of the edge of the opening in the floor slab more than 1,00 meter?

3.3 Is the width of the edge of the opening in the floor slab more than 1,00 meter?

The length is defined as the longest edge. The width is defined as the shortest edge. When they have de same dimensions, the length is defined as the first edge calculated. When rule 3.2 or 3.3 is answered 'True' the opening is seen as large for the system. This means the opening needs to be secured with safety railings. When rule 3.2 or 3.3 is answered 'False' it means the opening is seen as small for the system. The small opening is only a fall hazard if a construction worker can get its foot through the opening. The shortest length of the foot is around the 0,10 meters. This sets the next rules:

3.4 Is the length of the edge of the opening in the floor slab more than 0,10 meter?

3.5 Is the width of the edge of the opening in the floor slab more than 0,10 meter?

In table 3.4 the rule set of situation 3 is summarized. In the last column the reference for the dimensions in the rules are shown. Figure 3.8 gives a schema of the situation.

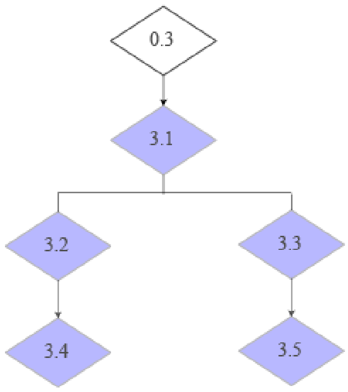


Figure 3.8 | Schema situation 3

Number	Description	Reference
3.1	Is the opening in the floor slab filled?	
3.2	Is the length of the edge of the opening in the floor slab more than 1,00 meter?	'QSHE'
3.3	Is the width of the edge of the opening in the floor slab more than 1,00 meter?	'QSHE'
3.4	Is the length of the edge of the opening in the floor slab more than 0,10 meter?	'QSHE'
3.5	Is the width of the edge of the opening in the floor slab more than 0,10 meter?	'QSHE'

Table 3.4 | Rule set situation 3

Situation 4

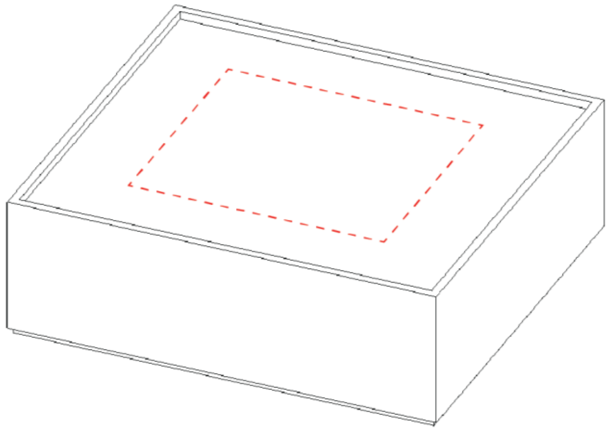


Figure 3.9 | Situation 4

This situation is defined by the roof of the building. A flat roof is defined as a partition structure at the top of a building, between the interior of a building and the surrounding outdoor space, at an angle of at most 15 degrees to the horizontal plane. Figure 3.9 gives a visual example of the situation. According to the ARBO rules working on the roof of a building is a special situation with a different set of rules. The work on the roof can be placing installations, solar panels, etc. Working on the roof means in most cases that there is no protection against the elements of nature. Hard winds contribute an extra risk. That is why working on the roof is always seen as a special situation.

Although the roof is a special situation the rule sets in the first 3 situations also need to be checked to see if there are walls with or without openings and to check if there are openings in the roof for skylights or vents. Although the chance and the number of openings and walls will be in most cases less then by a floor slab, the checks still need to be made. The reason these are separate rules is because they lead to a different fall prevention when work is done at the roof.

The first 3 rule sets (situation 1, 2 and 3) in situation 4 need to be checked to make sure all the unsafe situations are resolved. But in reality, when working on the roof there are usually no permanent obstructions which can prevent fall hazards. So, construction workers risk falling accidently from the edge of the roof when working near the edge. That is why in the area of 2.00 meters parallel to the roof, only the necessary work can be done if there is no alternative. 2.00 meters parallel to the edge of the roof a physical obstruction needs to be placed to indicate the area where construction workers can and cannot do their work. This obstruction needs to be 1.00 meters high. If it is necessary to work within the 2.00 meter area, extra fall prevention needs to be at place (SBD, 2014). An area of 4.00 meters also needs to be marked with a visible obstruction. Within the 4.00 meter area normal construction work can be done. This leads to the following rules:

4.1 Is there parallel to the edge of the roof a physical obstruction at a distance of 2.00 meters?

4.2 Is there parallel to the edge of the roof a visible obstruction at a distance of 4.00 meter?

When rule 4.1 is answered 'False' a physical obstruction needs to be place around the 2.00 meter area. When rule 4.2 is answered 'False' a visible obstruction needs to be places around the 4.00 meter area. This could be done by a set of poles and chain to indicate the area.

In table 3.5 the rule set of situation 3 is summarized. In the last column the reference for the dimensions in the rules are shown. Figure 3.10 gives a schema of the situation.

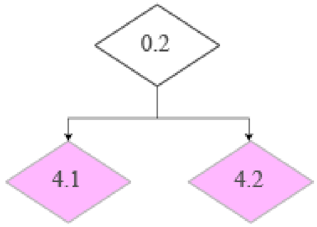


Figure 3.10 | Schema situation 4

Number	Description	Reference
4.1	Is there parallel to the edge of the roof a physical obstruction at a distance of 2.00 meters?	'SBD'
4.2	Is there parallel to the edge of the roof a visible obstruction at a distance of 4.00 meter?	'SBD'

Table 3.5 | Rule set situation 4

3.4.2. Requirements to the data representation

In the previous chapter the safety rules and best practice of the QHSE department were translated into rule sets which can be used by the fall hazard prevention system. Before a computer program can read these constraints, it is needed to see what type of data is needed to recognize the different building elements and the relationship between the different building elements. This chapter focusses on the question: What kind of data is needed to recognize the building elements and their relationship towards other building elements. Before analysing the data file itself and determining how building elements are modelled within the data file, there is analysed what the ideal method is to structure the data and determining what is required in the data to let the fall hazard prevention system work properly. In the next paragraph there is looked at a data type, developed by BuildingSmart as the new industry standard the Industry Foundation Classes, to see which of these requirements are already there. This data type is the ISO which is used for representing solid elements in CAD tools. First a short introduction of the ISO is given.

The International Organization for Standardization (ISO) has developed conceptual schemas for describing and manipulating the spatial characteristics of geographic features. These standardizations are the cornerstone for other geographic information standards. ISO is a worldwide federation of national standards bodies. A feature is an abstraction of a real world phenomenon, it is a geographic feature if it is associated with a location relative to the Earth. Vector data consists of geometric and topological primitives used, separately or in combination, to construct objects that express the spatial characteristics of geographic features. Raster data is based on the division of the extent covered into small units according to a tessellation of the space and the assignment to each unit of an attribute value (ISO, 2009).

Within the digital environment of the AEC sector spatial characteristics are described by one or more spatial attributes whose value is given by a geometric object or a topological object. Geometry provides the means for the quantitative description, by means of coordinates and mathematical functions, of the spatial characteristics of features, including dimension, position, size shape and orientation. The mathematical functions used for describing the geometry of an object depend on the type of coordinate reference system used to define the spatial position. Geometry is the only aspect of geographic information that changes when the information is transformed from one geodetic reference system of coordinate system to another (ISO, 2009). Topology deal with the characteristics of geometric figures that remain invariant if the space is deformed elastically and continuously. Within the context of geographic information, topology is commonly used to describe the connectivity of an n-dimensional graph, a property that is invariant under continuous transformation of the graph. Computational topology provides information about the connectivity of geometric primitives that can be derived from the underlying geometry (ISO, 2009). Geometric primitives are non-decomposed objects that present information about geometric configuration. They include points, curves, surfaces, and solids. Topological primitives include vertexes, edges, faces. Or easier said: Geometric data represents the individual properties (e.g., location and dimension) of building elements; however, topological data denotes spatial relationships among the building elements comprising connection, adjacency, containment, separation, and intersection (Nguyen, Oloufa, & Nassar, 2005).

Within the domain of geometric, topological or a combination of the two, in solid modelling and computer aided design, there are several ways to model building elements. The most used are Boundary Representation (B-Rep), Compound Solid Geometry (CSG) and swept geometry (sweeping volume) (Tobiáš, 2015). B-Reps are constructed with the main topological primitives. In CSG, simple primitives are combined by means of regularized Boolean set operators that are included directly in the representation (Foley, van Dam, Feiner, & Hughes, 1996). The sweep volume is a solid modelling technique which extrudes a predefined profile of face along a predefined path. In figure 3.11 the B-Rep, CSG and the sweep volume are shown visually.

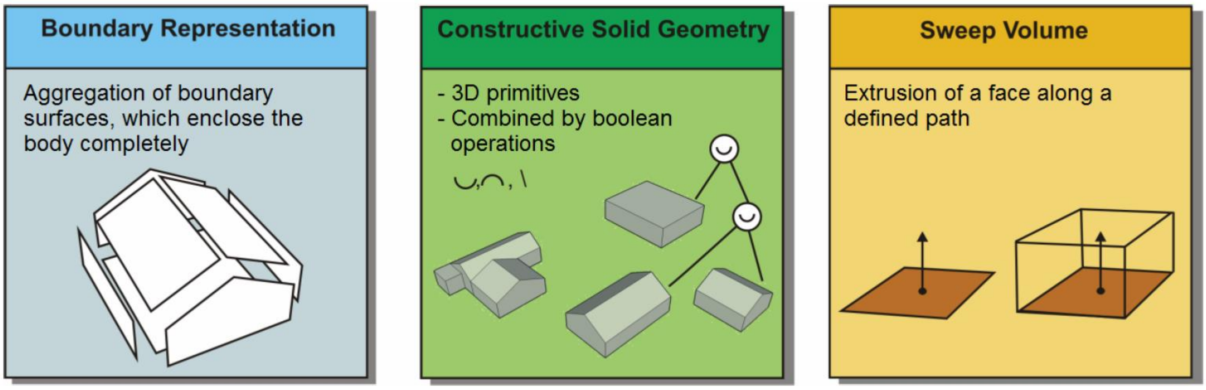


Figure 3.11 | visual representation of B-rep, CSG and Sweep volume (Tobiáš, 2015)

Before deciding how the building elements need to be modelled within the computational environment, there needs to be determined which building elements are important for the fall hazard prevention system and needed to be recognized in the data representation. When looked at the rule sets from the previous chapter. The general rule set (0.1, 0.2, 0.3 and 0.5) immediately gives the first four elements that need to be recognized. A floor slab (0.1), a roof element (0.2), an opening (0.3) and a wall element (0.5). Within the first situation it becomes a little more abstract. For the rules in the first situation an object needs to be recognized (1.1, 1.2, 1.3).

Let's start with the first building elements from the general rule set: the floor slab, the roof element and the wall element. When looked at the simplified geometry of a floor slab and a roof element it is nothing more than a flattened cube. The cube has six faces, eight corners and twelve edges. The length and the width are roughly said around the 3 to 20 meters and the thickness is around the 0,30 and 0,50 meters. This definition of a floor slab and a roof element is a little bit too simplistic because the profile of the floor slab and the roof element is in most cases not just a square. So, a better definition would be a 2-dimensional profile with a thickness. This suggest the sweeping volume method is the best choice for modelling a floor slab. Although the B-rep method can give the same visual result. As for the CSG, floor slabs and roof elements are not combined by different objects. As for the wall element the same simplification can be made. In this case the height and the length are the longest dimensions. Although these are the longest dimension it is not the most influential dimension. The path the wall element takes is defined in the horizontal plane. So just like with the floor slab and the roof element a profile is defined and then given a height. The choice between how these building elements are needed to be modelled depends on how the relationship between other building elements is made and the way the building elements can be found in the Euclidean space. The B-rep is constructed of the topological primitives. Vertexes relate to a coordinate. An edge is made by de distance between two vertexes. And a face is made by the connection of several edges. So, every corner of a solid made by a B-rep has a vertex so every corner has a coordinate. This contrasts with the Sweeping volume which has only one coordinate. The sweeping volume is made by setting one point in the Euclidean space with a coordinate. From this point a profile is drawn with a direction to create a surface. This surface is extruded along a predefined profile to create a 3-dimensional geometry. For a sweeping volume only one coordinate is given in the data representation. To get the remaining coordinates just a simple algorithm is needed to calculate the coordinates from the profile definition. So far for recognizing these building elements based on coordinate placement, which will not make a difference.

Maybe the relationship between the topological and geometrical primitives can suffice in a method to recognize the different building elements. When looked at the B-rep, a building element can be modelled as a wireframe with vertexes and edges. The length of the edges can define the difference between the wall element and the floor slab and roof element. When the edges in the z direction are longer then the edges in the x or y direction this suggests the element is a wall element and vice versa if the edges in the x or y direction are longer than the z direction it suggest there is a floor slab of roof element. This still leaves the difference between a floor slab and a roof element unresolved. Looking at the third primitive, the faces, the same conclusion can be made when analysing the relationship between the sizes of the faces. An alternative view at the relationship between these primitives is analysing the angle between them in the building element. But the statement that it is one of the building elements when they make an angle of 90 degrees will not resolve the question of which of these building elements. Overall there can be concluded that the geometrical relationship between the primitives will not indicated which building element it is. The topological relationship will also not indicate the difference between the building elements because topology deal with the characteristics of geometric figures that remain invariant if the space is deformed elastically and continuously.

The situation gets even worse when the question for how to recognize an opening comes to the table. When an opening is simplified like the other building elements, it only adds more topological and geometrical primitives to the model. In the B-rep this only gives more vertexes, edges and faces. The sweeping volume method can suffice in making an opening in floor slabs and roof elements by setting the profile of the opening in the profile of the floor slab or roof element and not extruding the opening profile with the rest. But this method will not suffice in the wall element because the opening is in a different direction as the wall element is extruded. When looked at the method of CSG and the opening, there could be a solution. If an opening is modelled as an element on its own the opening could be subtracted from the other building elements. So, the first requirement is to model an opening as an element on its own.

Req. 1. An opening within a building element needs to be modelled as a separate element.

This still not answers the question about how to recognize the building elements. The only way these building elements can be recognized as the right building element is to label or somehow define the geometry as the building element. This makes the second requirement to the data model:

Req. 2. All geometry which refers to an element should be defined as such in the data model.

Now there is a way to recognize the building elements and an opening within the building elements the dimensions of these elements need to able to be retrieved. Most of the rule sets depend on the dimensions of the building elements. As said earlier for the B-rep and the Extruded Volume, the dimension can be calculated with an simple algorithm (Khalili et al., 2015). In the case of a few elements this would not be a problem. But within a building model there could be hundreds or even thousands of different elements with a geometric representation. Although it is a simple algorithm, preforming it on all the building elements in the model would make the system slower. It also creates the chance of making a mistake in calculating the dimensions. It would be more efficient to have a list of the coordinates for the building elements in the data representation.

Req. 3. The representation of a building element within the data needs to include a list of the coordinates.

One of the most important information the system needs is to recognize the relationship between the different building elements. The system needs to be able to recognize if wall elements, floor slabs and roof elements are connected or not. And if an opening element is within another building element. In other words, the system needs to be able to recognize the different topological relationship between the elements. In the beginning of the chapter different topological relationships were defined as: connection, adjacency, containment, separation, and intersection. A connection is when a topological primitive is shared by more than one building element. A containment can be split into two types: partially touched and fully contained. Fully contained is when the closed shell of two objects is the same. Partially touched is when some, at least one, of the topological primitives are the same. Separation is when none of the topological primitives are the same. The intersection relationship identifies if two different spaces intersect one another by means of their faces or edges (Khalili et al., 2015). Adjacency is a too vague concept to use within the fall hazard prevention system and will not be further explained.

With these relationships between building elements, there can be defined if wall elements, floor slabs or roof elements are connected. When building elements share a face, edge of vertex there is connectivity between the building elements. When there are one or more shared topological primitives of the building elements then there is talk of partially touched. When there is separation between the building elements there is no useful relationship for the system. The intersection relationship allows the system to check if elements clash.

The relationship between an opening element and another building element is a containment. The opening element is inside the wall element, floor slab or roof element. To define if a floor slab or a roof element is connected to another floor slab or roof element an edge or a face needs to be shared. To see if a wall element has a relationship with a floor slab or a roof element, an edge or a face needs to be shared. It could also be that the face or edge from the floor slab or roof element is partially touched by the wall element. Figures 3.12, 3.13 and 3.14 gives a visual representation of the topological relationships and how they define the different relationships between the different building elements.

When a building element has one or more of these topological relationships with another building element the building element should be analysed to see if it influences the fall prevention. This reduces the amount of building elements that need to be analysed so the system can operate faster, instead of analysing all the building elements with each other. This sets the next requirement:

Req. 4. In the data file the topological relationship between building elements should be defined.

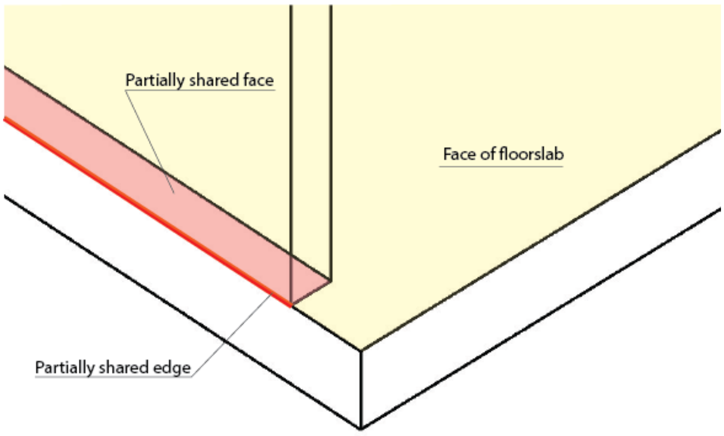


Figure 3.12 | Visual representation of partially shared edge

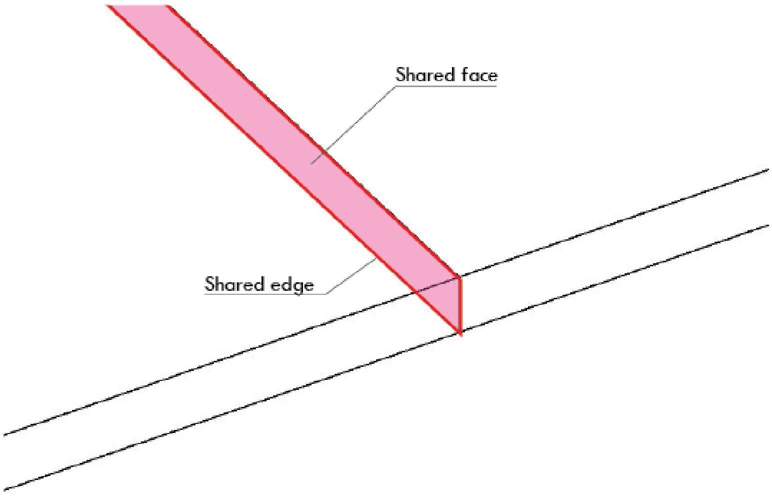


Figure 3.13 | Visual representation of shared edge

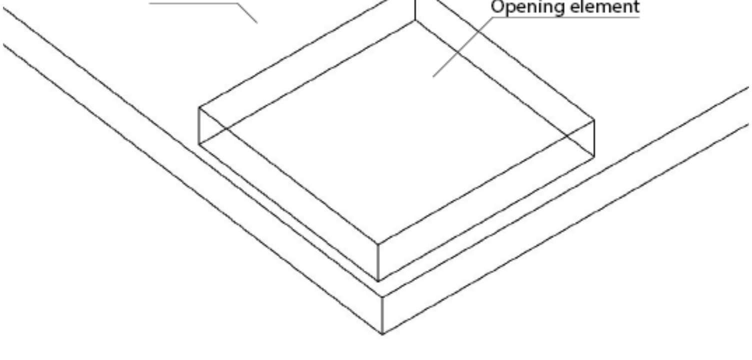


Figure 3.14 | Visual representation of containment

The method of analysing the topological relationships between building elements gives a way to determine if walls are on floor slabs or roof elements and if there are connected floor slabs or roof elements. It also allows a way to determine if an opening element is in another building element. The topological relationships are based on the topological primitives. This means that building elements need to be modelled as a B-rep of the solid model. There are algorithms that transform the Swept volume to a B-rep (Khalili et al., 2015; Wu & Hsieh, 2007) as in figure 3.15.

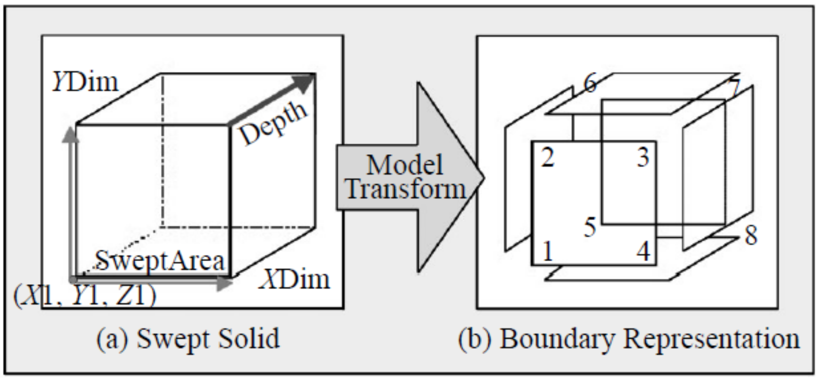


Figure 3.15 | Visual representation of algorithm swept solid to B-rep (Wu & Hsieh, 2007)

Req. 5. The building elements need to be modelled as B-reps in the data file.

Maybe one of the most abstract rules are in situation 1, rule 1.1, 1.2 and 1.3. These rules check for a fixed object at a certain height. The definition of a fixed object is ratter vague. This rule is set up in the situation where there are no walls. So, a fixed object can be almost anything except for a wall. During the design phase there are a selective amount of object that can be defined in the BIModel. So, the system can only look for these objects, for example: railing, ducts, HVAC equipment. But to search for all the available types of object will make the system slow and inefficient. Therefor the previous requirements of the data representation are needed. If an object has a relationship with the floor slab or the roof element the specific object can be checked. To search for the specific object the object should be defined as the right object.

In situation 2 and 3 there is a constraint that checks if an opening is filled (constraint 2.5 and 3.1). The first requirement states that an opening must be modelled as a separate element on its own. This allows, with the help of requirement 4, to check if the opening is filled. If a duct runs through the opening there is an intersection relationship. Or if a window is in an opening in the wall there is a connectivity relationship. Table 3.6 gives a list of the requirements.

Number	Description
Req. 1.	An opening within a building element needs to be modelled as a separate element.
Req. 2.	All geometry which refers to an element should be defined as such in the data model.

Req. 3.	The representation of a building element within the data needs to include a list of the coordinates.
Req. 4.	In the data file the topological relationship between building elements should be defined.
Req. 5.	The building elements need to be modelled as B-reps in the data file.

Table 3.6 | Requirements to the data representation

3.4.3. Comparing the requirements

In the first part of this chapter the rules were analysed to set up requirement for the data file. These rules are summarized in table X. In the next part the requirements are compared to the IFC 4 data type. The IFC 4 is the latest version of the open standard developed by BuildingSmart. There is looked if the IFC 4 satisfies the requirement, so the fall hazard system can work as efficient as possible. If a requirement is satisfied by the IFC 4 there will be explained how. If a requirement is not satisfied by the IFC 4 there will be advised to adopt these changes in upcoming versions of the open standard. The IFC 4 has two MVDs, the Reference View and the Design Transfer View. After all requirements are evaluated the MVD with the best fit will be chosen. A quick overview of the MVDs is given in figure 3.16. These requirements are not only helpful for the fall hazard system developed in this report. In many others analysing tools developed for the AEC sector, these requirements help the development and workflow of these tools. For example Energy performs tools, Mold optimization tools and Emergency response tools (Khalili et al., 2015; Lee et al., 2014)

comparison of the objectives and target work flows	
IFC4 Reference View	**IFC4 Design Transfer View**
goals	
▪ satisfy the referencing work flow, i.e. the result of the import is a "read-only" (not modifiable)	▪ satisfy the handover work flow, i.e. import for further editing (import into native elements)
scenario includes	
▪ background reference ▪ clash detection ▪ any viewer based work flow	▪ takeover architecture in structural ▪ import spaces into MEP ▪ takeover a previous design
expected user experience	
▪ ownership remains with the sender ▪ frequent updates ▪ fast export / import times ▪ 100% validity, no rework expected	▪ ownership handed over to receiver ▪ low frequency, sometimes "one of" ▪ longer export / import time tolerable ▪ some rework accepted, if limitations well known

Figure 3.16 | Short overview of the difference between reference view and design transfer view (http://www.buildingsmart-tech.org/specifications/ifc-view-definition/ifc4-reference-view/comparison-rv-dtv)

Req. 1.

The opening element stands for opening, recess or chase, all reflecting voids. It represents a void within any element that has physical manifestation. Openings can be inserted into walls, slabs, beams, columns, or other elements. The IFC specification provides two entities for opening elements: IfcOpeningStandardCase is used for all openings that have a constant profile along a linear extrusion. They are placed relative to the voided elements and the extrusion direction is perpendicular to the plane of the element (horizontally for walls, vertically for slabs). Only a single extrusion body is allowed. It cuts through the whole thickness of the voided element, i.e. it reflects a true opening. IfcOpeningElement is used for all other occurrences of openings and for niches or recesses. The 'Body' representation of IfcOpeningElement can be represented using the representation types 'SweptSolid', and 'Brep'. In figure 3.17 a visual representation of how an opening in a wall is modelled. The description above mentions that an opening is modelled as a separate element on its own. Requirement 1 is satisfied by the IFC 4.

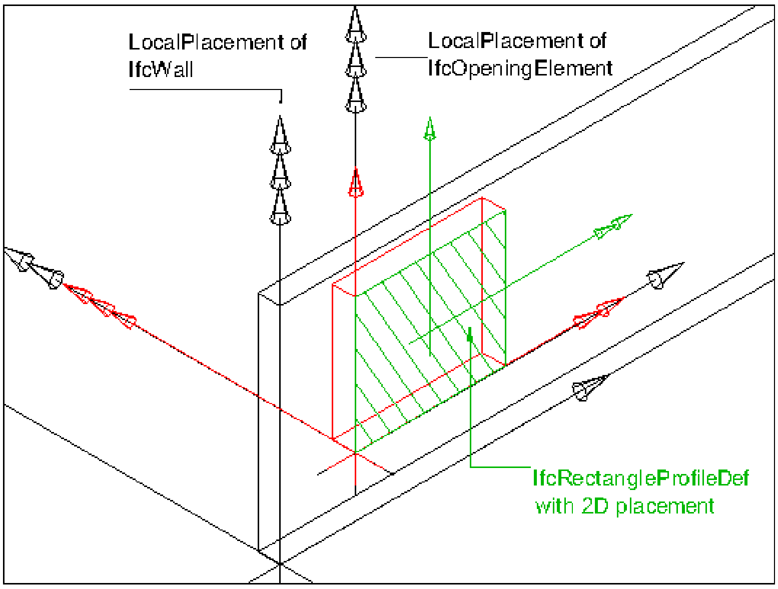
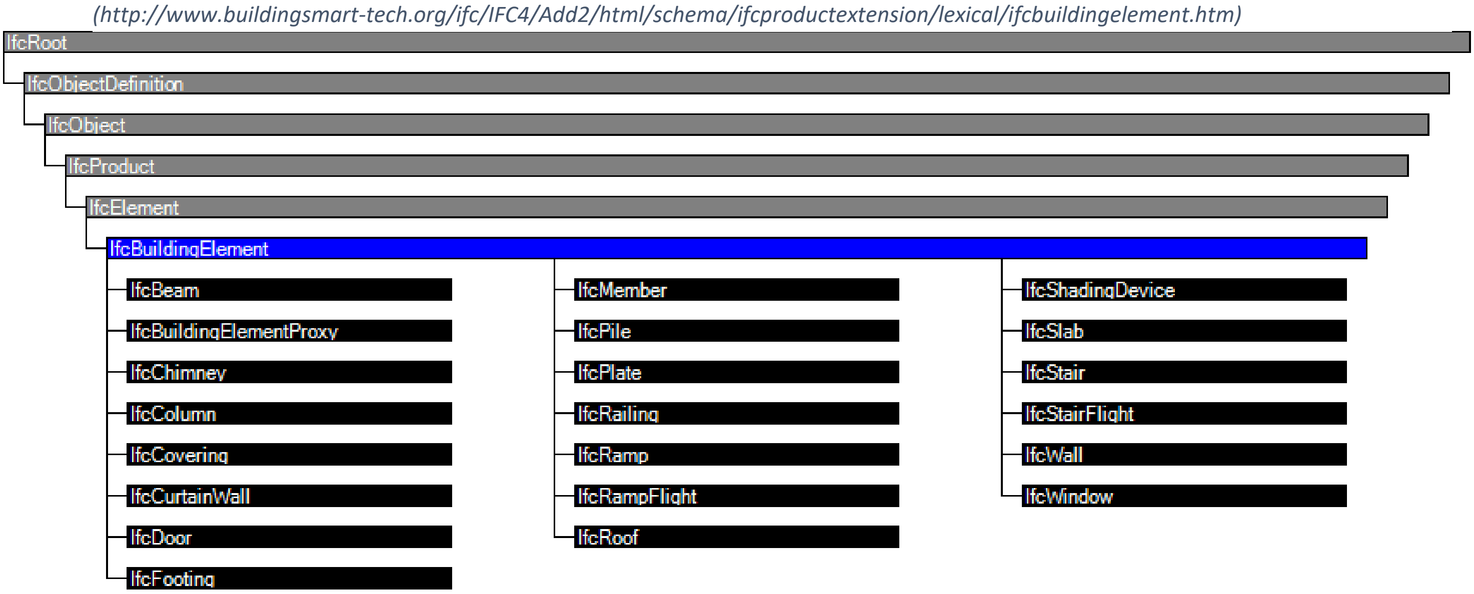


Figure 3.17 | Visual representation of opening in wall element (http://www.buildingsmart-tech.org/ifc/IFC4/final/html/schema/ifcproductextension/lexical/ifcopeningelement.htm)

Req. 2.

In the literature review there is mentioned the use of the Basic Dutch IDM (Nederlandse basis ILS). According to this IDM, building elements need to be modelled as the correct building

Figure 3.18 | Possible IfcBuildingElement entities (http://www.buildingsmart-tech.org/ifc/IFC4/Add2/html/schema/ifcproductextension/lexical/ifcbuildingelement.htm)



element. When this is done correct in the BIM altering tool the IFC 4 data file will refer to these building elements as an IFCBuildingElement. The building element comprises all elements that are primarily part of the construction of a building, i.e., its structural and space separating system. Building elements are all physically existent and tangible things. In figure 3.18 the entity inheritance is shown. It shows all the subtypes of the IfcBuildingElement. When a floor slab is modelled in a BIM altering tool, the IFC 4 will refer to the floor slab as IfcSlab with a specific ID. As so for all the other building elements shown in figure 3.18. When the modeller sticks to the Basic Dutch IDM the second requirement is satisfied.

In the first situation the fall hazard prevention system searches for an object. As said earlier this can be a railing or a duct. In figure 3.18 it shows the possible object that the system can check for. Building elements that are not defined as an IFC building element are subtypes of IfcBuildingElementProxy.

Req. 3.

The IFC 4 works with the righthanded cartesian coordinated system. Each cartesian point is provided as a three-dimensional point by a fixed list of three coordinates. In the IFC4 data file there is an extra method for representing a geometry beside the B-rep, CSG and Sweeping Volume. This is the Tessellated geometry. All surfaces are divided in a triangulated face set, which means that between the vertexes triangles are made. In figure 3.19 a visual example of a Tessellated geometry is given. A list of all the triangles are represented in the IFCTRIANGULATEDFACESET. The coordinates of these triangles, the coordinates of the vertexes, are listed in the IFCCARTESIANPOINTLIST3D. The IFCCARTESIANPOINTLIST3D is also used to list the points in a point cloud. For the geometric representation of solid models, the IFCCARTESIANPOINTLIST3D is only used by the Tessellated geometry. So, the ability to create a list of all the coordinates is possible but is not supported in all the solid models. This means that requirement 3 is partially met.

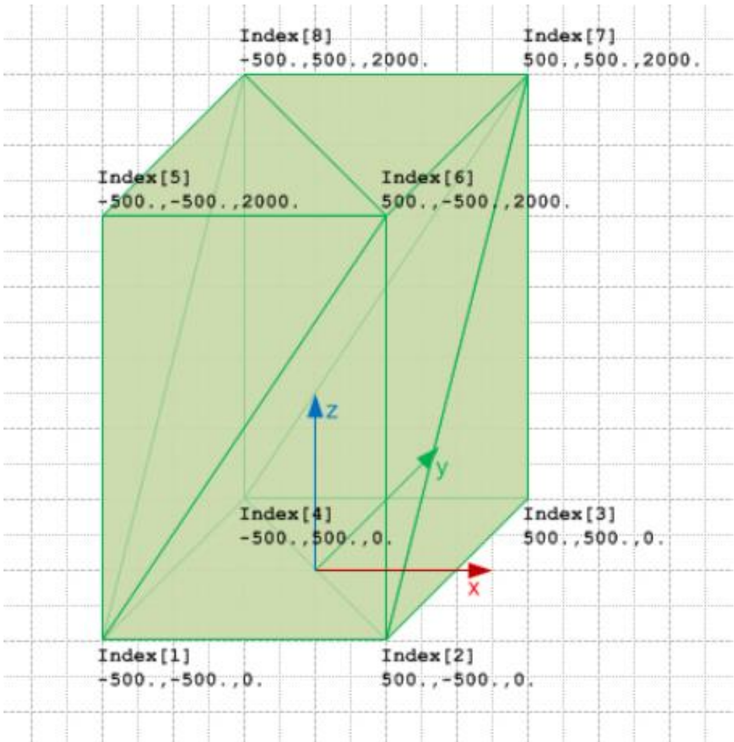


Figure 3.19 | Example of tesselated cube (http://www.buildingsmart-tech.org/ifc/IFC4/final/html/annex/annex-e/tessellation.htm)

Req. 4.

Besides the topological/geometric representation of 3D objects, the IFC model contains predefined relationships between objects. Two topological relationships, Connectivity and Assignment, have been used to reduce the pairwise comparison of 3D objects, to reduce computation time. These are defined in the IfcRelation entity within IfcProduct (Khalili et al., 2015). An IfcRelConnectsElements provides a one-to-one connectivity relationship between physical and virtual connected element. IfcRelConnetsPathElement provides a one-to-one connectivity relationship between two elements, which have path information (Khalili et al., 2015). With these two relationships a connectivity between building elements can be described. Within the attributes the two IfcElements are connected. Within the IFC4 MVDs the IfcRelation entity is not supported by the Reference View. Within in the Design Transfer View this relationship is not always given. In order to let the fall hazard system work efficient this relationship must be given to every IfcElement.

Another set of sub entities of IfcRelation are the IfcRelVoidElement and the IfcRelFillsElement. IfcRelVoidsElement specifies the one-to-one relationship between an element and one opening element that creates a void in the element. IfcRelFillsElement provides a one-to-one relationship between an opening element and a building element that fills (or partially fills) the opening element (Khalili et al., 2015). With these relationships there can be checked if building elements have a relationship with an opening, and if the opening is filled. When an opening is put in a data file these relationships are automatically made. An opening element always has a relationship with a building element. If the opening is filled the building element in the opening always has a relationship with the opening. As for requirement 4, the connectivity relationship part is possible but not automatically put in the data file. The opening part of the requirement is met. Requirement 4 is partially met.

Req. 5.

Within the IFC4 MVDs the B-rep is only supported in the Design Transfer View. Within this MVD the entity for the B-rep is the IfcManifoldSolidBrep. The IfcManifoldSolidBrep has two subtypes: the IfcAdvancedBrep (figure 3.21) and the IfcFacetedBrep (figure 3.20).

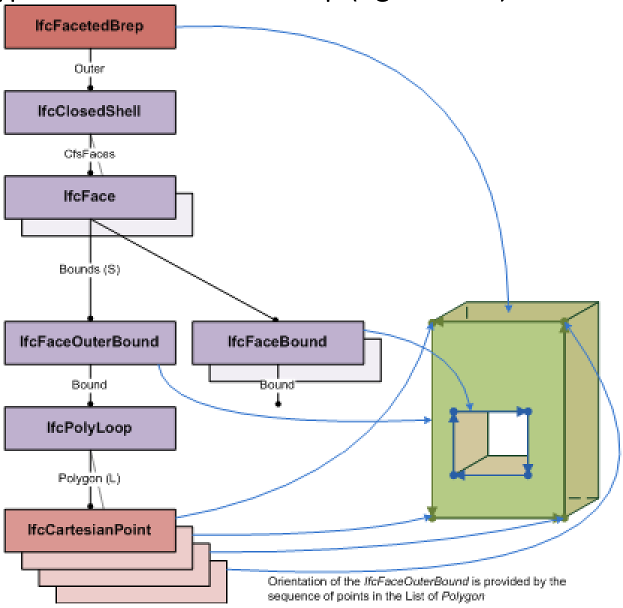


Figure 3.20 | Schema of IfcFacetedBrep (http://www.buildingsmart-tech.org/ifc/IFC2x4/rc2/html/schema/ifcgeometricmodelresource/lexical/ifcfacetedbrep.htm)

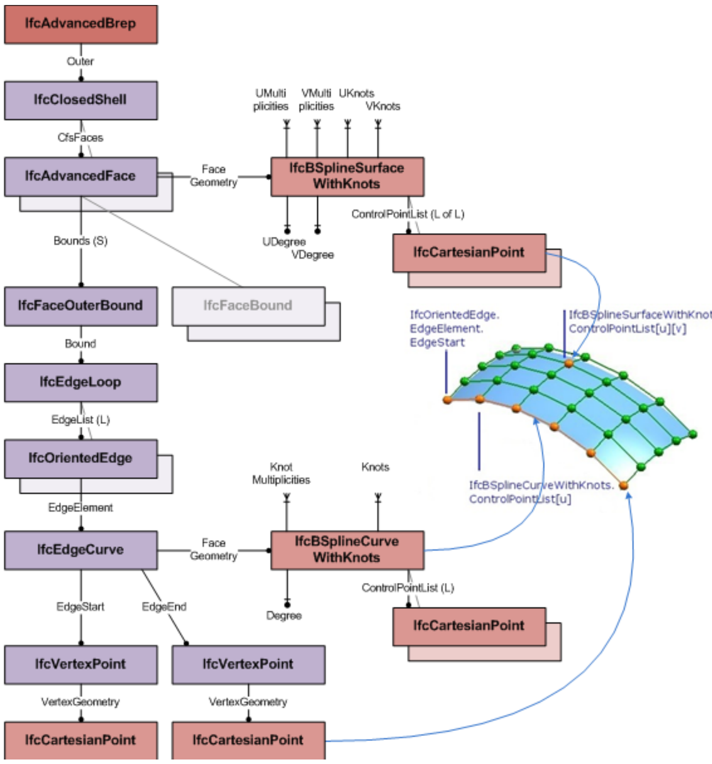


Figure 3.21 | Schema of IfcAdvancedBrep (http://www.buildingsmart-tech.org/ifc/IFC4/final/html/schema/ifcgeometricmodelresource/lexical/ifcadvancedbrep.htm)

Although it is possible to represent a solid model as a B-rep in the data file, a standard case wall, flat roof or floor slab is modelled as a sweeping solid. To meet requirement 5 a standard case building element needs to be modelled as a B-reps instead of Sweeping Volume.

In this chapter the rule sets of the previous chapter are evaluated. The topological and geometric approach towards solid geometry resulted into five requirements for the data model. The IFC 4 data file has two MVDs, the Refence View and the Design Transfer View. The first two requirements have no influence on which MVD is the best choice for the fall hazard prevention systems and the development of other BIM tools. The third requirement askes for a list of all the coordinates. Within solid model representation only the Tessellated representation is supported by a list of all the 3D Cartesian points. The Tessellated representation is supported in both the MVDs. The fourth requirement askes to define the relationships between the building elements. In the IFC4 data file this is done by the IfcRelation entity. The IfcRelConnectsElement entity is only supported by the Design Transfer View. Although the IfcRelation entity is supported by the Design Transfer View, not all building elements are given the relationship they have in the data file. The last requirement askes that building elements are modelled as a B-rep in the data file. Within IFC 4 the B-rep is named IfcManifoldSolidBrep. This entity is only supported within the Design Transfer View. The Refence View uses the Tessellated representation for solid models. When in the BIM CAD tool a standard case building element is modelled and exported to an IFC 4, the building elements are represented as a Sweeping Solid.

Because some of the requirement are not supported by the IFC4 Reference View, the IFC4 Design Transfer View is the best choice for the fall hazard prevention system and other BIM tools. There are still some recommendations for the development of the IFC file type so this system, but also others can work more effectively and efficient. These are: (1) All geometric representations need to contain a coordinate list; (2) All building elements need to have defined all the topological relationships with other building elements; (3) All building elements need to be represented as a B-rep.

3.4.4. Obtaining dimensions

Somewhere in the process the system needs to obtain the building elements dimensions to determine if a building element is high enough or near or connected to another building element. Because the recommendations given in the previous chapter are not yet satisfied in the current IFC4 file the system needs to work a little different. It is still possible to obtain the dimension without the recommendations, but it will be less efficient. In this chapter there will be shown how the fall hazard prevention system obtains the dimensions and relationship info of a building element. The file used is an IFC 4 file exported with the Design Transfer View. This means that the building elements are modelled as a Sweeping Solid. Where it is possible the dimensions and relationships of the building elements are also determined according to the requirements set in the previous chapter. First the dimensions and the local placement of the building elements are discussed. Next the dimensions and local placement of an opening element is discussed. After that the relationship between building elements and opening elements are discussed.

Dimensions building elements

IfcSlab (IfcRoof)

A geometric representation of a floor slab is defined within an IFC4 data file as an IfcSlab. The IfcSlab has the following attributes: Globalid, OwnerHistory, Name, Description, ObjectType, ObjectPlacement, Representation, Tag, and PredefinedType. In this order. This is shown in figure 3.22. The geometric representation of a roof element is made by the IfcSlab is made. The IfcRoof refers to an IfcSlab.

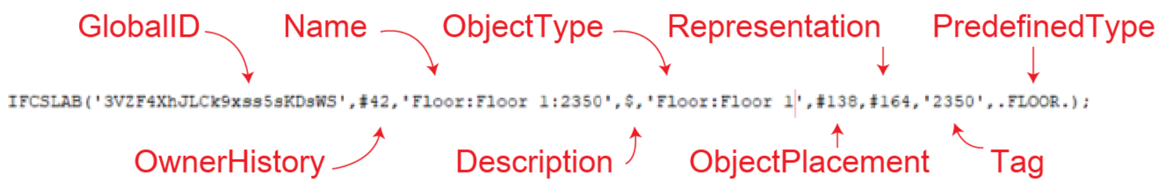
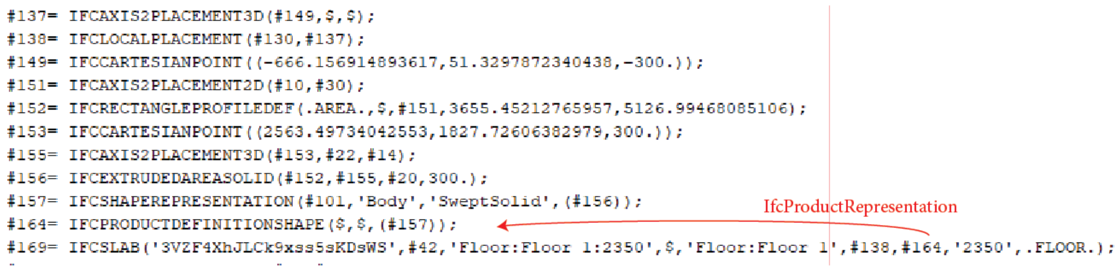


Figure 3.22 | IfcSlab entity with attributes

The IfcProductRepresentation, in figure x indicated with #164, defines a representation of a product, including its geometric or topological representation. A product can have zero, one or many geometric representations, and a single geometric representation can be shared among various products using mapped representations. The IfcProductRepresentation has an IfcReprecentation, as shown in figure 3.23, which defines the general concept of representing product properties and in particular the product shape.



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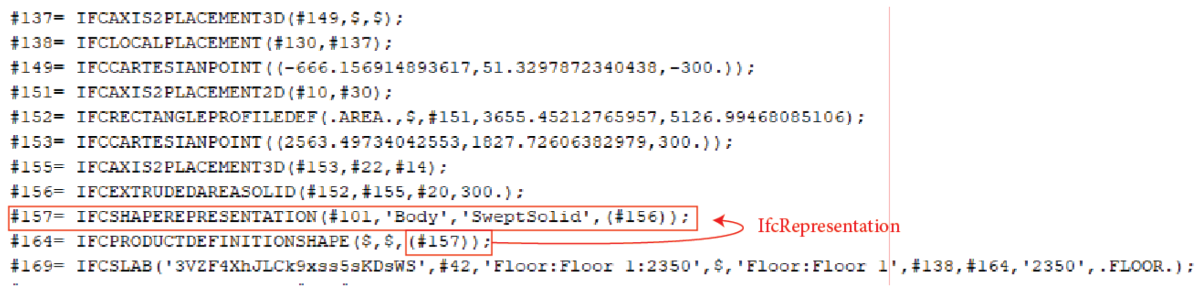
#138= IFCLOCALPLACEMENT(#130,#137);
#149= IFCCARTESIANPOINT((-666.156914893617,51.3297872340438,-300.));
#151= IFCAXIS2PLACEMENT2D(#10,#30);
#152= IFCRECTANGLEPROFILEDEF(.AREA.,$,#151,3655.45212765957,5126.99468085106);
#153= IFCCARTESIANPOINT((2563.49734042553,1827.72606382979,300.));
#155= IFCAXIS2PLACEMENT3D(#153,#22,#14);
#156= IFCEXTRUDEDAREASOLID(#152,#155,#20,300.);
#157= IFCSHAPEREPRESENTATION(#101,'Body','SweptSolid',(#156));
#164= IFCPRODUCTDEFINITIONSHAPE($,$,(#157));
#169= IFCSLAB('3VZF4XhJLCk9xss5sKDsWS',#42,'Floor:Floor 1:2350',$,'Floor:Floor 1',#138,#164,'2350',.FLOOR.);
```


Figure 3.23 | IfcProductRepresentation IfcSlab

Each representation has either an IfcShapeRepresentation or an IfcTopologyRepresentation. This is defined in the IfcRepresentationItem, in figure 3.24 indicated with #157. This model has an IfcShapeRepresentation. In figure 3.24 it shows that this floor slab is represented with a 'SweptSolid' which refers to the Sweeping Volume representation. The IfcRepresentationItem is an ExtrudeAreaSolid. The profile is made by #152 and extruded.



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#151= IFCAXIS2PLACEMENT2D(#10,#30);
#152= IFCRECTANGLEPROFILEDEF(.AREA.,$,#151,3655.45212765957,5126.99468085106);
#153= IFCCARTESIANPOINT((2563.49734042553,1827.72606382979,300.));
#155= IFCAXIS2PLACEMENT3D(#153,#22,#14);
#156= IFCEXTRUDEDAREASOLID(#152,#155,#20,300.);
#157= IFCSHAPEREPRESENTATION(#101,'Body','SweptSolid',(#156));
#164= IFCPRODUCTDEFINITIONSHAPE($,$,(#157));
#169= IFCSLAB('3VZF4XhJLCk9xss5sKDsWS',#42,'Floor:Floor 1:2350',$,'Floor:Floor 1',#138,#164,'2350',.FLOOR.);
```


Figure 3.24 | IfcRepresentation IfcSlab

With the IfcRectangleProfileDef there is defined that the profile is a rectangle with the dimensions of 3655.45 by 5126.99 millimetres. #153 refers to the placement of the axis where the profile is made within the cartesian space. The two-dimensional profile is extruded in the z-direction. Line #156 creates an extruded area solid with a thickness of 300 millimetre. In figure 3.25 the steps are visualized for the creation of an IfcSlab. It is also possible the profile is defined by a polyline. If this is the case the polyline is drawn between a series of vertexes. These vertexes each have a coordinate.

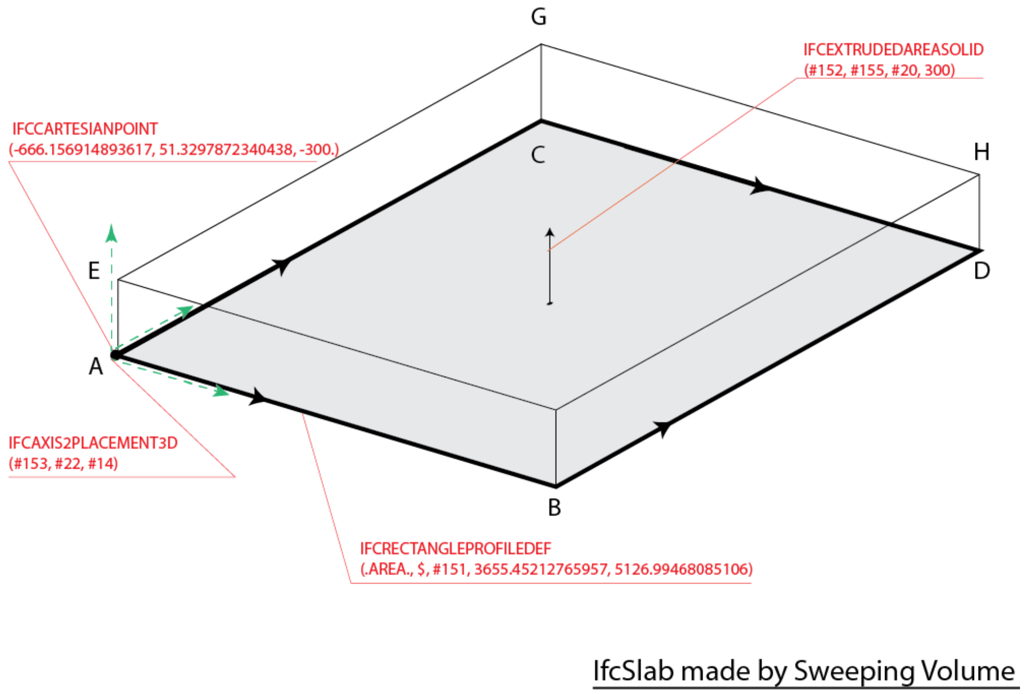


Figure 3.25 | IfcSlab made by sweeping volume

Now that the geometry of the solid building element is made, the coordinates of the corner points and the dimensions can be calculated. In figure x the coordinates of the floor slab are shown. To calculate the coordinates the following calculations need to be made. In table X the coordinates are listed:

Point A = IfcCartesianPoint (-666.16, 51.33, -300)
Point B = Point A + x-direction of the IfcRectangleProfileDef =
((-666.16 + 5126.99), 51.33, -300) = (4460.83, 51.33, -300)
Point C = Point A + y-direction of the IfcRectangleProfileDef =
(-666.16, (51.33 + 3655.45), -300) = (-666.16, 3706.78, -300)
Point D = Point A + x,y-direction of the IfcRectangleProfileDef =
((-666.16 + 5126.99), (51.33+3655.45), -300) = (4460.83, 3706.78, -300)
Point E = Point A + IfcExtrudeAreaSolid.Dim =
(-666.16, 51.33, (-300 + 300)) = (-666.16, 51.33, 0)
Point F = Point B + IfcExtrudeAreaSolid.Dim =
(4460.83, 51.33, (-300 + 300)) = (4460.83, 51.33, 0)
Point G = Point C + IfcExtrudeAreaSolid.Dim =
(-666.16, 3706.78, (-300 + 300)) = (-666.16, 3706.78, 0)
Point H = Point D + IfcExtrudeAreaSolid.Dim =
(4460.83, 3706.78, (-300 + 300)) = (4460.83, 3706.78, 0)

Coordinate name	X-Coordinate	Y-Coordinate	Z-Coordinate
A	*-666.16*	*51.33*	*-300*
B	*4460.83*	*51.33*	*-300*
C	*-666.16*	*3706.78*	*-300*

D	*4460.83*	*3706.78*	*-300*
E	*-666.16*	*51.33*	*0*
F	*4460.83*	*51.33*	*0*
G	*-666.16*	*3706.78*	*0*
H	*4460.83*	*3706.78*	*0*

Table 3.7 | Coordinates of IfcSlab

IfcWall

There are three different ways for the geometric representations of a wall element within the IFC4 data file: the IfcWallStandardCase, the IfcWallElementedCase and the IfcWall. IfcWallStandardCase is used for all occurrences of walls, that have a non-changing thickness along the wall path and where the thickness dimension can be fully described by a material layer set. These walls are always represented geometrically by an 'Axis' and a 'SweptSolid' shape representation (or by a 'Clipping' geometry based on 'SweptSolid'), if a 3D geometric representation is assigned. In addition they have to have a corresponding IfcMaterialProfileSetUsage assigned. IfcWallElementedCase is used for occurrences of walls which are aggregated from subordinate elements, following specific decomposition rules expressed by the mandatory use of IfcRelAggregatesrelationship. IfcWall used for all other occurrences of wall, particularly for walls with changing thickness along the wall path (e.g. polygonal walls), or walls with a non-rectangular cross sections (e.g. L-shaped retaining walls), and walls having an extrusion axis that is unequal to the global Z axis of the project (i.e. non-vertical walls), or walls having only 'Brep', or 'SurfaceModel' geometry (BuildingSmart, 2016b).

In most cases the IfcWallstandardCase is used in the data file to describe a wall element. The IfcWallStandardCase has the following attributes: Globalid, OwnerHistory, Name, Description, ObjectType, ObjectPlacement, Representation, Tag, and PredefinedType. In this order. This is shown in figure 3.26.

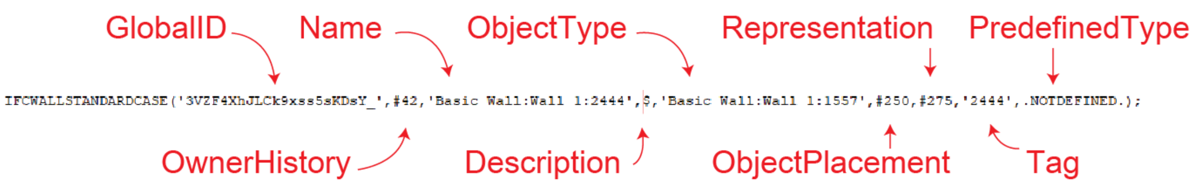
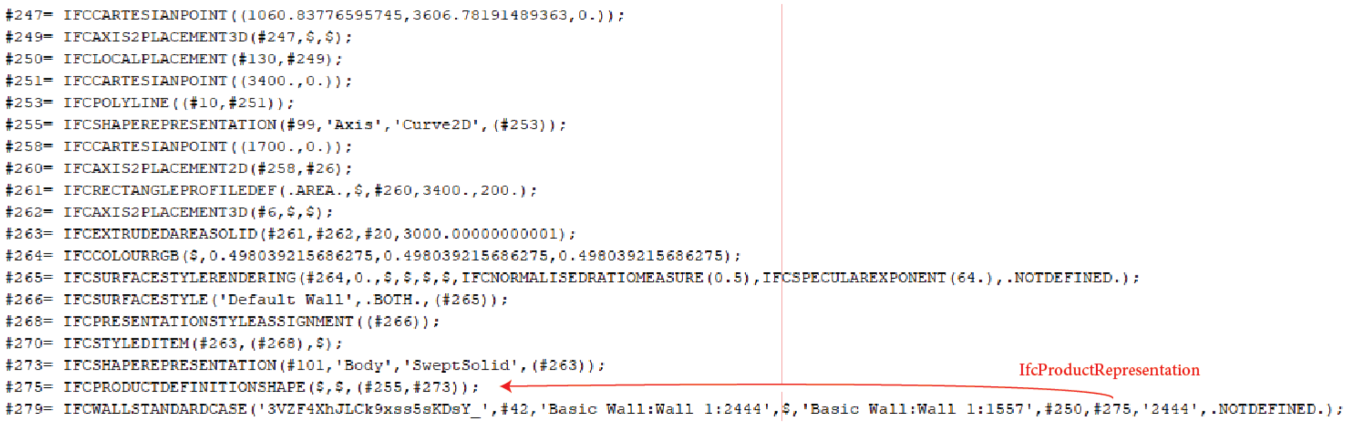


Figure 3.26 | IfcWallStandardCase entity with attributes

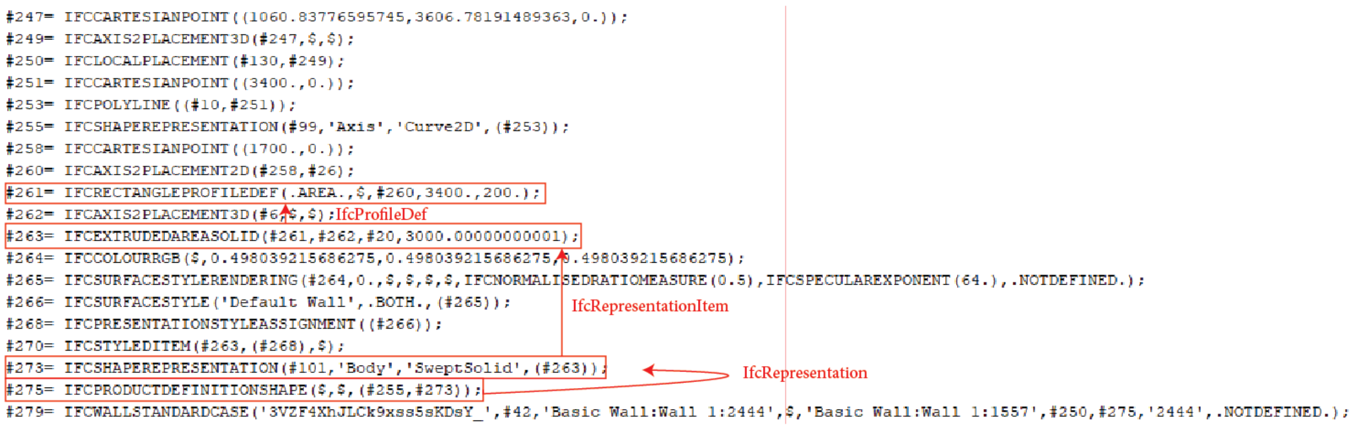
The flow through the data for the wall element is the same as for the IfcSlab. The IfcProductRepresentation, in figure 3.27 indicated with #275, defines a representation of a product, including its geometric or topological representation. A product can have zero, one or many geometric representations, and a single geometric representation can be shared among various products using mapped representations. The IfcProductRepresentation has a IfcReprecentation, as shown in figure 3.27, which defines the general concept of representing product properties and in particular the product shape.



```
#247= IFCCARTESIANPOINT((1060.83776595745,3606.78191489363,0.));
#249= IFCAXIS2PLACEMENT3D(#247,$,$);
#250= IFCLOCALPLACEMENT(#130,#249);
#251= IFCCARTESIANPOINT((3400.,0.));
#253= IFCPOLYLINE((#10,#251));
#255= IFCSHAPEREPRESENTATION(#99,'Axis','Curve2D',(#253));
#258= IFCCARTESIANPOINT((1700.,0.));
#260= IFCAXIS2PLACEMENT2D(#258,#26);
#261= IFCRECTANGLEPROFILEDEF(.AREA.,$,#260,3400.,200.);
#262= IFCAXIS2PLACEMENT3D(#6,$,$);
#263= IFCEXTRUDEDAREASOLID(#261,#262,#20,3000.00000000001);
#264= IFCCOLOURRGB($,0.498039215686275,0.498039215686275,0.498039215686275);
#265= IFCSURFACESTYLERENDERING(#264,0.,$,$,$,$,IFCNORMALISEDRATIOMEASURE(0.5),IFCSPECULAREXPONENT(64.),.NOTDEFINED.);
#266= IFCSURFACESTYLE('Default Wall',.BOTH.,(#265));
#268= IFCPRESENTATIONSTYLEASSIGNMENT((#266));
#270= IFCSTYLEDITEM(#263,(#268),$);
#273= IFCSHAPEREPRESENTATION(#101,'Body','SweptSolid',(#263));
#275= IFCPRODUCTDEFINITIONSHAPE($,$,(#255,#273));
#279= IFCWALLSTANDARDCASE('3VZF4XhJLCk9xss5sKDsY_',#42,'Basic Wall:Wall 1:2444',$,'Basic Wall:Wall 1:1557',#250,#275,'2444',.NOTDEFINED.);
```


Figure 3.27 | IfcProductRepresentation wall element

Each representation has either an IfcShapeRepresentation or an IfcTopologyRepresentation. This is defined in the IfcRepresentationItem, in figure 3.28 indicated with #273. This model has an IfcShapeRepresentation. In figure 3.28 it shows that this floor slab is represented with a 'SweptSolid' which refers to the Sweeping Volume representation. The IfcRepresentationItem is an ExtrudeAreaSolid. The profile is made by #261 and extruded.



```
#247= IFCCARTESIANPOINT((1060.83776595745,3606.78191489363,0.));
#249= IFCAXIS2PLACEMENT3D(#247,$,$);
#250= IFCLOCALPLACEMENT(#130,#249);
#251= IFCCARTESIANPOINT((3400.,0.));
#253= IFCPOLYLINE((#10,#251));
#255= IFCSHAPEREPRESENTATION(#99,'Axis','Curve2D',(#253));
#258= IFCCARTESIANPOINT((1700.,0.));
#260= IFCAXIS2PLACEMENT2D(#258,#26);
#261= IFCRECTANGLEPROFILEDEF(.AREA.,$,#260,3400.,200.);
#262= IFCAXIS2PLACEMENT3D(#6,$,$);
#263= IFCEXTRUDEDAREASOLID(#261,#262,#20,3000.00000000001);
#264= IFCCOLOURRGB($,0.498039215686275,0.498039215686275,0.498039215686275);
#265= IFCSURFACESTYLERENDERING(#264,0.,$,$,$,$,IFCNORMALISEDRATIOMEASURE(0.5),IFCSPECULAREXPONENT(64.),.NOTDEFINED.);
#266= IFCSURFACESTYLE('Default Wall',.BOTH.,(#265));
#268= IFCPRESENTATIONSTYLEASSIGNMENT((#266));
#270= IFCSTYLEDITEM(#263,(#268),$);
#273= IFCSHAPEREPRESENTATION(#101,'Body','SweptSolid',(#263));
#275= IFCPRODUCTDEFINITIONSHAPE($,$,(#255,#273));
#279= IFCWALLSTANDARDCASE('3VZF4XhJLCk9xss5sKDsY_',#42,'Basic Wall:Wall 1:2444',$,'Basic Wall:Wall 1:1557',#250,#275,'2444',.NOTDEFINED.);
```


Figure 3.28 | IfcReprecentation and IfcRepresentationItem for wall element

With the IfcRectangleProfileDef there is defined that the profile is a rectangle with the dimensions of 3400 by 200 millimetres. #247 refers to the placement of the axis where the profile is made within the cartesian space. The two-dimensional profile is extruded in the z-direction. Line #263 creates an extruded area solid with a thickness of 3000 millimetre. In figure 3.29 the steps are visualized for the creation of an IfcWallStandardCase. Notice that the wall element is placed according to a polyline. The polyline creates the path which the wall element follows in the X,Y-surface. The IfcRectangleProfileDef is drawn on both sides of the polyline.

Now that the geometry of the solid building element is made, the coordinates of the corner points and the dimensions can be calculated. In figure x the coordinates of the wall element are shown. To calculate the coordinates the following calculations need to be made. In table 3.8 the coordinates are listed:

*Point A = IfcCartesianPoint + ½ * y-direction of the IfcRectangleProfileDef =*

*(1060.84, 3606.78 + ½ * 200, 0) = (1060.84, 3706.78, 0)*

*Point B = IfcCartesianPoint - ½ * y-direction of the IfcRectangleProfileDef =*
*(1060.84, 3606.78 - ½ * 200, 0) = (1060.84, 3506.78, 0)*
Point C = Point A + x-direction of the IfcRectangleProfileDef =
(1060.84 + 3400, 3706.78, 0) = (4460.84, 3706.78, 0)
Point D = Point B + x-direction of the IfcRectangleProfileDef =
(1060.84 + 3400, 3506.78, 0) = (4460.84, 3506.78, 0)
Point E = Point A + IfcExtrudeAreaSolid.Dim =
(1060.84, 3706.78, 0 + 3000) = (1060.84, 3706.78, 3000)
Point F = Point B + IfcExtrudeAreaSolid.Dim =
(1060.84, 3506.78, 0 + 3000) = (1060.84, 3506.78, 3000)
Point G = Point C + IfcExtrudeAreaSolid.Dim =
(4460.84, 3706.78, 0 + 3000) = (4460.84, 3706.78, 3000)
Point H = Point H + IfcExtrudeAreaSolid.Dim =
(4460.84, 3506.78, 0 + 3000) = (4460.84, 3506.78, 3000)

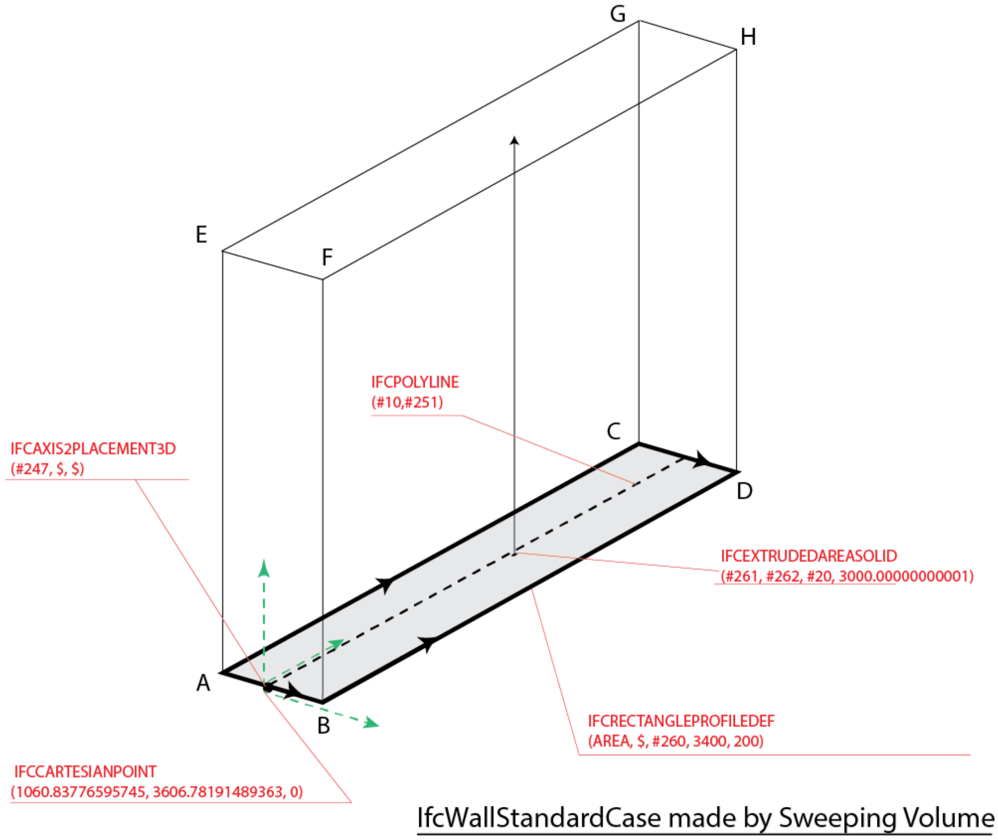


Figure 3.29 | IfcWallStandardCase made by Sweeping Volume

Coordinate name	X-Coordinate	Y-Coordinate	Z-Coordinate
A	*1060.84*	*3706.78*	*0*
B	*1060.84*	*3506.78*	*0*
C	*4460.84*	*3706.78*	*0*
D	*4460.83*	*3506.78*	*0*
E	*1060.84*	*3706.78*	*3000*
F	*1060.84*	*3506.78*	*3000*
G	*4460.84*	*3706.78*	*3000*

H	4460.83	3506.78	3000

Table 3.8 | Coordinates of IfcWallStandardCase

IfcOpeningElement

The opening element stands for opening, recess or chase, all reflecting voids. It represents a void within any element that has physical manifestation. Openings can be inserted into walls, slabs, beams, columns, or other elements. The IFC specification provides two entities for opening elements: IfcOpeningStandardCase is used for all openings that have a constant profile along a linear extrusion. They are placed relative to the voided elements and the extrusion direction is perpendicular to the plane of the element (horizontally for walls, vertically for slabs). Only a single extrusion body is allowed. It cuts through the whole thickness of the voided element, i.e. it reflects a true opening. IfcOpeningElement is used for all other occurrences of openings and in particular also for niches or recesses (BuildingSmart, 2016a).

In this research only the IfcOpeningStandardCase is used. The IfcOpeningStandardCase has the following attributes: Globalid, OwnerHistory, Name, Description, ObjectType, ObjectPlacement, Representation, Tag, and PredefinedType. In this order. This is shown in figure 3.30.

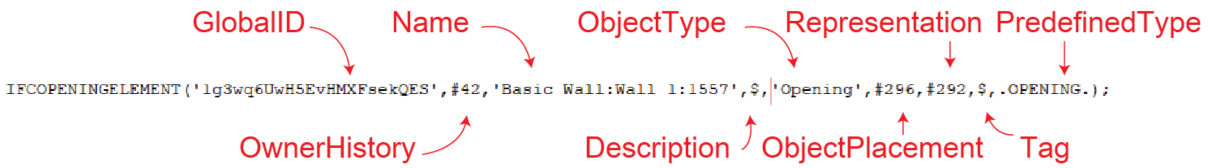


Figure 3.30 | IfcOpeningelement entity with attributes

The flow through the data for the opening element is the same as for the IfcSlab and the IfcWallStandardCase. The IfcProductRepresentation, in figure 3.31 indicated with #292, defines a representation of a product, including its geometric or topological representation. A product can have zero, one or many geometric representations, and a single geometric representation can be shared among various products using mapped representations. The IfcProductRepresentation has an IfcReprecentation, as shown in figure 3.31, which defines the general concept of representing product properties and in particular the product shape.

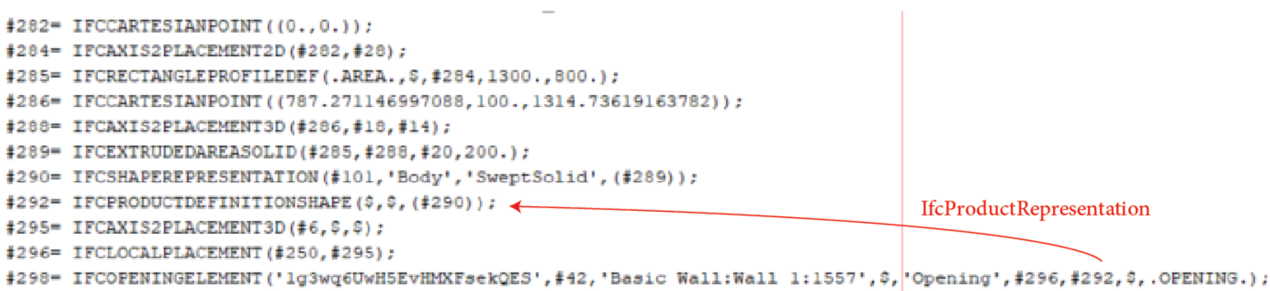
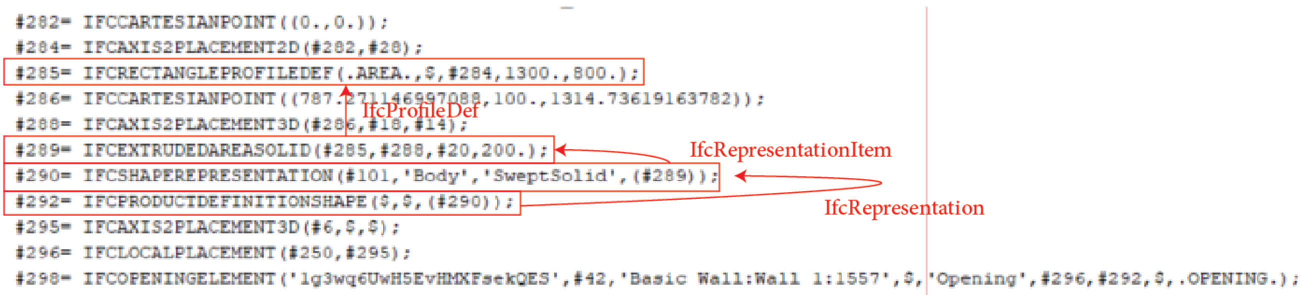


Figure 3.31 | IfcProductRepresentation for Opening element

Each representation has either a IfcShapeRepresentation or an IfcTopologyRepresentation. This is defined in the IfcRepresentationItem, in figure 3.32 indicated with #290. This model has an IfcShapeRepresentation. In figure 3.32 it shows that this floor slab is represented with a ‘SweptSolid’ which refers to the Sweeping Volume representation. The IfcRepresentationItem is an ExtrudeAreaSolid. The profile is made by #289 and extruded.



```
#282= IFCCARTESIANPOINT((0.,0.));
#284= IFCAXIS2PLACEMENT2D(#282,#28);
#285= IFCRECTANGLEPROFILEDEF(.AREA.,$,#284,1300.,800.);
#286= IFCCARTESIANPOINT((787.271146997088,100.,1314.73619163782));
#288= IFCAXIS2PLACEMENT3D(#286,#18,#14);
#289= IFCEXTRUDEDAREASOLID(#285,#288,#20,200.);
#290= IFCSHAPEREPRESENTATION(#101,'Body','SweptSolid',(#289));
#292= IFCPRODUCTDEFINITIONSHAPE($,$,(#290));
#295= IFCAXIS2PLACEMENT3D(#6,$,$);
#296= IFCLOCALPLACEMENT(#250,#295);
#298= IFCOPENINGELEMENT('1g3wq6UwH5EvHMXFsekQES',#42,'Basic Wall:Wall 1:1557',$,'Opening',#296,#292,$,.OPENING.);
```


Figure 3.32 | IfcRepresentation and IfcRepresentationItem for opening element

With the IfcRectangleProfileDef there is defined that the profile is a rectangle with the dimensions of 1300 by 800 millimetres. #286 refers to the placement of the axis where the profile is made within the cartesian space. The placement of the IfcCartesianPoint with the reference #286 is made relative to the axis of the element the opening is in. The two-dimensional profile is extruded in the x-direction (y-direction is also possible). Line #289 creates an extruded area solid with a thickness of 200 millimetre. In figure 3.33 the steps are visualized for the creation of an IfcOpeningElement. Notice that the opening element has a profile definition drawn in the z direction and is extrude in the x or y direction for an opening in a wall element. For an opening in a floor slab or roof element the profile is drawn in the x,y-surface and extruded in the z-direction.

Now that the geometry of the solid building element is made, the coordinates of the corner points and the dimensions can be calculated. In figure 3.33 the coordinates of the opening element are shown. To calculate the coordinates the following calculations need to be made. In table 3.9 the coordinates are listed. Notice that these coordinates are relative to the axis of the building element containing the opening:

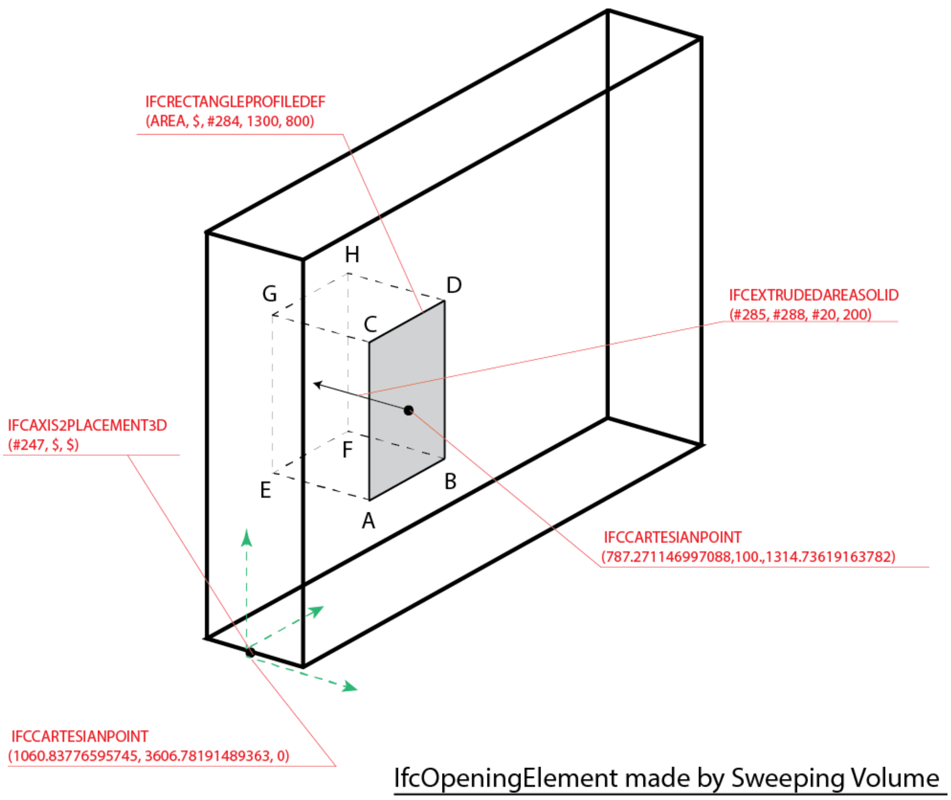


Figure 3.33 | IfcOpeningElement made by sweeping volume

*Point A = IfcCartesianPoint – ½ * x,z-dimension or the IfcRectangleProfileDef =*
*((787.27 – ½ * 800), 100, (1314.74 – ½ * 1300)) = (387.27, 100, 664.74)*
*Point B = (IfcCartesianPoint – ½ * z-dimension + 1/2 * x-dimension of the IfcRectangleProfileDef =*
*((787.27 + ½ * 800), 100, (1314.74 – ½ * 1300)) = (1187.27, 100, 664.74)*
*Point C = (IfcCartesianPoint + ½ * z-dimension - 1/2 * x-dimension of the IfcRectangleProfileDef =*
*((787.27 - ½ * 800), 100, (1314.74 + ½ * 1300)) = (387.27, 100, 1964.74)*
*Point A = IfcCartesianPoint + ½ * x,z-dimension or the IfcRectangleProfileDef =*
*((787.27 + ½ * 800), 100, (1314.74 + ½ * 1300)) = (1187.27, 100, 1964.74)*
Point E = Point A + IfcExtrudeAreaSolid.Dim =
(387.27, 100 - 200, 664.74)) = (387.27, -100, 664.74)
Point F = Point B + IfcExtrudeAreaSolid.Dim =
(1187.27, 100 - 200, 664.74) = (1187.27, -100, 664.74)
Point G = Point C + IfcExtrudeAreaSolid.Dim =
(387.27, 100 - 200, 1964.74) = (387.27, -100, 1964.74)
Point H = Point H + IfcExtrudeAreaSolid.Dim =
(1187.27, 100 - 200, 1964.74)) = (1187.27, -100, 1964.74)

Coordinate name	X-Coordinate	Y-Coordinate	Z-Coordinate
A	*387.27*	*100*	*664.74*
B	*1187.27*	*100*	*664.74*
C	*387.27*	*100*	*1964.74*
D	*1187.27*	*100*	*1964.74*
E	*387.27*	*-100*	*664.74*

F	*1187.27*	*-100*	*664.74*
G	*387.27*	*-100*	*1964.74*
H	*1187.27*	*-100*	*1964.74*

Table 3.9 | Coordinates of IfcOpeningElement

Notice that when requirement 3 of the previous chapter was satisfied in the IFC4 data representation these calculations would be unnecessary. A list of coordinates makes it possible for systems like this to work more efficient.

Object dimensions

Objects can be modelled in a huge variety of ways. For this research only the railing will be discussed. Railings are defined by the IfcRailing entity. An IfcRailing has the same structure as the other building elements. It has: Globalid, OwnerHistory, Name, Description, ObjectType, ObjectPlacement, Representation, Tag, and PredefinedType. The IfcShapeRepresentation has multiple profiles that are extruded in different directions.

```
#858= IFCSHAPEREPRESENTATION(#101,'Body','SweptSolid',(#777,#785,#793,#801,#809,#817,#825,#833,#841,#849,#857));
#860= IFCCARTESIANPOINT((-2973.25834534579,-7763.33152738265,0.));
#862= IFCPRODUCTDEFINITIONSHAPE($,$,(#858));
#865= IFCRAILING('3PiPR_A6j7i8xsflslhXJd',#42,'Railing:900mm Pipe:272287',$,'Railing:900mm Pipe',#769,#862,'272287',.NOTDEFINED.);
```

Figure 3.34 | IfcRailing entity with attributes

The height of the railing is extruded in the first six IfcShapeRepresentationItems and the length in the last five. This depends on the length and the type of the railing. The direction of the extrusion is defined in the IfcAxis2Placement3D. The thickness of the railing is the thickness of the extruded profile. To define the height of the railing the extruded solid in the x,y plane with the highest cartesianpoint in the z-direction needs to be found.

Relationships

The next step after obtaining the coordinates is obtaining the relationship of the building elements. As said in the previous chapter, these systems would benefit if all the relationships where defined in the data representation. As for now the IFC4 data representation does not include the connectivity relationship between two building elements. This means that every IfcSlab, IfcRoof and IfcWall element need to be check with each other to determine if there is a relationship between them. In table 3.7 and 3.8. the coordinates of an IfcWallStandardCase and a IfcSlab are calculated. To see if these to building elements are connected the coordinates need to be compared and see if the IfcWallStandardCase is on top of the IfcSlab edge. Therefor the following steps need to be taken:

1. Obtain the coordinates of the upper profile of the IfcSlab

   Coordinates E_{Slab}, F_{slab}, G_{slab} and H_{slab} → (-666.16, 51.33, 0), (4460.83, 51.33, 0), (-666.16, 3706.78, 0) and (4460.83, 3706.78, 0)

2. Obtain the coordinates of the lower profile of the IfcWallStandardCase

   Coordinates A_{Wall}, B_{Wall}, C_{Wall} and D_{Wall} → (1060.84, 3706.78, 0), (1060.84, 3506.78, 0), (4460.84, 3706.78, 0) and (4460.84, 3506.78, 0)

3. Are the z-coordinates (x,y,z) of the IfcSlab and the IfcWallStandardCase similar? When they are not similar there is not connection which is relevant for the system.

   Both the z-coordinates of the IfcSlab and the IfcWallStandardCase are 0.

4. Create edges A_{Wall}-B_{Wall}, B_{Wall}-D_{Wall}, C_{Wall}-D_{Wall}, A_{Wall}-C_{Wall}, E_{Slab}-F_{Wall}, F_{Wall}-H_{Wall}, G_{Wall}-H_{Wall}, E_{Wall}-G_{Wall} within the X,Y-plane.

Edge name	Start	End
A_{Wall}-B_{Wall}	*(1060.84, 3706.78)*	*(1060.84, 3506.78)*
B_{Wall}-D_{Wall}	*(1060.84, 3506.78)*	*(4460.84, 3506.78)*
C_{Wall}-D_{Wall}	*(4460.84, 3706.78)*	*(4460.84, 3506.78)*
A_{Wall}-C_{Wall}	*(1060.84, 3706.78)*	*(4460.84, 3706.78)*
E_{Slab}-F_{Wall}	*(-666.16, 51.33)*	*(4460.84, 51.33)*
F_{Wall}-H_{Wall}	*(4460.84, 51.33)*	*(4460.84, 3706.78)*
G_{Wall}-H_{Wall}	*(-666.16, 3706.78)*	*(4460.84, 3706.78)*
E_{Wall}-G_{Wall}	*(-666.16, 51.33)*	*(-666.16, 3706.78)*

Table 3.10 | Edges with coordinates

5. Compare the x-coordinates of the edges of the wall element with the x-coordinates of the edges of the floor slab with each other.

   The edge of the floor slab, F_{Wall}-H_{Wall}, and the edge of the wall element, C_{Wall}-D_{Wall}, have the same x-coordinate.

6. Compare the y-coordinates of the edges of the wall element with the y-coordinates of the edges of the floor slab with each other.

   The edge of the floor slab, G_{Wall}-H_{Wall}, and the edge of the wall element, A_{Wall}-C_{Wall}, have the same y-coordinate.

   When there are no matching edges with the same x-coordinate and the same y-coordinate there are no wall elements on the edge of the floor slab.

7. To see if the wall element is on the edge of the floor slab. The edge of the wall element needs to be between the start and endpoint of the floor slab.

   Is C_{Wall}-D_{Wall} between F_{wall} and H_{wall}? → $51.33 \leq 3506.78$ and $3706.78 \geq 3706.78$
   True, the wall is on the edge of the floor slab

   Is A_{Wall}-C_{Wall} between G_{Wall} and H_{Wall}? → $-666.16 \leq 1060.84$ and $4460.84 \geq 4460.84$
   True, the wall is on the edge of the floor slab

Edges do not always follow the direction of the axis. Therefor the Phytagoras theorem needs to be done to calculated the length of the edges.

Without the relationship defined, these steps need to be taken for every IfcSlab and every IfcWallStandardCase and every IfcRoof. To determine if there is a topological relationship. The entity IfcRelconnectsElements can define a connectivity relationship to the building elements. For example the situation above:

#297 IFCRELCONNECTSELEMENTS (‘GlobalId’,#42,’Name’,$,RelatingElement,RelatedElement)
With RelatingElement as the IfcSlab with line #168.
And with RelatedElement as the IfcWallStandardCase with line #279

Note that the combination of requirement 4 and 5 can reduce most of the steps. With the topological relationship given only the wall elements with an connectivity relationship needed to be evaluated if they are on the edge of the floor slab. If both of the building elements were B-reps the edges were already in the data representation and do not needed to be calculated. Further if the IfcSlab and the IfcWallStandardCase had an shared edge this would mean the wall would be on the edge of the floor slab. In this small example the impact of these requirements do not seem to be large but imagine if there was a model with ten floor slab and 50 wall elements. These steps and calculation all need to be done for every combination of every building element.

The topological relationship between an opening and a building element is supported by the IFC4 data representation. With the IfcRelVoidsElement entity an IfcOpeningElement and an IfcElement are connected.

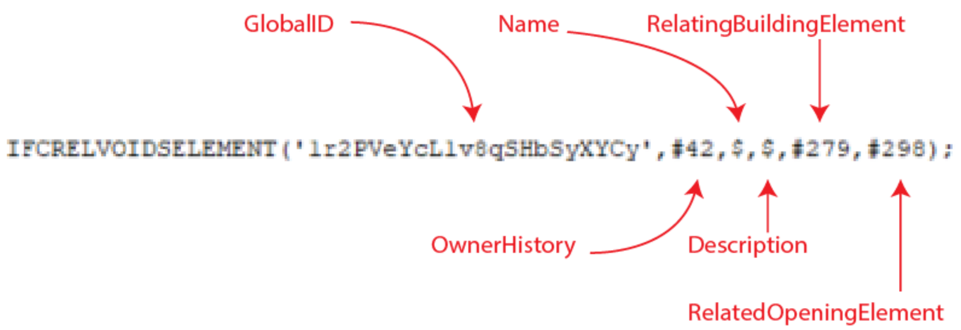


Figure 3.35 | IfcRelVoidsElement entity with attributes

When determining if there is an opening in the building element only these entities need to be evaluated. The comparison between the coordinates of the building elements do not need to be made.

3.4.5. Multiple walls on edge

It is possible to have multiple wall elements on one edge of a floor slab or roof element. It also might occur that a wall element does not stretch over the full length of the edge. The system needs to make sure that only that specific part of the edge is marked as having a wall element and not the entire edge. Otherwise places where no wall elements are on the same edge as where a wall element is could become an unsafe situation. In the previous paragraph there is shown how a list of the topological primitives, vertexes and edges, is created for a floor slab or roof element. These edges need to be split up in to parts with wall elements on top of it and parts without wall elements on top of it. This paragraph describes how the edges of a slab are split up in to parts with or without wall elements.

First the list of the vertexes with the coordinates and the list with the uppers edges of the slab need to be imported. Also, the list with the lower edges of the wall elements needs to be imported. Only the wall elements that are on the edge of the slab are needed. Around the outer edges of the slab a fictional polyline is drawn. The polyline starts in the first vertex of the upper section of the slab. Then it runs across the other vertexes in the upper section. The polyline is compared with lower edges of the wall elements. At the intersection of the polyline and the wall edges an extra vertex is placed. The polyline is updated with the new vertexes. The new edges in the polyline are marked with 'Wall' and the other edges of the polyline are marked with 'No wall'. Figure3.35 and tables 3.11, 3.12, 3.13, 3.14, 3.15 and 3.16 show a visual example of the process. This process is done for all the floor slabs, roof elements and openings in the model.

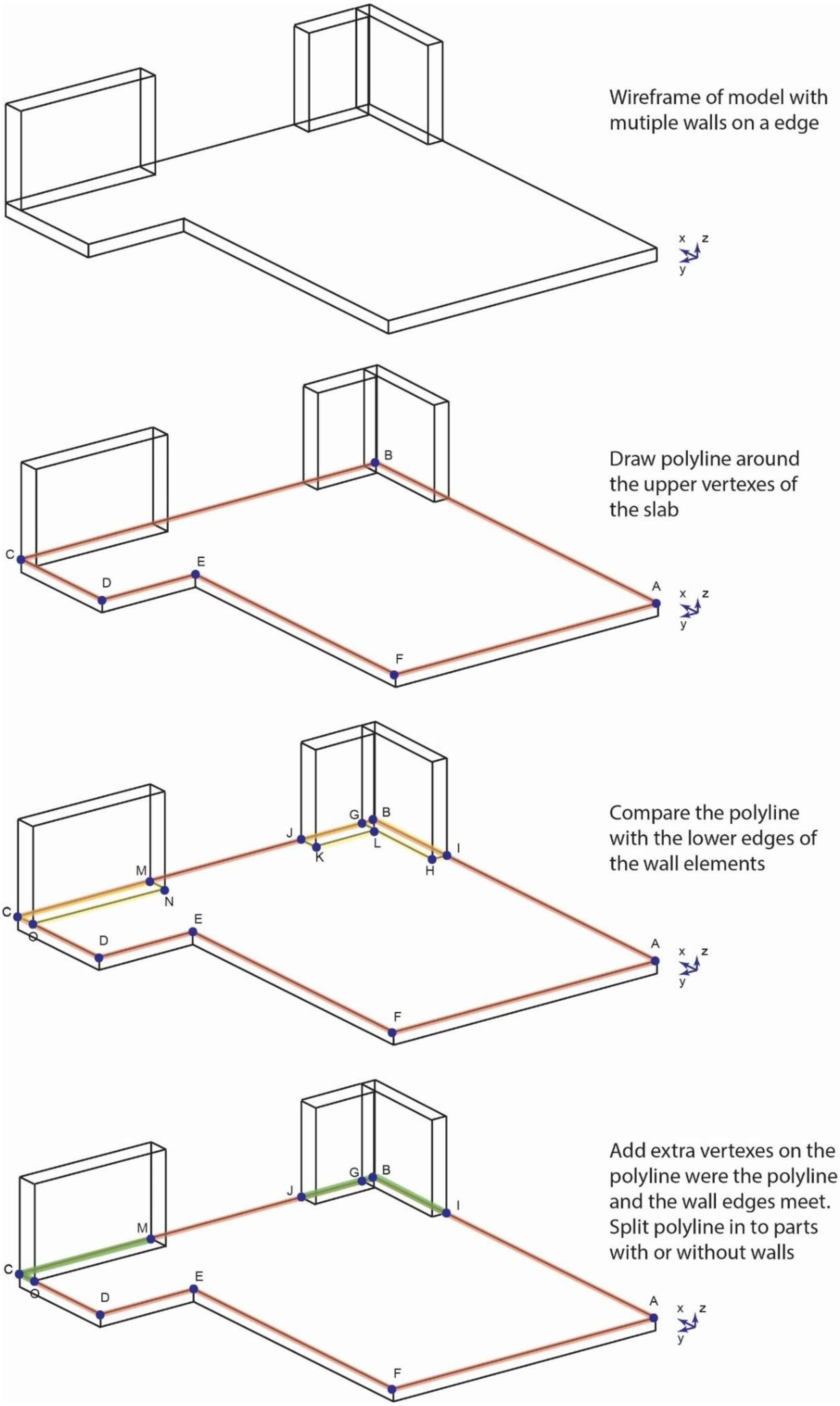


Figure 3.36 | Drawing the polyline and comparing with the edges of the wall elements

1. Import information about the upper vertexes of the slab and the upper edges.

ID	#nr.	Name	Vertex	X coordinate	Y coordinate	Z Coordinate
XLIX	#100	Slab 1	A	0	0	0
XLIX	#100	Slab 1	B	10	0	0
XLIX	#100	Slab 1	C	10	10	0
XLIX	#100	Slab 1	D	8	10	0
XLIX	#100	Slab 1	E	8	8	0
XLIX	#100	Slab 1	F	0	8	0

Table 3.11 | Example coordinates

ID	#nr.	Name	Edge	Length	Direction (x.y.z)
XLIX	#100	Slab 1	A → B	10	(1.0.0)
XLIX	#100	Slab 1	B → C	10	(0.1.0)
XLIX	#100	Slab 1	C → D	2	(-1.0.0)
XLIX	#100	Slab 1	D → E	2	(0.-1.0)
XLIX	#100	Slab 1	E → F	8	(-1.0.0)
XLIX	#100	Slab 1	F → A	8	(0.-1.0)

Table 3.12 | Example edges

1. Draw polyline along the outer edges of the slab from vertex to vertex.
2. Import information about the lower vertexes of the wall elements and the lower edges.

ID	#nr.	Name	Vertex	X coordinate	Y coordinate	Z Coordinate
LVIII	#200	Wall 1	B	10	0	0
LVIII	#200	Wall 1	G	10	0.3	0
LVIII	#200	Wall 1	H	8	0.3	0
LVIII	#200	Wall 1	I	8	0	0
LIX	#300	Wall 2	G	10	0.3	0
LIX	#300	Wall 2	J	10	1.30	0
LIX	#300	Wall 2	K	9.70	1.30	0
LIX	#300	Wall 2	L	9.70	9.70	0
LX	#400	Wall 3	C	10	10	0
LX	#400	Wall 3	M	10	8	0
LX	#400	Wall 3	N	9.70	8	0
LX	#400	Wall 3	O	9.70	10	0

Table 3.13 | Example original coordinates

ID	#nr.	Name	Edge	Length	Direction (x.y.z)
LVIII	#200	Wall 1	B → G	0.3	(0.1.0)
LVIII	#200	Wall 1	G → H	2	(-1.0.0)
LVIII	#200	Wall 1	H → I	0.3	(0.-1.0)
LVIII	#200	Wall 1	I → B	2	(1.0.0)
LIX	#300	Wall 2	G → J	1	(0.1.0)
LIX	#300	Wall 2	J → K	0.3	(-1.0.0)
LIX	#300	Wall 2	K → L	1	(0.-1.0)
LIX	#300	Wall 2	L → G	0.3	(1.0.0)
LX	#400	Wall 3	M → C	2	(0.1.0)
LX	#400	Wall 3	C → O	0.3	(-1.0.0)
LX	#400	Wall 3	O → N	2	(0.-1.0)
LX	#400	Wall 3	N → M	0.3	(1.0.0)

Table 3.14 | Example original edges

3. Compare the edges of the wall elements with the polyline.

   Edge I → B is on A → B

   Edge B → G is on B → C

   Edge G → J is on B → C

   Edge M → C is on B → C

   Edge C → O is on C → D

4. Place extra vertexes on the polyline were polyline and wall edges intersect

ID	#nr.	Name	Vertex	X coordinate	Y coordinate	Z Coordinate
XLIX	#100	Slab 1	A	0	0	0
XLIX	#100	Slab 1	B	10	0	0
XLIX	#100	Slab 1	C	10	10	0
XLIX	#100	Slab 1	D	8	10	0
XLIX	#100	Slab 1	E	8	8	0
XLIX	#100	Slab 1	F	0	8	0
LVIII	#200	Wall 1,2	G	10	0.3	0
LVIII	#200	Wall 1	I	8	0	0
LIX	#300	Wall 2	J	10	1.30	0
LX	#400	Wall 3	M	10	8	0
LX	#400	Wall 3	O	9.70	10	0

Table 3.15 | Updated coordinates

5. Update polyline with new edges.

Edge	Length	Direction	Wall	Wall ref.
A → I	8	(1.0.0)	No wall	-
I → B	2	(1.0.0)	Wall	#200
B → G	0.30	(0.1.0)	Wall	#200
G → J	1	(0.1.0)	Wall	#300
J → M	6.70	(0.1.0)	No wall	-
M → C	2	(0.1.0)	Wall	#400
C → O	0.3	(-1.0.0)	Wall	#400
O → D	1.70	(-1.0.0)	No wall	-
D → E	2	(0.-1.0)	No wall	-
E → F	8	(-1.0.0)	No wall	-
F → A	8	(0.-1.0)	No wall	-

Table 3.16 | Update edges

3.4.6. Processing the rule sets

In the previous chapter the method for how the coordinates and the topological relationships between building elements can be derived from the current IFC4 data representation. Also, the differences when the requirements are satisfied in the data representation are mentioned. In this part of the research the processing of the rule sets is discussed. The safety rules are defined, as is the method for deriving the coordinates and the relationships.

The rules, which are defined in chapter 3.3, can be answered with 'True' or with 'False'. But one rule does not always rules-out another rule. For example, in situation 1 all the different heights need to be checked. If there is an obstruction at 1.00 meters from the floor slab it does not mean there is an obstruction at 0.15 meters. And this is the case for multiple rules. Therefore, there must be a method to determine the right situation and combine it with the appropriate prevention method.

The method of a summation value code is used to define which situation is the case and what kind of prevention method needs to be placed. The method works as followed: Every answer to a rule has a specific value like 100 or 1000. After all the rules of a rule set are answered, the different values of the rules are added up. The summation of the value is a code that refers to a specific situation and a specific category of fall prevention methods.

For example, in situation 1:

Rule 1.1 and 1.3 answers 'False' and 1.2 answers 'True'. When 1.1 answers 'True' it will give the value 1 and when it is 'False' it will give the value 2. If 1.2 answers 'True' is will give the value of 10 and when 'False' it will give the value 20. And so, for 1.3 the values are 100 and 200. The sum will be as followed in this example, (1.1) 2 + (1.1) 10 + (1.3) 200 = 212. The code 212 will then refer to a prevention method which sits at 0.62 meters and 0.15 meters to the floor slab. Which output will be discussed in the next chapter.

In table 3.17 the rule is given with the value for the answers.

Rule	When 'True'	When 'False'
1.1	1	2
1.2	10	20
1.3	100	200
2.1	1000	2000
2.2	10000	20000
2.3	100000	200000
2.6	1000000	2000000
2.7	10000000	20000000
2.8	100000000	200000000
2.9	1000000000	2000000000
3.2	10000000000	20000000000
3.3	100000000000	200000000000
3.4	1000000000000	2000000000000
3.5	10000000000000	20000000000000
0.2	100000000000000	200000000000000
4.1	1000000000000000	2000000000000000
4.2	10000000000000000	20000000000000000

Table 3.17 | Values when true or false

3.4.7. Creating output

Most of the Dutch construction companies do not have their own stock of fall preventions. In this case the construction company rents the needed equipment from a third party. A company like Strukton Worksphere obtain most of the fall prevention from a company called Boels. On the one hand renting equipment allows the construction company to order a specific amount of equipment and it does not need storage space for when the equipment is not used. On the other hand renting equipment makes the company rely on a third party. In the optimal situation the fall hazard prevention system should provide output in line with the available equipment at the third party. This way from the output an order form can be created with real products.

The first step towards creating output is by analysing the possible reference codes given by processing the rule sets. Each combination of the different values within a rule set (situation) can refer to a prevention method. So, in table 3.18 the possible value summations are listed and a description of the prevention methods is given. Note that not all the possible combinations are given because the summation only covers the rules per rule set. Also, some combinations of rule can give an error. For example, if a wall is higher than 0.15 it must be higher than 0.62 and 1.0 meters.

Situation	Summation value	Description	Prevention method
1	200000000000111	Obstruction at 0.15, 0.62 and 1.00 meter	None
1	200000000000112	Obstruction needed from slab to 0.15 meter	Baffle kick plate
1	200000000000121	Obstruction needed at 1.00 meter	Safety railing 1.00 meter

1	200000000000122	Obstruction needed at 1.00 meter and 0.15 meter to the slab	Safety railing from top slab to 1.00 meter
1	200000000000211	Obstruction needed at 0.62 meter	Safety railing 0.62 meter
1	200000000000212	Obstruction needed at 0.62 and 0.15 meter	Safety railing from top slab to 0.62 meter
1	200000000000221	Obstruction needed at 0.15 and 1.00 meter	Safety railing from top slab to 1.00 meter
1	200000000000222	No obstruction present	Safety railing from top slab to 1.00 meter
2	200000000111000	Wall has a height of 1.00 meters of higher	None
2	200000000112000	Wall has a height between the 0.62 and 1.00 meters	Safety railing at 1.00 meters
2	200000000122000	Wall has a height between the 0.15 and 0.62 meters	Safety railing at 0.62 and 1.00 meters
2	200000000222000	Wall has a height between the 0 and 0.15 meters	Safety railing at 0.15, 0.62 and 1.00 meters
2	200001111000000	Opening up to 1.0 meters in height and less than 0.3 meters in width	None
2	200001112000000	Opening up to 1.0 meters in height and more than 0.3 meters in width	None
2	200002111000000	Opening up to 0.62 meters in height and less than 0.3 meters in width	None
2	200002112000000	Opening up to 0.62 meters in height and more than 0.3 meters in width	Safety railing at 1.0 meters
2	200002211000000	Opening up to 0.15 meters in height and less than 0.3 meters in width	None
2	200002212000000	Opening up to 0.15 meters in height and more than 0.3 meters in width	Safety railing at 1.0 meters and 0.62 meters
2	200002221000000	Opening less than 0.15 meters in height and less than 0.3 meters in width	None
2	200002222000000	Opening less than 0.15 meters in height and more than 0.3 meters in width	Safety railing at 1.0 meters, 0.62 meters and 0.15 meters

3	11110000000000	Opening has length of more than 1.0 meter and width of more than 1.0 meter	Safety railing around the opening
3	11120000000000	Opening has length between 1.0 and 0.1 meter and a width of more than 1.0 meter	Safety railing around the opening
3	11210000000000	Opening has length of more than 1.0 meter and a width between 1.0 and 0.1 meter	Safety railing around the opening
3	11220000000000	Opening has a length and a width between 1.0 and 0.1 meters	Cover opening with plywood plate
3	12120000000000	Opening has a length less than 0.1 meter and a width of more than 1.0 meter	None
3	12220000000000	Opening has a length less than 0.1 meter and a width between 1.0 and 0.1 meter	None
3	21210000000000	Opening has a length of more than 1.0 meter and a width of less than 0.1 meter	None
3	21220000000000	Opening has a length between the 1.0 and 0.1 meter and a width less than 0.1 meter	None
3	22220000000000	Opening has a length and an width of less than 0.1 meter	None
4	Between 1000000000000000-9999999999999999	On the roof, there is no physical obstruction 2.00 meters parallel to the edge of the roof	Place physical obstruction 2.00 meters parallel to the edge of the roof
4	Between 10000000000000000-99999999999999999	On the roof, there is no visible obstruction 4.00 meters parallel to the edge of the roof	Place visible obstruction 4.00 meters parallel to the edge of the roof
4	100000000000111	Obstruction at 0.15, 0.62 and 1.00 meter	None
4	100000000000112	Obstruction needed from slab to 0.15 meter	Baffle kick plate
4	100000000000121	Obstruction needed at 1.00 meter	Safety railing 1.00 meter
4	100000000000122	Obstruction needed at 1.00 meter and 0.15 meter to the slab	Safety railing from top slab to 1.00 meter
4	100000000000211	Obstruction needed at 0.62 meter	Safety railing 0.62 meter

4	100000000000212	Obstruction needed at 0.62 and 0.15 meter	Safety railing from top slab to 0.62 meter
4	100000000000221	Obstruction needed at 0.15 and 1.00 meter	Safety railing from top slab to 1.00 meter
4	100000000000222	No obstruction present	Safety railing from top slab to 1.00 meter
4	100000000111000	Wall has a height of 1.00 meters of higher	None
4	100000000112000	Wall has a height between the 0.62 and 1.00 meters	Safety railing at 1.00 meters
4	100000000122000	Wall has a height between the 0.15 and 0.62 meters	Safety railing at 0.62 and 1.00 meters
4	100000000222000	Wall has a height between the 0 and 0.15 meters	Safety railing at 0.15, 0.62 and 1.00 meters
4	100001111000000	Opening up to 1.0 meters in height and less than 0.3 meters in width	None
4	100001112000000	Opening up to 1.0 meters in height and more than 0.3 meters in width	None
4	100002111000000	Opening up to 0.62 meters in height and less than 0.3 meters in width	None
4	100002112000000	Opening up to 0.62 meters in height and more than 0.3 meters in width	Safety railing at 1.0 meters
4	100002211000000	Opening up to 0.15 meters in height and less than 0.3 meters in width	None
4	100002212000000	Opening up to 0.15 meters in height and more than 0.3 meters in width	Safety railing at 1.0 meters and 0.62 meters
4	100002221000000	Opening less than 0.15 meters in height and less than 0.3 meters in width	None
4	100002222000000	Opening less than 0.15 meters in height and more than 0.3 meters in width	Safety railing at 1.0 meters, 0.62 meters and 0.15 meters

Table 3.18 | Possible values with situation reference

There is no one or few perfect fall prevention method available in the construction industry. According to executors at Strukton Worksphere the factor 'time' makes it complicated to just use a few fall prevention methods on the construction site. The construction site is a dynamic process where situations changes from day to day. Sometimes fall prevention is placed, removed and placed back after the task is done. Because of these dynamic changes the best practices of executors is needed to choose the appropriate fall prevention. What this means for the fall prevention system is that when the system has identified the safety hazard and given it a code, the code should refer to a couple of different choice the user can choose from. According to the experience within Strukton Worksphere such a system will not be used in real life if the output is not in line with the situations at the construction site. This research will not go further in to the topic of the ideal fall prevention. But to fully understand the situation it is important to notice the factor time when developing BIM altering tools for during the construction phase.

4.Results

4.1 Introduction

In the previous chapter the research is done towards developing the building blocks of a flowchart for a fall hazard prevention system. In this chapter the results of that research will be discussed. This chapter begins with the requirements to the model and the data representation so the system will work properly. Next the flowchart is discussed: how does it works and what happens in the different blocks. And in the end of this chapter a test case will prove the fall hazard prevention works.

Readers guide: Paragraph 4.2 is meant for all readers to understand the limitations and the preconditions to the building model.

Paragraph 4.3 and 4.4 is meant for readers who want to understand the different steps of the flowchart or want to translated the flowchart into programming language. Experience with programming languages preferred. The steps of the testcase can be found in appendix X.

Paragraph 4.5 is meant for all readers to understand how the output can be used for safety management.

Paragraph 4.6 is meant for all readers. Here the results and the process are discussed.

4.2 Requirements to the model

In the previous chapter requirements for the data representation are given. This paragraph will focus on the requirements to the model and how this data is generated. When following these requirements it secures that the system makes the right decisions and the right output is created.

The first requirement to the model is one that is already mentioned in this report several times. But it is very important to make sure the input data is correct. When modelling the building project is must be in line with the Basis Dutch Information Delivery Manual. When exchanging information, it is important that every stakeholder speaks the same language. The Basis Dutch IDM states that building elements are modelled as the right element. When a wall is modelled as a stretched column the system is not able to identify the building element as a wall.

The second requirement to the model is that when it is exported to a IFC4 file it must be done with the Model View Definition recommended in the previous chapter, the Design Transfer View for IFC4. The research is conducted with a topological and geometric approach to what is possible in the ISO standard. This is compared with the latest version of the IFC to avoid recommendations which might be already be resolved in the latest version. The IFC4 has two MDVs. The Design Transfer View and the Reference View. The Reference View does not support all the entities which are supported in the Design Transfer View. Including the entities that refer to the topological relationships. The IFC 2x3 does support these topological relationship entities as well. It is the most used IFC type in the AEC-sector by construction companies at the time of writing this report. The main difference between the IFC 4 and the IFC 2x3 is that IFC has more subtypes defined. This does not mean the IFC 2x3 cannot be used by the flowchart. The right entities are present to create a working system based on IFC 2x3. But this research focusses on the IFC4 because it is the latest version and to prevent addressing issues which are already resolved in later versions. The option to create a new MVD specially designed for this type of tools might be every effective. In the Design Transfer View, a lot of information is put in the data representation that is unnecessary like material information. When designing a new MDV just for this system it should contain the information to gain the dimensions of all the building elements, the topological relationships and building elements should be represented as B-reps to make the process more efficient.

The third requirement for the model is the use of standard case entity of building elements. This means that the building elements are constructed out of straight lines with an constant height. Shape representations of curved edges need to be further researched and developed as are building elements which have a variety in height.

Next for the building elements is that the building elements need to be modelled per building storey. A wall for example should not span multiple building storeys. The wall should be a separate element on all the building storeys.

The last requirement is the use of exclusively flat roofs. Because most of the projects for Strukton Worksphere are in the utility sector and these buildings have flat roofs in most cases, the expertise used in this research focusses on flat roofs only.

4.3. flowchart

In this part of the chapter the flowchart is presented. First every step in the flowchart is discussed. At the end of this paragraph the flowchart is shown in figure X. Every step in the flowchart has an type, ID, Name and a description. There are four types of steps in the flowchart: Events; Tasks; Gateways; and in/output. The Events represent the start and the end of the process. Tasks are subprocesses in the flowchart with no choice in output. The Gateways are subprocesses with a choice. In a gateway it is possible to answer 'True' or 'False'. The answer determines which path the flowchart follows. The input is a IFC 4 file. The Output are the situation defined by a code. This situation has one or multiple solutions (table X). The ID and the name of the step refers to the step in figure X. The description shows the processes that are done in that specific step.

Some changes have been made in comparison with the situations in paragraph X. Situation 4 refers to fall hazards on the roof of a building. But on a roof, there are also walls and openings. This makes it that the system still needs to check for these building elements. To reduce the steps in the flowchart there is chosen to not search for the roof in the beginning of the process. The system will search for roofs and floor slabs at the same time. The difference between these building elements are checked at the end of the situations. As for openings, it does not matter if they are in a floor slab or in a roof element.

Type	Event
ID	E001
Name	Start
Description	The flowchart for the fall hazard prevention system starts

Type	Input/Output
ID	I001
Name	Insert IFC file
Description	Insert a IFC 4 file exported with a Design Transfer View MDV.

Type	Task
ID	T001
Name	Search for Building storey
Description	The system will search for the different Building storeys by searching for 'IFCBUILDINGSTOREY'. Out of the results the system will create a list named T001 of all the building storeys with the following information: the #nr.; the GlobalID; and the Name.

Type	Gateway
ID	G001
Name	Is there a building storey
Description	Get list T001. When there are no building storeys answer 'False'. When there are one or more building storeys answer 'True'. Retrieve information of the first building storey in the list. Search for 'IFCRELCONTAINEDINSPATIALSTRUCTURE' with the corresponding #nr. of the right building storey. Create a list named G001 of all the IfcBuildingelements on the building storey with the following information; the #nr.; the GlobalID; Type; and the Name. When the list is created remove building storey from the list in T001.
When True	Continue with T002.
When False	Continue with E002.

Type	Task
ID	T002
Name	Search for floor slab and roof element
Description	Get list G001. The system will search for the different floor slabs and roof elements by searching for 'IFCSLAB' and 'IFCROOF' in list G001. Out of the results the system will create a list named T002, of all the floor slabs and roof elements with the following information: the #nr.; the GlobalID; and the Name.

Type	Gateway
ID	G002
Name	Is there a floor slab or roof element
Description	Get list T002. When there are no floor slabs or roof elements answer 'False' and return to G001. When there are one or more items in the list answer 'True'. Retrieve information of the first item in the list. Search for that item in the IFC schema.
When True	Continue with T003
When False	Continue with G001

Type	Task
ID	T003
Name	Obtain dimensions of a floor slab or roof element
Description	Retrieve and calculate the dimensions of the floor slab or roof element. This method is specified in paragraph 3.4.4. Create a list for the topological primitives: vertexes with coordinates, edges with coordinates. Name this list T003. *Note that when all requirement to the data representation are satisfied the coordinate list is an already existing entity. The edges and the faces are defined in the IFC schema. Create list of all edges and faces.*

Type	Task
ID	T004
Name	Find related building elements
Description	Get list T002. Retrieve information of the first item in the list. Search for 'IFCRELCONNETCTSELEMENTS' and the corresponding #nr. of the building element. Create a list of all related building elements with the following information: the #nr.; the GlobalID; and the Name. Name the list T004 *Note that this step is only possible if the topological relationships are defined in the IFC schema. When not possible do:* Search for 'IFCWALL'. *Select all walls on the building storey selected in G001. Create list T004 with all walls on the building storey.*

Type	Task
ID	T005
Name	Obtain wall dimensions
Description	Get list T004. Search for 'IFCWALL' in the list. Retrieve and calculate the dimensions of all related wall elements. This method is specified in paragraph 3.4.4. Create a list per wall element for the topological primitives: vertexes with coordinates, edges with coordinates. Name the list T005.1, T005.1, etc. *Note that when all requirement to the data representation are satisfied the coordinate list is an already existing entity. The edges and the faces are defined in the IFC schema. Create list of all edges and faces.*

Type	Gateway
ID	G003
Name	Opening in floor slab / roof element
Description	Does list G003 exist? When true, are there items in the list? When true continue with G004. When there are no items in the list continue with T018. When G003 does not exist continue with: Get list T002. Retrieve information of the first item in the list. Search for 'IFCRELVOIDSELEMENT' and the corresponding #nr. of the building

	element. When noting is found answer 'False'. When one or more openings are found create list named G003 and answer 'True'.
When True	Continue with G004.
When False	Continue with T018

Type	Gateway
ID	G004
Name	Is opening filled?
Description	Get list G003. Retrieve information of first item of the list. Search for 'IFCRELFILLSELEMENT' and the corresponding #nr. of the opening. When nothing is found answer 'False'. When something is found answer 'True'.
When True	Continue with G003.
When False	Continue with T006.

Type	Task
ID	T006
Name	Obtain opening dimensions
Description	Get list G003. Retrieve information of first item of the list. Retrieve and calculate the dimensions of all related opening elements. This method is specified in paragraph X. Create a list of the edges with coordinates and the length. Name the list T006.

Type	Task
ID	T007
Name	Draw polyline opening
Description	Get list T005.1, T005.2, etc. and T006 with corresponding dimension list. Draw a polyline along the upper vertexes of the opening. This method is described in paragraph 3.4.5.

Type	Task
ID	T008
Name	Compare polyline with wall dimensions opening
Description	Compare and update the polyline created in T007 according to the method described in paragraph 3.4.5. Create new update list of edges of the polyline. Name the list T008.

Type	Gateway
ID	G005
Name	Wall element on opening
Description	Get list T008. Is there an edge marked 'Wall'. When a match is found answer 'True'. When no match is found answer 'False'.
When True	Continue with G020.
When False	Continue with G006 and G007.

Type	Gateway
ID	G006
Name	Length >= 1.00
Description	Get list T006.2. Find the edges that represents the length of the opening. Is the length more or equal to 1.00 meter?
When True	Continue with T009.
When False	Continue with T018.

Type	Task
ID	T009
Name	Value = 10000000000
Description	Give value = 10000000000

Type	Task
ID	T010
Name	Value = 20000000000
Description	Give value = 20000000000

Type	Gateway
ID	G007
Name	Width >= 1.00
Description	Get list T006.2. Find the edges that represents the width of the opening. Is the width more or equal to 1.00 meter?
When True	Continue with T013.
When False	Continue with T014.

Type	Task
ID	T013
Name	Value = 1000000000000
Description	Give value = 1000000000000

Type	Task
ID	T014
Name	Value = 2000000000000
Description	Give value = 2000000000000

Type	Gateway
ID	G008
Name	Length < 0.10
Description	Get list T006.2. Find the edges that represents the length of the opening. Is the length less than 0.10 meter?
When True	Continue with T011.
When False	Continue with T012.

Type	Task
ID	T011
Name	Value = 100000000000
Description	Give value = 100000000000

Type	Task
ID	T012
Name	Value = 200000000000
Description	Give value = 200000000000

Type	Gateway
ID	G009
Name	width < 0.10
Description	Get list of T006.2. Find the edges that represents the width of the opening. Is the width less than 0.10 meter?
When True	Continue with T015.
When False	Continue with T016.

Type	Task
ID	T015
Name	Value = 10000000000000
Description	Give value = 10000000000000

Type	Task
ID	T016
Name	Value = 20000000000000
Description	Give value = 20000000000000

Type	Task
ID	T017
Name	Processing rule set situation 3
Description	Retrieve the values answered by G006, G007, G008 and G009. Add the values. Compare the answer of the added values with the summation values in table X. Send the right type of fall prevention as output. When done remove all lists created after G003.

Type	Task
ID	T018
Name	Draw polyline Slab
Description	Get list T005.1, T005.2, etc. and T003 with corresponding dimension list. Draw a polyline along the upper vertexes of the opening. This method is described in paragraph 3.4.5.

Type	Task
ID	T019
Name	Compare polyline with wall dimensions slab
Description	Compare and update the polyline created in T018 according to the method described in paragraph 3.4.5. Create new update list of edges of the polyline. Name the list T019.

Type	Gateway
ID	G010
Name	Is there an edge of the floor slab or roof element.
Description	Get list T019.2. Retrieve information of the first item in the list. When there is no item in the list answer 'False' and remove first item in list T002. When there is an item in the list answer 'True'.
When True	Continue with G011.
When False	Continue with G002.

Type	Gateway
ID	G011
Name	Is there another slab connected.
Description	Get list T019. Retrieve information of the first item in the list. Is there another edge of a slab connected? This method is described in paragraph 3.4.4. When there is another slab connected answer 'True'. When there is no slab connected answer 'False'.
When True	Continue with G010.
When False	Continue with G012.

Type	Gateway
ID	G012
Name	Wall element on floor slab or roof element
Description	Get list T019. Retrieve information of the first item in the list. Is the edge marked 'Wall'. When a match is found answer 'True'. When no match is found answer 'False'.
When True	Continue with G020.
When False	Continue with T020.

Type	Task
ID	T020
Name	Search for objects
Description	Get list G001. The system will search for the different objects by searching for 'IFCBUILDINGELEMENTPROXY' and 'IFCRAILING' in list G001. Out of the results the system will create a list named T020, of all the objects with the following information: the #nr.; the GlobalID; and the Name.

Type	Task
ID	T021
Name	Obtain object dimensions
Description	Get list T020. Retrieve and calculate the dimensions of all related objects and railings. Create a list per object for the topological primitives: vertexes with coordinates, edges with coordinates. Name the list T021 *Note that when all requirement to the data representation are satisfied the coordinate list is an already existing entity. The edges and the faces are defined in the IFC schema. Create list of all edges and faces.*

Type	Gateway
ID	G013
Name	object on edge
Description	Get list T019 and T021. Compare the coordinates of the edges with each other. When a match is found answer 'True'. Create a list named G013 with the objects and railings that are on the edge. When no match is found answer 'False' and give value 222.
When True	Continue with G014, G015 and G016.
When False	Continue with G017.

Type	Gateway
ID	G014
Name	object at 0.15
Description	Get list G013. Is there an object at 0.15 meter in the z- direction and begins at the same height as the floor slab or roof element.
When True	Continue with T022.
When False	Continue with T023.

Type	Task
ID	T022
Name	Value = 1
Description	Give value = 1

Type	Task
ID	T023
Name	Value = 2
Description	Give value = 2

Type	Gateway
ID	G015
Name	object at 1.00
Description	Get list G013. Is there an object at 1.00 meter in the z- direction relative to the floor slab or roof element.

When True	Continue with T024.
When False	Continue with T025.

Type	Task
ID	T024
Name	Value = 10
Description	Give value = 10

Type	Task
ID	T025
Name	Value = 20
Description	Give value = 20

Type	Gateway
ID	G016
Name	object at 0.62
Description	Get list G013. Is there an object at 0.62 meter in the z- direction relative to the floor slab or roof element.
When True	Continue with T026.
When False	Continue with T027.

Type	Task
ID	T026
Name	Value = 100
Description	Give value = 100

Type	Task
ID	T027
Name	Value = 200
Description	Give value = 200

Type	Gateway
ID	G017
Name	Is it a roof element
Description	Get first item from list T002. When IFCROOF answer ‘True’. When IFCSLAB answer ‘False’.
When True	Continue with G018 and G019.
When False	Continue with T032.

Type	Gateway
ID	G018

Name	2.00 meter area roof
Description	Is there an object 2.00 meters parallel to the edge? When no object is found answer with false.
When True	Continue with T028.
When False	Continue with T029.

Type	Task
ID	T028
Name	Value = 1000000000000000
Description	Give value = 1000000000000000

Type	Task
ID	T029
Name	Value = 2000000000000000
Description	Give value = 2000000000000000

Type	Gateway
ID	G019
Name	4.00 meter area roof
Description	Is there an object 4.00 meters parallel to the edge? When no object is found answer with false
When True	Continue with T030
When False	Continue with T031.

Type	Task
ID	T030
Name	Value = 10000000000000000
Description	Give value = 10000000000000000

Type	Task
ID	T031
Name	Value = 20000000000000000
Description	Give value = 20000000000000000

Type	Task
ID	T032
Name	Processing rule set
Description	Retrieve the values answered by G014, G015, G016, G017, G018 and G019. Add the values. Compare the answer of the added values with the summation values in table 3.18. Send the right type of fall prevention as output. When done remove all lists created after G012.

Type	Gateway
ID	G020
Name	Wall height >= 1.00
Description	Get the corresponding sub list of T005. Retrieve information about the edges in the z-direction. Is the length of the edges in z-direction more than 1.00 meter?
When True	Continue with T033.
When False	Continue with T034.

Type	Task
ID	T033
Name	Value = 1000
Description	Give value = 1000

Type	Task
ID	T034
Name	Value = 2000
Description	Give value = 2000

Type	Gateway
ID	G021
Name	Wall height >= 0.62
Description	Get the corresponding sub list of T005. Retrieve information about the edges in the z-direction. Is the length of the edges in z-direction more than 0.62 meter?
When True	Continue with T035.
When False	Continue with T036.

Type	Task
ID	T035
Name	Value = 10000
Description	Give value = 10000

Type	Task
ID	T036
Name	Value = 20000
Description	Give value = 20000

Type	Gateway
ID	G022
Name	Wall height >= 0.15
Description	Get the corresponding sub list of T005. Retrieve information about the edges in the z-direction. Is the length of the edges in z-direction more than 0.15 meter?

When True	Continue with T037.
When False	Continue with T038.

Type	Task
ID	T037
Name	Value = 100000
Description	Give value = 100000

Type	Task
ID	T038
Name	Value = 200000
Description	Give value = 200000

Type	Gateway
ID	G017
Name	Is it a roof element
Description	Get first item from list T002. When IFCROOF answer 'When IFCSLAB answer 'False'.
When True	Continue with G018 and G019.
When False	Continue with T032

Type	Gateway
ID	G018
Name	2.00 meter area roof
Description	Is there an object 2.00 meters parallel to the edge? When no object is found answer with false
When True	Continue with T028.
When False	Continue with T029.

Type	Task
ID	T028
Name	Value = 1000000000000000
Description	Give value = 1000000000000000

Type	Task
ID	T029
Name	Value = 2000000000000000
Description	Give value = 2000000000000000

Type	Gateway
ID	G019
Name	4.00 meter area roof
Description	Is there an object 4.00 meters parallel to the edge? When no object is found answer with value false

When True	Continue with T030.
When False	Continue with T031.

Type	Task
ID	T030
Name	Value = 10000000000000000
Description	Give value = 10000000000000000

Type	Task
ID	T031
Name	Value = 20000000000000000
Description	Give value = 20000000000000000

Type	Task
ID	T032
Name	Processing rule set
Description	Retrieve the values answered by G017, G018, G019, G020, G021 and G022. Add the values. Compare the answer of the added values with the summation values in table 3.18. Send the right type of fall prevention as output.

Type	Gateway
ID	G023
Name	Opening in wall
Description	Get list T019.2. Retrieve information of the first item in the list. Search for 'IFCRELVOIDSELEMENT' and the corresponding #nr. of the wall element. When noting is found answer 'False' and remove first item from list T019.2. When one or more openings are found create list named G023 and answer 'True'.
When True	Continue with G024.
When False	Continue with G010.

Type	Gateway
ID	G024
Name	Is opening in wall filled?
Description	Get list G023. Retrieve information of first item of the list. Search for 'IFCRELFILLSELEMENT' and the corresponding #nr. of the opening. When nothing is found answer 'False'. When something is found answer 'True'.
When True	Continue with T039.
When False	Continue with G023.

Type	Task
ID	T039
Name	Obtain opening dimensions

Description	Get list G023. Retrieve information of first item of the list. Retrieve and calculate the dimensions of all related wall elements. This method is specified in paragraph 3.18. Create a list of the edges with coordinates and the length for every opening. Name the list T039.

Type	Gateway
ID	G025
Name	Width of the opening
Description	Get list T039. Determine the direction of the wall element. Is the length of the edge in de same direction 0.3 or less?
When True	Continue with T040.
When False	Continue with G041.

Type	Task
ID	T040
Name	Value = 1000000
Description	Give value = 1000000

Type	Task
ID	T041
Name	Value = 2000000
Description	Give value = 2000000

Type	Gateway
ID	G026
Name	Opening height >= 0.15
Description	Get list T039. Determine the coordinate with the lowest value in the z-direction. Is the z-coordinate of the edges in z-direction more than 0.15 meter?
When True	Continue with T042.
When False	Continue with T041.

Type	Task
ID	T042
Name	Value = 10000000
Description	Give value = 10000000

Type	Task
ID	T043
Name	Value = 20000000
Description	Give value = 20000000

Type	Gateway
ID	G027

Name	Wall height >= 0.62
Description	Get list T039. Determine the coordinate with the lowest value in the z-direction. Is the z-coordinate of the edges in z-direction more than 0.62 meter?
When True	Continue with T044.
When False	Continue with T045.

Type	Task
ID	T044
Name	Value = 100000000
Description	Give value = 100000000

Type	Task
ID	T045
Name	Value = 200000000
Description	Give value = 200000000

Type	Gateway
ID	G028
Name	Wall height >= 1.00
Description	Get list T039. Determine the coordinate with the lowest value in the z-direction. Is the z-coordinate of the edges in z-direction more than 1.00 meter?
When True	Continue with T046.
When False	Continue with T047.

Type	Task
ID	T046
Name	Value = 1000000000
Description	Give value = 1000000000

Type	Task
ID	T047
Name	Value = 2000000000
Description	Give value = 2000000000

Type	Task
ID	T048
Name	Processing rule set situation 2
Description	Retrieve the values answered by G016, G017, G018, G024, G025, G026 and G027. Add the values. Compare the answer of the added values with the summation values in table 3.18. Send the right type of fall prevention as output. When done remove all lists created after G022.

The flowchart contains several loops to repeat actions. The first loop is at G002. When all the IFCSLABs and IFCROOFs on a building storey are checked the system will loop back to G001 to search for the next building storey. The next loop is at G003. The system will loop around all the items in list G003 which represents all the openings in the IFCSLAB or IFCROOF. After all the openings are check in the building element the system will continue. The next loop is for the edges of the polyline of either an opening of or a slab. The system will loop around list T019.2 until all edges are checked for fall hazards. The next loop is to check for several openings in a wall when there is a wall on the edge. After all the edges of a building element are checked the system will loop back to check other building elements on the same building storey. When the system loops back, all the list created in the loop are deleted.

In the figures below the flowchart is presented. In figure 4.1 shows the entire flowchart. Figure 4.2, 4.3, 4.4, and 4.5 show each an enlarged part of a specific situation of the flowchart. In Appendix D there is also a figure of the flowchart which can be folded out to follow the process easily.

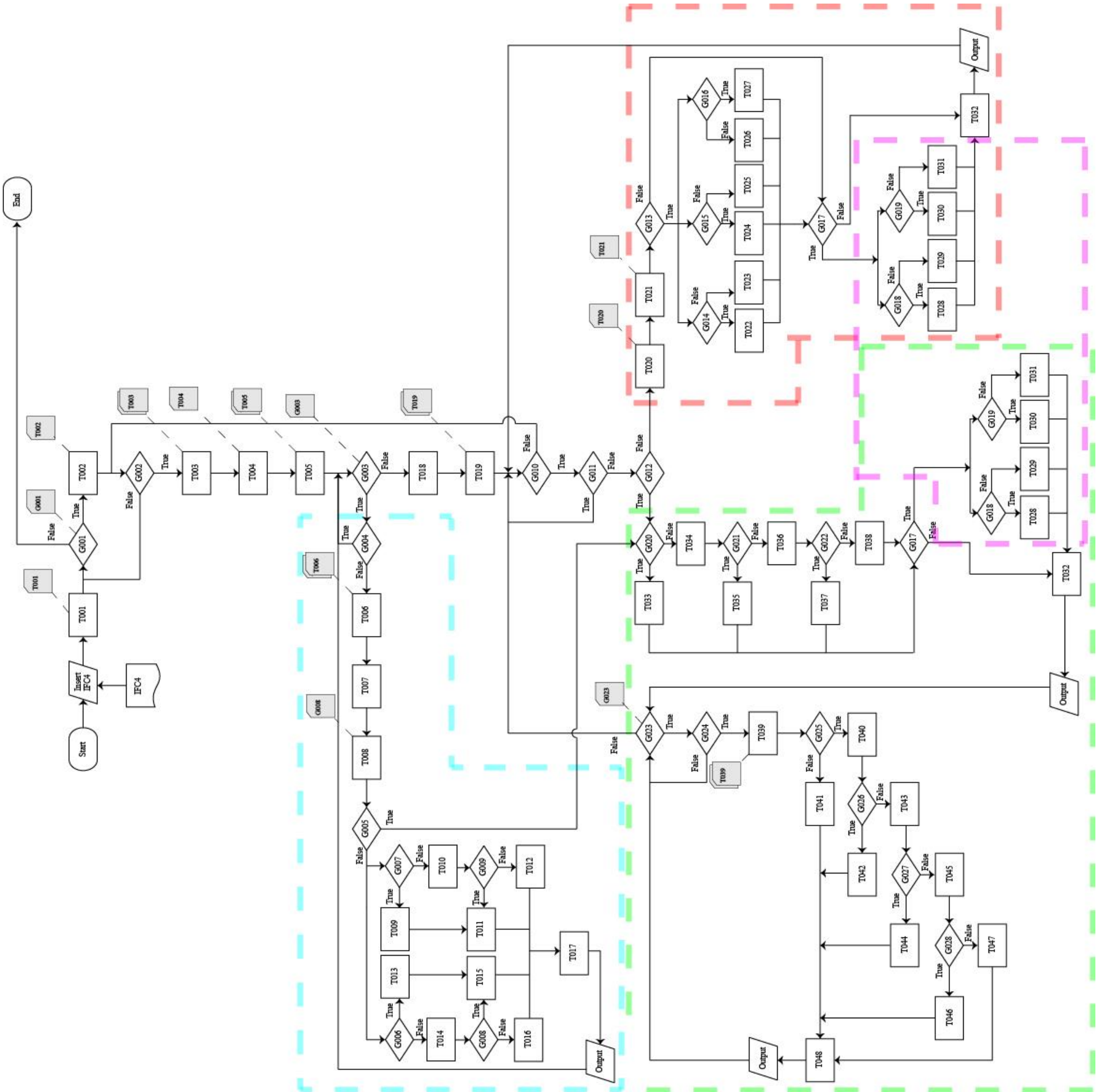


Figure 4.1 | Flowchart fall hazard prevention system

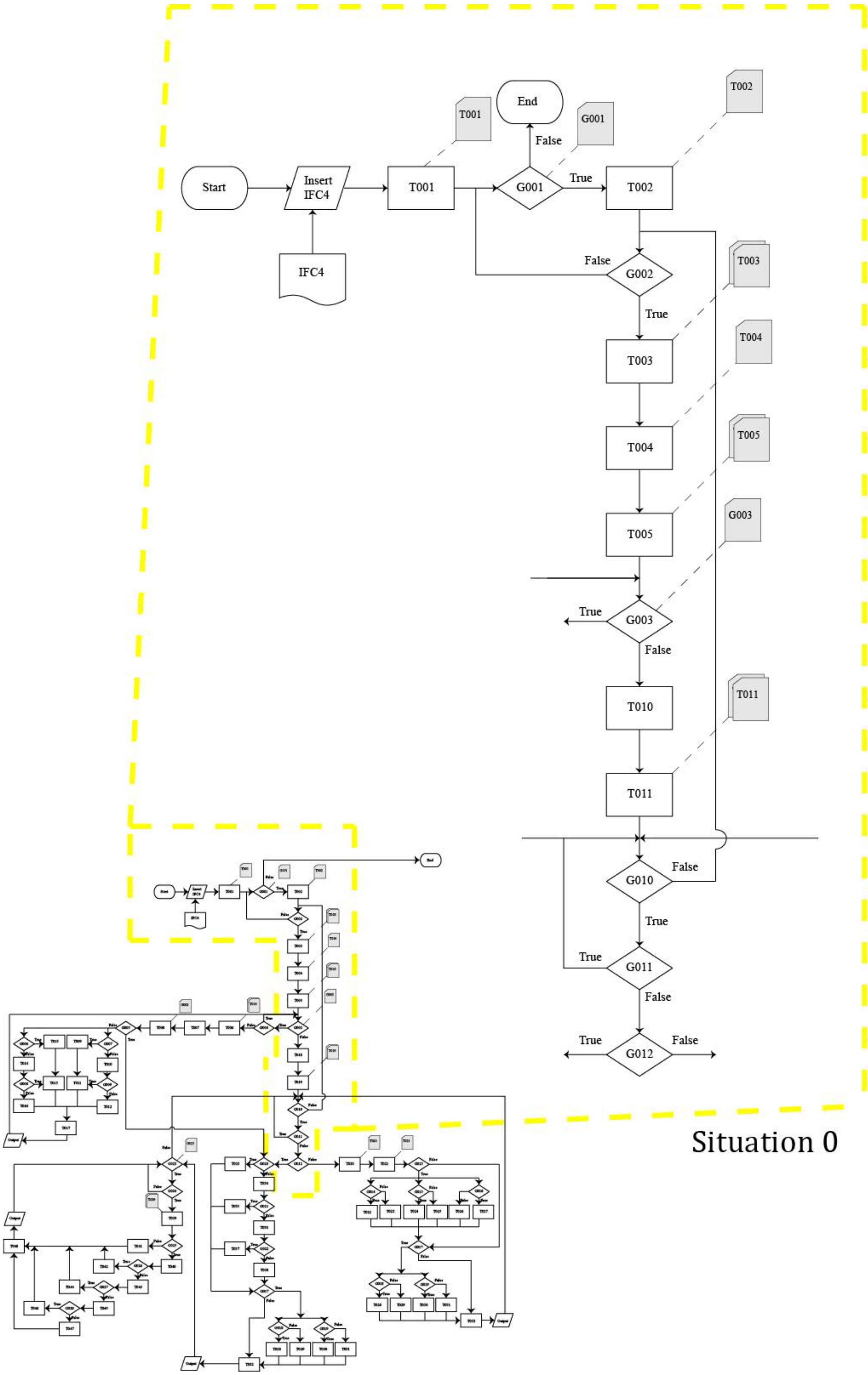


Figure 4.2 | Flowchart situation 0

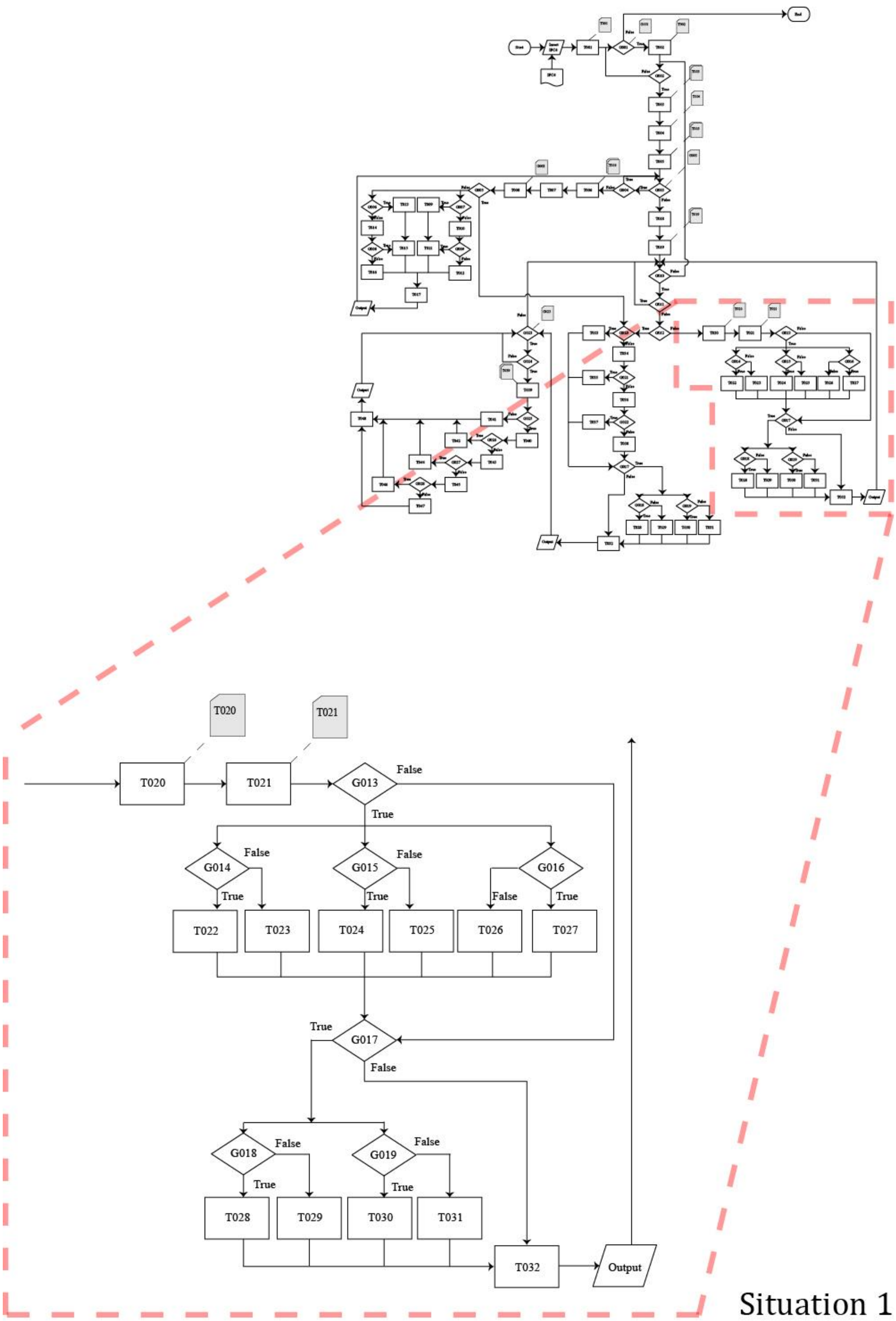


Figure 4.3 | Flowchart situation 1

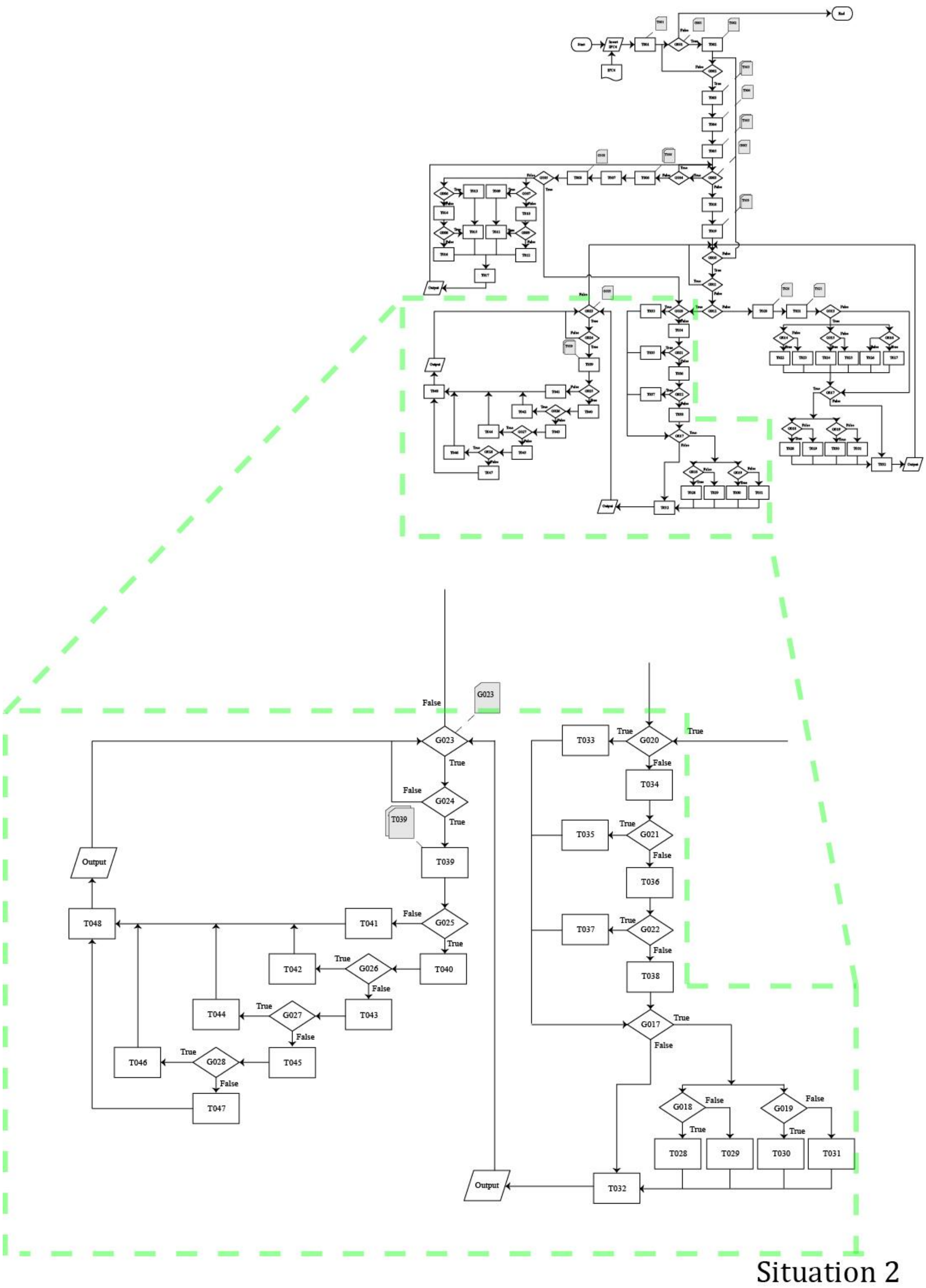


Figure 4.4 | Flowchart situation 2

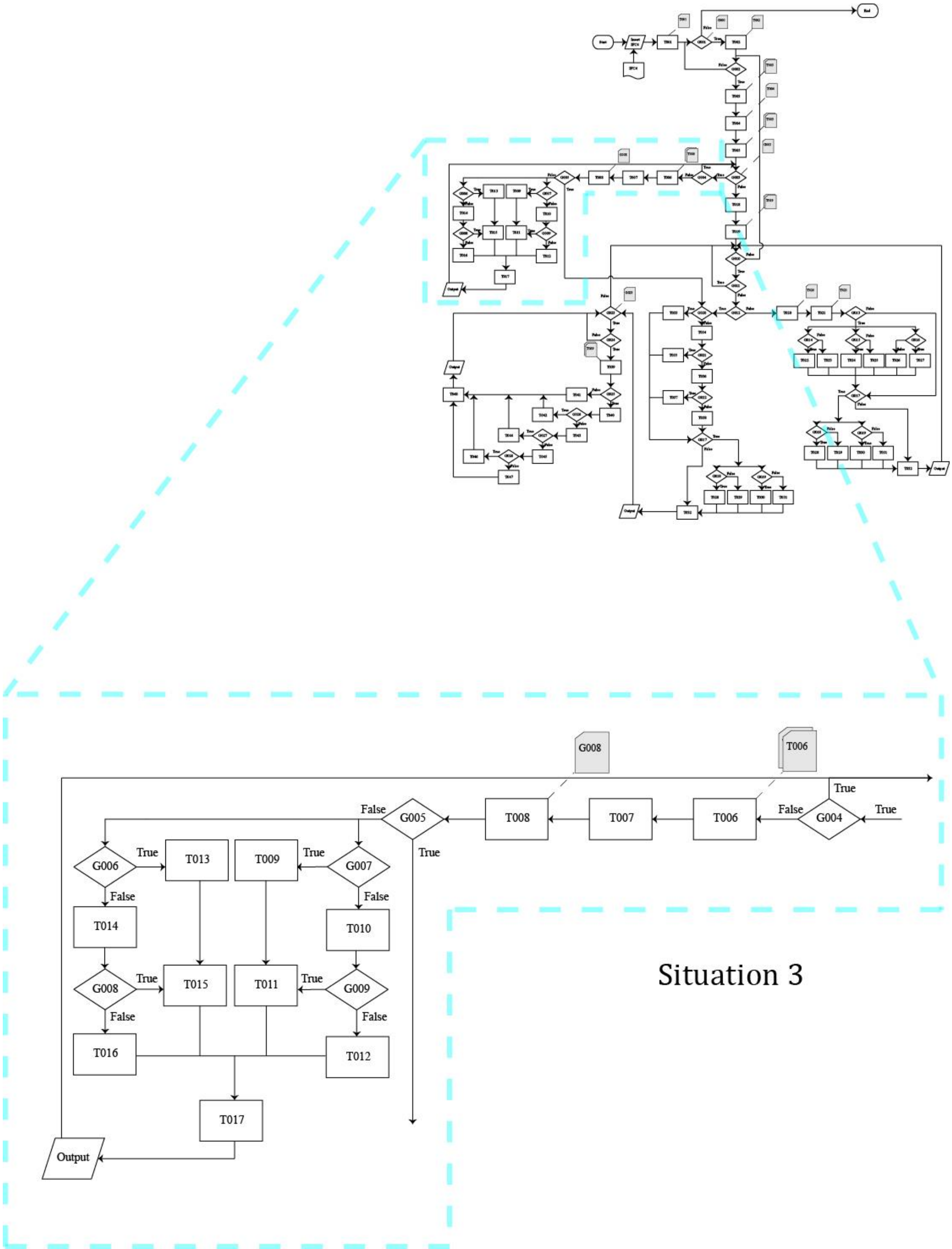


Figure 4.5 | Flowchart situation 3

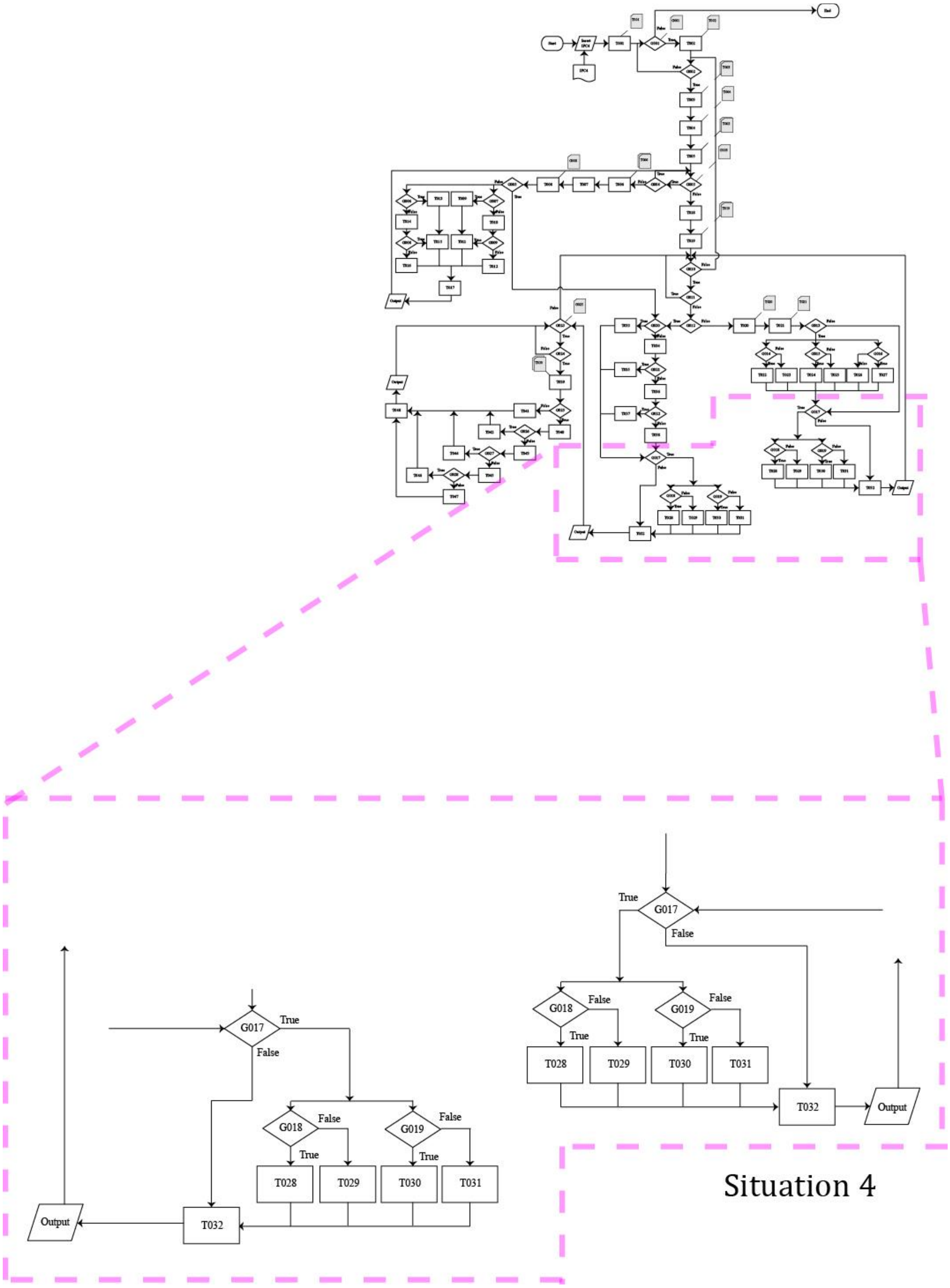


Figure 4.6 | Flowchart situation 4

4.4. Testcase

In this paragraph a testcase of the fall hazard prevention system is conducted. A model with two building storeys, a roof, a slab, five walls, four openings and a railing is made to prove the fall hazard prevention system works. In figure 4.7. an illustration of the model is given. The testcase will follow the steps in the flowchart. A gateway can result in to two different follow up steps. Which direction is answered by 'True' or 'False'. The ID's in the steps of the testcase correspond to the steps in the previous paragraph. The steps of the testcase as the IFC 4 schema used for the testcase can be found in Appendix E. In Appendix D an illustration of the flowchart can be found to help follow the steps in the testcase.

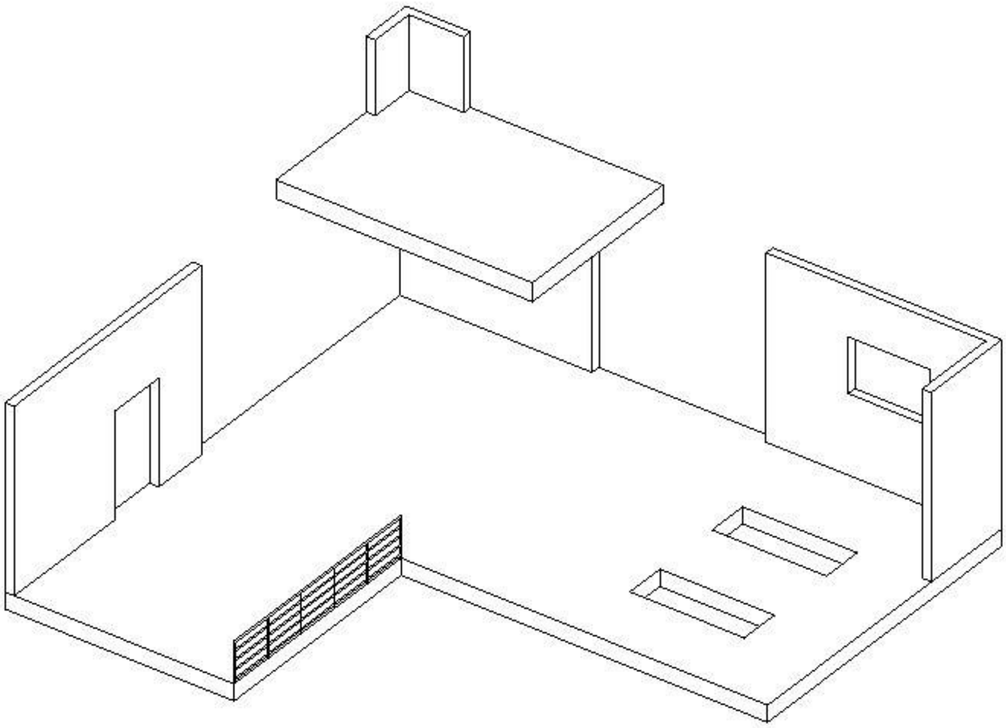


Figure 4.7 | Visual presentation of the testcase model

The testcase presented proves that the fall hazard prevention system can be used to detect unsafe situations and provide the solution for the situation. Figure 4.8 shows the model with all the edges. The edges are marked with the value code which corresponds to a situation with a specific solution. Also the length of the edges are given. This can be used to calculate the amount of prevention equipment needed.

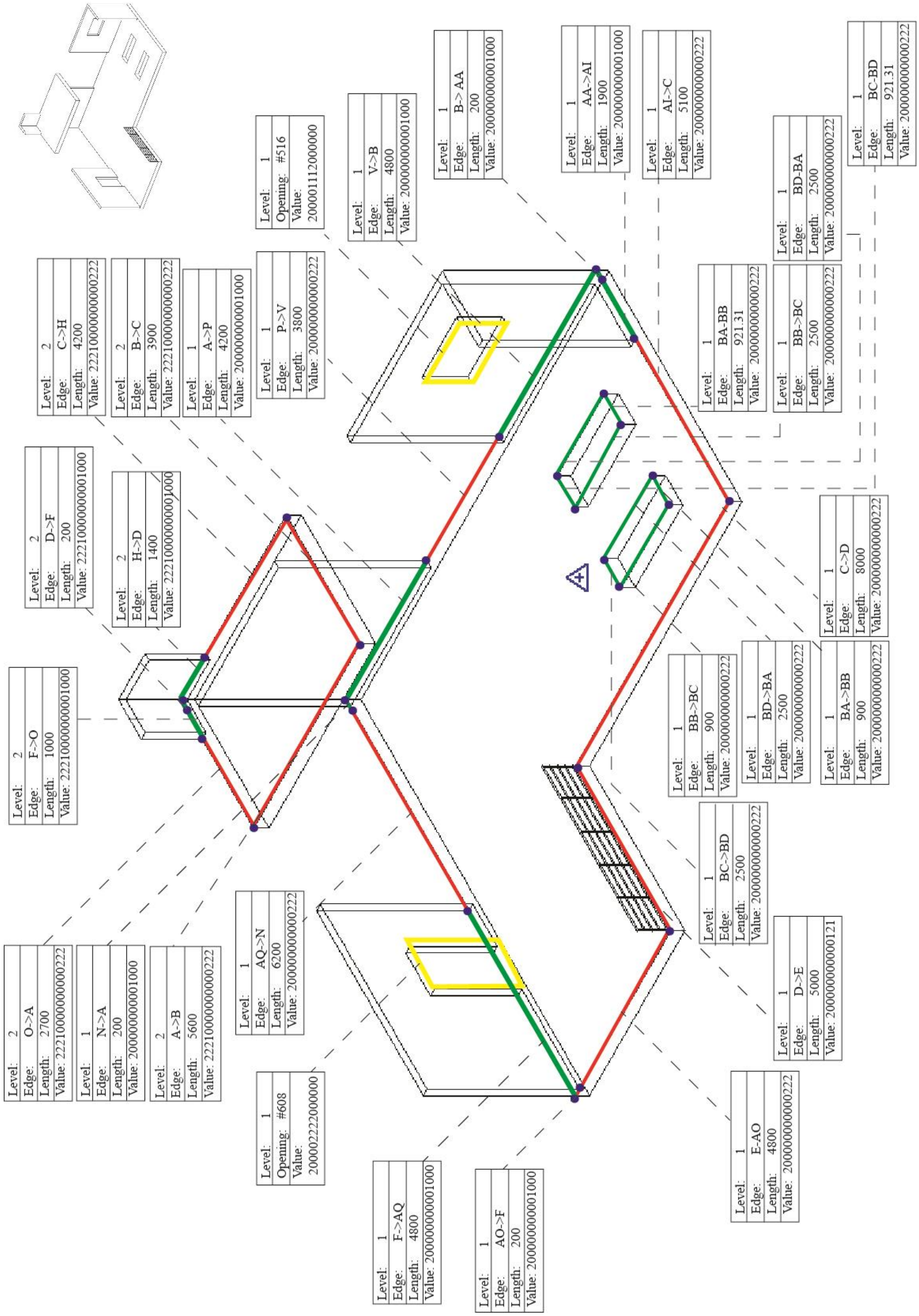
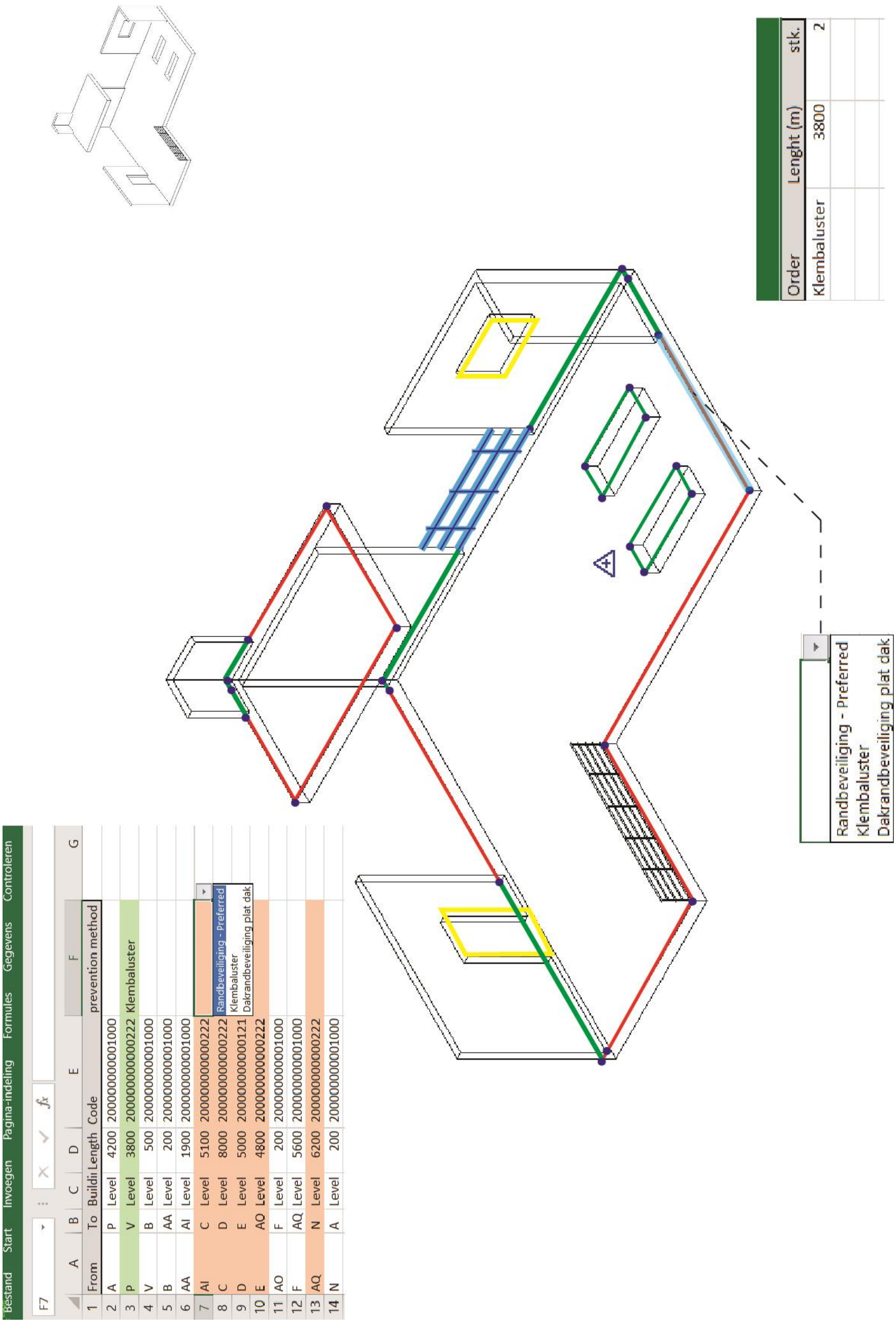


Figure 4.8 | Visual representation of the output



	A	B	C	D	E	F
1	From	To	Buildi	Length	Code	prevention method
2	A	P	Level	4200	2000000000001000	
3	P	V	Level	3800	2000000000000222	Klembaluster
4	V	B	Level	500	2000000000001000	
5	B	AA	Level	200	2000000000001000	
6	AA	AI	Level	1900	2000000000001000	
7	AI	C	Level	5100	2000000000000222	
8	C	D	Level	8000	2000000000000222	
9	D	E	Level	5000	2000000000000121	
10	E	AO	Level	4800	2000000000000222	
11	AO	F	Level	200	2000000000001000	
12	F	AQ	Level	5600	2000000000001000	
13	AQ	N	Level	6200	2000000000000222	
14	N	A	Level	200	2000000000001000	

Figure 4.9 | Visual representation of the interface design

4.5. Using the results

In this paragraph the output after running the testcase are discussed to give an understanding of the ways the output can be used to help safety management. Every time the system run past the step 'Output' information about the specific edge, that is analysed, is sent to an external table. For example a Microsoft Excel file. Between which vertexes is the edge placed; On which building storey is the edge placed; the length of the edge; and the summarised value of the edge after running through the system.

The summarised value could refer to a set of possible safety prevention methods. As mentioned earlier, due to the factor of time in the construction process executors need to bring in their expertise to decide which is the best prevention method. What the system will do is allow a summarized value to be connected with a couple of prevention methods. It will give the preferred option for the situation but it is possible to choose another method. This process is shown in figure 4.9. By means of a dropdown window the user can choose the possible prevention method that could resolve the fall hazard. Because different companies work with a different set of available prevention equipment the prevention methods should be selected by the safety manager of the company itself. This creates an extra responsibility for the safety manager to keep the database of available safety equipment updated.

Because the lengths of the edges are known and the safety equipment available is known in the optimal situation, an order list can be extracted from the output. Figure 4.9 shows a little part of such an order list with the information that can be extracted. The hazard on edge P→V is resolved with a 'Klembaluster', which can be ordered by Strukton at Boels. The length of the 'Klembaluster' is 2 meter. So, two pieces are needed. When more edges are resolved with the same safety method the order list for 'Klembaluster' will increase.

How the interface of the fall prevention system would look like and how the user is able to run through all the hazard is not defined yet. But in discussions with possible users the preferred method would be with a visual representation of the digital model. Figure 4.9 give a possible representation of how the interface should look like. It contains a viewer of the digital model. Hazards could be resolved by selecting the edge with a hazard. A dropdown widow will appear and give the possible safety method to resolve the hazard. A list of the hazard will be available to see is all the hazard are resolved and a table for the order list shows

If the user wants to place the safety equipment in the actual IFC file it is possible. Somethings should be taken in consideration: The safety equipment should be defined as a building element in the IFC schema. The most obvious entity would be the IfcBuildingElementProxy or the IfcRailing; The placement of the axis needs to refer to the axis of the IfcSlab where the edge is on. By using the vertexes and the coordinates the edge is placed between the placement of the safety equipment can be decided. Modelling the safety equipment's into the CAD tool can have several other benefits. Setting up the safety equipment can be taken into account when implementing 4D BIM. Or building elements like walls and slab can be ordered with fixation point for the safety equipment.

4.6. Discussion

The results of the fall hazard prevention system show that it is possible to create an automated system that recognizes fall hazards in a building project and create a prevention for the fall hazard. This paragraph will discuse the results and the process. Starting at the data collection and the safety rules. The safety rules and regulations used in this research are the Dutch safety rules and regulations. It is important to realize that these rules can vary in different countries in the world. The basis of these rules lies in the constraint they put on the dimensions to the building elements in the model This makes it easy to change if safety rules changes or the system is implemented in a country with different rules. Also the best practice of the QHSE department is used. Although there expertise comes with years of experience the solutions they suggest is there opinion. It could be that other safety inspectors or safety managers would give an alternative number for the dimensions. The Dutch safety rule says that due to the fact that every situation is different there is not one solution to a problem and construction workers should be aware of what is and what is not a safety hazard.

Next are the requirements to the data representation. What is striking in the testcase is the amount of calculations that are repeated which could be avoided if the requirements to the data representations are met. Calculating the coordinates of all the vertexes of all the building elements takes up a large part of the report. What kind of effect it has on the efficiency of a program is not clear but it certain is not positive. Another calculation that could be avoided if the requirements to the data model are met is determining if building elements are connected. In the current way the IFC schema works there can be filtered to the point of building elements on a building storey. But only 4 wall on a building storey took a long time. The result of this thesis is the flowchart which is able to work with the current version of the IFC4. But the thesis strongly recommends taking these requirements into account when developing an next version of the IFC schema.

Next are the part about obtaining the dimensions. The methods used to calculated the dimensions of the building elements will only work for the standard case version of the building elements. This research does not go into how to calculate the dimensions of other shape representations. This does not mean the steps in the flowchart needs to change if these methods wanted to be added to the current system. Only the process within the step needs to be compatible with multiple shape representations. The order of the steps in the flowchart still stays the same.

The next part is the creation and the splitting up of the polyline. The creation of a polyline allows the original model to stay intact. To give a better understanding of what is happening a figure was drawn to have a visual representation. Without the figure the process would have taken a lot longer. Also the direction of the edges is important. Mistakes could easily be made when the edge is in a negative direction. When implementing other shape representations, the polyline should also be able to have curved edges.

When creating the flowchart some gateways will result in the same next step. This may look like a flaw in the flowchart. But the outcome of the gateway creates a different value which leads to a different solution in the step 'processing the rule set'. It can be argued that this gateway has qualities of a process. This is not untrue. But in this research it was decided it was more clear for further development toward an actual program it would be a gateway. The gateways would represent an if-statement. Which implies there is a choice.

Another limitation to the system for a situation that can exist in real life is where building elements are near the edge of a slab but not actually on the edge. This means that if a wall or an object like a HVAC system is on 0.20 meters from the edge the system would think there is still a fall hazard. Although in real life no construction worker can come there. This would create a falls positive in the system, an safe situation where the system thinks it is a hazard. It is unlikely that this situation will occur because of the current building methods but still the system would be incorrect. This situation could be resolved by working with ranges around the edges. The specific dimension for the this range could not be retrieved for this research.

In most building projects scaffolding is used. The system does not take scaffolding into account when deciding if an situation is a fall hazard. There is no entity which defines a geometry as scaffolding. In the current IFC schema scaffolding would be defined as IfcBuildingElementProxy. Future research should look into updating the fall hazard prevention system to check for scaffolding.

While conducting the research, one thing that came back was the misconception of what BIM means within employee in the AEC-sector. The main understanding of BIM was that it just was a 3 dimensional CAD tool. Instead of a platform to increase collaboration and work more efficient. This misunderstanding amplifies the lack of acceptation of the BIM method within the AEC-sector. Now a day the motivation to use BIM for a project comes from the site of the client. But it should come from the construction company itself. This way more investment toward the switch to BIM is available. And benefits for being the first to the market with innovative processes can profit the company. Which will increases the investment even more and more systems like the one in this research can be developed. Saving costs and life during the project lifecycle.

During the development of the fall hazard prevention system another discussion kept coming back. How and to what extend should such a system be implemented. Who is responsible for when errors in the system will lead to an unsafe situation. For certain the system, in this stage, is not a replacement for the way safety management is done today. If it will ever be a total replacement is not certain. In its current stage it is more an extra tool to determine which situations are hazards. Or even more the first steps toward future research. By implementing a method to let an executor determine between different solutions for a situation the responsibility lays still with the executor to make sure the construction site is safe.

5. Conclusion

In the previous chapter the results of the research is given and discussed. In this chapter the answer to the research questions will be given. Next a refection towards the scientific relevance and the societal relevance is done. This is a critical evaluation of the project. Is the objective been achieved? What could have gone better?. After the reflection recommendations for follow-up research is presented.

5.1. Answer to the research questions

In this paragraph the answer to the research question and the sub questions are given. First the sub question are answered. These answers will result in the answer to the main research question.

(Sub 1) "Where in the project lifecycle should the system be implemented?"

This sub question is answered in the literature research. For the system to work properly the model must has at least a LOD of 300 or 350. This also determines when the fall hazard prevention system can be implemented in the design process. If the BIModel is not detailed enough the system cannot retrieve the right information or the output is not reliable. The goal is to implement the fall hazard prevention system in the design phase. With a LOD of 300 this is possible. For building models at the design development phase, which is the most typical stage where a building model is complete enough for code compliance submission, LOD 300 or LOD 350 is generally sufficient.

(Sub 2) "What are the safety rules and regulations towards fall hazards?"

This sub question is answered in the data collection of the safety rules. In the Dutch construction sector, the safety rules consist of the Dutch law and the ARBO rules. Many construction workers work in different situations every day. Although the Dutch law and the ARBO rules cover a lot of the safety spectrum it is not waterproof. Due to all the different possible situation that can exist on the construction site it is impossible to cover every situation. Therefor the ARBO rules states that it is important for everybody who is working on the construction site to think for themselves if the situation or work might contain risks. . If there is a dimension which is not described between the Dutch law and the ARBO rules the best practices of the Quality, Health & Safety and Environment department of Strukton Worksphere is taken as the dimension. The safety rules and regulations are based on the dimensions of the building elements. An edge is safe when there is an obstruction or a wall with a minimal height of 1.00 meter. This also includes openings in walls. Further it needs to be impossible to kick an item over the edge of the slab. So an obstruction or wall needs to be from the top of the slab to 0.15 meters in height. Between these heights there needs to be an extra obstruction at 0.62 meters. An opening in a wall must have a width of 0.3 meter to be a fall hazard. Openings in the slab are always an fall hazard if the with or the length is more than 0.1 meters. The same rules apply on the roof. If it is necessary to work within the 2.00 meter area on the roof, extra fall prevention needs to be at place. An area of 4.00 meters also needs to be marked with a visible obstruction. Within the 4.00 meter area normal construction work can be done.

(Sub 3) "What are the requirement to the data representation?"

This sub question is answered in paragraph X, requirements to the data representation. The ISO has developed conceptual schemas for describing and manipulating the spatial characteristics of geographic features. A topological and geometrical approach towards these conceptual schemas resulted in 5 requirements to the data representation. The requirements are: 1) An opening within a building element needs to be modelled as a separate element. 2) All geometry which refers to an element should be defined as such in the data model. 3) The representation of a building element within the data needs to include a list of the coordinates. 4) In the data file the topological relationship between building elements should be defined. 5) The building elements need to be modelled as B-reps in the data file. Because some of the requirement are not supported by the IFC4 Reference View, the IFC4 Design Transfer View is the best choice for the fall hazard prevention system and other BIM tools. There are still some recommendations for the development of the IFC file type so this system, but also others, can work more effectively and efficient. These are: (1) All geometric representations need to contain a coordinate list; (2) All building elements need to have defined all the topological relationships with other building elements; (3) All building elements need to be represented as a B-rep.

(Sub 4) “What are the requirements to the building model? “

This sub question is answered in chapter Results. The requirements to the building model are set because of limitation in the system. The first requirement to the building model is: When modelling the building project is must be in line with the Basis Dutch Information Delivery Manual. When exchanging information, it is important that every stakeholder speaks the same language. The second requirement to the model is that when it is exported to a IFC4 file it must be done with the Design Transfer View for IFC4 as MVD. The third requirement for the model is the use of standard case entity of building elements. This means that the building elements are constructed out of straight lines with an constant height. Next for the building elements is that the building elements need to be modelled per building storey. The last requirement is the use of exclusively flat roofs. Because most of the projects for Strukton Worksphere are in the utility sector and these buildings have flat roofs in most cases, the expertise used in this research focusses on flat roofs only.

Now the sub questions are answered it is time to answer the main research question of this thesis.

“How should a BIM related system work to help prevent fall hazards in an early design phase?”

To create a BIM related system to help prevent fall hazards in an early design phase the level of detail of the model must be at least 300. This means during the design development phase. The system works with the Dutch safety rule and regulations and the best practice of the experts at Strukton Worksphere. The safety rules are focused on the dimensions of the building elements. To develop the system as efficient as possible some requirement to the data representation are needed. The requirements that are not already satisfied by the IFC 4 schema are recommended to take in consideration when developing a new version of the IFC to stimulated the development of BIM analysing tools. The flowchart presented in this thesis has some limitations towards how the building model needs to be modelled. To make sure the output is correct these requirements must be met before inserting the IFC file into the system.

5.2. Scientific relevance

This thesis is first of all a scientific research project. This means there is a scientific relevance. For this research it could be found in the method of analysing already existing methods for creating solid models and searching for more efficient and effective methods to create solid models specific for these types of analysing tools. Combining BIM and Safety for a fall hazard prevention is not a new concept in the academic world. Some researchers have gone before me and given their view on the matter. This thesis is inspired by the method used by (Zhang et al., 2015). Where with the BIM tool Tekla Structures, a fall hazard prevention system is developed. What differs this thesis from the fall hazard prevention system of Zhang et al. are a several of elements. Firstly this research uses the Dutch safety regulations. Second, this research is based on the IFC schema as it data file. The most difference between both researches is the method used to develop the system. This research began with an topological and geometrical approach compare to the conceptual schemes of the ISO. Here the ideal situations for the development of the data representation has been analysed. This topological and geometrical approach has also been used earlier in other studies comparing evacuation plans and energy performance but never for safety analysis. This method resulted in recommendations for the development of the next version of the IFC schema. In its current state the fall hazard prevention system will be able to analyse around the 80% of all cases in the normal workflow of a Dutch construction company.

The objective for this thesis is to develop a flowchart for a fall hazard prevention system that is used in the BIM mythology to identify fall hazards using IFC. The fall hazard prevention system is designed to be implemented before construction is started. This objective is designed to ensure that the building site is a safer working environment for all construction workers worldwide. Worker safety as top priority. Is the objective? To begins with there is a flowchart developed for a system that can use data before construction commences. The flowchart is tested to prove it can detect fall hazards and refer to a solution. If this thesis can assist to make the AEC sector safer is not yet clear. Although, it does have the potential to prevent fall hazards. The time factor on the construction site together with the expertise of executors is still the preferred option.

What could have contributed to a better result? What could have sped up the process, the answer is experience with programming languages at commencement and deciding not to program earlier on in the project. I highly recommend that the researcher how decides to follow up on this research has experience with programming languages.

5.3. Societal relevance

The societal relevance of this thesis can be found in the topic of safety. Preventing (fatal) injuries benefits all facets in the community. Firstly family and friends often suffer from a psychological cost of injury. Employees with work related injuries also could potentially harm other areas of the community. Health care, rehabilitation and reintegration costs can also be spread over multiple groups. Providing a safe working environment within the construction company could also encourage better employees with in the building sector because the of reduced chances of work related injuries.

Another part of the social relevance of this thesis is the acceptance or upgrading of the BIM method within the current working methods of the construction company. The BIM method has proven to be a cost saver over the entire span of the project lifecycle. To totally gain these benefits the entire project must make use the BIM method. Benefits gained on projects this size could reduce costs, not only for stakeholders but also stimulate other sections of the economy.

5.4. Recommendation for possible follow-up research

Developing this fall hazard prevention system has led to recommendations for follow-up research in other areas. These topics are listed below.

- The implementation of a programming language. The logical next step in this research is to translate the flowchart into a programming language. This would create an automated version of the fall hazard prevention system.

- Extend the possibilities of the fall hazard prevention system with more shape representations. Adding the possibilities to also analyse curved edges and building elements that differ in height over the length of the element.

- Including other types of roof elements. Extend the fall hazard prevention system with the possibility to analyse more types of rooves than just flat ones.

- Including scaffolding into the system. Extend the fall hazard prevention system with the possibility to recognize scaffolding in the building model. For this the IfcBuildingElment for scaffolding should be defined first.

- Extend the fall hazard prevention system with more safety checks than only fall hazards. Developing the system to recognize other safety issues than just fall hazards. This would create a system that could perform a full safety check of the construction process. For this the most important of the safety issues need to be analysed to review what checks need to be made.

- Implementation other than in the early design phase. The system could be transformed into a system that could check the process of the construction process day by day. The executor could carry out a safety check of the construction in its present state at the start of works each day. Then, the necessary changes to safety measures can be communicated. For this, the time factor and 4D BIM must be fully implemented into the BIModel.

- Creating a specific Model View Definition for safety checks. In the current MVD used for the fall hazard prevention system unnecessary information is exported from the building model. For larger projects it would be beneficial to only export the information that is required for the safety checks. For example, material properties are not important for a construction process safety check.

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Appendix A

Interview Quality, Health & Safety and Environment department

Interviewer: Dustin Bolte

Geïnterviewde: Marcel Pruijsten

Vincent Morsink

Arjan Bempt

Donderdag 13 September 2018 om 12:00

- Wat zijn de meest voorkomend ongelukken binnen Strukton?

Het aantal ongelukken valt best mee. Het aantal ongelukken wordt gemeten door middel van het aantal meldingen. Bij een melding betekent het niet dat er een ongeluk is gebeurt maar dat er een situatie is waarbij het kan gebeuren. Een soort van klikken. De meest voorkomende ongelukken binnen Strukton zijn de psychologische ongelukken. Dit zijn meldingen over dingen als seksueel ongewenste handelingen maar ook Burn-outs. Maar als je het echt over ongelukken op de bouwplaats hebt dan staat val gerelateerde ongelukken wel op nummer 1.

- Hoe groot is het probleem van val gerelateerde ongelukken?

Zoals we zeiden is het aantal ongelukken dat wordt gemeten aan de hand van het aantal meldingen. Er komen veel meldingen binnen over val gevaar. Dit is dus niet perse dat er iemand van een hoogte valt maar bijvoorbeeld dat er de kans is dat het gebeurt. Dus dat er een hekwerk ergens mist.

- Zijn deze ongelukken te voorkomen?

Sommige van deze ongelukken zullen zeker te voorkomen zijn. Maar een groot deel is ook zeker domme pech of niet goed opletten.

- Wordt er een computerprogramma gebruikt voor het realiseren om val gerelateerde ongelukken te voorkomen?

Nee er worden geen computerprogramma's gebruikt voor het realiseren van veiligheidsvoorzieningen.

- Hoe komt het dat de ongelukken nog kunnen gebeuren? Is dit omdat er nog onveilige situaties aanwezig zijn? Of is dit omdat deze niet herkent worden?

Vaak is het gewoon domme pech of onoplettendheid. Laatst was er een verhaal van een man die een plaat oppakte om deze op te ruimen. Deze plaat was bedoelt om een gat af te dekken. Hierdoor heeft hij de plaat nooit gezien en is gewoon naar beneden gevallen. Een andere reden is ook dat we weleens met buitenlands personeel werken. Hierdoor ontstaat er een taal barrière. Deze mensen kunnen de veiligheidsinstructies dan niet volgen.

- Ziet u toekomst in een geautomatiseerd val preventie systeem?

Als het ongelukken voorkomt dan is dat zeker de toekomst. Maar wij zien meer de opkomst van VR technologie als volgende stap.

- In welke fase zou zo een programma moeten worden geïmplementeerd

Het liefst zouden we zien dat dit elke ochtend voor het beginnen op de bouwplaats zou worden toegepast om te zien wat er moet gebeuren die dag. Een soort update check per dag.

- Hoe gaat het huidige proces van onveilige situaties herkennen?

Nou de QHSE afdeling doet eigenlijk helemaal geen tekeningen checken. Er is gewoon teveel werk omdat te doen en wij zijn niet bekent met elke specifieke situatie. Een uitvoerder maakt een VGA plan en een plan van aanpak. Wij kijken of deze plannen met elkaar overeen komen en of de uitvoerder bewust is van de veiligheid op zijn bouwplaats. Het is niet zo dat wij met een bouwtekening lijntje lopen te zetten waar leuningwerk moet komen.

- Is er terug koppeling over onveilige situaties met ontwerpers?

Wij als Strukton doen in de meeste gevallen niks aan het ontwerp van een gebouw. Als wij de tekeningen krijgen is het ontwerp al af. Terugkoppeling is dus vaak niet mogelijk.

- Nu verder ingaand op de specifieke situaties. Hoe hoog moet leuningwerk zijn om val gevaar te voorkomen?

Er is een verschil tussen het bouwbesluit en de ARBO. Volgens mij zegt de ARBO rond de 1 meter hoogte. Ook is het belangrijk om schopplanken te hebben zodat je geen spullen over de rand heen schopt. En er moet nog iets komen zodat je niet tussen dit gat kan vallen.

- Wat is de minimale breedte voor een opening in een muur?

Voor dit soort gevallen zijn er niet perse regels. Het is de taak van de uitvoerder om hier bewust mee om te gaan. Als je perse een hard getal wilt dan is dat een moeilijke. Van belang is dat je er niet zomaar doorheen moet kunnen vallen. Dus dat zal 30 centimeter zijn ongeveer.

- Hoe lossen jullie gaten in de vloer op? En welke afmetingen horen daarbij?

Gaten in de vloer kunnen op twee manieren worden opgelost. Met een multiplex plaat en met leuningwerk. De afmetingen zijn ook niet echt gedefinieerd. Een plank moet een minimale sterkte hebben. Wanneer de overspanning te groot is of er een hele constructie onder de plank moet komen is het misschien makkelijker om leuningwerk te plaatsen. De minimale afmetingen zullen zijn zo gauw je voet er niet meer tussen past. Dit is ongeveer 10 centimeter.

- Zijn er nog andere belangrijke gevallen waar extra preventie maatregelen nodig zijn?

Er zijn een aantal speciale situaties. Zoals bijvoorbeeld op het dak. Maar ook werk boven de weg of boven water is een speciale situatie waar extra aandacht naartoe moet gaan. Ook kan het wel eens zijn dat er wapeningsstaven uitsteken. Je hoeft dan echt niet van 2,5 meter te vallen om gewond te raken. Dat kan ook vanaf 40 centimeter als je pech hebt.

Appendix B

Interview uitvoerder

Interviewer: Dustin Bolte

Geïnterviewde: Jeroen van de Veerdonk (Werkvoorbereider/Uitvoerder MMC)

Dinsdag 11 December 2018 om 10:00

- Is een uitvoerder verantwoordelijk voor de veiligheid op de bouwplaats?

De uitvoerder is verantwoordelijk voor de gehele bouwplaats. Dus ook de veiligheid.

- Waar halen jullie de veiligheidsvoorzieningen vandaan?

Volgens mij huren we dat altijd bij Boels en Reco. Dit kan nog wel eens verschillen wanneer er niet genoeg materieel bij een te verkrijgen is.

- Wat is de beste plek om een preventie systeem te implementeren?

Zo vroeg mogelijk. Bij het MMC hadden ze dat al bij het ontwerpen van de prefab elementen al meegenomen waardoor de fixatie punten al werden meegeleverd met de elementen. Hierdoor kon er snel en efficiënt worden gewerkt aan de veiligheid want het waren maar een paar handelingen.

- Waardoor gebeuren de meeste ongelukken

Ongelukken zijn vooral menselijke fouten. Vanaf de voorkant wordt alles wel goed geregeld maar ongelukken blijven gebeuren zolang je met mensen blijft werken. Domme acties, per ongeluk iets doen, of verschillende werkzaamheden zorgen dat veiligheidsvoorzieningen tijdelijk worden weg gehaald. De factor tijd zorgt ook voor de keuze van welk preventie middel. Er zijn tig verschillende mogelijke preventies voor een rand of een gat deze keuze moet ook blijven bestaan anders wordt een mogelijk programma nooit gebruikt.

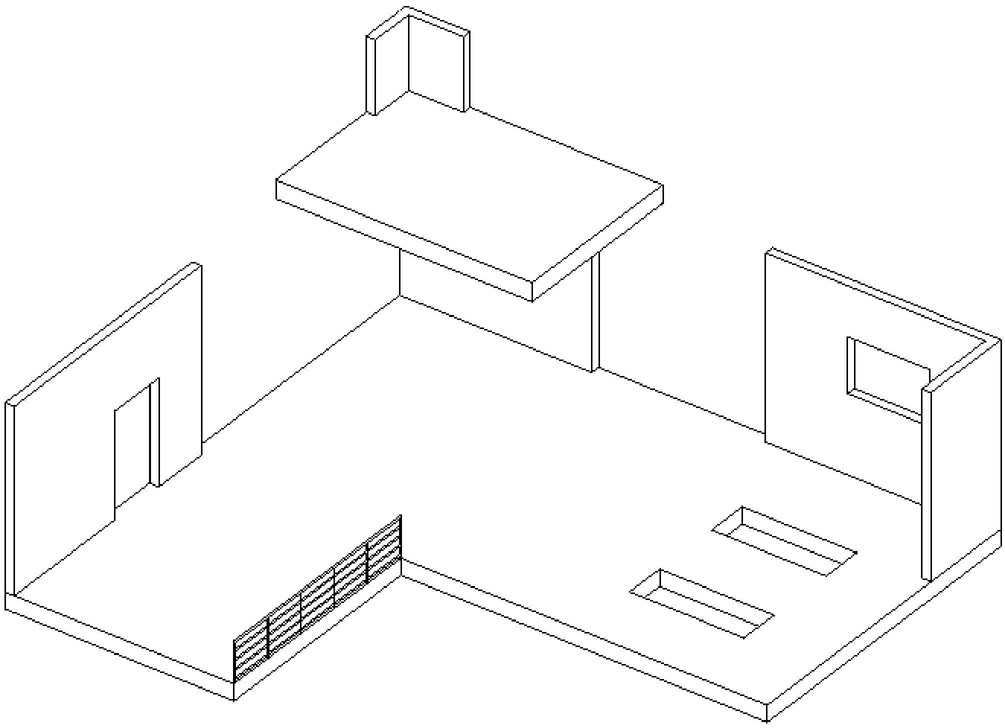
- Wat zijn de meest voorkomende ongelukken?

Val gerelateerde ongelukken zijn wel een van de meest voorkomende ongelukken op de bouwplaats.

Appendix C

Testcase

In this paragraph a testcase of the fall hazard prevention system is conducted. A model with two building storeys, a roof, a slab, five walls, four openings and a railing is made to prove the fall hazard prevention system works. In figure X. a illustration of the model is given. The testcase will follow the steps in the flowchart. A gateway can result in to two different follow up steps. Which direction is answered by ‘True’ or ‘False’. The ID’s in the steps of the testcase correspond to the steps in the previous paragraph. The IFC 4 schema used the testcase can be found in Appendix X. In Appendix Y a illustration of the flowchart can be found to help follow the steps in the testcase.



Type	Event
ID	E001
Name	Start
Action	*Start event*

Type	Input/Output
ID	I001
Name	Insert IFC file
Action	*An IFC 4 file exported with a Design Transfer View MDV is inserted.*

Type	Task
ID	T001
Name	Search for Building storey

Action
- Search for 'IFCBUILDINGSTOREY'. 2 matches found.
- Create list T001:

List T001		
#nr.	**Global ID**	**Name**
#156	*38FHvs4sbAXBc7ToVG5$tE*	*Level 1*
#162	*38FHvs4sbAXBc7ToVG5$Q2*	*Level 2*

Type	Gateway
ID	G001
Name	Is there a building storey

Action
- Get first item in list T001.

#156, 38FHvs4sbAXBc7ToVG5$tE, Level 1

- Search for 'IFCRELCONTAINEDINSPATIALSTRUCTURE' and '#156'
  1 matches found
- Create list G001:

List G001			
#nr.	**Global ID**	**Type**	**Name**
#230	*3PiPR_A6j7i8xsfls1hXVA*	*IFCSLAB*	*Floor:Concrete-Commercial 362mm:271538*
#436	*3PiPR_A6j7i8xsfls1hXLp*	*IFCWALLSTANDARDCASE*	*Basic Wall:Generic - 200mm:271883*
#497	*3PiPR_A6j7i8xsfls1hXNw*	*IFCWALLSTANDARDCASE*	*Basic Wall:Generic - 200mm:27200*
#554	*3PiPR_A6j7i8xsfls1hXNR*	*IFCWALLSTANDARDCASE*	*Basic Wall:Generic - 200mm:272035*
#589	*3PiPR_A6j7i8xsfls1hXGx*	*IFCWALLSTANDARDCASE*	*Basic Wall:Generic - 200mm:272195*
#865	*3PiPR_A6j7i8xsfls1hXJd*	*IFCRAILING*	*Railing:900mm Pipe:272287*

- Remove first item in list T001

List T001		
#nr.	**Global ID**	**Name**
~~*#156*~~	~~*38FHvs4sbAXBc7ToVG5$tE*~~	~~*Level 1*~~
#162	*38FHvs4sbAXBc7ToVG5$Q2*	*Level 2*

Type Task
ID T002
Name Search for floor slab and roof element

Description
- Get list G001 and search for 'IFCSLAB' and 'IFCROOF'.
  1 match found
- Create list T002:

List T002			
#nr.	**Global ID**	**Type**	**Name**
#230	*3PiPR_A6j7i8xsfls1hXVA*	*IFCSLAB*	*Floor:Concrete-Commercial 362mm:271538*

Type Gateway
ID G002
Name Is there a floor slab or roof element

Action
- Get list T002
  'True'
- Get first item in the list

#230, 3PiPR_A6j7i8xsfls1hXVA, IFCSLAB, Floor:Concrete-Commercial 362mm:271538

Type Task
ID T003
Name Obtain parameters of a floor slab or roof element

Action
- Retrieve and calculate the parameters of the floor slab or roof element.
- Create list T003.1

List T003.1 Vertexes				
#nr.	**Vertex**	**X**	**Y**	**Z**
#230	*A*	*-7951,66*	*4238,26*	*0*
#230	*B*	*5048,34*	*4238,26*	*0*
#230	*C*	*5048,34*	*-2761,74*	*0*
#230	*D*	*-2951,66*	*-2761,74*	*0*
#230	*E*	*-2951,66*	*-7761,74*	*0*
#230	*F*	*-7951,66*	*-7761,74*	*0*

- Create list T003.2

List T003.2 Edges

#nr.	Edge	Length	Direction (x.y.z)
#230	*A→B*	*13000*	*(1.0.0)*
#230	*B→C*	*7000*	*(0.-1.0)*
#230	*C→D*	*8000*	*(-1.0.0)*
#230	*D→E*	*5000*	*(0.-1.0)*
#230	*E→F*	*5000*	*(-1.0.0)*
#230	*F→A*	*12000*	*(0.1.0)*

Type Task
ID T004
Name Find related building elements

Action
- Get first item in list T002

#230, 3PiPR_A6j7i8xsfls1hXVA, IFCSLAB, Floor:Concrete-Commercial 362mm:271538
- Search for 'IFCRELCONNETCTSELEMENTS' and '#230'

No matches found
- Search for 'IFCSTANDARDCASEWALL' in list G001
  4 matches found
- Create list T004:

List T004		
#nr.	**Global ID**	**Name**
#436	*3PiPR_A6j7i8xsfls1hXLp*	*Basic Wall:Generic - 200mm:271883*
#497	*3PiPR_A6j7i8xsfls1hXNw*	*Basic Wall:Generic - 200mm:27200*
#554	*3PiPR_A6j7i8xsfls1hXNR*	*Basic Wall:Generic - 200mm:272035*
#589	*3PiPR_A6j7i8xsfls1hXGx*	*Basic Wall:Generic - 200mm:272195*

Type Task
ID T005
Name Obtain wall parameters

Action
- Retrieve and calculated parameters from list T004
- Create lists T005.1, T005.2, T005.3, T005.4, T005.5, T005.6, T005.7 and T005.8

T005.1 Vertexes				
#nr.	**Veterx**	**X**	**Y**	**Z**
#436	*M*	*-7951,66*	*4238,26*	*0*
#436	*N*	*-7951,66*	*403826*	*0*
#436	*O*	*-3751,66*	*4038,26*	*0*
#436	*P*	*-3751,66*	*4238,26*	*0*

#436	*Q*	*-7951,66*	*4238,26*	*4000*
#436	*R*	*-7951,66*	*403826*	*4000*
#436	*S*	*-3751,66*	*4038,26*	*4000*
#436	*T*	*-3751,66*	*4238,26*	*4000*

List T005.2 Edges			
#nr.	**Edge**	**Length**	**Direction (x.y.z)**
#436	*M→N*	*200*	*(0.-1.0)*
#436	*N→O*	*4200*	*(1.0.0)*
#436	*O→P*	*200*	*(0.1.0)*
#436	*P→M*	*4200*	*(-1.0.0)*
#436	*Q→R*	*200*	*(0.-1.0)*
#436	*R→S*	*4200*	*(1.0.0)*
#436	*S→T*	*200*	*(0.1.0)*
#436	*T→Q*	*4200*	*(-1.0.0)*

T005.3 Vertexes				
#nr.	**Veterx**	**X**	**Y**	**Z**
#497	*U*	*48,34*	*4038,26*	*0*
#497	*V*	*48,34*	*4238,26*	*0*
#497	*W*	*5048,34*	*4238,26*	*0*
#497	*AA*	*5048,34*	*4038,26*	*0*
#497	*AB*	*48,34*	*4038,26*	*4000*
#497	*AC*	*48,34*	*4238,26*	*4000*
#497	*AD*	*5048,34*	*4238,26*	*4000*
#497	*AE*	*5048,34*	*4038,26*	*4000*

List T005.4 Edges			
#nr.	**Edge**	**Length**	**Direction (x.y.z)**
#497	*U→V*	*200*	*(0.-1.0)*
#497	*V→W*	*5000*	*(1.0.0)*
#497	*W→AA*	*200*	*(0.1.0)*
#497	*AA→U*	*5000*	*(-1.0.0)*
#497	*AB→AC*	*200*	*(0.-1.0)*
#497	*AC→AD*	*5000*	*(1.0.0)*
#497	*AD→AE*	*200*	*(0.1.0)*
#497	*AE→AB*	*5000*	*(-1.0.0)*

T005.5 Vertexes				
#nr.	**Veterx**	**X**	**Y**	**Z**
#554	*AF*	*5048,34*	*4038,26*	*0*
#554	*AG*	*4848,34*	*4038,26*	*0*
#554	*Ah*	*4848,34*	*2138,26*	*0*
#554	*AI*	*5048,34*	*2138,26*	*0*
#554	*AJ*	*5048,34*	*4038,26*	*4000*
#554	*AK*	*4848,34*	*4038,26*	*4000*
#554	*AL*	*4848,34*	*2138,26*	*4000*
#554	*AM*	*5048,34*	*2138,26*	*4000*

List T005.6 Edges			
#nr.	**Edge**	**Length**	**Direction (x.y.z)**
#554	*AF→AG*	*200*	*(-1.0.0)*
#554	*AG→AH*	*1900*	*(0.-1.0)*
#554	*AH→AI*	*200*	*(1.0.0)*
#554	*AI→AF*	*1900*	*(0.-1.0)*
#554	*AJ→AK*	*200*	*(-1.0.0)*
#554	*AK→AL*	*1900*	*(0.-1.0)*
#554	*AL→AM*	*200*	*(1.0.0)*
#554	*AM→AJ*	*1900*	*(0.-1.0)*

T005.7 Vertexes				
#nr.	**Veterx**	**X**	**Y**	**Z**
#589	*AN*	*-7951,66*	*-7761,74*	*0*
#589	*AO*	*-7751,66*	*-7761,74*	*0*
#589	*AP*	*-7751,66*	*-2161,74*	*0*
#589	*AQ*	*-7951,66*	*-2161,74*	*0*
#589	*AR*	*-7951,66*	*-7761,74*	*4000*
#589	*AS*	*-7751,66*	*-7761,74*	*4000*
#589	*AT*	*-7751,66*	*-2161,74*	*4000*
#589	*AU*	*-7951,66*	*-2161,74*	*4000*

List T005.8 Edges			
#nr.	**Edge**	**Length**	**Direction (x.y.z)**
#436	*AN→AO*	*200*	*(1.0.0)*
#436	*AO→AP*	*5600*	*(0.1.0)*
#436	*AP→AQ*	*200*	*(-1.0.0)*
#436	*AQ→AN*	*5600*	*(0.-1.0)*

#436	*AR→AS*	*200*	*(1.0.0)*
#436	*AS→AT*	*5600*	*(0.1.0)*
#436	*AT→AU*	*200*	*(-1.0.0)*
#436	*AU→AR*	*5600*	*(0.-1.0)*

Type	Gateway
ID	G003
Name	Opening in floor slab / roof element

Action

- List G003 does not exist
- Get first item in list T002

#230, 3PiPR_A6j7i8xsfls1hXVA, IFCSLAB, Floor:Concrete-Commercial 362mm:271538

- Search for 'IFCRELVOIDSELEMENT' and #230

  2 matches found

  'True'
- Create list G003:

List G003			
#nr.	**Global ID**	**Ref #nr.**	**Ref ID**
#269	*3AvhUYuLj9wuNI_6lHneYv*	*#264*	*3PiPR_A6j7i8xsfls1hXQn*
#293	*09x3YnI0f4IRzANiAauZBt*	*#290*	*3PiPR_A6j7i8xsfls1hXQa*

Type	Gateway
ID	G004
Name	Is opening filled?

Action

- Get first item of list G003

#269, 3AvhUYuLj9wuNI_6lHneYv, #264, 3PiPR_A6j7i8xsfls1hXQn

- Search for 'IFCRELFILLSELEMENT' and #264

  No matches found

  'False'

Type	Task
ID	T006
Name	Obtain opening parameters

Action

Get list G003. Retrieve information of first item of the list. Retrieve and calculate the parameters of all related opening elements. This method is specified in paragraph X. Create a list of the edges with coordinates and the edges. Name the list T006.

- Get first item of list G003

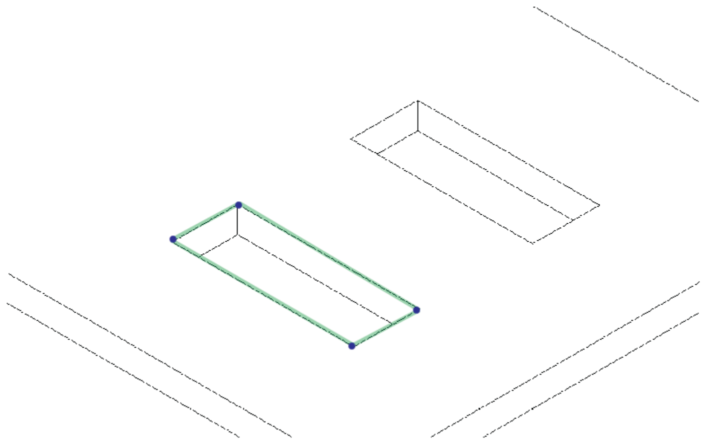
#269, 3AvhUYuLj9wuNI_6lHneYv, #264, 3PiPR_A6j7i8xsfls1hXQn

- Calculated opening parameters
- Create list T006.1 and T006.2:

List T006.1 vertex				
#nr.	**Vertex**	**X**	**Y**	**Z**
#264	*BA*	*3442,73*	*-358,18*	*0*
#264	*BB*	*3442,73*	*-1258,18*	*0*
#264	*BC*	*942,73*	*-1258,18*	*0*
#264	*BD*	*942,73*	*-358,18*	*0*
#264	*BE*	*3442,73*	*-358,18*	*-362*
#264	*BF*	*3442,73*	*-1258,18*	*-362*
#264	*BG*	*942,73*	*-1258,18*	*-362*
#264	*BH*	*942,73*	*-358,18*	*-362*

List T006.2 edges			
#nr.	**Edge**	**Length**	**Direction**
#264	*BA →BB*	*900*	*(0.-1.0)*
#264	*BB →BC*	*2500*	*(-1.0.0)*
#264	*BC →BD*	*900*	*(0.1.0)*
#264	*BD →BA*	*2500*	*(1.0.0)*
#264	*BE →BF*	*900*	*(0.-1.0)*
#264	*BF →BG*	*2500*	*(-1.0.0)*
#264	*BG →BH*	*900*	*(0.1.0)*
#264	*BH →BE*	*2500*	*(1.0.0)*

Type	Task
ID	T007
Name	Draw polyline opening
Action	- Get list T005.1, T005.2, etc. and T006 with corresponding parameter list. - Draw a polyline along the upper vertexes of the opening.



Type Task
ID T008
Name Compare polyline with wall parameters opening

Action
- Compare and update the polyline created in T007.

List T008 update opening edges				
#nr.	**Edge**	**Length**	**Wall?**	**Wall ref.**
#264	*BA→BB*	*900*	No	-
#264	*BB→BC*	*2500*	No	-
#264	*BC→BD*	*900*	No	-
#264	*BD→BA*	*2500*	No	-

Type Gateway
ID G005
Name Wall element on opening

Action
- Get list T008.
- No wall on the edge
  'False'

Type Gateway
ID G006
Name Length >= 1.00

Action
- Get list T006.2.
- BB→BC represents the length
- 2500 >= 1000
  'True'

Type Task
ID T009
Name Value is *10000000000*

Action *Value: 10000000000*

Type Gateway
ID G007
Name Width >= 1.00

Action
- Get list T006.2.
- BA→BB represents the width
- 900 < 1000
  'False'

Type Task
ID T014

Name	Value is *200000000000*
Action	*Value: 10000000000*

Type	Gateway
ID	G008
Name	Length < 0.10
Action	- Get list T006.2. - BB→BC represents the length - 2500 >= 0.10 *'True'*

Type	Task
ID	T015
Name	Value is *1000000000000*
Action	*Value: 10000000000*

Type	Gateway
ID	G009
Name	width < 0.10
Action	- Get list T006.2. - BB→BC represents the length - 900 >= 0.10 *'True'* *Value: 10000000000000*

Type	Task
ID	T011
Name	Value is *10000000000*
Action	*Value: 10000000000*

Type	Task
ID	T009
Name	Processing rule set situation 3
Action	- Retrieve the values answered by T009, T014, T015 and T011. Add the values. *T009: 10000000000* *T011: 200000000000* *T014: 1000000000000* *T015: <u>10000000000000 +</u>*

Value: 11210000000000

- Remove first item in list G003

List G003			
#nr.	**Global ID**	**Ref #nr.**	**Ref ID**
~~*#269*~~	~~*3AvhUYuLj9wuNl_6lHneYv*~~	~~*#264*~~	~~*3PiPR_A6j7i8xsfls1hXQn*~~
#293	*09x3YnI0f4IRzANiAauZBt*	*#290*	*3PiPR_A6j7i8xsfls1hXQa*

- Remove list T006.1, T006.2 and T008

Type Gateway
ID G003
Name Opening in floor slab / roof element

Action
- List G003 does exist
- There are items in list G003

Continue with T006

Type Task
ID T006
Name Obtain opening parameters

Action Get list G003. Retrieve information of first item of the list. Retrieve and calculate the parameters of all related opening elements. This method is specified in paragraph X. Create a list of the edges with coordinates and the edges. Name the list T006.

- Get first item of list G003

#293, 09x3YnI0f4IRzANiAauZBt, #290, 3PiPR_A6j7i8xsfls1hXQa

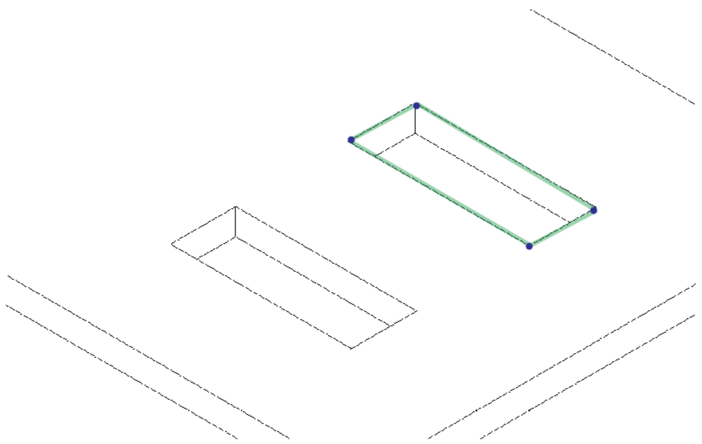
- Calculated opening parameters
- Create list T006.1 and T006.2:

List T006.1 vertex				
#nr.	**Vertex**	**X**	**Y**	**Z**
#264	*BA*	*3442,73*	*2119,965*	*0*
#264	*BB*	*3442,73*	*1198,655*	*0*
#264	*BC*	*942,73*	*1198,655*	*0*
#264	*BD*	*942,73*	*2119,965*	*0*
#264	*BE*	*3442,73*	*2119,965*	*-362*
#264	*BF*	*3442,73*	*1198,655*	*-362*
#264	*BG*	*942,73*	*1198,655*	*-362*
#264	*BH*	*942,73*	*2119,965*	*-362*

List T006.2 edges			
#nr.	**Edge**	**Length**	**Direction**
#264	*BA →BB*	*921.31*	*(0.-1.0)*
#264	*BB →BC*	*2500*	*(-1.0.0)*
#264	*BC →BD*	*921.31*	*(0.1.0)*
#264	*BD →BA*	*2500*	*(1.0.0)*
#264	*BE →BF*	*921.31*	*(0.-1.0)*
#264	*BF →BG*	*2500*	*(-1.0.0)*
#264	*BG →BH*	*921.31*	*(0.1.0)*
#264	*BH →BE*	*2500*	*(1.0.0)*

Type Task
ID T007
Name Draw polyline opening

Action
- Get list T005.1, T005.2, etc. and T006 with corresponding parameter list.
- Draw a polyline along the upper vertexes of the opening.



Type Task
ID T008
Name Compare polyline with wall parameters opening

Action
- Compare and update the polyline created in T007.

List T008 update opening edges				
#nr.	**Edge**	**Length**	**Wall?**	**Wall ref.**
#264	*BA →BB*	*921.31*	No	-
#264	*BB →BC*	*2500*	No	-
#264	*BC →BD*	*921.31*	No	-
#264	*BD →BA*	*2500*	No	-

Type	Gateway
ID	G005
Name	Wall element on opening
Action	- Get list T008. - No wall on the edge *‘False’*

Type	Gateway
ID	G006
Name	Length >= 1.00
Action	- Get list T006.2. - BB→BC represents the length - 2500 >= 1000 *‘True’*

Type	Task
ID	T009
Name	Value is *10000000000*
Action	*Value: 10000000000*

Type	Gateway
ID	G007
Name	Width >= 1.00
Action	- Get list T006.2. - BA→BB represents the width - 921.31 < 1000 *‘False’*

Type	Task
ID	T014
Name	Value is *200000000000*
Action	*Value: 10000000000*

Type	Gateway
ID	G008
Name	Length < 0.10
Action	- Get list T006.2. - BB→BC represents the length - 2500 >= 0.10 *‘True’*

Type	Task
ID	T015
Name	Value is *1000000000000*
Action	*Value: 10000000000*

Type	Gateway
ID	G009
Name	width < 0.10
Action	- Get list T006.2. - BB→BC represents the length - 921.31 >= 0.10 *'True'*

Type	Task
ID	T011
Name	Value is *10000000000*
Action	*Value: 10000000000*

Type	Task
ID	T009
Name	Processing rule set situation 3
Action	- Retrieve the values answered by T009, T014, T015 and T011. Add the values. *T009: 10000000000* *T011: 200000000000* *T014: 1000000000000* *T015: 10000000000000 +* *Value: 11210000000000*

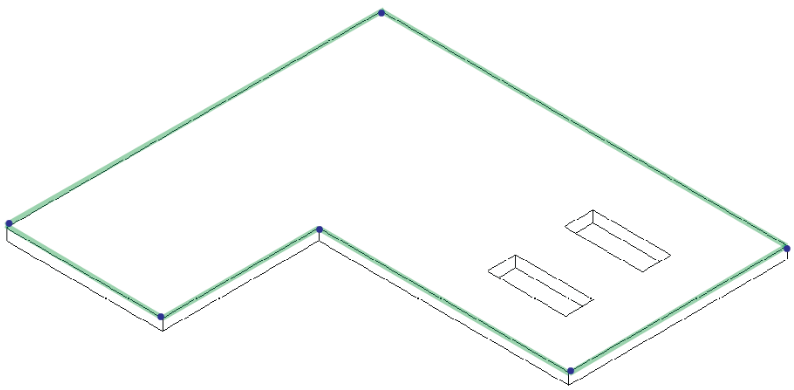
- Remove first item in list G003

List G003			
#nr.	**Global ID**	**Ref #nr.**	**Ref ID**
~~#269~~	~~3AvhUYuLj9wuNI_6lHneYv~~	~~#264~~	~~3PiPR_A6j7i8xsfls1hXQn~~
~~#293~~	~~09x3YnI0f4IRzANiAquZBt~~	~~#290~~	~~3PiPR_A6j7i8xsfls1hXQa~~

- Remove list T006.1, T006.2 and T008

Type	Gateway
ID	G003
Name	Opening in floor slab / roof element
Action	- List G003 does exist - There are no items in list G003 *'False'* *Continue with T018*

Type	Task
ID	T018
Name	Draw polyline Slab
Action	- Get list T005.1, T005.2, etc. and T003 with corresponding parameter list. - Draw a polyline along the upper vertexes of the opening.



Type	Task
ID	T019
Name	Compare polyline with wall parameters slab
Action	- Compare and update the polyline created in T018.

List T019.1 updated slab vertexes				
#nr.	**Vertex**	**X**	**Y**	**Z**
#230	*A*	*-7951,66*	*4238,26*	*0*
#230	*B*	*5048,34*	*4238,26*	*0*
#230	*C*	*5048,34*	*-2761,74*	*0*
#230	*D*	*-2951,66*	*-2761,74*	*0*
#230	*E*	*-2951,66*	*-7761,74*	*0*
#230	*F*	*-7951,66*	*-7761,74*	*0*
#463	*P*	*-3751,66*	*4238,26*	*0*
#463	*N*	*-7951,66*	*4038,26*	*0*
#495	*V*	*48,34*	*4238,26*	*0*
#495	*AA*	*5048,34*	*4038,26*	*0*

#554	*AI*	*5048,34*	*2138,26*	*0*
#589	*AO*	*-7751,66*	*-7761,74*	*0*
#589	*AQ*	*-7951,66*	*-2161,74*	*0*

	List T019.2 updated slab edges			
Edge	**Length**	**Direction**	**Wall?**	**Wall ref.**
A →P	*4200*	(1.0.0)	Wall	#463
P →V	*3800*	(1.0.0)	No	-
V →B	*5000*	(1.0.0)	Wall	#495
B →AA	*200*	(0.-1.0)	Wall	#495
AA →AI	*1900*	(0.-1.0)	Wall	#554
AI →C	*5100*	(0.-1.0)	No	-
C →D	*8000*	(-1.0.0)	No	-
D →E	*5000*	(0.-1.0)	No	-
E →AO	*4800*	(-1.0.0)	No	-
AO →F	*200*	(-1.0.0)	Wall	#589
F →AQ	*5600*	(0.1.0)	Wall	#589
AQ →N	*6200*	(0.1.0)	No	-
N →A	*200*	(0.1.0)	Wall	#463

Type Gateway
ID G010
Name Is there an edge of the floor slab or roof element.

Action
- Get first item in list T019.2

A →P, 4200, (1.0.0), Wall, #436

'True'

Type Gateway
ID G011
Name Is there another slab connected.

Action
- Get first item in list T019.2

A →P, 4200, (1.0.0), Wall, #436

- Check for other floor slab or roof element connected

  No other floor slab or roof element on the building storey

  'False'

Type Gateway
ID G012
Name Wall element on floor slab or roof element

Action
- Get first item in list T019.2

A →P, 4200, (1.0.0), Wall, #436

- Is the edge marked wall?

  'True'

Type	Gateway
ID	G020
Name	Wall height >= 1.00

Action

- Get list T005.1

T005.1 Vertexes				
#nr.	**Veterx**	**X**	**Y**	**Z**
#436	*M*	*-7951,66*	*4238,26*	*0*
#436	*N*	*-7951,66*	*403826*	*0*
#436	*O*	*-3751,66*	*4038,26*	*0*
#436	*P*	*-3751,66*	*4238,26*	*0*
#436	*Q*	*-7951,66*	*4238,26*	*4000*
#436	*R*	*-7951,66*	*403826*	*4000*
#436	*S*	*-3751,66*	*4038,26*	*4000*
#436	*T*	*-3751,66*	*4238,26*	*4000*

- Z-value = 4000
- 4000 >= 1000
  'True'

Type	Task
ID	T033
Name	Value is *1000*

Action *Value: 1000*

Type	Gateway
ID	G017
Name	Is it a roof element

Action

- Get first item from list T002.

#230, 3PiPR_A6j7i8xsfls1hXVA, IFCSLAB, Floor:Concrete-Commercial 362mm:271538

'False'

Value = 200000000000000

Type	Task
ID	T032
Name	Processing rule set situation 2.2

Action

- Retrieve the values answered by G017 and G020. Add the values.

G017: 200000000000000

T033: 1000 +

Value: 200000000001000

Type	Gateway
ID	G023
Name	Opening in wall

Action
- Get first item from list T019.2

A →P, 4200, (1.0.0), Wall, #436

- Search for 'IFCRELVOIDSELEMENT' and #436
  No match found
  'False'
- Remove first item from T019.2

	List T019.2 updated slab edges			
Edge	**Length**	**Direction**	**Wall?**	**Wall ref.**
~~*A →P*~~	~~*4200*~~	~~(1.0.0)~~	~~Wall~~	~~#463~~
P →V	*3800*	(1.0.0)	No	-
V →B	*5000*	(1.0.0)	Wall	#495
B →AA	*200*	(0.-1.0)	Wall	#495
AA →AI	*1900*	(0.-1.0)	Wall	#554
AI →C	*5100*	(0.-1.0)	No	-
C →D	*8000*	(-1.0.0)	No	-
D →E	*5000*	(0.-1.0)	No	-
E →AO	*4800*	(-1.0.0)	No	-
AO →F	*200*	(-1.0.0)	Wall	#589
F →AQ	*5600*	(0.1.0)	Wall	#589
AQ →N	*6200*	(0.1.0)	No	-
N →A	*200*	(0.1.0)	Wall	#463

Type	Gateway
ID	G010
Name	Is there an edge of the floor slab or roof element.

Action
- Get first item in list T019.2

P →V, 3800, (1.0.0), No, -
'False'

Type	Gateway
ID	G011
Name	Is there another slab connected.

Action
- Get first item in list T019.2

P →V, 3800, (1.0.0), No, -

- Check for other floor slab or roof element connected
  No other floor slab or roof element on the building storey
  'False'

Type	Gateway
ID	G012
Name	Wall element on floor slab or roof element

Action
- Get first item in list T019.2

	P →V, 3800, (1.0.0), No, - - Is the edge marked wall? *'False'*

Type	Task
ID	T020
Name	Search for objects

Action
- Get list G001 and search for 'IFCBUILDINGELEMENTPROXY' and 'IFCRAILING'
  1 match found
- Create list T020

List T020			
#nr.	**Global ID**	**Type**	**Name**
#865	*3PiPR_A6j7i8xsfls1hXJd*	*IFCRAILING*	*Railing:900mm Pipe:272287*

Type	Task
ID	T021
Name	Obtain object parameters

Action
- Calculate all parameters of T020
- Create list T021

List T021				
#nr.	**Vertex**	**X**	**Y**	**Z**
#865	*CA*	*-2951,66*	*-7761,7*	*0*
#865	*CB*	*-2994,86*	*-7761,7*	*0*
#865	*CC*	*-2994,86*	*-2761,7*	*0*
#865	*CD*	*-2951,66*	*-2761,7*	*0*
#865	*CE*	*-2951,66*	*-7761,7*	*880*
#865	*CF*	*-2994,86*	*-7761,7*	*880*
#865	*CG*	*-2994,86*	*-2761,7*	*880*
#865	*CH*	*-2951,66*	*-2761,7*	*880*

Type	Gateway
ID	G013
Name	object on edge

Action
- Compare coordinates
  Railing is on edge D →E
  'False'

Type	Gateway
ID	G017
Name	Is it a roof element
Description	- Get first item from list T002.

#230, 3PiPR_A6j7i8xsfls1hXVA, IFCSLAB, Floor:Concrete-Commercial 362mm:271538

'False'

Value = 200000000000000

Type	Task
ID	T032
Name	Processing rule set situation 2.2
Action	- Retrieve the values answered by G017 and G020. Add the values.

G017: 200000000000000

G013: 222 +

Value: 200000000000222

- Remove first item from T019.2

	List T019.2 updated slab edges			
Edge	**Length**	**Direction**	**Wall?**	**Wall ref.**
~~*A→P*~~	~~*4200*~~	~~(1.0.0)~~	~~Wall~~	~~#463~~
~~*P→V*~~	~~*3800*~~	~~(1.0.0)~~	~~No~~	~~-~~
V→B	*5000*	(1.0.0)	Wall	#497
B→AA	*200*	(0.-1.0)	Wall	#497
AA→AI	*1900*	(0.-1.0)	Wall	#554
AI→C	*5100*	(0.-1.0)	No	-
C→D	*8000*	(-1.0.0)	No	-
D→E	*5000*	(0.-1.0)	No	-
E→AO	*4800*	(-1.0.0)	No	-
AO→F	*200*	(-1.0.0)	Wall	#589
F→AQ	*5600*	(0.1.0)	Wall	#589
AQ→N	*6200*	(0.1.0)	No	-
N→A	*200*	(0.1.0)	Wall	#463

Type	Gateway
ID	G010
Name	Is there an edge of the floor slab or roof element.
Action	- Get first item in list T019.2

V→B, 5000, (1.0.0), Wall, #497

'True'

Type	Gateway
ID	G011
Name	Is there another slab connected.
Action	- Get first item in list T019.2

V→B, 5000, (1.0.0), Wall, #497

- Check for other floor slab or roof element connected
  No other floor slab or roof element on the building storey
  'False'

Type	Gateway
ID	G012
Name	Wall element on floor slab or roof element

Action
- Get first item in list T019.2

V→B, 5000, (1.0.0), Wall, #497
- Is the edge marked wall?
  'True'

Type	Gateway
ID	G020
Name	Wall height >= 1.00

Action
- Get list T005.3

T005.3 Vertexes				
#nr.	**Veterx**	**X**	**Y**	**Z**
#497	*U*	*48,34*	*4038,26*	*0*
#497	*V*	*48,34*	*4238,26*	*0*
#497	*W*	*5048,34*	*4238,26*	*0*
#497	*AA*	*5048,34*	*4038,26*	*0*
#497	*AB*	*48,34*	*4038,26*	*4000*
#497	*AC*	*48,34*	*4238,26*	*4000*
#497	*AD*	*5048,34*	*4238,26*	*4000*
#497	*AE*	*5048,34*	*4038,26*	*4000*

- Z-value = 4000
- 4000 >= 1000
  'True'

Type	Task
ID	T033
Name	Value is *1000*

Action
Value: 1000

Type	Gateway
ID	G017
Name	Is it a roof element

Action
- Get first item from list T002.

#230, 3PiPR_A6j7i8xsfls1hXVA, IFCSLAB, Floor:Concrete-Commercial 362mm:271538

'False'
Value = 200000000000000

Type	Task
ID	T032
Name	Processing rule set situation 2.2
Action	- Retrieve the values answered by G017 and G020. Add the values. G017: 200000000000000 T033: 1000 + Value: 200000000001000

Type	Gateway
ID	G023
Name	Opening in wall
Action	- Get first item from list T019.2 *V →B, 5000, (1.0.0), Wall, #497* - Search for 'IFCRELVOIDSELEMENT' and #497 One match found - Create list G023

List G023			
#nr.	**Global ID**	**Ref #nr.**	**Ref ID**
#519	*38hBDVXr5BdudoVXzQKEF*	*#516*	*2XKVnl5wL8PQFyjReVa4sG*

Type	Gateway
ID	G024
Name	Is opening in wall filled?
Action	- Get first item from list G023 *#519, 38hBDVXr5BdudoVXzQKEF, #516, 2XKVnl5wL8PQFyjReVa4sG* - Search for 'IFCRELFILLSELEMENT' and #516 *No match found* *'False'*

Type	Task
ID	T039
Name	Obtain opening parameters
Action	- Get first item of list G023 *#519, 38hBDVXr5BdudoVXzQKEF, #516, 2XKVnl5wL8PQFyjReVa4sG* - Calculated opening parameters - Create list T039.1 and T039.2:

List T039.1				
#nr.	**Vertex**	**X**	**Y**	**Z**
#516	*DA*	*1844,31*	*4038,26*	*1722,86*

#516	*DB*	*3644,31*	*4038,26*	*1722,86*
#516	*DC*	*3644,31*	*4038,26*	*2922,86*
#516	*DD*	*1844,31*	*4038,26*	*2922,86*
#516	*DE*	*1844,31*	*4238,26*	*1722,86*
#516	*DF*	*3644,31*	*4238,26*	*1722,86*
#516	*DG*	*3644,31*	*4238,26*	*2922,86*
#516	*DH*	*1844,31*	*4238,26*	*2922,86*

List T039.2			
#nr.	**Edge**	**Length**	**Direction**
#516	*DA→DB*	*1800*	(1.0.0)
#516	*DB→DC*	*1200*	(0.0.1)
#516	*DC→DD*	*1800*	(-1.0.0)
#516	*DD→DA*	*1200*	(0.0.-1)

Type Gateway
ID G025
Name Width of the opening

Action
- Get list T039.2
- DA→DB represents the width
- 1800 >= 300
  'False'

Type Task
ID T040
Name *Value =* 2000000

Action *Value =* 2000000

Type Gateway
ID G026
Name Wall height >= 0.15

Action
- Get list T039.1
- Search for lowest z-value
  A has the lowest z-value
  1722.86 >= 150
  'True'

Type Task
ID T043
Name *Value = 10*000000

Action *Value = 10*000000

Type	Gateway
ID	G027
Name	Wall height >= 0.62

Action
- Get list T039.1
- Search for lowest z-value

  A has the lowest z-value

  1722.86 >= 620

  'True'

Type	Task
ID	T045
Name	*Value is* 100000000

Action *Value =* 100000000

Type	Gateway
ID	G028
Name	Wall height >= 1.00

Action
- Get list T039.1
- Search for lowest z-value

  A has the lowest z-value

  1722.86 >= 1000

  'True'

Value = 1000000000

Type	Task
ID	T047
Name	Value is 1000000000

Action *Value* = 1000000000

Type	Task
ID	T032
Name	Processing rule set situation 2.2

Action
- Retrieve the values answered by G017, G025, G026, G027 and G028.

Add the values.

T040: 2000000

T043: 10000000

T045: 100000000

T047: 1000000000 +

Value: 1112000000

- Remove list T039.1 and T039.2

- Remove first item from list G023

List G023			
#nr.	**Global ID**	**Ref #nr.**	**Ref ID**
~~*#519*~~	~~*38hBDVXr5BdudoVXzQKEF*~~	~~*#516*~~	~~*2XKVnl5wL8PQFyjReVa4sG*~~

- Remove first item from list T019.2

	List T019.2 updated slab edges			
Edge	**Length**	**Direction**	**Wall?**	**Wall ref.**
~~*A→P*~~	~~*4200*~~	~~(1.0.0)~~	~~Wall~~	~~#463~~
~~*P→V*~~	~~*3800*~~	~~(1.0.0)~~	~~No~~	~~-~~
~~*V→B*~~	~~*5000*~~	~~(1.0.0)~~	~~Wall~~	~~#497~~
B→AA	*200*	(0.-1.0)	Wall	#497
AA→AI	*1900*	(0.-1.0)	Wall	#554
AI→C	*5100*	(0.-1.0)	No	-
C→D	*8000*	(-1.0.0)	No	-
D→E	*5000*	(0.-1.0)	No	-
E→AO	*4800*	(-1.0.0)	No	-
AO→F	*200*	(-1.0.0)	Wall	#589
F→AQ	*5600*	(0.1.0)	Wall	#589
AQ→N	*6200*	(0.1.0)	No	-
N→A	*200*	(0.1.0)	Wall	#463

No items in G023. Continue with G010

Type	Gateway
ID	G010
Name	Is there an edge of the floor slab or roof element.
Action	- Get first item in list T019.2 *B→AA, 200, (0.-1.0), Wall, #497* *'True'*

Type	Gateway
ID	G011
Name	Is there another slab connected.
Action	- Get first item in list T019.2 *B→AA, 200, (0.-1.0), Wall, #497* - Check for other floor slab or roof element connected *No other floor slab or roof element on the building storey* *'False'*

Type	Gateway
ID	G012
Name	Wall element on floor slab or roof element

Action
- Get first item in list T019.2

B →AA, 200, (0.-1.0), Wall, #497
- Is the edge marked wall?

  'True'

Type	Gateway
ID	G020
Name	Wall height >= 1.00

Action
- Get list T005.3

T005.3 Vertexes				
#nr.	**Veterx**	**X**	**Y**	**Z**
#497	*U*	*48,34*	*4038,26*	*0*
#497	*V*	*48,34*	*4238,26*	*0*
#497	*W*	*5048,34*	*4238,26*	*0*
#497	*AA*	*5048,34*	*4038,26*	*0*
#497	*AB*	*48,34*	*4038,26*	*4000*
#497	*AC*	*48,34*	*4238,26*	*4000*
#497	*AD*	*5048,34*	*4238,26*	*4000*
#497	*AE*	*5048,34*	*4038,26*	*4000*

- Z-value = 4000
- 4000 >= 1000

  'True'

Type	Task
ID	T033
Name	Value is *1000*

Action

Value: 1000

Type	Gateway
ID	G017
Name	Is it a roof element

Action
- Get first item from list T002.

#230, 3PiPR_A6j7i8xsfls1hXVA, IFCSLAB, Floor:Concrete-Commercial 362mm:271538

'False'

Value = 200000000000000

Type Task

ID	T032
Name	Processing rule set situation 2.2

Action

- Retrieve the values answered by G017 and G020. Add the values.

G017: 200000000000000
T033: 1000 +

Value: 200000000001000

Type	Gateway
ID	G023
Name	Opening in wall

Action

- Get first item from list T019.2

B→AA, 200, (0.-1.0), Wall, #497

- Search for 'IFCRELVOIDSELEMENT' and #497

  No match found

  'False'

- Remove first item from T019.2

	List T019.2 updated slab edges			
Edge	**Length**	**Direction**	**Wall?**	**Wall ref.**
~~*A→P*~~	~~*4200*~~	~~(1.0.0)~~	~~Wall~~	~~#463~~
~~*P→V*~~	~~*3800*~~	~~(1.0.0)~~	~~No~~	~~-~~
~~*V→B*~~	~~*5000*~~	~~(1.0.0)~~	~~Wall~~	~~#497~~
~~*B→AA*~~	~~*200*~~	~~(0.-1.0)~~	~~Wall~~	~~#497~~
AA→AI	*1900*	(0.-1.0)	Wall	#554
AI→C	*5100*	(0.-1.0)	No	-
C→D	*8000*	(-1.0.0)	No	-
D→E	*5000*	(0.-1.0)	No	-
E→AO	*4800*	(-1.0.0)	No	-
AO→F	*200*	(-1.0.0)	Wall	#589
F→AQ	*5600*	(0.1.0)	Wall	#589
AQ→N	*6200*	(0.1.0)	No	-
N→A	*200*	(0.1.0)	Wall	#463

Type	Gateway
ID	G010
Name	Is there an edge of the floor slab or roof element.

Action

- Get first item in list T019.2

AA→AI, 1900, (0.-1.0), Wall, #554

'False'

Type	Gateway
ID	G011

Name	Is there another slab connected.

Action
- Get first item in list T019.2

AA →AI, 1900, (0.-1.0), Wall, #554
- Check for other floor slab or roof element connected

  No other floor slab or roof element on the building storey

  'False'

Type	Gateway
ID	G012
Name	Wall element on floor slab or roof element

Action
- Get first item in list T019.2

AA →AI, 1900, (0.-1.0), Wall, #554
- Is the edge marked wall?

  'True'

Type	Gateway
ID	G020
Name	Wall height >= 1.00

Action
- Get list T005.5

T005.5 Vertexes				
#nr.	**Veterx**	**X**	**Y**	**Z**
#554	*AF*	*5048,34*	*4038,26*	*0*
#554	*AG*	*4848,34*	*4038,26*	*0*
#554	*Ah*	*4848,34*	*2138,26*	*0*
#554	*AI*	*5048,34*	*2138,26*	*0*
#554	*AJ*	*5048,34*	*4038,26*	*4000*
#554	*AK*	*4848,34*	*4038,26*	*4000*
#554	*AL*	*4848,34*	*2138,26*	*4000*
#554	*AM*	*5048,34*	*2138,26*	*4000*

- Z-value = 4000
- 4000 >= 1000

  'True'

Type	Task
ID	T033
Name	Value is *1000*

Action *Value: 1000*

Type	Gateway
ID	G017
Name	Is it a roof element

Action
- Get first item from list T002.

#230, 3PiPR_A6j7i8xsfls1hXVA, IFCSLAB, Floor:Concrete-Commercial 362mm:271538

'False'

Value = 200000000000000

Type Task
ID T032
Name Processing rule set situation 2.2

Action
- Retrieve the values answered by G017 and G020. Add the values.

G017: 200000000000000
T033: 1000 +

Value: 200000000001000

Type Gateway
ID G023
Name Opening in wall

Action
- Get first item from list T019.2
- *AA→AI, 1900, (0.-1.0), Wall, #554*
- Search for 'IFCRELVOIDSELEMENT' and #554
  No match found
  'False'
- Remove first item from T019.2

	List T019.2 updated slab edges			
Edge	**Length**	**Direction**	**Wall?**	**Wall ref.**
~~*A→P*~~	~~*4200*~~	~~(1.0.0)~~	~~Wall~~	~~#463~~
~~*P→V*~~	~~*3800*~~	~~(1.0.0)~~	~~No~~	~~-~~
~~*V→B*~~	~~*5000*~~	~~(1.0.0)~~	~~Wall~~	~~#497~~
~~*B→AA*~~	~~*200*~~	~~(0.-1.0)~~	~~Wall~~	~~#497~~
~~*AA→AI*~~	~~*1900*~~	~~(0.-1.0)~~	~~Wall~~	~~#554~~
AI→C	*5100*	(0.-1.0)	No	-
C→D	*8000*	(-1.0.0)	No	-
D→E	*5000*	(0.-1.0)	No	-
E→AO	*4800*	(-1.0.0)	No	-
AO→F	*200*	(-1.0.0)	Wall	#589
F→AQ	*5600*	(0.1.0)	Wall	#589
AQ→N	*6200*	(0.1.0)	No	-
N→A	*200*	(0.1.0)	Wall	#463

Type Gateway
ID G010

Name	Is there an edge of the floor slab or roof element.
Action	- Get first item in list T019.2 *AI→C, 5100, (0.-1.0), No, -* *'False'*

Type	Gateway
ID	G011
Name	Is there another slab connected.
Action	- Get first item in list T019.2 *AI→C, 5100, (0.-1.0), No, -* - Check for other floor slab or roof element connected *No other floor slab or roof element on the building storey* *'False'*

Type	Gateway
ID	G012
Name	Wall element on floor slab or roof element
Action	- Get first item in list T019.2 *AI→C, 5100, (0.-1.0), No, -* - Is the edge marked wall? *'False'*

Type	Task
ID	T020
Name	Search for objects
Action	- Get list G001 and search for 'IFCBUILDINGELEMENTPROXY' and 'IFCRAILING' *1 match found* - Create list T020

List T020			
#nr.	**Global ID**	**Type**	**Name**
#865	*3PiPR_A6j7i8xsfls1hXJd*	*IFCRAILING*	*Railing:900mm Pipe:272287*

Type	Task
ID	T021
Name	Obtain object parameters
Action	- Calculate all parameters of T020 - Create list T021

List T021				
#nr.	**Vertex**	**X**	**Y**	**Z**
#865	*CA*	*-2951,66*	*-7761,7*	*0*
#865	*CB*	*-2994,86*	*-7761,7*	*0*

#865	*CC*	*-2994,86*	*-2761,7*	*0*
#865	*CD*	*-2951,66*	*-2761,7*	*0*
#865	*CE*	*-2951,66*	*-7761,7*	*880*
#865	*CF*	*-2994,86*	*-7761,7*	*880*
#865	*CG*	*-2994,86*	*-2761,7*	*880*
#865	*CH*	*-2951,66*	*-2761,7*	*880*

Type Gateway
ID G013
Name object on edge

Action
- Compare coordinates
  Railing is on edge D→E
  'False'
  Value = 222

Type Gateway
ID G017
Name Is it a roof element

Description
- Get first item from list T002.

#230, 3PiPR_A6j7i8xsfls1hXVA, IFCSLAB, Floor:Concrete-Commercial 362mm:271538
'False'
Value = 200000000000000

Type Task
ID T032
Name Processing rule set situation 2.2

Action
- Retrieve the values answered by G013 and G017 . Add the values.

G017: 200000000000000
G013 222+

Value: 200000000000222

- Remove first item from T019.2

	List T019.2 updated slab edges			
Edge	**Length**	**Direction**	**Wall?**	**Wall ref.**
~~*A→P*~~	~~*4200*~~	~~(1.0.0)~~	~~Wall~~	~~#463~~
~~*P→V*~~	~~*3800*~~	~~(1.0.0)~~	~~No~~	~~-~~
~~*V→B*~~	~~*5000*~~	~~(1.0.0)~~	~~Wall~~	~~#497~~
~~*B→AA*~~	~~*200*~~	~~(0.-1.0)~~	~~Wall~~	~~#497~~
~~*AA→AI*~~	~~*1900*~~	~~(0.-1.0)~~	~~Wall~~	~~#554~~
~~*AI→C*~~	~~*5100*~~	~~(0.-1.0)~~	~~No~~	~~-~~
C→D	*8000*	(-1.0.0)	No	-
D→E	*5000*	(0.-1.0)	No	-
E→AO	*4800*	(-1.0.0)	No	-
AO→F	*200*	(-1.0.0)	Wall	#589

F→AQ	*5600*	(0.1.0)	Wall	#589
AQ→N	*6200*	(0.1.0)	No	-
N→A	*200*	(0.1.0)	Wall	#463

Type	Gateway
ID	G010
Name	Is there an edge of the floor slab or roof element.

Action
- Get first item in list T019.2

C→D, 8000, (-1.0.0), No, -

'False'

Type	Gateway
ID	G011
Name	Is there another slab connected.

Action
- Get first item in list T019.2

C→D, 8000, (-1.0.0), No, -
- Check for other floor slab or roof element connected

  No other floor slab or roof element on the building storey

  'False'

Type	Gateway
ID	G012
Name	Wall element on floor slab or roof element

Action
- Get first item in list T019.2

C→D, 8000, (-1.0.0), No, -
- Is the edge marked wall?

  'False'

Type	Task
ID	T020
Name	Search for objects

Action
- Get list G001 and search for 'IFCBUILDINGELEMENTPROXY' and 'IFCRAILING'

  1 match found
- Create list T020

List T020			
#nr.	**Global ID**	**Type**	**Name**
#865	*3PiPR_A6j7i8xsfls1hXJd*	*IFCRAILING*	*Railing:900mm Pipe:272287*

Type	Task
ID	T021
Name	Obtain object parameters

Action

- Calculate all parameters of T020
- Create list T021

List T021				
#nr.	**Vertex**	**X**	**Y**	**Z**
#865	*CA*	*-2951,66*	*-7761,7*	*0*
#865	*CB*	*-2994,86*	*-7761,7*	*0*
#865	*CC*	*-2994,86*	*-2761,7*	*0*
#865	*CD*	*-2951,66*	*-2761,7*	*0*
#865	*CE*	*-2951,66*	*-7761,7*	*880*
#865	*CF*	*-2994,86*	*-7761,7*	*880*
#865	*CG*	*-2994,86*	*-2761,7*	*880*
#865	*CH*	*-2951,66*	*-2761,7*	*880*

Type Gateway
ID G013
Name object on edge

Action
- Compare coordinates
  Railing is on edge D→E
  'False'
  Value = 222

Type Gateway
ID G017
Name Is it a roof element
Description
- Get first item from list T002.

#230, 3PiPR_A6j7i8xsfls1hXVA, IFCSLAB, Floor:Concrete-Commercial 362mm:271538

'False'
Value = 200000000000000

Type Task
ID T032
Name Processing rule set situation 2.2

Action
- Retrieve the values answered by G013 and G017 . Add the values.

G017: 200000000000000
G013 222+

Value: 200000000000222

- Remove first item from T019.2

	List T019.2 updated slab edges			
Edge	**Length**	**Direction**	**Wall?**	**Wall ref.**
~~A→P~~	~~4200~~	~~(1.0.0)~~	~~Wall~~	~~#463~~
~~P→V~~	~~3800~~	~~(1.0.0)~~	~~No~~	~~——~~
~~V→B~~	~~5000~~	~~(1.0.0)~~	~~Wall~~	~~#497~~
~~B→AA~~	~~200~~	~~(0.-1.0)~~	~~Wall~~	~~#497~~

~~*AA→AI*~~	~~*1900*~~	~~(0.-1.0)~~	~~Wall~~	~~#554~~
~~*AI→C*~~	~~*5100*~~	~~(0.-1.0)~~	~~No~~	~~-~~
~~*C→D*~~	~~*8000*~~	~~(-1.0.0)~~	~~No~~	~~-~~
D→E	*5000*	(0.-1.0)	No	-
E→AO	*4800*	(-1.0.0)	No	-
AO→F	*200*	(-1.0.0)	Wall	#589
F→AQ	*5600*	(0.1.0)	Wall	#589
AQ→N	*6200*	(0.1.0)	No	-
N→A	*200*	(0.1.0)	Wall	#463

Type Gateway
ID G010
Name Is there an edge of the floor slab or roof element.

Action
- Get first item in list T019.2

D→E, 5000, (0.-1.0), No, -
'False'

Type Gateway
ID G011
Name Is there another slab connected.

Action
- Get first item in list T019.2

D→E, 5000, (0.-1.0), No, -
- Check for other floor slab or roof element connected
  No other floor slab or roof element on the building storey
  'False'

Type Gateway
ID G012
Name Wall element on floor slab or roof element

Action
- Get first item in list T019.2

D→E, 5000, (0.-1.0), No, -
- Is the edge marked wall?
  'False'

Type Task
ID T020
Name Search for objects

Action
- Get list G001 and search for 'IFCBUILDINGELEMENTPROXY' and 'IFCRAILING'
  1 match found
- Create list T020

List T020			
#nr.	**Global ID**	**Type**	**Name**

#865	*3PiPR_A6j7i8xsfls1hXJd*	*IFCRAILING*	*Railing:900mm Pipe:272287*

Type Task
ID T021
Name Obtain object parameters

Action

- Calculate all parameters of T020
- Create list T021

List T021				
#nr.	**Vertex**	**X**	**Y**	**Z**
#865	*CA*	*-2951,66*	*-7761,7*	*0*
#865	*CB*	*-2994,86*	*-7761,7*	*0*
#865	*CC*	*-2994,86*	*-2761,7*	*0*
#865	*CD*	*-2951,66*	*-2761,7*	*0*
#865	*CE*	*-2951,66*	*-7761,7*	*880*
#865	*CF*	*-2994,86*	*-7761,7*	*880*
#865	*CG*	*-2994,86*	*-2761,7*	*880*
#865	*CH*	*-2951,66*	*-2761,7*	*880*

Type Gateway
ID G013
Name object on edge

Action

- Compare coordinates
  Railing is on edge D→E
  'True'

Type Gateway
ID G014
Name object at 0.15

Action

- Get list G013

List T021				
#nr.	**Vertex**	**X**	**Y**	**Z**
#865	*CA*	*-2951,66*	*-7761,7*	*0*
#865	*CB*	*-2994,86*	*-7761,7*	*0*
#865	*CC*	*-2994,86*	*-2761,7*	*0*
#865	*CD*	*-2951,66*	*-2761,7*	*0*
#865	*CE*	*-2951,66*	*-7761,7*	*880*
#865	*CF*	*-2994,86*	*-7761,7*	*880*
#865	*CG*	*-2994,86*	*-2761,7*	*880*
#865	*CH*	*-2951,66*	*-2761,7*	*880*

Z-value = 0 t/m 880
150 is between 0 and 880

'True'

Type	Task
ID	T022
Name	Value is 1
Action	Value = 1

Type	Gateway
ID	G015
Name	object at 1.00
Action	- Get list G013

List T021				
#nr.	**Vertex**	**X**	**Y**	**Z**
#865	*CA*	*-2951,66*	*-7761,7*	*0*
#865	*CB*	*-2994,86*	*-7761,7*	*0*
#865	*CC*	*-2994,86*	*-2761,7*	*0*
#865	*CD*	*-2951,66*	*-2761,7*	*0*
#865	*CE*	*-2951,66*	*-7761,7*	*880*
#865	*CF*	*-2994,86*	*-7761,7*	*880*
#865	*CG*	*-2994,86*	*-2761,7*	*880*
#865	*CH*	*-2951,66*	*-2761,7*	*880*

Z-value = 0 t/m 880
1000 is not between 0 and 880
'False'
Value = 20

Type	Task
ID	T025
Name	Value is 20
Action	Value = 20

Type	Gateway
ID	G016
Name	object at 0.62
Action	- Get list G013

List T021				
#nr.	**Vertex**	**X**	**Y**	**Z**
#865	*CA*	*-2951,66*	*-7761,7*	*0*
#865	*CB*	*-2994,86*	*-7761,7*	*0*
#865	*CC*	*-2994,86*	*-2761,7*	*0*

#865	*CD*	*-2951,66*	*-2761,7*	*0*
#865	*CE*	*-2951,66*	*-7761,7*	*880*
#865	*CF*	*-2994,86*	*-7761,7*	*880*
#865	*CG*	*-2994,86*	*-2761,7*	*880*
#865	*CH*	*-2951,66*	*-2761,7*	*880*

Z-value = 0 t/m 880
620 is between 0 and 880
'True'
Value = 100

Type	Task
ID	T027
Name	Value is 100
Action	Value = 100

Type	Gateway
ID	G017
Name	Is it a roof element
Description	- Get first item from list T002. *#230, 3PiPR_A6j7i8xsfls1hXVA, IFCSLAB, Floor:Concrete-Commercial 362mm:271538* *'False'* *Value* = 200000000000000

Type	Task
ID	T032
Name	Processing rule set situation 2.2
Action	- Retrieve the values answered by G017 and G020. Add the values. G017: 200000000000000 T022: 1 G025: 20 G027: 100 + Value: 200000000000121 - Remove first item from T019.2

	List T019.2 updated slab edges			
Edge	**Length**	**Direction**	**Wall?**	**Wall ref.**
~~*A→P*~~	~~*4200*~~	~~(1.0.0)~~	~~Wall~~	~~#463~~
~~*P→V*~~	~~*3800*~~	~~(1.0.0)~~	~~No~~	~~-~~
~~*V→B*~~	~~*5000*~~	~~(1.0.0)~~	~~Wall~~	~~#497~~
~~*B→AA*~~	~~*200*~~	~~(0.-1.0)~~	~~Wall~~	~~#497~~
~~*AA→AI*~~	~~*1900*~~	~~(0.-1.0)~~	~~Wall~~	~~#554~~

~~*AI→C*~~	~~*5100*~~	~~(0.-1.0)~~	~~No~~	~~-~~
~~*C→D*~~	~~*8000*~~	~~(-1.0.0)~~	~~No~~	~~-~~
~~*D→E*~~	~~*5000*~~	~~(0.-1.0)~~	~~No~~	~~-~~
E→AO	*4800*	(-1.0.0)	No	-
AO→F	*200*	(-1.0.0)	Wall	#589
F→AQ	*5600*	(0.1.0)	Wall	#589
AQ→N	*6200*	(0.1.0)	No	-
N→A	*200*	(0.1.0)	Wall	#463

ID G010
Name Is there an edge of the floor slab or roof element.

Action
- Get first item in list T019.2
E→AO, 4800, (-1.0.0), No, -
'False'

Type Gateway
ID G011
Name Is there another slab connected.

Action
- Get first item in list T019.2
E→AO, 4800, (-1.0.0), No, -
- Check for other floor slab or roof element connected
No other floor slab or roof element on the building storey
'False'

Type Gateway
ID G012
Name Wall element on floor slab or roof element

Action
- Get first item in list T019.2
E→AO, 4800, (-1.0.0), No, -
- Is the edge marked wall?
'False'

Type Task
ID T020
Name Search for objects

Action
- Get list G001 and search for 'IFCBUILDINGELEMENTPROXY' and 'IFCRAILING'
1 match found
- Create list T020

List T020			
#nr.	**Global ID**	**Type**	**Name**
#865	*3PiPR_A6j7i8xsfls1hXJd*	*IFCRAILING*	*Railing:900mm Pipe:272287*

Type	Task
ID	T021
Name	Obtain object parameters

Action

- Calculate all parameters of T020
- Create list T021

List T021				
#nr.	**Vertex**	**X**	**Y**	**Z**
#865	*CA*	*-2951,66*	*-7761,7*	*0*
#865	*CB*	*-2994,86*	*-7761,7*	*0*
#865	*CC*	*-2994,86*	*-2761,7*	*0*
#865	*CD*	*-2951,66*	*-2761,7*	*0*
#865	*CE*	*-2951,66*	*-7761,7*	*880*
#865	*CF*	*-2994,86*	*-7761,7*	*880*
#865	*CG*	*-2994,86*	*-2761,7*	*880*
#865	*CH*	*-2951,66*	*-2761,7*	*880*

Type	Gateway
ID	G013
Name	object on edge

Action

- Compare coordinates

Railing is on edge D→E

'False'

Value = 222

Type	Gateway
ID	G017
Name	Is it a roof element

Description

- Get first item from list T002.

#230, 3PiPR_A6j7i8xsfls1hXVA, IFCSLAB, Floor:Concrete-Commercial 362mm:271538

'False'

Value = 200000000000000

Type	Task
ID	T032
Name	Processing rule set situation 2.2

Action

- Retrieve the values answered by G013 and G017 . Add the values.

G017: 200000000000000

G013 222+

Value: 200000000000222

- Remove first item from T019.2

	List T019.2 updated slab edges			
Edge	**Length**	**Direction**	**Wall?**	**Wall ref.**

~~*A→P*~~	~~*4200*~~	~~(1.0.0)~~	~~Wall~~	~~#463~~
~~*P→V*~~	~~*3800*~~	~~(1.0.0)~~	~~No~~	~~-~~
~~*V→B*~~	~~*5000*~~	~~(1.0.0)~~	~~Wall~~	~~#497~~
~~*B→AA*~~	~~*200*~~	~~(0.-1.0)~~	~~Wall~~	~~#497~~
~~*AA→AI*~~	~~*1900*~~	~~(0.-1.0)~~	~~Wall~~	~~#554~~
~~*AI→C*~~	~~*5100*~~	~~(0.-1.0)~~	~~No~~	~~-~~
~~*C→D*~~	~~*8000*~~	~~(-1.0.0)~~	~~No~~	~~-~~
~~*D→E*~~	~~*5000*~~	~~(0.-1.0)~~	~~No~~	~~-~~
~~*E→AO*~~	~~*4800*~~	~~(-1.0.0)~~	~~No~~	~~-~~
AO→F	*200*	(-1.0.0)	Wall	#589
F→AQ	*5600*	(0.1.0)	Wall	#589
AQ→N	*6200*	(0.1.0)	No	-
N→A	*200*	(0.1.0)	Wall	#463

Type Gateway
ID G010
Name Is there an edge of the floor slab or roof element.

Action
- Get first item in list T019.2

A0→F, 200, (-1.0.0), Wall, #589
'True'

Type Gateway
ID G011
Name Is there another slab connected.

Action
- Get first item in list T019.2

A0→F, 200, (-1.0.0), Wall, #589
- Check for other floor slab or roof element connected
  No other floor slab or roof element on the building storey
  'False'

Type Gateway
ID G012
Name Wall element on floor slab or roof element

Action
- Get first item in list T019.2

A0→F, 200, (-1.0.0), Wall, #589
- Is the edge marked wall?
  'True'

Type Gateway
ID G020
Name Wall height >= 1.00

Action
- Get list T005.7

T005.7 Vertexes				
#nr.	**Veterx**	**X**	**Y**	**Z**
#589	*AN*	*-7951,66*	*-7761,74*	*0*
#589	*AO*	*-7751,66*	*-7761,74*	*0*
#589	*AP*	*-7751,66*	*-2161,74*	*0*
#589	*AQ*	*-7951,66*	*-2161,74*	*0*
#589	*AR*	*-7951,66*	*-7761,74*	*4000*
#589	*AS*	*-7751,66*	*-7761,74*	*4000*
#589	*AT*	*-7751,66*	*-2161,74*	*4000*
#589	*AU*	*-7951,66*	*-2161,74*	*4000*

- Z-value = 4000
- 4000 >= 1000
  'True'

Type	Task
ID	T033
Name	Value is *1000*
Action	*Value: 1000*

Type	Gateway
ID	G017
Name	Is it a roof element
Action	- Get first item from list T002. *#230, 3PiPR_A6j7i8xsfls1hXVA, IFCSLAB, Floor:Concrete-Commercial 362mm:271538* *'False'* *Value* = 200000000000000

Type	Task
ID	T032
Name	Processing rule set situation 2.2
Action	- Retrieve the values answered by G017 and G020. Add the values. G017: 200000000000000 T033: 1000 + Value: 200000000001000

Type	Gateway
ID	G023

Name	Opening in wall	
Action	- Get first item from list T019.2	

A0→F, 200, (-1.0.0), Wall, #589

- Search for 'IFCRELVOIDSELEMENT' and #497
  No match found
  'False'
- Remove first item from T019.2

	List T019.2 updated slab edges			
Edge	**Length**	**Direction**	**Wall?**	**Wall ref.**
~~*A→P*~~	~~*4200*~~	~~(1.0.0)~~	~~Wall~~	~~#463~~
~~*P→V*~~	~~*3800*~~	~~(1.0.0)~~	~~No~~	~~-~~
~~*V→B*~~	~~*5000*~~	~~(1.0.0)~~	~~Wall~~	~~#497~~
~~*B→AA*~~	~~*200*~~	~~(0.-1.0)~~	~~Wall~~	~~#497~~
~~*AA→AI*~~	~~*1900*~~	~~(0.-1.0)~~	~~Wall~~	~~#554~~
~~*AI→C*~~	~~*5100*~~	~~(0.-1.0)~~	~~No~~	~~-~~
~~*C→D*~~	~~*8000*~~	~~(-1.0.0)~~	~~No~~	~~-~~
~~*D→E*~~	~~*5000*~~	~~(0.-1.0)~~	~~No~~	~~-~~
~~*E→AO*~~	~~*4800*~~	~~(-1.0.0)~~	~~No~~	~~-~~
~~*AO→F*~~	~~*200*~~	~~(-1.0.0)~~	~~Wall~~	~~#589~~
F→AQ	*5600*	(0.1.0)	Wall	#589
AQ→N	*6200*	(0.1.0)	No	-
N→A	*200*	(0.1.0)	Wall	#463

Type	Gateway
ID	G010
Name	Is there an edge of the floor slab or roof element.
Action	- Get first item in list T019.2

F→AQ, 5600, (0.1.0), Wall, #589
'True'

Type	Gateway
ID	G011
Name	Is there another slab connected.
Action	- Get first item in list T019.2

F→AQ, 5600, (0.1.0), Wall, #589

- Check for other floor slab or roof element connected
  No other floor slab or roof element on the building storey
  'False'

Type	Gateway
ID	G012
Name	Wall element on floor slab or roof element
Action	- Get first item in list T019.2

F→AQ, 5600, (0.1.0), Wall, #589
- Is the edge marked wall?
  'True'

Type Gateway
ID G020
Name Wall height >= 1.00

Action
- Get list T005.3

T005.7 Vertexes				
#nr.	**Veterx**	**X**	**Y**	**Z**
#589	*AN*	*-7951,66*	*-7761,74*	*0*
#589	*AO*	*-7751,66*	*-7761,74*	*0*
#589	*AP*	*-7751,66*	*-2161,74*	*0*
#589	*AQ*	*-7951,66*	*-2161,74*	*0*
#589	*AR*	*-7951,66*	*-7761,74*	*4000*
#589	*AS*	*-7751,66*	*-7761,74*	*4000*
#589	*AT*	*-7751,66*	*-2161,74*	*4000*
#589	*AU*	*-7951,66*	*-2161,74*	*4000*

- Z-value = 4000
- 4000 >= 1000
  'True'

Type Task
ID T033
Name Value is *1000*

Action *Value: 1000*

Type Gateway
ID G017
Name Is it a roof element

Action
- Get first item from list T002.

#230, 3PiPR_A6j7i8xsfls1hXVA, IFCSLAB, Floor:Concrete-Commercial 362mm:271538
'False'
Value = 200000000000000

Type Task
ID T032
Name Processing rule set situation 2.2

Action
- Retrieve the values answered by G017 and G020. Add the values.

G017: 200000000000000

T033: 1000 +

Value: 200000000001000

Type Gateway
ID G023
Name Opening in wall

Action
- Get first item from list T019.2

F→AQ, 5600, (0.1.0), Wall, #589

- Search for 'IFCRELVOIDSELEMENT' and #497
  One match found
- Create list G023

List G023			
#nr.	**Global ID**	**Ref #nr.**	**Ref ID**
#611	*0gCn_1xwH3dwUNWi9ci36x*	*#608*	*1xSCIvCgn7LfhjPTq8$IFK*

Type Gateway
ID G024
Name Is opening in wall filled?

Action
- Get first item from list G023

#611, 0gCn_1xwH3dwUNWi9ci36x, #608, 1xSCIvCgn7LfhjPTq8$IFK

- Search for 'IFCRELFILLSELEMENT' and #608

No match found

'False'

Type Task
ID T039
Name Obtain opening parameters

Action
- Get first item of list G023

#611, 0gCn_1xwH3dwUNWi9ci36x, #608, 1xSCIvCgn7LfhjPTq8$IFK

- Calculated opening parameters
- Create list T039.1 and T039.2:

List T039.1				
#nr.	**Vertex**	**X**	**Y**	**Z**
#608	*DI*	*-7751,66*	*-3442,07*	*0*
#608	*DJ*	*-7751,66*	*-4742,07*	*0*
#608	*DK*	*-7751,66*	*-4742,07*	*2300*
#608	*DL*	*-7751,66*	*-3442,07*	*2300*
#608	*DM*	*-7951,66*	*-3442,07*	*0*
#608	*DN*	*-7951,66*	*-4742,07*	*0*
#608	*DO*	*-7951,66*	*-4742,07*	*2300*
#608	*DP*	*-7951,66*	*-3442,07*	*2300*

List T039.2			
#nr.	**Edge**	**Length**	**Direction**
#516	*DI→DJ*	*1300*	(0.1.0)
#516	*DJ→DK*	*2300*	(0.0.1)
#516	*DK→DL*	*1300*	(0.-1.0)
#516	*DL→DI*	*2300*	(0.0.-1)

Type Gateway
ID G025
Name Width of the opening

Action
- Get list T039.2
- DI→DJ represents the width
- 1300 >= 300

'False'

Type Task
ID T040
Name *Value* = 2000000

Action *Value* = 2000000

Type Gateway
ID G026
Name Wall height >= 0.15

Action
- Get list T039.1
- Search for lowest z-value

A has the lowest z-value
0 < 150
'False'

Type Task
ID T042
Name *Value* = 20000000

Action *Value* = 20000000

Type Task
ID T048
Name Processing rule set situation 2.2

Action
- Retrieve the values answered by G017, G025, G026, G027 and G028. Add the values.

T040: *2000000*
T042: *20000000+*
Value: 22000000

- Remove list T039.1 and T039.2
- Remove first item from list G023

List G023			
#nr.	**Global ID**	**Ref #nr.**	**Ref ID**
~~*#519*~~	~~*38hBDVXr5BdudoVXzQKEF*~~	~~*#516*~~	~~*2XKVnl5wL8PQFyjReVa4sG*~~

- Remove first item from list T019.2

	List T019.2 updated slab edges			
Edge	**Length**	**Direction**	**Wall?**	**Wall ref.**
~~*A→P*~~	~~*4200*~~	~~(1.0.0)~~	~~Wall~~	~~#463~~
~~*P→V*~~	~~*3800*~~	~~(1.0.0)~~	~~No~~	~~-~~
~~*V→B*~~	~~*5000*~~	~~(1.0.0)~~	~~Wall~~	~~#497~~
~~*B→AA*~~	~~*200*~~	~~(0.-1.0)~~	~~Wall~~	~~#497~~
~~*AA→AI*~~	~~*1900*~~	~~(0.-1.0)~~	~~Wall~~	~~#554~~
~~*AI→C*~~	~~*5100*~~	~~(0.-1.0)~~	~~No~~	~~-~~
~~*C→D*~~	~~*8000*~~	~~(-1.0.0)~~	~~No~~	~~-~~
~~*D→E*~~	~~*5000*~~	~~(0.-1.0)~~	~~No~~	~~-~~
~~*E→AO*~~	~~*4800*~~	~~(-1.0.0)~~	~~No~~	~~-~~
~~*AO→F*~~	~~*200*~~	~~(-1.0.0)~~	~~Wall~~	~~#589~~
~~*F→AQ*~~	~~*5600*~~	~~(0.1.0)~~	~~Wall~~	~~#589~~
AQ→N	*6200*	(0.1.0)	No	-
N→A	*200*	(0.1.0)	Wall	#463

No items in G023. Continue with G010

ID G010
Name Is there an edge of the floor slab or roof element.

Action
- Get first item in list T019.2

AQ→N, 6200, (0.1.0), No, -
'False'

Type Gateway
ID G011
Name Is there another slab connected.

Action
- Get first item in list T019.2

AQ→N, 6200, (0.1.0), No, -

- Check for other floor slab or roof element connected
  No other floor slab or roof element on the building storey
  'False'

Type	Gateway
ID	G012
Name	Wall element on floor slab or roof element

Action
- Get first item in list T019.2

AQ→N, 6200, (0.1.0), No, -
- Is the edge marked wall?
  'False'

Type	Task
ID	T020
Name	Search for objects

Action
- Get list G001 and search for 'IFCBUILDINGELEMENTPROXY' and 'IFCRAILING'
  1 match found
- Create list T020

List T020			
#nr.	**Global ID**	**Type**	**Name**
#865	*3PiPR_A6j7i8xsfls1hXJd*	*IFCRAILING*	*Railing:900mm Pipe:272287*

Type	Task
ID	T021
Name	Obtain object parameters

Action
- Calculate all parameters of T020
- Create list T021

List T021				
#nr.	**Vertex**	**X**	**Y**	**Z**
#865	*CA*	*-2951,66*	*-7761,7*	*0*
#865	*CB*	*-2994,86*	*-7761,7*	*0*
#865	*CC*	*-2994,86*	*-2761,7*	*0*
#865	*CD*	*-2951,66*	*-2761,7*	*0*
#865	*CE*	*-2951,66*	*-7761,7*	*880*
#865	*CF*	*-2994,86*	*-7761,7*	*880*
#865	*CG*	*-2994,86*	*-2761,7*	*880*
#865	*CH*	*-2951,66*	*-2761,7*	*880*

Type	Gateway
ID	G013
Name	object on edge

Action - Compare coordinates
Railing is on edge D→E
'False'
Value = 222

Type Gateway
ID G017
Name Is it a roof element
Description - Get first item from list T002.
#230, 3PiPR_A6j7i8xsfls1hXVA, IFCSLAB, Floor:Concrete-Commercial 362mm:271538
'False'
Value = 200000000000000

Type Task
ID T032
Name Processing rule set situation 2.2

Action - Retrieve the values answered by G013 and G017 . Add the values.
G017: 200000000000000
<u>G013 222+</u>

Value: 200000000000222

- Remove first item from T019.2

	List T019.2 updated slab edges			
Edge	**Length**	**Direction**	**Wall?**	**Wall ref.**
~~*A→P*~~	~~*4200*~~	~~(1.0.0)~~	~~Wall~~	~~#463~~
~~*P→V*~~	~~*3800*~~	~~(1.0.0)~~	~~No~~	~~-~~
~~*V→B*~~	~~*5000*~~	~~(1.0.0)~~	~~Wall~~	~~#497~~
~~*B→AA*~~	~~*200*~~	~~(0.-1.0)~~	~~Wall~~	~~#497~~
~~*AA→AI*~~	~~*1900*~~	~~(0.-1.0)~~	~~Wall~~	~~#554~~
~~*AI→C*~~	~~*5100*~~	~~(0.-1.0)~~	~~No~~	~~-~~
~~*C→D*~~	~~*8000*~~	~~(-1.0.0)~~	~~No~~	~~-~~
~~*D→E*~~	~~*5000*~~	~~(0.-1.0)~~	~~No~~	~~-~~
~~*E→AO*~~	~~*4800*~~	~~(-1.0.0)~~	~~No~~	~~-~~
~~*AO→F*~~	~~*200*~~	~~(-1.0.0)~~	~~Wall~~	~~#589~~
~~*F→AQ*~~	~~*5600*~~	~~(0.1.0)~~	~~Wall~~	~~#589~~
~~*AQ→N*~~	~~*6200*~~	~~(0.1.0)~~	~~No~~	~~-~~
N→A	*200*	(0.1.0)	Wall	#463

Type Gateway
ID G010
Name Is there an edge of the floor slab or roof element.

Action - Get first item in list T019.2
N→A, 200, (0.1.0), Wall, #436
'True'

Type	Gateway
ID	G011
Name	Is there another slab connected.

Action
- Get first item in list T019.2

N →A, 200, (0.1.0), Wall, #436

- Check for other floor slab or roof element connected

  No other floor slab or roof element on the building storey

  'False'

Type	Gateway
ID	G012
Name	Wall element on floor slab or roof element

Action
- Get first item in list T019.2

N →A, 200, (0.1.0), Wall, #436

- Is the edge marked wall?

  'True'

Type	Gateway
ID	G020
Name	Wall height >= 1.00

Action
- Get list T005.1

T005.1 Vertexes				
#nr.	**Veterx**	**X**	**Y**	**Z**
#436	*M*	*-7951,66*	*4238,26*	*0*
#436	*N*	*-7951,66*	*403826*	*0*
#436	*O*	*-3751,66*	*4038,26*	*0*
#436	*P*	*-3751,66*	*4238,26*	*0*
#436	*Q*	*-7951,66*	*4238,26*	*4000*
#436	*R*	*-7951,66*	*403826*	*4000*
#436	*S*	*-3751,66*	*4038,26*	*4000*
#436	*T*	*-3751,66*	*4238,26*	*4000*

- Z-value = 4000
- 4000 >= 1000

  'True'

Type	Task
ID	T033
Name	Value is *1000*

Action *Value: 1000*

Type	Gateway
ID	G017

Name	Is it a roof element
Action	- Get first item from list T002. *#230, 3PiPR_A6j7i8xsfls1hXVA, IFCSLAB, Floor:Concrete-Commercial 362mm:271538* *'False'* *Value* = 200000000000000

Type	Task
ID	T032
Name	Processing rule set situation 2.2
Action	- Retrieve the values answered by G017 and G020. Add the values. G017: 200000000000000 T033: 1000 + Value: 200000000001000

Type	Gateway
ID	G023
Name	Opening in wall
Action	- Get first item from list T019.2 *N→A, 200, (0.1.0), Wall, #436* - Search for 'IFCRELVOIDSELEMENT' and #436 *No match found* *'False'* - Remove first item from T019.2

	List T019.2 updated slab edges			
Edge	**Length**	**Direction**	**Wall?**	**Wall ref.**
~~*A→P*~~	~~*4200*~~	~~(1.0.0)~~	~~Wall~~	~~#463~~
~~*P→V*~~	~~*3800*~~	~~(1.0.0)~~	~~No~~	~~-~~
~~*V→B*~~	~~*5000*~~	~~(1.0.0)~~	~~Wall~~	~~#495~~
~~*B→AA*~~	~~*200*~~	~~(0.-1.0)~~	~~Wall~~	~~#495~~
~~*AA→AI*~~	~~*1900*~~	~~(0.-1.0)~~	~~Wall~~	~~#554~~
~~*AI→C*~~	~~*5100*~~	~~(0.-1.0)~~	~~No~~	~~-~~
~~*C→D*~~	~~*8000*~~	~~(-1.0.0)~~	~~No~~	~~-~~
~~*D→E*~~	~~*5000*~~	~~(0.-1.0)~~	~~No~~	~~-~~
~~*E→AO*~~	~~*4800*~~	~~(-1.0.0)~~	~~No~~	~~-~~
~~*AO→F*~~	~~*200*~~	~~(-1.0.0)~~	~~Wall~~	~~#589~~
~~*F→AQ*~~	~~*5600*~~	~~(0.1.0)~~	~~Wall~~	~~#589~~
~~*AQ→N*~~	~~*6200*~~	~~(0.1.0)~~	~~No~~	~~-~~
~~*N→A*~~	~~*200*~~	~~(0.1.0)~~	~~Wall~~	~~#463~~

Type	Gateway
ID	G010
Name	Is there an edge of the floor slab or roof element.

Action	- Get first item in list T019.2	

No item in the list

'False'

Remove first item in list T002

List T002			
#nr.	**Global ID**	**Type**	**Name**
~~*#230*~~	~~*3PiPR_A6j7i8xsfls1hXVA*~~	~~*IFCSLAB*~~	~~*Floor:Concrete-Commercial 362mm:271538*~~

Type	Gateway
ID	G002
Name	Is there a floor slab or roof element
Action	- Get list T002 *'False*

Type	Gateway
ID	G001
Name	Is there a building storey
Action	- Get first item in list T001.

#162, 38FHvs4sbAXBc7ToVG5$Q2, Level 2

- Search for 'IFCRELCONTAINEDINSPATIALSTRUCTURE' and '#162'
  1 matches found
- Create list G001:

List G001			
#nr.	**Global ID**	**Type**	**Name**
#626	*3PiPR_A6j7i8xsfls1hXIE*	*IFCROOF*	*Basic Roof:Generic - 400mm:272374*
#723	*3PiPR_A6j7i8xsfls1hXjS*	*IFCWALLSTANDARDCASE*	*Basic Wall:Generic - 200mm: 272420*
#758	*3PiPR_A6j7i8xsfls1hXig*	*IFCWALLSTANDARDCASE*	*Basic Wall:Generic - 200mm: 272466*

- Remove first item in list T001

List T001		
#nr.	**Global ID**	**Name**
#156	*38FHvs4sbAXBc7ToVG5$tE*	*Level 1*
#162	*38FHvs4sbAXBc7ToVG5$Q2*	*Level 2*

Type	Task
ID	T002
Name	Search for floor slab and roof element

Description
- Get list G001 and search for 'IFCSLAB' and 'IFCROOF'.
  1 match found
- Create list T002:

List T002			
#nr.	**Global ID**	**Type**	**Name**
#626	*3PiPR_A6j7i8xsfls1hXIE*	*IFCROOF*	*Basic Roof:Generic - 400mm:272374*

Type	Gateway
ID	G002
Name	Is there a floor slab or roof element

Action
- Get list T002
  'True'
- Get first item in the list

#626, 3PiPR_A6j7i8xsfls1hXIE, IFCROOF, Basic Roof:Generic - 400mm:272374

Type	Task
ID	T003
Name	Obtain parameters of a floor slab or roof element

Action
- Retrieve and calculate the parameters of the floor slab or roof element.
- Create list T003.1

List T003.1 Vertexes				
#nr.	**Vertex**	**X**	**Y**	**Z**
#626	*A*	*-7951,66*	*338,26*	*0*
#626	*B*	*-2351,66*	*338,26*	*0*
#626	*C*	*-2351,66*	*4238,26*	*0*
#626	*D*	*-7951,66*	*4238,26*	*0*

- Create list T003.2

List T003.2 Edges			
#nr.	**Edge**	**Length**	**Direction (x.y.z)**
#626	*A→B*	*5600*	*(1.0.0)*
#626	*B→C*	*3900*	*(0.1.0)*
#626	*C→D*	*5600*	*(-1.0.0)*
#626	*D→A*	*3900*	*(0.-1.0)*

Type	Task
ID	T004

Name	Find related building elements

Action
- Get first item in list T002
- *#626, 3PiPR_A6j7i8xsfls1hXIE, IFCROOF, Basic Roof:Generic - 400mm:272374*
- Search for 'IFCRELCONNETCTSELEMENTS' and '#626'

No matches found
- Search for 'IFCSTANDARDCASEWALL' in list G001
  2 matches found
- Create list T004:

List T004		
#nr.	**Global ID**	**Name**
#723	*3PiPR_A6j7i8xsfls1hXjS*	*Basic Wall:Generic - 200mm: 272420*
#758	*3PiPR_A6j7i8xsfls1hXig*	*Basic Wall:Generic - 200mm: 272466*

Type	Task
ID	T005
Name	Obtain wall parameters

Action
- Retrieve and calculated parameters from list T004
- Create lists T005.1, T005.2, T005.3 and T005.4

List T005.1 vetrexes				
#nr.	**Vertex**	**X**	**Y**	**Z**
#723	*E*	*-7951,66*	*4238,26*	*0*
#723	*F*	*-7951,66*	*4038,26*	*0*
#723	*G*	*-6551,66*	*4038,26*	*0*
#723	*H*	*-6551,66*	*4238,26*	*0*
#723	*I*	*-7951,66*	*4238,26*	*1600*
#723	*J*	*-7951,66*	*4038,26*	*1600*
#723	*K*	*-6551,66*	*4038,26*	*1600*
#723	*L*	*-6551,66*	*4238,26*	*1600*

List T005.2 Edges			
#nr.	**Edge**	**Length**	**Direction**
#723	*E→F*	*200*	*(0.-1.0)*
#723	*F→G*	*1400*	*(1.0.0)*
#723	*G→H*	*200*	*(0.1.0)*
#723	*H→ E*	*1400*	*(-1.0.0)*
#723	*I→J*	*200*	*(0.-1.0)*
#723	*J→K*	*1400*	*(1.0.0)*
#723	*K→L*	*200*	*(0.1.0)*
#723	*L→I*	*1400*	*(-1.0.0)*

List T005.3 Vertexes				
#nr.	**Vertex**	**X**	**Y**	**Z**

#758	*M*	*-7751,66*	*4038,26*	*0*
#758	*N*	*-7951,66*	*4038,26*	*0*
#758	*O*	*-7951,66*	*3038,26*	*0*
#758	*P*	*-7751,66*	*3038,26*	*0*
#758	*Q*	*-7751,66*	*4038,26*	*1600*
#758	*R*	*-7951,66*	*4038,26*	*1600*
#758	*S*	*-7951,66*	*3038,26*	*1600*
#758	*T*	*-7751,66*	*3038,26*	*1600*

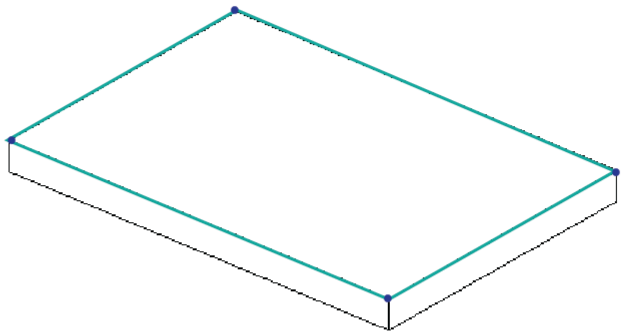
List T005.4 Edges			
#nr.	**Edge**	**Length**	**Direction**
#758	*M→N*	*200*	*(-1.0.0)*
#758	*N→O*	*1000*	*(0.-1.0)*
#758	*O→P*	*200*	*(1.0.0)*
#758	*P→M*	*1000*	*(0.1.0)*
#758	*Q→R*	*200*	*(-1.0.0)*
#758	*R→S*	*1000*	*(0.-1.0)*
#758	*S→T*	*200*	*(1.0.0)*
#758	*T→Q*	*1000*	*(0.1.0)*

Type Gateway
ID G003
Name Opening in floor slab / roof element

Action
- List G003 does not exist
- Get first item in list T002
- *#626, 3PiPR_A6j7i8xsfls1hXIE, IFCROOF, Basic Roof:Generic - 400mm:272374*
- Search for 'IFCRELVOIDSELEMENT' and #626
  No matches found
  'False'
  Continue with T018

Type Task
ID T018
Name Draw polyline Slab

Action
- Get list T005.1, T005.2, etc. and T003 with corresponding parameter list.
- Draw a polyline along the upper vertexes of the opening.



Type Task
ID T019
Name Compare polyline with wall parameters slab

Action
- Compare and update the polyline created in T018.

List T019.1 updated slab vertexes				
#nr.	**Vertex**	**X**	**Y**	**Z**
#626	*A*	*-7951,66*	*338,26*	*0*
#626	*B*	*-2351,66*	*338,26*	*0*
#626	*C*	*-2351,66*	*4238,26*	*0*
#723	*H*	*-6551,66*	*4238,26*	*0*
#626	*D*	*-7951,66*	*4238,26*	*0*
#723	*F*	*-7951,66*	*4038,26*	*0*
#758	*O*	*-7951,66*	*3038,26*	*0*

List T019.2 updated slab edges				
Edge	**Length**	**Direction**	**Wall?**	**Wall ref.**
A→B	*5600*	*(1.0.0)*	*No*	-
B→C	*3900*	*(0.1.0)*	*No*	-
C→H	*4200*	*(-1.0.0)*	*No*	-
H→D	*1400*	*(-1.0.0)*	*Wall*	*#723*
D→F	*200*	*(0.-1.0)*	*Wall*	*#723*
F→O	*1000*	*(0.-1.0)*	*Wall*	*#758*
0→A	*2700*	*(0.-1.0)*	*No*	-

Type Gateway
ID G010
Name Is there an edge of the floor slab or roof element.

Action
- Get first item in list T019.2

A→B, 5600, (1.0.0), No, -

'False'

Type Gateway

ID	G011
Name	Is there another slab connected.

Action
- Get first item in list T019.2

A →B, 5600, (1.0.0), No, -

- Check for other floor slab or roof element connected

  No other floor slab or roof element on the building storey

  'False'

Type	Gateway
ID	G012
Name	Wall element on floor slab or roof element

Action
- Get first item in list T019.2

A →B, 5600, (1.0.0), No, -

- Is the edge marked wall?

  'False'

Type	Task
ID	T020
Name	Search for objects

Action
- Get list G001 and search for 'IFCBUILDINGELEMENTPROXY' and 'IFCRAILING'

  No Match found

Type	Task
ID	T021
Name	Obtain object parameters
Action	No object on building storey

Type	Gateway
ID	G013
Name	object on edge

Action
- Compare coordinates

  'False'

  Value = 222

Type	Gateway
ID	G017
Name	Is it a roof element

Action
- Get first item from list T002.

#626, 3PiPR_A6j7i8xsfls1hXIE, IFCROOF, Basic Roof:Generic - 400mm:272374

  'True'

  Value = 100000000000000

Type	Gateway
ID	G018
Name	2.00 meter area roof
Action	- *No object found* *'False'* *Value* = 2000000000000000

Type	Gateway
ID	G019
Name	4.00 meter area roof
Action	- *No object found* *'False'* *Value* = 20000000000000000

Type	Task
ID	T048
Name	Processing rule set situation 1
Action	- Retrieve the values answered by G013, G017, G018 and G019. Add the values. G013: 222 G017: 100000000000000 G018: 2000000000000000 G019 20000000000000000 + Value: 22210000000000222 - Remove first item form list T019.2

List T019.2 updated slab edges				
Edge	**Length**	**Direction**	**Wall?**	**Wall ref.**
~~*A→B*~~	~~*5600*~~	~~*(1.0.0)*~~	~~*No*~~	~~-~~
B→C	*3900*	*(0.1.0)*	*No*	-
C→H	*4200*	*(-1.0.0)*	*No*	-
H→D	*1400*	*(-1.0.0)*	*Wall*	*#723*
D→F	*200*	*(0.-1.0)*	*Wall*	*#723*
F→O	*1000*	*(0.-1.0)*	*Wall*	*#758*
0→A	*2700*	*(0.-1.0)*	*No*	-

Type	Gateway
ID	G010
Name	Is there an edge of the floor slab or roof element.
Action	- Get first item in list T019.2

B →C, 3900, (0.1.0), No, -
'False'

Type	Gateway
ID	G011
Name	Is there another slab connected.
Action	- Get first item in list T019.2 *B →C, 3900, (0.1.0), No, -* - Check for other floor slab or roof element connected *No other floor slab or roof element on the building storey* *'False'*

Type	Gateway
ID	G012
Name	Wall element on floor slab or roof element
Action	- Get first item in list T019.2 *B →C, 3900, (0.1.0), No, -* - Is the edge marked wall? *'False'*

Type	Task
ID	T020
Name	Search for objects
Action	- Get list G001 and search for 'IFCBUILDINGELEMENTPROXY' and 'IFCRAILING' *No Match found*

Type	Task
ID	T021
Name	Obtain object parameters
Action	No object on building storey

Type	Gateway
ID	G013
Name	object on edge
Action	- Compare coordinates *'False'* Value = 222

Type	Gateway
ID	G017
Name	Is it a roof element
Action	- Get first item from list T002.

	#626, 3PiPR_A6j7i8xsfls1hXIE, IFCROOF, Basic Roof:Generic - 400mm:272374 *'True'* *Value* = 100000000000000

Type	Gateway
ID	G018
Name	2.00 meter area roof
Action	- *No object found* *'False'* *Value* = 2000000000000000

Type	Gateway
ID	G019
Name	4.00 meter area roof
Action	- *No object found* *'False'* *Value* = 20000000000000000

Type	Task
ID	T048
Name	Processing rule set situation 1
Action	- Retrieve the values answered by G013, G017, G018 and G019. Add the values. G013: 222 G017: 100000000000000 G018: 2000000000000000 G019 20000000000000000 + Value: 22210000000000222 - Remove first item form list T019.2

List T019.2 updated slab edges				
Edge	**Length**	**Direction**	**Wall?**	**Wall ref.**
~~*A→B*~~	~~*5600*~~	~~*(1.0.0)*~~	~~*No*~~	~~-~~
~~*B→C*~~	~~*3900*~~	~~*(0.1.0)*~~	~~*No*~~	~~-~~
C→H	*4200*	*(-1.0.0)*	*No*	-
H→D	*1400*	*(-1.0.0)*	*Wall*	*#723*
D→F	*200*	*(0.-1.0)*	*Wall*	*#723*
F→O	*1000*	*(0.-1.0)*	*Wall*	*#758*
0→A	*2700*	*(0.-1.0)*	*No*	-

Type	Gateway
ID	G010

Name	Is there an edge of the floor slab or roof element.
Action	- Get first item in list T019.2 *C→H, 4200, (-1.0.0), No, -* *'False'*

Type	Gateway
ID	G011
Name	Is there another slab connected.
Action	- Get first item in list T019.2 *C→H, 4200, (-1.0.0), No, -* - Check for other floor slab or roof element connected *No other floor slab or roof element on the building storey* *'False'*

Type	Gateway
ID	G012
Name	Wall element on floor slab or roof element
Action	- Get first item in list T019.2 *C→H, 4200, (-1.0.0), No, -* - Is the edge marked wall? *'False'*

Type	Task
ID	T020
Name	Search for objects
Action	- Get list G001 and search for 'IFCBUILDINGELEMENTPROXY' and 'IFCRAILING' *No Match found*

Type	Task
ID	T021
Name	Obtain object parameters
Action	No object on building storey

Type	Gateway
ID	G013
Name	object on edge
Action	- Compare coordinates *'False'* Value = 222

Type	Gateway
ID	G017

Name	Is it a roof element
Action	- Get first item from list T002. *#626, 3PiPR_A6j7i8xsfls1hXIE, IFCROOF, Basic Roof:Generic - 400mm:272374* *'True'* *Value* = 100000000000000

Type	Gateway
ID	G018
Name	2.00 meter area roof
Action	- *No object found* *'False'* *Value* = 2000000000000000

Type	Gateway
ID	G019
Name	4.00 meter area roof
Action	- *No object found* *'False'* *Value* = 20000000000000000

Type	Task
ID	T048
Name	Processing rule set situation 1
Action	- Retrieve the values answered by G013, G017, G018 and G019. Add the values. G013: 222 G017: 100000000000000 G018: 2000000000000000 G019 20000000000000000 + Value: 22210000000000222 - Remove first item form list T019.2

List T019.2 updated slab edges				
Edge	**Length**	**Direction**	**Wall?**	**Wall ref.**
~~*A→B*~~	~~*5600*~~	~~*(1.0.0)*~~	~~*No*~~	~~-~~
~~*B→C*~~	~~*3900*~~	~~*(0.1.0)*~~	~~*No*~~	~~-~~
~~*C→H*~~	~~*4200*~~	~~*(-1.0.0)*~~	~~*No*~~	~~-~~
H→D	*1400*	*(-1.0.0)*	*Wall*	*#723*
D→F	*200*	*(0.-1.0)*	*Wall*	*#723*
F→O	*1000*	*(0.-1.0)*	*Wall*	*#758*
0→A	*2700*	*(0.-1.0)*	*No*	-

Type	Gateway
ID	G010
Name	Is there an edge of the floor slab or roof element.

Action
- Get first item in list T019.2

H→D, 1400, (-1.0.0), Wall, #723

'False'

Type	Gateway
ID	G011
Name	Is there another slab connected.

Action
- Get first item in list T019.2

H→D, 1400, (-1.0.0), Wall, #723

- Check for other floor slab or roof element connected

  No other floor slab or roof element on the building storey

  'False'

Type	Gateway
ID	G012
Name	Wall element on floor slab or roof element

Action
- Get first item in list T019.2

H→D, 1400, (-1.0.0), Wall, #723

- Is the edge marked wall?

  'True'

Type	Gateway
ID	G020
Name	Wall height >= 1.00

Action
- Get list T005.1

List T005.1 vetrexes				
#nr.	**Vertex**	**X**	**Y**	**Z**
#723	*E*	*-7951,66*	*4238,26*	*0*
#723	*F*	*-7951,66*	*4038,26*	*0*
#723	*G*	*-6551,66*	*4038,26*	*0*
#723	*H*	*-6551,66*	*4238,26*	*0*
#723	*I*	*-7951,66*	*4238,26*	*1600*
#723	*J*	*-7951,66*	*4038,26*	*1600*
#723	*K*	*-6551,66*	*4038,26*	*1600*
#723	*L*	*-6551,66*	*4238,26*	*1600*

- Z-value = 1600
- 1600 >= 1000

  'True'

  Value = 1000

Type	Gateway
ID	G017
Name	Is it a roof element
Action	- Get first item from list T002. *#626, 3PiPR_A6j7i8xsfls1hXIE, IFCROOF, Basic Roof:Generic - 400mm:272374* *'True'* *Value* = 100000000000000

Type	Gateway
ID	G018
Name	2.00 meter area roof
Action	- *No object found* *'False'* *Value* = 2000000000000000

Type	Gateway
ID	G019
Name	4.00 meter area roof
Action	- *No object found* *'False'* *Value* = 20000000000000000

Type	Task
ID	T048
Name	Processing rule set situation 1
Action	- Retrieve the values answered by G017, G018, G020 and G020. Add the values. *G017: 100000000000000* *G018: 2000000000000000* *G019 20000000000000000* *G020 1000 +* *Value: 22210000000001000*

Type	Gateway
ID	G023
Name	Opening in wall
Action	- Get first item from list T019.2 - *H→D, 1400, (-1.0.0), Wall, #723* - Search for 'IFCRELVOIDSELEMENT' and #723 *No match found* *'False'* - Remove first item from T019.2

List T019.2 updated slab edges				
Edge	**Length**	**Direction**	**Wall?**	**Wall ref.**
~~A→B~~	~~5600~~	~~(1.0.0)~~	~~No~~	~~-~~
~~B→C~~	~~3900~~	~~(0.1.0)~~	~~No~~	~~-~~
~~C→H~~	~~4200~~	~~(-1.0.0)~~	~~No~~	~~-~~
~~H→D~~	~~1400~~	~~(-1.0.0)~~	~~Wall~~	~~#723~~
D→F	*200*	*(0.-1.0)*	*Wall*	*#723*
F→O	*1000*	*(0.-1.0)*	*Wall*	*#758*
0→A	*2700*	*(0.-1.0)*	*No*	*-*

Type Gateway
ID G010
Name Is there an edge of the floor slab or roof element.

Action
- Get first item in list T019.2

D→F, 2000, (0.-1.0), Wall, #723

'False'

Type Gateway
ID G011
Name Is there another slab connected.

Action
- Get first item in list T019.2

D→F, 2000, (0.-1.0), Wall, #723

- Check for other floor slab or roof element connected

  No other floor slab or roof element on the building storey

  'False'

Type Gateway
ID G012
Name Wall element on floor slab or roof element

Action
- Get first item in list T019.2

D→F, 2000, (0.-1.0), Wall, #723

- Is the edge marked wall?

  'True'

Type Gateway
ID G020
Name Wall height >= 1.00

Action
- Get list T005.1

List T005.1 vetrexes				
#nr.	**Vertex**	**X**	**Y**	**Z**
#723	*E*	*-7951,66*	*4238,26*	*0*
#723	*F*	*-7951,66*	*4038,26*	*0*

#723	*G*	*-6551,66*	*4038,26*	*0*
#723	*H*	*-6551,66*	*4238,26*	*0*
#723	*I*	*-7951,66*	*4238,26*	*1600*
#723	*J*	*-7951,66*	*4038,26*	*1600*
#723	*K*	*-6551,66*	*4038,26*	*1600*
#723	*L*	*-6551,66*	*4238,26*	*1600*

- Z-value = 1600
- 1600 >= 1000
  'True'
  Value = 1000

Type Gateway
ID G017
Name Is it a roof element

Action
- Get first item from list T002.

#626, 3PiPR_A6j7i8xsfls1hXIE, IFCROOF, Basic Roof:Generic - 400mm:272374
'True'
Value = 100000000000000

Type Gateway
ID G018
Name 2.00 meter area roof

Action
- *No object found*
  'False'
  Value = 2000000000000000

Type Gateway
ID G019
Name 4.00 meter area roof

Action
- *No object found*
  'False'
  Value = 20000000000000000

Type Task
ID T048
Name Processing rule set situation 1

Action
- Retrieve the values answered by G017, G018, G020 and G020. Add the values.

G017: 100000000000000
G018: 2000000000000000
G019 20000000000000000
G020 1000 +

Value: 2221000000001000

Type	Gateway
ID	G023
Name	Opening in wall

Action
- Get first item from list T019.2

D→F, 2000, (0.-1.0), Wall, #723

- Search for 'IFCRELVOIDSELEMENT' and #723

  No match found

  'False'
- Remove first item from T019.2

List T019.2 updated slab edges				
Edge	**Length**	**Direction**	**Wall?**	**Wall ref.**
~~*A→B*~~	~~*5600*~~	~~*(1.0.0)*~~	~~*No*~~	~~-~~
~~*B→C*~~	~~*3900*~~	~~*(0.1.0)*~~	~~*No*~~	~~-~~
~~*C→H*~~	~~*4200*~~	~~*(-1.0.0)*~~	~~*No*~~	~~-~~
~~*H→D*~~	~~*1400*~~	~~*(-1.0.0)*~~	~~*Wall*~~	~~*#723*~~
~~*D→F*~~	~~*200*~~	~~*(0.-1.0)*~~	~~*Wall*~~	~~*#723*~~
F→O	*1000*	*(0.-1.0)*	*Wall*	*#758*
0→A	*2700*	*(0.-1.0)*	*No*	-

Type	Gateway
ID	G010
Name	Is there an edge of the floor slab or roof element.

Action
- Get first item in list T019.2

F→O, 1000, (0.-1.0), Wall, #758

  'False'

Type	Gateway
ID	G011
Name	Is there another slab connected.

Action
- Get first item in list T019.2

F→O, 1000, (0.-1.0), Wall, #758

- Check for other floor slab or roof element connected

  No other floor slab or roof element on the building storey

  'False'

Type	Gateway
ID	G012
Name	Wall element on floor slab or roof element

Action
- Get first item in list T019.2

F→O, 1000, (0.-1.0), Wall, #758

- Is the edge marked wall?
  'True'

Type	Gateway
ID	G020
Name	Wall height >= 1.00

Action

- Get list T005.3

List T005.3 Vertexes				
#nr.	**Vertex**	**X**	**Y**	**Z**
#758	*M*	*-7751,66*	*4038,26*	*0*
#758	*N*	*-7951,66*	*4038,26*	*0*
#758	*O*	*-7951,66*	*3038,26*	*0*
#758	*P*	*-7751,66*	*3038,26*	*0*
#758	*Q*	*-7751,66*	*4038,26*	*1600*
#758	*R*	*-7951,66*	*4038,26*	*1600*
#758	*S*	*-7951,66*	*3038,26*	*1600*
#758	*T*	*-7751,66*	*3038,26*	*1600*

- Z-value = 1600
- 1600 >= 1000
  'True'
  Value = 1000

Type	Gateway
ID	G017
Name	Is it a roof element

Action

- Get first item from list T002.

#626, 3PiPR_A6j7i8xsfls1hXIE, IFCROOF, Basic Roof:Generic - 400mm:272374
'True'
Value = 100000000000000

Type	Gateway
ID	G018
Name	2.00 meter area roof

Action

- *No object found*
  'False'
  Value = 2000000000000000

Type	Gateway
ID	G019
Name	4.00 meter area roof

Action

- *No object found*
  'False'

Value = 20000000000000000

Type	Task
ID	T048
Name	Processing rule set situation 1

Action - Retrieve the values answered by G017, G018, G020 and G020. Add the values.

G017: 100000000000000
G018: 2000000000000000
G019 20000000000000000
G020 1000 +

Value: 22210000000001000

Type	Gateway
ID	G023
Name	Opening in wall

Action
- Get first item from list T019.2

F→O, 1000, (0.-1.0), Wall, #758

- Search for 'IFCRELVOIDSELEMENT' and #758
  No match found
  'False'
- Remove first item from T019.2

List T019.2 updated slab edges				
Edge	**Length**	**Direction**	**Wall?**	**Wall ref.**
~~*A→B*~~	~~*5600*~~	~~*(1.0.0)*~~	~~*No*~~	~~-~~
~~*B→C*~~	~~*3900*~~	~~*(0.1.0)*~~	~~*No*~~	~~-~~
~~*C→H*~~	~~*4200*~~	~~*(-1.0.0)*~~	~~*No*~~	~~-~~
~~*H→D*~~	~~*1400*~~	~~*(-1.0.0)*~~	~~*Wall*~~	~~*#723*~~
~~*D→F*~~	~~*200*~~	~~*(0.-1.0)*~~	~~*Wall*~~	~~*#723*~~
~~*F→O*~~	~~*1000*~~	~~*(0.-1.0)*~~	~~*Wall*~~	~~*#758*~~
0→A	*2700*	*(0.-1.0)*	*No*	-

Type	Gateway
ID	G010
Name	Is there an edge of the floor slab or roof element.

Action
- Get first item in list T019.2

O→A, 2700, (0.-1.0), No, -
'False'

Type	Gateway
ID	G011
Name	Is there another slab connected.

Action
- Get first item in list T019.2

O→A, 2700, (0.-1.0), No, -

	- Check for other floor slab or roof element connected *No other floor slab or roof element on the building storey* *'False'*

Type	Gateway
ID	G012
Name	Wall element on floor slab or roof element
Action	- Get first item in list T019.2 *O→A, 2700, (0.-1.0), No, -* - Is the edge marked wall? *'False'*

Type	Task
ID	T020
Name	Search for objects
Action	- Get list G001 and search for 'IFCBUILDINGELEMENTPROXY' and 'IFCRAILING' *No Match found*

Type	Task
ID	T021
Name	Obtain object parameters
Action	No object on building storey

Type	Gateway
ID	G013
Name	object on edge
Action	- Compare coordinates *'False'* Value = 222

Type	Gateway
ID	G017
Name	Is it a roof element
Action	- Get first item from list T002. *#626, 3PiPR_A6j7i8xsfls1hXIE, IFCROOF, Basic Roof:Generic - 400mm:272374* *'True'* *Value* = 100000000000000

Type	Gateway
ID	G018
Name	2.00 meter area roof

Action	-	*No object found* *'False'* *Value* = 2000000000000000

Type	Gateway
ID	G019
Name	4.00 meter area roof
Action	- *No object found* *'False'* *Value* = 20000000000000000

Type	Task
ID	T048
Name	Processing rule set situation 1
Action	- Retrieve the values answered by G013, G017, G018 and G019. Add the values. G013: 222 G017: 100000000000000 G018: 2000000000000000 G019 20000000000000000 + Value: 22210000000000222 - Remove first item form list T019.2

List T019.2 updated slab edges				
Edge	**Length**	**Direction**	**Wall?**	**Wall ref.**
~~A→B~~	~~5600~~	~~(1.0.0)~~	~~No~~	~~—~~
~~B→C~~	~~3900~~	~~(0.1.0)~~	~~No~~	~~—~~
~~C→H~~	~~4200~~	~~(-1.0.0)~~	~~No~~	~~—~~
~~H→D~~	~~1400~~	~~(-1.0.0)~~	~~Wall~~	~~#723~~
~~D→F~~	~~200~~	~~(0.-1.0)~~	~~Wall~~	~~#723~~
~~F→O~~	~~1000~~	~~(0.-1.0)~~	~~Wall~~	~~#758~~
~~O→A~~	~~2700~~	~~(0.-1.0)~~	~~No~~	~~—~~

Type	Gateway
ID	G010
Name	Is there an edge of the floor slab or roof element.
Action	- Get first item in list T019.2 *No item in the list* *'False'* *Remove first item in list T002*

List T002			
#nr.	**Global ID**	**Type**	**Name**

~~*#230*~~	~~*3PiPR_A6j7i8xsfls1hXVA*~~	~~*IFCSLAB*~~	~~*Floor:Concrete-Commercial 362mm:271538*~~

Type	Gateway
ID	G002
Name	Is there a floor slab or roof element
Action	- Get list T002 *'False*

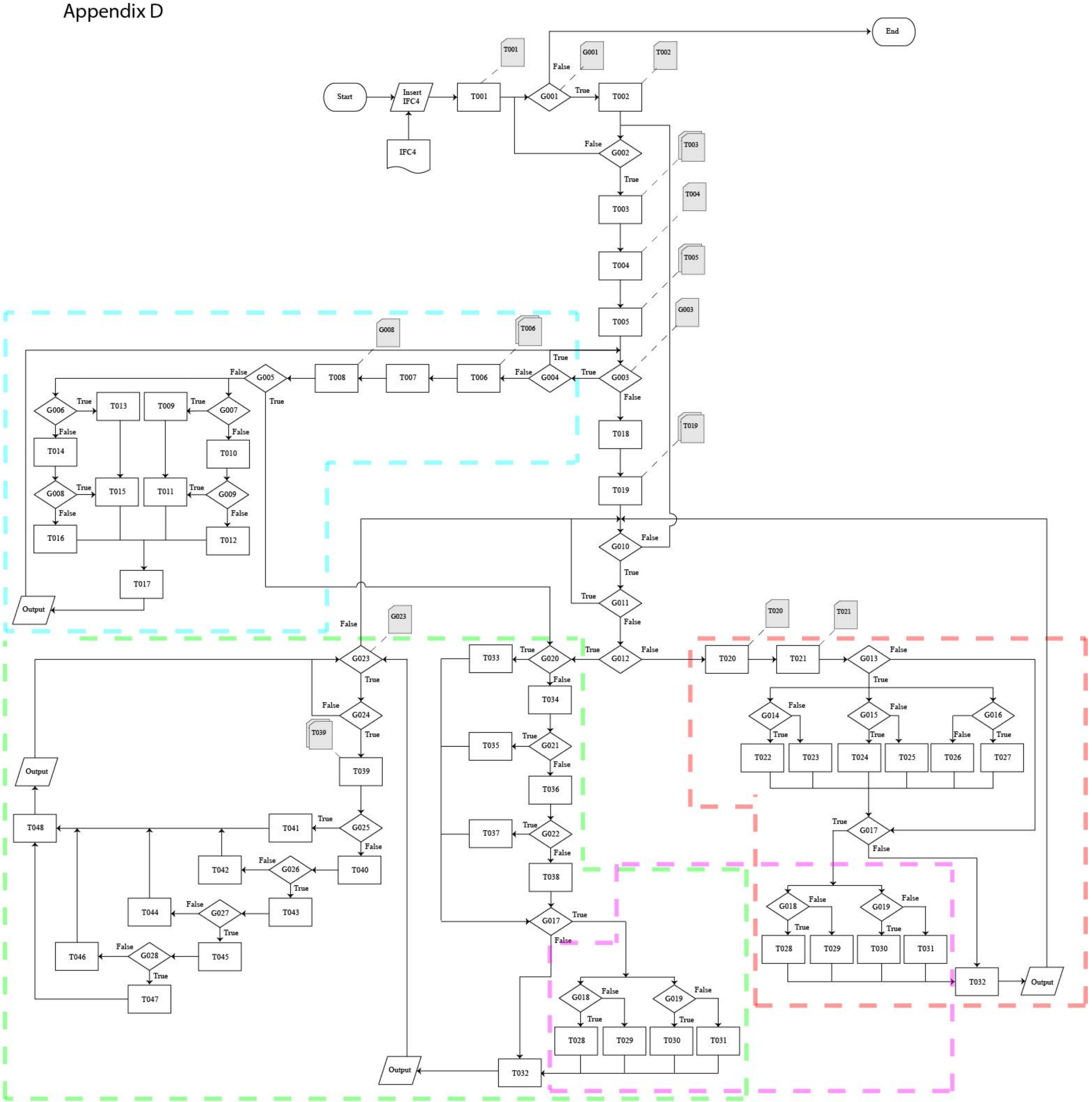
Type	Gateway
ID	G001
Name	Is there a building storey
Action	- Get first item in list T001. 'False'

Type	Event
ID	E002
Name	End
Action	*End system*

The testcase presented proves that the fall hazard prevention system can be used to detect unsafe situations and provide the solution for the situation. Figure X shows the model with all the edges. The edges are marked with the value code which corresponds to a situation with a specific solution. Also the length of the edges are given. This can be used to calculate the amount of prevention equipment needed.

Appendix D

	ID	Name
Tasks	T001	Search for building storey
	T002	Search for floor slab or roof element
	T003	Obtain parameters floor slab
	T004	Find related building elements
	T005	Obtain wall dimensions
	T006	Obtain opening dimensions
	T007	Draw polyline opening
	T008	Compare polyline opening
	T009	Value = 10000000000
	T010	Value = 20000000000
	T011	Value = 1000000000000
	T012	Value = 2000000000000
	T013	Value = 100000000000
	T014	Value = 200000000000
	T015	Value = 10000000000000
	T016	Value = 20000000000000
	T017	Processing rule set 3
	T018	Draw polyline slab
	T019	Compare polyline slab
	T020	Search for objects
`	T021	Obtain object dimensions
	T022	Value = 1
	T023	Value = 2
	T024	Value = 10
	T025	Value = 20
	T026	Value = 100
	T027	Value = 200
	T028	Value = 1000000000000000
	T029	Value = 2000000000000000
	T030	Value = 10000000000000000
	T031	Value = 20000000000000000
	T032	Processing rule set
	T033	Value = 1000
	T034	Value = 2000
	T035	Value = 10000
	T036	Value = 20000
	T037	Value = 100000
	T038	Value = 200000
	T039	Obtain wall opening dimension
	T040	Value = 1000000
	T041	Value = 2000000
	T042	Value = 10000000
	T043	Value = 200000000
	T044	Value = 1000000000
	T045	Value = 2000000000
	T046	Value = 10000000000
	T047	Value = 20000000000
	T048	Processing rule set 2
Gateway	G001	Is there a building storey?
	G002	Is there a floor slab or roof element?
	G003	Opening in slab?
	G004	Is opening filled?
	G005	Is there a wall on the opening?
	G006	Length >= 1.00m?
	G007	Width >= 1.00m?
	G008	Length < 0.10m?
	G009	Width < 0.10m?
	G010	Is there an edge of the slab?
	G011	Is there another slab connected?
	G012	Is there a wall on the edge?
	G013	Is there an object on the edge?
	G014	Is there an object at 0.15m?
	G015	Is there an object at 1.00m?
	G016	Is there an object at 0.62m?
	G017	Is it a roof element?
	G018	2.00m area?
	G019	4.00m area?
	G020	Is wall height >= 1.00m?
	G021	Is wall height >= 0.62m?
	G022	Is wall height >= 0.15m?
	G023	Is there a opening in the wall?
	G024	Is the opening in the wall filled?
	G025	Is width of opening 0.3m or less?
	G026	Is opening height >= 0.15m?
	G027	Is opening height >= 0.62m?
	G028	Is opening height >= 0.15m?



Appendix E

ISO-10303-21;
HEADER;
/**
****
STEP Physical File produced by: The EXPRESS Data Manager Version 5.02.0100.07
: 28 Aug 2013
Module: EDMstepFileFactory/EDMstandAlone
Creation date: Wed Dec 12 14:39:41 2018* Host: LAPTOP-C5172PAU
Database:
C:\Users\Dustin\AppData\Local\Temp\{9F02328C-3E0F-4CD1-BDD0-9ACC4B811F0D}\ifc
Database version: 5507
Database creation date: Wed Dec 12 14:39:40 2018
Schema: IFC4
Model: DataRepository.ifc
Model creation date: Wed Dec 12 14:39:40 2018
Header model: DataRepository.ifc_HeaderModel
Header model creation date: Wed Dec 12 14:39:40 2018
EDMuser: sdai-user
EDMgroup: sdai-group
License ID and type: 5605 : Permanent license. Expiry date:
EDMstepFileFactory options: 020000
****
**********/
FILE_DESCRIPTION(('ViewDefinition [DesignTransferView_V1.0]'),'2;1');
FILE_NAME('','2018-12-12T14:39:41',(''),(''),'The EXPRESS Data Manager Version
5.02.0100.07 : 28 Aug 2013','20160225_1515(x64) - Exporter 17.0.416.0 -
Alternate UI 17.12.14.0','');
FILE_SCHEMA(('IFC4'));
ENDSEC;
DATA;
#1= IFCORGANIZATION($,'Autodesk Revit 2017 (ENU)',$,$,$);
#5= IFCAPPLICATION(#1,'2017','Autodesk Revit 2017 (ENU)','Revit');
#6= IFCCARTESIANPOINT((0.,0.,0.));
#10= IFCCARTESIANPOINT((0.,0.));
#12= IFCDIRECTION((1.,0.,0.));
#14= IFCDIRECTION((-1.,0.,0.)); #16= IFCDIRECTION((0.,1.,0.));
#18= IFCDIRECTION((0.,-1.,0.)); #20= IFCDIRECTION((0.,0.,1.));
#22= IFCDIRECTION((0.,0.,-1.));
#24= IFCDIRECTION((1.,0.));
#26= IFCDIRECTION((-1.,0.)); #28= IFCDIRECTION((0.,1.));
#30= IFCDIRECTION((0.,-1.));
#32= IFCAXIS2PLACEMENT3D(#6,$,$);
#33= IFCLOCALPLACEMENT(#396,#32);
#36= IFCPERSON($,'','Dustin',$,$,$,$,$);
#38= IFCORGANIZATION($,'','',$,$);
#39= IFCPERSONANDORGANIZATION(#36,#38,$);
#42= IFCOWNERHISTORY(#39,#5,$,.NOCHANGE.,$,$,$,1541497088);
#43= IFCSIUNIT(*,.LENGTHUNIT.,.MILLI.,.METRE.);
#44= IFCSIUNIT(*,.LENGTHUNIT.,$,.METRE.);
#45= IFCSIUNIT(*,.AREAUNIT.,$,.SQUARE_METRE.);
#46= IFCSIUNIT(*,.VOLUMEUNIT.,$,.CUBIC_METRE.);
#47= IFCSIUNIT(*,.PLANEANGLEUNIT.,$,.RADIAN.);
#48= IFCDIMENSIONALEXPONENTS(0,0,0,0,0,0,0);
#49= IFCMEASUREWITHUNIT(IFCRATIOMEASURE(0.0174532925199433),#47);

#50= IFCCONVERSIONBASEDUNIT(#48,.PLANEANGLEUNIT.,'DEGREE',#49);
#52= IFCSIUNIT(*,.MASSUNIT.,.KILO.,.GRAM.);
#53= IFCSIUNIT(*,.TIMEUNIT.,$,.SECOND.);
#54= IFCSIUNIT(*,.FREQUENCYUNIT.,$,.HERTZ.);
#55= IFCSIUNIT(*,.THERMODYNAMICTEMPERATUREUNIT.,$,.KELVIN.);
#56= IFCSIUNIT(*,.THERMODYNAMICTEMPERATUREUNIT.,$,.DEGREE_CELSIUS.);
#57= IFCDERIVEDUNITELEMENT(#52,1);
#58= IFCDERIVEDUNITELEMENT(#55,-1);
#59= IFCDERIVEDUNITELEMENT(#53,-3);
#60= IFCDERIVEDUNIT((#57,#58,#59),.THERMALTRANSMITTANCEUNIT.,$);
#62= IFCSIUNIT(*,.LENGTHUNIT.,.DECI.,.METRE.);
#63= IFCDERIVEDUNITELEMENT(#44,3);
#64= IFCDERIVEDUNITELEMENT(#53,-1);
#65= IFCDERIVEDUNIT((#63,#64),.VOLUMETRICFLOWRATEUNIT.,$);
#67= IFCSIUNIT(*,.ELECTRICCURRENTUNIT.,$,.AMPERE.);
#68= IFCSIUNIT(*,.ELECTRICVOLTAGEUNIT.,$,.VOLT.);
#69= IFCSIUNIT(*,.POWERUNIT.,$,.WATT.);
#70= IFCSIUNIT(*,.FORCEUNIT.,.KILO.,.NEWTON.);
#71= IFCSIUNIT(*,.ILLUMINANCEUNIT.,$,.LUX.);
#72= IFCSIUNIT(*,.LUMINOUSFLUXUNIT.,$,.LUMEN.);
#73= IFCSIUNIT(*,.LUMINOUSINTENSITYUNIT.,$,.CANDELA.);
#74= IFCDERIVEDUNITELEMENT(#52,-1);
#75= IFCDERIVEDUNITELEMENT(#44,-2);
#76= IFCDERIVEDUNITELEMENT(#53,3);
#77= IFCDERIVEDUNITELEMENT(#72,1);
#78= IFCDERIVEDUNIT((#74,#75,#76,#77),.USERDEFINED.,'Luminous Efficacy');
#80= IFCDERIVEDUNITELEMENT(#44,1);
#81= IFCDERIVEDUNITELEMENT(#53,-1);
#82= IFCDERIVEDUNIT((#80,#81),.LINEARVELOCITYUNIT.,$);
#84= IFCSIUNIT(*,.PRESSUREUNIT.,$,.PASCAL.);
#85= IFCDERIVEDUNITELEMENT(#44,-2); #86= IFCDERIVEDUNITELEMENT(#52,1);
#87= IFCDERIVEDUNITELEMENT(#53,-2);
#88= IFCDERIVEDUNIT((#85,#86,#87),.USERDEFINED.,'Friction Loss');
#90=
IFCUNITASSIGNMENT((#43,#45,#46,#50,#52,#53,#54,#56,#60,#65,#67,#68,#69,#70,#71,#
72,#73,#78,#82,#84,#88));
#92= IFCAXIS2PLACEMENT3D(#6,$,$);
#93= IFCDIRECTION((6.12303176911189E-17,1.));
#95= IFCGEOMETRICREPRESENTATIONCONTEXT($,'Model',3,0.01,#92,#93);
#99=
IFCGEOMETRICREPRESENTATIONSUBCONTEXT('Axis','Model',*,*,*,*,#95,$,.GRAPH_VIEW.,$
);
#101= IFCGEOMETRICREPRESENTATIONSUBCONTEXT('Body','Model',*,*,*,*,#95,$,.MODEL_VIEW.,$
);
#102=
IFCGEOMETRICREPRESENTATIONSUBCONTEXT('Box','Model',*,*,*,*,#95,$,.MODEL_VIEW.,$)
;
#103=
IFCGEOMETRICREPRESENTATIONSUBCONTEXT('FootPrint','Model',*,*,*,*,#95,$,.MODEL_VI EW.,$);
#104= IFCPROJECT('3vB5XNXDb9EO$2rl$0o2xU',#42,'',$,$,'','',(#95),#90);
#115= IFCPOSTALADDRESS($,$,$,$,(),$,'','','','');
#119=
IFCBUILDING('3vB5XNXDb9EO$2rl$0o2xV',#42,'',$,$,#33,$,'',.ELEMENT.,$,$,#115);
#129= IFCAXIS2PLACEMENT3D(#6,$,$);
#130= IFCLOCALPLACEMENT(#33,#129);
#132= IFCBUILDINGSTOREY('3vB5XNXDb9EO$2rly$DzJO',#42,'Level 1',$,$,#130,$,'Level
1',.ELEMENT.,0.);

#137= IFCAXIS2PLACEMENT3D(#149,$,$);
#138= IFCLOCALPLACEMENT(#130,#137);
#149= IFCCARTESIANPOINT((-666.156914893617,51.3297872340438,-300.));
#151= IFCAXIS2PLACEMENT2D(#10,#30);
#152= IFCRECTANGLEPROFILEDEF(.AREA.,$,#151,3655.45212765957,5126.99468085106);
#153= IFCCARTESIANPOINT((2563.49734042553,1827.72606382979,300.));
#155= IFCAXIS2PLACEMENT3D(#153,#22,#14);
#156= IFCEXTRUDEDAREASOLID(#152,#155,#20,300.);
#157= IFCSHAPEREPRESENTATION(#101,'Body','SweptSolid',(#156));
#164= IFCPRODUCTDEFINITIONSHAPE($,$,(#157));
#169= IFCSLAB('3VZF4XhJLCk9xss5sKDsWS',#42,'Floor:Floor 1:2350',$,'Floor:Floor 1',#138,#164,'2350',.FLOOR.);
#184= IFCAXIS2PLACEMENT2D(#10,#24);
#185= IFCRECTANGLEPROFILEDEF(.AREA.,$,#184,400.,700.);
#186= IFCAXIS2PLACEMENT3D(#6,#22,#18);
#187= IFCEXTRUDEDAREASOLID(#185,#186,#20,300.);
#188= IFCSHAPEREPRESENTATION(#101,'Body','SweptSolid',(#187));
#190= IFCPRODUCTDEFINITIONSHAPE($,$,(#188));
#193= IFCCARTESIANPOINT((1118.88297872341,617.686170212766,300.));
#195= IFCAXIS2PLACEMENT3D(#193,$,$);
#196= IFCLOCALPLACEMENT(#138,#195);
#198= IFCOPENINGELEMENT('3VZF4XhJLCk9xss5sKDsWD',#42,'Floor:Floor 1:2350:2',$,'Opening',#196,#190,'2350',$);
#203= IFCRELVOIDSELEMENT('20RS6_Qqf70PtPc3awaE99',#42,$,$,#169,#198);
#206= IFCMATERIAL(' <Unnamed>',$,$);
#213= IFCMATERIALLAYER(#206,300.,$,$,$,$,$);
#215= IFCMATERIALLAYERSET((#213),'Floor:Floor 1',$);
#218= IFCMATERIALLAYERSETUSAGE(#215,.AXIS3.,.POSITIVE.,0.,$);
#220= IFCPROPERTYSINGLEVALUE('Reference',$,IFCIDENTIFIER('Floor 1'),$);
#228= IFCPROPERTYSINGLEVALUE('IsExternal',$,IFCBOOLEAN(.F.),$);
#229= IFCPROPERTYSINGLEVALUE('LoadBearing',$,IFCBOOLEAN(.T.),$);
#230=
IFCPROPERTYSET('3VZF4XhJLCk9xsqwQKDsWS',#42,'Pset_SlabCommon',$,(#220,#228,#229));
#240= IFCRELDEFINESBYPROPERTIES('25wiOJtFT4JxHvOILfKY9b',#42,$,$,(#169),#230);
#244= IFCCLASSIFICATION('http://www.csiorg.net/uniformat','1998',$,'Uniformat',$,$,$);
#247= IFCCARTESIANPOINT((1060.83776595745,3606.78191489363,0.));
#249= IFCAXIS2PLACEMENT3D(#247,$,$); #250= IFCLOCALPLACEMENT(#130,#249);
#251= IFCCARTESIANPOINT((3400.,0.));
#253= IFCPOLYLINE((#10,#251)); #255= IFCSHAPEREPRESENTATION(#99,'Axis','Curve2D',(#253));
#258= IFCCARTESIANPOINT((1700.,0.));
#260= IFCAXIS2PLACEMENT2D(#258,#26);
#261= IFCRECTANGLEPROFILEDEF(.AREA.,$,#260,3400.,200.);
#262= IFCAXIS2PLACEMENT3D(#6,$,$);
#263= IFCEXTRUDEDAREASOLID(#261,#262,#20,3000.00000000001);
#264= IFCCOLOURRGB($,0.498039215686275,0.498039215686275,0.498039215686275); #265=
IFCSURFACESTYLERENDERING(#264,0.,$,$,$,$,IFCNORMALISEDRATIOMEASURE(0.5),IFCSPECULAREXPONENT(64.),.NOTDEFINED.);
#266= IFCSURFACESTYLE('Default Wall',.BOTH.,(#265));
#268= IFCPRESENTATIONSTYLEASSIGNMENT((#266));
#270= IFCSTYLEDITEM(#263,(#268),$);
#273= IFCSHAPEREPRESENTATION(#101,'Body','SweptSolid',(#263));
#275= IFCPRODUCTDEFINITIONSHAPE($,$,(#255,#273));
#279= IFCWALLSTANDARDCASE('3VZF4XhJLCk9xss5sKDsY_',#42,'Basic Wall:Wall 1:2444',$,'Basic Wall:Wall 1:1557',#250,#275,'2444',.NOTDEFINED.);
#282= IFCCARTESIANPOINT((0.,0.));
#284= IFCAXIS2PLACEMENT2D(#282,#28);
#285= IFCRECTANGLEPROFILEDEF(.AREA.,$,#284,1300.,800.);

#286= IFCCARTESIANPOINT((787.271146997088,100.,1314.73619163782));
#288= IFCAXIS2PLACEMENT3D(#286,#18,#14);
#289= IFCEXTRUDEDAREASOLID(#285,#288,#20,200.);
#290= IFCSHAPEREPRESENTATION(#101,'Body','SweptSolid',(#289));
#292= IFCPRODUCTDEFINITIONSHAPE($,$,(#290));
#295= IFCAXIS2PLACEMENT3D(#6,$,$);
#296= IFCLOCALPLACEMENT(#250,#295);
#298= IFCOPENINGELEMENT('1g3wq6UwH5EvHMXFsekQES',#42,'Basic Wall:Wall 1:1557',$,'Opening',#296,#292,$,.OPENING.);
#301= IFCRELVOIDSELEMENT('1r2PVeYcL1v8qSHbSyXYCy',#42,$,$,#279,#298);
#304= IFCCARTESIANPOINT((5.40012479177676E-13,0.));
#306= IFCAXIS2PLACEMENT2D(#304,#28);
#307= IFCRECTANGLEPROFILEDEF(.AREA.,$,#306,1964.73619163781,675.979915109545);
#308= IFCCARTESIANPOINT((2475.56624188908,100.,982.368095818914));
#310= IFCAXIS2PLACEMENT3D(#308,#18,#12);
#311= IFCEXTRUDEDAREASOLID(#307,#310,#20,200.);
#312= IFCSHAPEREPRESENTATION(#101,'Body','SweptSolid',(#311));
#314= IFCPRODUCTDEFINITIONSHAPE($,$,(#312));
#317= IFCAXIS2PLACEMENT3D(#6,$,$);
#318= IFCLOCALPLACEMENT(#250,#317);
#319= IFCOPENINGELEMENT('1IhWYEGErDGxqwuQ$fA4bH',#42,'Basic Wall:Wall 1:1557',$,'Opening',#318,#314,$,.OPENING.);
#322= IFCRELVOIDSELEMENT('1SUrvP0nz7o9iEmPNY96aC',#42,$,$,#279,#319);
#324= IFCMATERIAL('Default Wall',$,$);
#325= IFCPRESENTATIONSTYLEASSIGNMENT((#266));
#327= IFCSTYLEDITEM($,(#325),$);
#329= IFCSTYLEDREPRESENTATION(#95,'Style','Material',(#327));
#332= IFCMATERIALDEFINITIONREPRESENTATION($,$,(#329),#324);
#336= IFCMATERIALLAYER(#324,200.,$,$,$,$,$);
#337= IFCMATERIALLAYERSET((#336),'Basic Wall:Wall 1',$);
#340= IFCMATERIALLAYERSETUSAGE(#337,.AXIS2.,.NEGATIVE.,100.,$);
#341= IFCWALLTYPE('3VZF4XhJLCk9xss5sKDsSd',#42,'Basic Wall:Wall 1',$,$,$,$,'1557',$,.NOTDEFINED.);
#344= IFCPROPERTYSINGLEVALUE('Reference',$,IFCIDENTIFIER('Wall 1'),$); #345= IFCPROPERTYSINGLEVALUE('LoadBearing',$,IFCBOOLEAN(.F.),$);
#346= IFCPROPERTYSINGLEVALUE('ExtendToStructure',$,IFCBOOLEAN(.F.),$);
#347= IFCPROPERTYSINGLEVALUE('IsExternal',$,IFCBOOLEAN(.T.),$);
#348= IFCPROPERTYSET('3VZF4XhJLCk9xsqw2KDsY_',#42,'Pset_WallCommon',$,(#344,#345,#346, #347));
#354= IFCRELDEFINESBYPROPERTIES('0bljfqW6PA_ObZaZaFHSGl',#42,$,$,(#279),#348);
#358= IFCCARTESIANPOINT((4360.83776595745,3506.78191489362,0.));
#360= IFCAXIS2PLACEMENT3D(#358,#20,#18);
#361= IFCLOCALPLACEMENT(#130,#360);
#362= IFCCARTESIANPOINT((3455.45212765958,-0.));
#364= IFCPOLYLINE((#10,#362));
#366= IFCSHAPEREPRESENTATION(#99,'Axis','Curve2D',(#364));
#368= IFCCARTESIANPOINT((1727.72606382979,-2.84217094304040E-14)); #370= IFCAXIS2PLACEMENT2D(#368,#26);
#371= IFCRECTANGLEPROFILEDEF(.AREA.,$,#370,3455.45212765958,200.);
#372= IFCAXIS2PLACEMENT3D(#6,$,$);
#373= IFCEXTRUDEDAREASOLID(#371,#372,#20,1200.);
#374= IFCSTYLEDITEM(#373,(#268),$);
#377= IFCSHAPEREPRESENTATION(#101,'Body','SweptSolid',(#373));
#379= IFCPRODUCTDEFINITIONSHAPE($,$,(#366,#377));
#383= IFCWALLSTANDARDCASE('3VZF4XhJLCk9xss5sKDsZ4',#42,'Basic Wall:Wall 1:2550',$,'Basic Wall:Wall 1:1557',#361,#379,'2550',.NOTDEFINED.);
#386= IFCMATERIALLAYERSETUSAGE(#337,.AXIS2.,.NEGATIVE.,100.,$); #387=

IFCPROPERTYSET('3VZF4XhJLCk9xsqw2KDsZ4',#42,'Pset_WallCommon',$,(#344,#345,#346, #347));
#389= IFCRELDEFINESBYPROPERTIES('20Kwzvp052MxLdwPh3RKcf',#42,$,$,(#383),#387);
#393= IFCCARTESIANPOINT((666.156914893616,-51.3297872340438,0.));
#395= IFCAXIS2PLACEMENT3D(#393,$,$);
#396= IFCLOCALPLACEMENT($,#395);
#397=
IFCSITE('3vB5XNXDb9EO$2rl$0o2xS',#42,'Default',$,'',#396,$,$,.ELEMENT.,(42,24,53 ,508911),(-71,-15,-29,-58837),0.,$,$);
#402= IFCPROPERTYSINGLEVALUE('AboveGround',$,IFCLOGICAL(.U.),$);
#403=
IFCPROPERTYSET('3VZF4XhJLCk9xsqx6KDsJ4',#42,'Pset_BuildingStoreyCommon',$,(#402));
#406= IFCRELDEFINESBYPROPERTIES('3KAUV_50v32wwPaY_SEt7c',#42,$,$,(#132),#403); #410=
IFCRELCONTAINEDINSPATIALSTRUCTURE('3VZF4XhJLCk9xss5oKDsJ4',#42,$,$,(#169,#279,#3 83),#132);
#416= IFCRELAGGREGATES('0fjhi53ODDv8FdQjKIE_EU',#42,$,$,#104,(#397));
#420= IFCRELAGGREGATES('1ZI9aVD2X6VQVriEallJ2O',#42,$,$,#397,(#119));
#424= IFCRELAGGREGATES('3VZF4XhJLCk9xss5wKDsGp',#42,$,$,#119,(#132));
#428= IFCPROPERTYSINGLEVALUE('Reference',$,IFCIDENTIFIER('Project Information'),$);
#429= IFCPROPERTYSINGLEVALUE('NumberOfStoreys',$,IFCINTEGER(1),$);
#430=
IFCPROPERTYSET('3VZF4XhJLCk9xsqxQKDsGp',#42,'Pset_BuildingCommon',$,(#428,#429)) ;
#434= IFCRELDEFINESBYPROPERTIES('3dBblRn1X6lPVQTFYOMQQF',#42,$,$,(#119),#430);
#438= IFCRELASSOCIATESMATERIAL('1A8velfQbCpxNIdBQinYM$',#42,$,$,(#169),#218);
#442= IFCRELASSOCIATESMATERIAL('2yirdjcEb5IeysFYYCnmuk',#42,$,$,(#279),#340);
#446= IFCRELASSOCIATESMATERIAL('0DYC5OmOn0IPI9CnfdcifL',#42,$,$,(#341),#337);
#450= IFCRELASSOCIATESMATERIAL('01IaOUjSjBdOGPp6WFMXkM',#42,$,$,(#383),#386); #454=
IFCRELDEFINESBYTYPE('3TMvWa3Nz30gh0KUO9s_z7',#42,$,$,(#279,#383),#341); #459=
IFCRELCONNECTSPATHELEMENTS('23Wpgmq3DDFxc7EGoccCQC',#42,'3VZF4XhJLCk9xss5sKDsY_|
3VZF4XhJLCk9xss5sKDsZ4','Structural',$,#279,#383,(),(),.ATSTART.,.ATEND.);
#464= IFCPRESENTATIONLAYERASSIGNMENT('A-FLOR-____-OTLN',$,(#157,#188),$); #468=
IFCPRESENTATIONLAYERASSIGNMENT('A-NPLT-____-OTLN',$,(#290,#312),$); #472=
IFCPRESENTATIONLAYERASSIGNMENT('A-WALL-____-OTLN',$,(#255,#273,#366,#377),$); ENDSEC;
END-ISO-10303-21;