Graduation report

Enabling construction companies to connect System Engineering, BIM and the Quality Assurance law

Written by:

ing. Nisam Shami 0974112

Graduation program MSc Construction Management and Engineering

Graduation committee:

prof.dr.ir. B. De Vries	*Eindhoven University of Technology (Chairman)*
ir. T. Krijnen	*Eindhoven University of Technology (First supervisor)*
dr. ir. S. van Nederveen	*Delft University of Technology (Second supervisor)*
ing. I. Schipper	*Hurks bouw & vastgoedontwikkeling (Company's advisor)*
ir. S. Kauffeld	*Hurks bouw & vastgoedontwikkeling (Company's advisor)*
ing. R. Lak	*Hurks bouw & vastgoedontwikkeling (Company's advisor)*

Organizations: *Eindhoven University of Technology, Hurks Bouw Eindhoven and Delft University of Technology*

Date of final presentation: *19 – 02 - 2018*

Table of contents

Summary (English)

The building industry is based on a collaboration environment. This requires repeated, iterative data exchanges and communication among different domains and applications in a high frequency. To automate information processing, standardized and qualified data is necessary for efficient working processes (Zhang, 2015). As the complexity level of the design and construction processes is increasing, traditional information medium such as paper-based documents cannot satisfy the required integrity, precision and timeliness (Zhang, 2015). The concept of Building Information Modeling (BIM), Systems Engineering (SE) and the Quality Assurance Law (QAL) are contribute to satisfy this. These concepts form the base elements for this graduation thesis.

The need for computerizing and automating the requirements checking is becoming more critical. Based on the problem area, this research outlines the next main research question:

> *"How can the validation and verification of requirements for construction works be visualized in phase 2 and 3 of the System Engineering process (definition/design/ development/implementation), based on open standards and software (visual programming)? And how can this be documented based on the Quality Assurance act?"*

At first, the relationship between Systems Engineering and BIM and the relationship of the Quality Assurance Law on SE and BIM is discussed. BIM is not just a technology change, but also a process change. By enabling a building to be represented by intelligent objects that carry detailed information about themselves and have links and relationships with other objects in the building model, BIM not only changes how building drawings and visualizations are created but also dramatically alters all the key processes involved in putting a building together (Eastman et al., 2011).

SE focusses on defining customer needs and requested functionality early in development, capturing the requirements, design synthesis and system validation (ProRail, 2015).

One of the first similarities between SE and BIM are the benefits which occur when applying these working methods. Both working methods aim for a better design, production quality, better customer service and access to lifecycle data. Another link between both working methods is the integral approach. Thereby, the phasing between the BIM and SE working method is also a link between the two approaches. Between the BIM and SE phases, a link can be generated by coupling each phase of the construction process to LODs. For both work methods, open standards have been created. These open standards ensure common agreements that enable information transfer (Krechmer, 2006).

A law only has value to the people of a society if its problem-solving benefit is greater than its costs and other burdens (Quality of Laws, 2017). The Quality Assurance law can easily be implemented within SE and BIM and the Quality Assurance law can be applied in Dutch construction with minimal costs and a cost saving of more than €100 million (Koning, 2016).

Due to the increasing complexity in construction, revision of the current quality assurance system is necessary.

Based on open standards (IFC and SE exchange standard), visual programming and the four classes of functionality a requirement checking system should support from Eastman (2009) a data integration platform is developed to connect BIM, SE and the QAL.

To use the tool, the first step that needs to be taken is the generation and extraction of data from the original IFC and SE file. Important is to take into account the certain import settings within the tool. After adding information in the widgets "Assignee" and "Evidence", The added and uploaded information can be managed in the widget "Mange requirements". The user can also can view information in the widget "Projectdetails" and "How-to?".

After conducting the research, it can be concluded that by developing a data integration platform is developed which connects BIM, SE and the QAL. A low-threshold, easy to use tool is developed.

The tool should be further developed in the future. Firstly, a limitation of the tool is limited use of valuable data in an IFC-file. In addition, an opportunity for development the tool is to make the generic tool more specific for use.

The tool and research are interesting for contracting/construction companies, clients, project developers, software developers and SE and BIM experts.

Summary (Dutch)

De bouwsector is gebaseerd op een samenwerkingsomgeving. Dit vereist herhaalde, iteratieve gegevensuitwisseling en communicatie tussen verschillende domeinen en applicaties in een hoge frequentie. Voor het automatiseren van informatieverwerking zijn gestandaardiseerde en gekwalificeerde gegevens nodig voor efficiënte werkprocessen (Zhang, 2015). Naarmate het complexiteitsniveau van het ontwerp- en bouwproces toeneemt, kan traditioneel informatiemedium zoals papieren documenten niet voldoen aan de vereiste integriteit, precisie en snelheid (Zhang, 2015). Het concept van Building Information Modeling (BIM), Systems Engineering (SE) en de wet kwaliteitsborging kunnen hieraan bijdragen. Deze concepten vormen de basiselementen voor deze afstudeerscriptie.

De behoefte aan computerisering en automatisering van de controle van de eisen wordt steeds groter. Op basis van het probleemgebied schetst dit onderzoek de volgende hoofdonderzoeksvraag:

> *"Hoe kan de validatie en verificatie van eisen voor bouwwerken worden gevisualiseerd in fase 2 en 3 van het System Engineering-proces (definitie/ontwerp/ontwikkeling/implementatie), op basis van open standaarden en software (visuele prograpmmering)? En hoe kan dit worden gedocumenteerd op basis van de wet kwaliteitsborging? "*

Allereerst wordt de relatie tussen Systems Engineering en BIM en de relatie tussen de wet kwaliteitsborging op SE en BIM onderzocht. BIM is niet alleen een technologische verandering, maar ook een procesverandering. Door een gebouw weer te geven door intelligente objecten die gedetailleerde informatie over zichzelf bevatten en koppelingen en relaties hebben met andere objecten in het bouwmodel bevatten, verandert BIM niet alleen de manier waarop bouwtekeningen en visualisaties worden gemaakt, maar verandert het ook dramatisch alle belangrijke processen die betrokken zijn bij een gebouw samenstellen (Eastman et al., 2011).

SE richt zich vroeg in ontwikkeling fase op het definiëren van klantbehoeften, het vastleggen van de eisen, ontwerpsynthese en systeemvalidatie (ProRail, 2015).

Een van de eerste overeenkomsten tussen SE en BIM heeft betrekking op de voordelen die zich voordoen bij de toepassing van deze werkmethoden. Beide werkmethoden zijn gericht op een beter ontwerp, betere productiekwaliteit, betere klantenservice en toegang tot levenscyclusdata. Een andere link tussen beide werkmethoden is de integrale aanpak. Daarbij is de fasering tussen de BIM en de SE-werkmethode ook een koppeling tussen de twee benaderingen. Tussen de BIM en SE-fasen kan een koppeling worden gegenereerd door elke fase van het bouwproces aan LOD's te koppelen. Voor beide werkmethoden zijn open standaarden gecreëerd. Deze open standaarden zorgen voor informatieoverdracht door middel van gemeenschappelijke afspraken (Krechmer, 2006).

Een wet heeft alleen waarde voor de mensen van een samenleving als het probleemoplossend vermogen ervan groter is dan de kosten en andere lasten (Quality of Laws, 2017). De wet kwaliteitsborging kan eenvoudig worden geïmplementeerd binnen SE

en BIM en kan worden toegepast in de Nederlandse bouw met minimale kosten en een kostenbesparing van meer dan € 100 miljoen (Koning, 2016).

Vanwege de toenemende complexiteit in de bouw is een herziening van het huidige kwaliteitsborgingssysteem noodzakelijk.

Op basis van open standaarden (IFC en SE-uitwisselingsstandaard), visual programming en de vier klassen van functionaliteit vanuit Eastman (2009), is een data-integratieplatform ontwikkeld gebaseerd op BIM, SE en de wet kwaliteitsborging.

Om de tool te gebruiken, is de eerste stap die moet worden gezet, het genereren van data van de originele IFC en SE-bestanden. Belangrijk is om rekening te houden met de bepaalde importinstellingen binnen de tool. Na het toevoegen van informatie in de widgets "Assignee" en "Evidence", kunnen de toegevoegde en geüploade informatie worden beheerd in de widget "Manage Requirements". De gebruiker kan ook informatie bekijken in de widget "Projectdetails" en "How-to?".

Na het uitvoeren van het onderzoek kan worden geconcludeerd dat door het ontwikkelen van een data-integratieplatform is ontwikkeld dat BIM, SE en de QAL met elkaar verbindt. Er is een laagdrempelig en eenvoudig te gebruiken tool ontwikkeld.

De tool moet in de toekomst verder worden ontwikkeld. Ten eerste zou de tool meer waardevolle informatie uit een IFC-bestand moeten gebruiken. Bovendien is het mogelijk om de generieke tool specifieker te maken voor gebruik. Het is mogelijk om microflows te maken voor eisen die vaak voorkomen.

De tool en het onderzoek zijn interessant voor contract en constructiebedrijven, klanten, projectontwikkelaars, softwareontwikkelaars en SE- en BIM-experts.

Abstract

The building industry is based on a collaboration environment. This requires repeated, iterative data exchanges and communication among different domains and applications in a high frequency. To automate information processing, standardized and qualified data is necessary for efficient working processes (Zhang, 2015). As the complexity level of the design and construction processes is increasing, traditional information medium such as paper-based documents cannot satisfy the required integrity, precision and timeliness (Zhang, 2015). The concept of Building Information Modeling (BIM), Systems Engineering (SE) and the Quality Assurance Law (QAL) are contribute to achieve this. These concepts form the base elements for this graduation thesis.

The need for computerizing and automating the requirements checking is becoming more critical. Based on the problem area, this research outlines the next main research question:

> *"How can the validation and verification of requirements for construction works be visualized in phase 2 and 3 of the System Engineering process (definition/design/ development/implementation), based on open standards and software (visual programming)? And how can this be documented based on the Quality Assurance act?"*

Based on open standards (IFC and SE exchange standard), visual programming and the four classes of functionality a requirement checking system should support from Eastman (2009) a data integration platform is developed to connect BIM, SE and the QAL.

The tool should be further developed in the future. Firstly, a limitation of the tool is limited use of valuable data in an IFC-file. In addition, an opportunity for development the tool is to make the generic tool more specific for use.

Preface

This graduation report is carried out in collaboration with the University of Technology Eindhoven and the company Hurks Bouw en vastgoedontwikkeling Eindhoven. This graduation research forms the last part of the master Construction Management and Engineering (CME). The whole research was a very learning and challenging proses. During this graduation research I learnt a lot about the promising field of the AEC industry.

I would like to thank Hurks Bouw en vastgoedontwikkeling for all the cooperation they have provided and would especially like to thank Inge Schipper.

I would like to thank my whole graduation committee and especially Thomas Krijnen for the feedback sessions every 2 weeks.

Last but not least, I would like to thank my family and friends for listening to my achievements, difficulties and progress during my graduation proses.

List of Abbreviations

API	Application programming interface
BDS	Building Description Systems
BIM	Building Information Modeling
BIR	Bouw Informatie Raad
DBF(M)(O)	Design Build Finance Maintain Operate
HpaPaaS	High Productivity Application Platform as a Service
IFC	Industry Foundation Classes
liS	Internet Information Server
INCOSE	The International Council on Systems Engineering
IPD	Integrated Project Delivery
IPM	Integrated project management
LOD	Level of development
OWL	Web Ontology Language
SE	Systems Engineering
QAL	Quality Assurance Law
QC	Quality control
QM	Quality management
XML	Extensible Markup Language

List of Figures

List of Tables

1. Introduction
The building industry is based on a collaboration environment. This requires repeated, iterative data exchanges and communication among different domains and applications in a high frequency. To automate information processing, standardized and qualified data is necessary for efficient working processes (Zhang, 2015). As the complexity level of the design and construction processes is increasing, traditional information medium such as paper-based documents cannot satisfy the required integrity, precision and timeliness (Zhang, 2015). The concept of Building Information Modeling (BIM), Systems Engineering (SE) and the Quality Assurance Law (QAL) are contribute to achieve this. These concepts form the base elements for this graduation thesis.

Building Information Modeling (BIM) as a methodology is becoming more common practice within the AEC (architecture, engineering, construction)-industry, models become more complex and detailed. It is no longer practical for users to ensure the models are of good quality and adhere to requirements. Therefore, it calls for an urgent need to define robust and rigorous test criteria, processes and tools (Solihin, 2015).

Systems Engineering (SE) as a methodology focusing on producing a successful facility that meets requirements and development objectives, is successful in its operation and achieves its desired operating life. SE differs from traditional disciplines in that it is focused on the system as a whole, it is concerned with customer needs and operational environment, it leads system conceptual design and it bridges traditional engineering disciplines and gaps between specialties (Kossiakoff, 2011).

The implementation of an automate information processing, standardized and qualified data forms an interesting topic for graduation. According to the theory, the advantages of applying BIM and SE is huge. But on the other hand, there is resistant against the implementation of BIM and SE. The gap between theory and practice form an interesting topic to research.

This graduation project intends to address the topics within an organization. This work is carried out with the support of the company Hurks Bouw en Vastgoedontwikkeling.

1.1 Problem definition
Construction projects are becoming increasingly complex and customers are demanding more, but there are concerns about the poor performance of the construction industry (Koutsos, 2016; Barlow, 2000). This results in more extensive forms of contracting that move liabilities into the contracting organizations. In addition to the contract forms, the law will also contribute to the shift of liabilities into the contracting organizations. The Quality Assurance Law (QAL) indicates that when the construction work is completed, the contractor must demonstrate the regulations have been met (Eerste Kamer der Staten-Generaal, 2017).

The construction of a new Food Technology Center in Dinteloord, Royal Cosun, is an example of a project with an extensive form of contracting that move the liability towards the contracting organization. The combination Hurks-Imtech has executed the project based on a Design, Build & Maintain contract. The contract represents a value of more than

€15.000.000, - for engineering and construction. Hurks Bouw en Vastgoedontwikkeling will also be responsible for fifteen years of maintenance (Hurks, 2017).

The new construction project did not provide the desired collaboration for both the client and the contractor. This project has not fulfilled its objectives and expectations, for several reasons:

- Little review on the requirement and requirements from the customer on the design and construction of the building. The requirements from the customer were not translated into measurable requirements.
- During the project two parallel processes were present. Two parallel processes on construction of the building and the System Engineering. System Engineering even happened afterwards.
- The contractor had little experience with extensive form of contracting. As a result, processes were based on a traditional contract form.

In these extensive collaboration forms, such as DBF(M)(O), the client/user is looking for a partner who can design, implement and operate an integral plan. Through collaboration between the client and the contractor, a client's project requirements can be achieved and this generates more added value compared to traditional construction projects.

A solution to this problem is a tool based on the concept of Building Information Modeling, Systems Engineering and the Quality Assurance Law.

1.2 Scope

The main subject of the thesis is a tool based on BIM, SE and the QAL, within this subject the thesis is focused on the exchange of data. The focus lies on the validation and verification of requirements.

The research is conducted at the construction department of the company Hurks Bouw en vastgoedontwikkeling Eindhoven. The used data is from the project Royal Cosun.

1.3 Research questions

The need for computerizing and automating information processing is necessary for efficient working processes and becoming more critical. Based on the problem definition and the scope, this section outlines the research questions of the proposed research. The main research question is:

> *"How can the validation and verification of requirements for construction works be visualized in phase 2 and 3 of the System Engineering process (definition/design/ development/implementation), based on open standards and software (visual programming)? And how can this be documented based on the Quality Assurance act?"*

A few sub questions are developed to support the main research question. The sub-questions are categorized in 3 sections: SE/BIM development phases, Information completeness (contract requirements) and application development (Data & Coding).
SE/BIM development phases:

1. What core concepts can be identified for BIM and SE? (workflow, stakeholders, relationships)
2. Which design phases can be identified in a BIM process and in which way this corresponds to the SE process?
3. What is the effect of the quality assurance law on the relationship between BIM and SE?

It is essential to generate background information on the related topics. Sub-questions 1 till 3 will provide background information on the related topics.

Information completeness (contract requirements):

4. How should the requirements be organized so that they can be automatically tested?
5. How should the information completeness of a building information model be verified?
6. What are the existing methods to verify the information completeness of a BIM?

At the current state it is not possible to provide an answer to the main research question. For this reason, sub-questions 4 till 6 will provide information on the current available tools in de market and a provide a base for the design and development of the final validation tool.

Application development (Data & Coding):

7. How can the project's requirements be verified based on BIM, SE and the QAL?
8. How can the project's requirements be presented based on BIM, SE and the QAL?

The main research question and sub questions lead to three final products:

1. A tool which connects BIM, SE and the QAL
2. Instructions on how to use the tool
3. Recommendations for further developing the tool

1.4 Research design

The aim of this graduation research is to find an answer to the research question. In order to answer the main and sub questions, this thesis is divided into an introduction, four chapters literature study, a chapter method and results and finally a conclusion. This research design is explained below and shown in Figure 1.

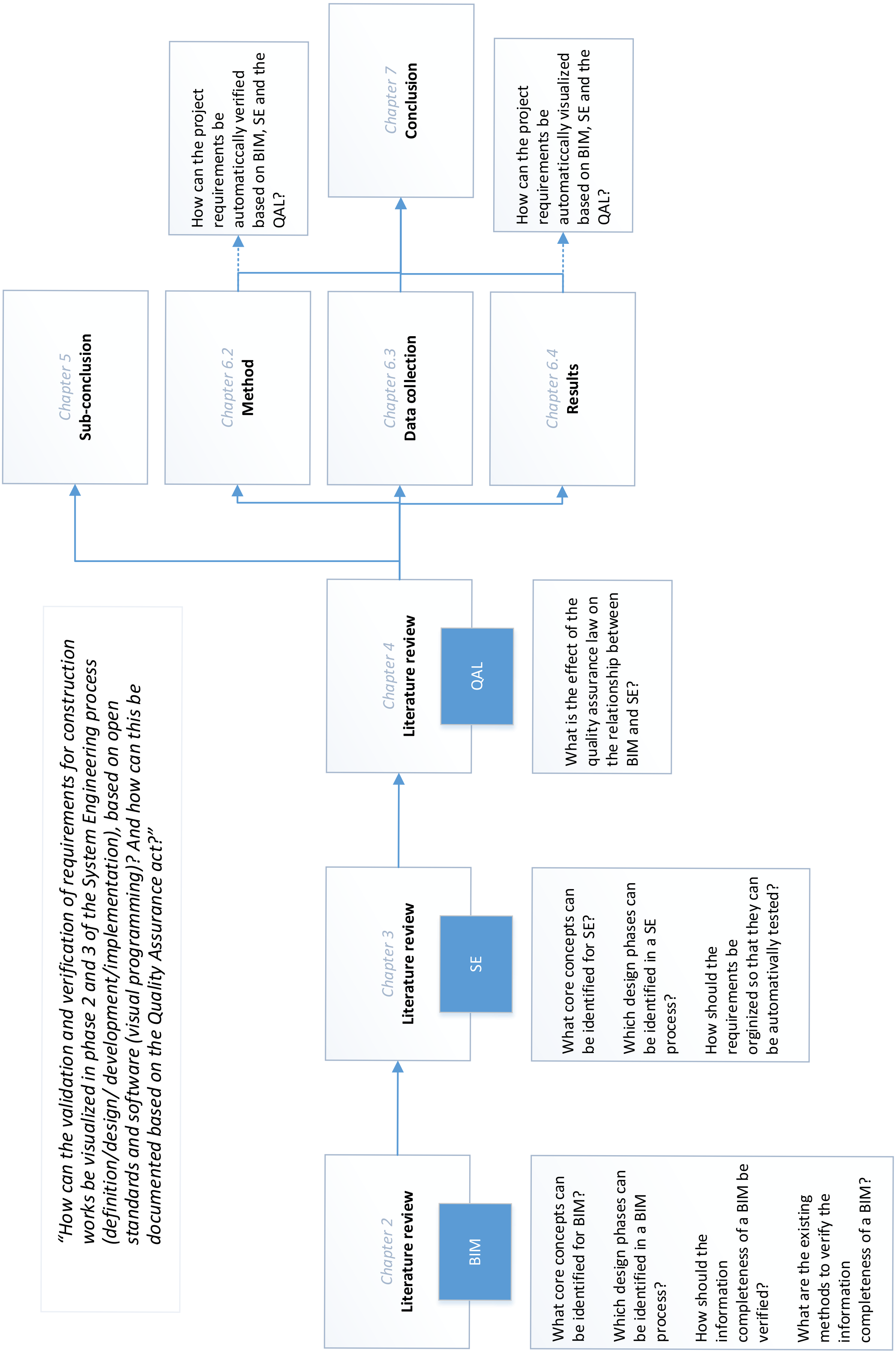


Figure 1: Research model

The first part of the research is about collecting information on the topics BIM, SE, and the QAL. The aim is to answer, with state-of-the-art literature, sub question 1 till 6. This data is required to answer the main question. Based on the findings and outcomes of the literature study, the tool will be developed. The literature study will clarify the core concepts of the related topics, the open standards of BIM and SE, the influence of the related topics on each other and the data exchange within BIM and SE.

Sub-questions 1, 2 and 3 are about Systems Engineering, Building Information Model and the quality assurance law. Sub-questions 4, 5 and 6 and used to complete the literature study and have enough information to design (sub-question 7) and develop (sub-question 8) the end-product.

1.4 The scientific importance

This research will be an added value for both academic and practical purposes. Connecting BIM and SE into a model checker has been carried out more often (Weerink, 2016) (Nieman, 2016), but this has not yet resulted in an easy-to-use outcome for practice which is based on BIM, SE and the QAL. The outcome of this report ensures construction companies to connect System Engineering, BIM and the Quality Assurance Law.

1.5 Expected results

This graduation thesis aims to develop a tool to connect BIM, SE and the QAL. In the second till fifth chapters (literature review) more insight is given about the key concepts of the related topics. Chapter six is an interesting chapter since more insight is gained about the available tools. Chapter six will also provide the design and development of the tool. Since I personally lack programming skills, the development of a tool will be challenging but also very informative.

The main research question and sub questions lead to three final products:

1. A tool which connects BIM, SE and the QAL
2. Instructions on how to use the tool
3. Recommendations for further developing the tool

1.6 Reading guide

Chapter 1 presents the cause of the problem and chapter 2, 3 and 4 discusses the relevant literature about BIM, Systems Engineering and the quality assurance law. Chapter 5 provides the conclusion of the literature study of chapter 2, 3 and 4. In chapter 6 the methodology is explained to generate the tool. Chapter 7 provides an overall conclusion of this thesis.

Introduction literature review

This literature review serves as a starting point for the graduation thesis. The problem and approach have been discussed in phase one, a literature study is performed in this second phase. A literature study is necessary in order to obtain sufficient knowledge about the research related topics: BIM, System Engineering and the new Quality Assurance law. The literature review aims to give understanding to the relationship between BIM and System Engineering as shown in Figure 2 relationship 1 and the effect of the new Quality Assurance law on the relationship between BIM and System Engineering as shown in Figure 2 relationship 2.

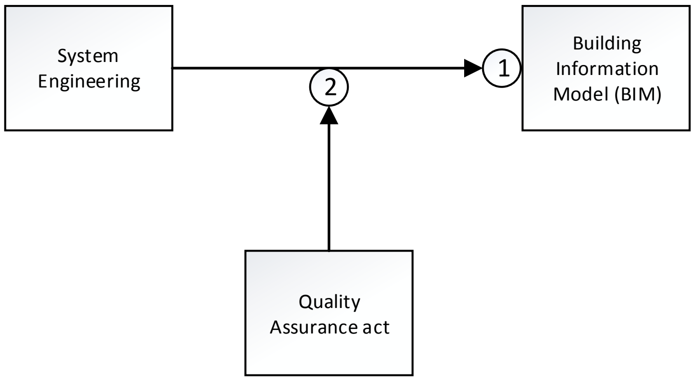


Figure 2: Conceptual model related topics

The literature review aims at the contemporary literature, but also will look back at the past to understand where it initially came from. The literature review elaborates on state-of-the-art advantages, workflow, implementation, standardization and methodology standards of BIM. Subsequently, the literature review focusses on the definition and the application of System Engineering in the construction sector. Finally, the literature review presents insight on the new Quality Assurance law. The literature study will be concluded with a conclusion explaining the relationships between the related topics.

2 BIM

Construction projects, particularly megaprojects, are becoming significantly complex and difficult to manage (Bryde, 2013). The rising interest in BIM can be seen in conjunction with new project management frameworks, such as Integrated Project Delivery (IPD), which increases the need for closer collaboration and more effective communication (Bryde, 2013). To cope with the increasing complexity and difficulty of project management, BIM has been developing at a rapid pace and becoming extensively utilized (He, 2017).

The National Building Information Model Standard Project Committee defines BIM as:

"Building Information Modeling (BIM) is a digital representation of physical and functional characteristics of a facility. A BIM is a shared knowledge resource for information about a facility forming a reliable basis for decisions during its life-cycle; defined as existing from earliest conception to demolition".

This definition claims that BIM is not just a product/3D model, but also a digital representation of the actual building with elements containing information about its geometry, material type, costs, maintenance, fire resistance, location and so on.

The aim of this chapter is to provide answer to the first sub questions. In this chapter, the following sub questions are addressed:

- What core concepts can be identified for BIM?
- Which design and development phases can be identified in a BIM process?

Goal of these sub questions is to get more insight about BIM. The literature review starts with an introduction to BIM with the general explanation of BIM. It is continued by the advantages and challenges of the working method BIM. Subsequently it is followed up by a section about the workflow in BIM. Furthermore, the standardization within the working method BIM is discussed. At the end of this chapter a section is provided in about the requirement management in a BIM. The chapter serves to answer the sub-conclusion on BIM, as input for the 3.5 and for chapter 5 for the conclusion on the related topics.

2.1 Introduction to BIM

BIM is originated from Professor Charles Eastman at the Georgia Tech School of Architecture in late 1970. During the late 1970s, Eastman claimed that drawings for construction were inefficient due to its limitation to visualize the buildings, as well as the drawings, were not updated. Therefore, there were several organizations in the USA and Finland which had developed a computer program using ICT to solve those problems (Latiffi, 2014).

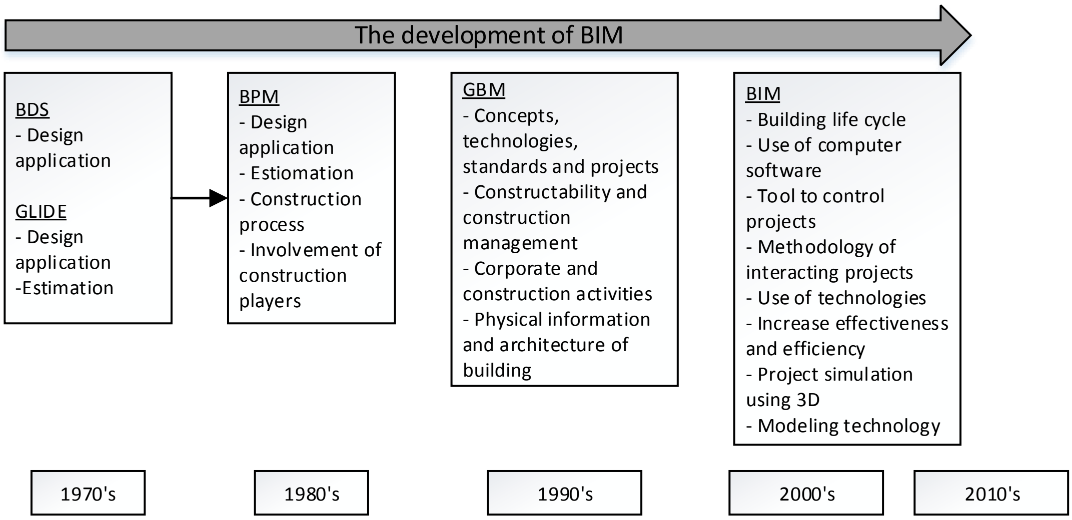


Figure 3: The Development of BIM from 1975 to 2013 (adapted from: Latiffi, 2014)

Figure 3 shows how the development of BIM has been expanded from 1975 to 2013. In 1975, Building Description Systems (BDS) had been introduced by Professor Charles Eastman for easier coordination during design development (Latiffi, 2014). The developments of GLIDE, BPM, and GBM have contributed to the development of BIM. In 2006, BIM was defined as a new methodology to manage and increase the AEC performance in completing and managing the projects. In the beginning, BIM was adapted as a project simulation that consisted of 3D-model of a project component. After 2008, BIM had been enlarged as a technology revolution that helped to transform the way buildings were conceived, designed, constructed as well as operated (Hardin, 2015).

2.2 Advantages and challenges of BIM

BIM is one of the most promising developments in the AEC industries. BIM is not just a technology change, but also a process change. By enabling a building to be represented by intelligent objects that carry detailed information about themselves and have links and relationships with other objects in the building model, BIM not only changes how building drawings and visualizations are created but also dramatically alters all the key processes involved in putting a building together (Eastman et al., 2011). BIM can support and improve many business practices. Significant improvements have already been realized in the AEC-sector (He, 2017). Below is the scope of changes that can be expected as BIM develops in an organization listed;

- Accurate and complete data ready for use when building completed, lowers data capture and operate and maintenance costs (Teicholz, 2013) (Eastman et al., 2011)

- Controlled whole-life costs and environmental data: Environmental performance is more predictable, and lifecycle costs are better understood (Azhar, 2011) (Eastman et al, 2011)
- Bridges the information gap between the A/E/C and owner (Teicholz, 2013)
- Improved collaboration (Eastman et al., 2011)
- More complete and accessible data allows faster analysis and correction of problems and fewer breakdowns (Teicholz, 2013)
- Faster and more effective processes: Information is more easily shared and can be value-added and reused (Azhar, 2011) (Bryde, 2013) (sbrcurnet, 2017) (Eastman et al., 2011)
- Better design: Building proposals can be rigorously analyzed, simulations performed quickly, and performance benchmarked, enabling improved and innovative solutions (Azhar, 2011) (Eastman et al., 2011)
- Better production quality: Documentation output is flexible and exploits automation (Azhar, 2011) (Eastman et al., 2011)
- Automated assembly: Digital product data can be exploited in downstream processes and used for manufacturing and assembly of structural systems (Azhar, 2011)
- Better customer service: Proposals are better understood through accurate visualization (Azhar, 2011) (Eastman et al., 2011)
- Lifecycle data: Requirements, design, construction, and operational information can be used in facilities management (Azhar, 2011) (Eastman et al., 2011)
- Accurate geometrical representation of the parts of a building in an integrated data environment (Azhar, 2011)
- Creating more sustainable communities/energy efficiency (Eadie, 2013) (Bryde, 2013) (Eastman et al., 2011)

BIM will also cause significant changes in relationships of project participants and the contractual agreements between them (Eastman et al., 2011). The challenges that can be expected as BIM develops in an organization are listed below;

- Lack of determination of ownership of the BIM data and the need to protect it through copyright laws and other legal channels (Azhar, 2011) (Bryde, 2013).
- The integrated concept of BIM blurs the level of responsibility so much that risk and liability are likely to be enhanced (Azhar, 2011) (Bryde, 2013).
- As the dimensions of cost and schedule are layered onto the building information model, responsibility for the proper technological interface among various programs becomes an issue (Azhar, 2011) (Bryde, 2013) (Eastman et al., 2011).
- High initial investment costs (Migilinskas, 2013) (Bryde, 2013)
- The time to learn how to use the software (related to people) (Migilinskas, 2013) (Bryde, 2013) (sbrcurnet, 2017)

2.3 Workflow BIM

BIM moves the AEC-sector forward from current task automation of project and paper-centric processes toward an integrated and interoperable workflow where these tasks are collapsed into a coordinated and collaborative process with that maximize computing capabilities (Eastman et al., 2011). Thus, BIM requires a different way of collaboration between stakeholders. Collaboration on construction projects is closely linked with communications and seamless information exchange among stakeholders. Computer-based collaboration has become the norm for contemporary construction projects where team members are scattered across several locations but use shared databases (Oraee, 2017). Figure 4 shows the BIM collaboration form and exchange of information compared to the traditional collaboration form. In the traditional collaboration form, information is exchanged between two team members. Whereas in the BIM collaboration form, information is stored, accessed and adjusted in a data environment. Each discipline outputs its own aspect model. The aspect models together form a BIM model.

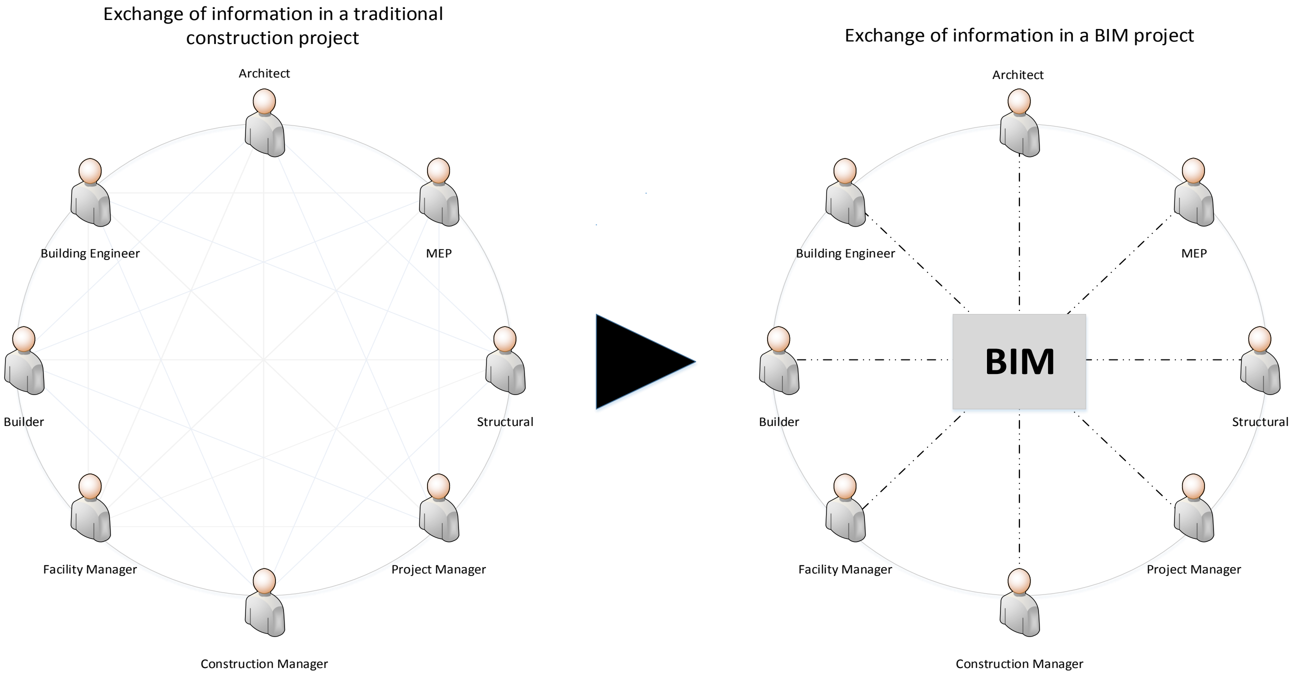


Figure 4: Traditional Approach vs BIM Approach (adapted from: IPC voor architecten, 2012)

In the traditional approach of exchanging information and communication, the process remains fragmented, and it depends on paper-based modes of communication. Errors and omissions in paper documents often cause unanticipated field costs and delays. One of the most common problems associated with a traditional approach of communication during the design phase is the considerable time and expense required to generate critical assessment information about a proposed design, including cost estimates, energy-use analysis and structural details. These analyses are normally done last when it is already too late to make important changes (Eastman et al., 2011).

The effort curve of line 4 in Figure 5 is shifting to the left to have a higher ability to control costs and performance in an earlier phase where the cost changes in the design are lower. The added value of BIM is clearly represented in the workflow, by making design changes in the early phases of a project, with less documentation.

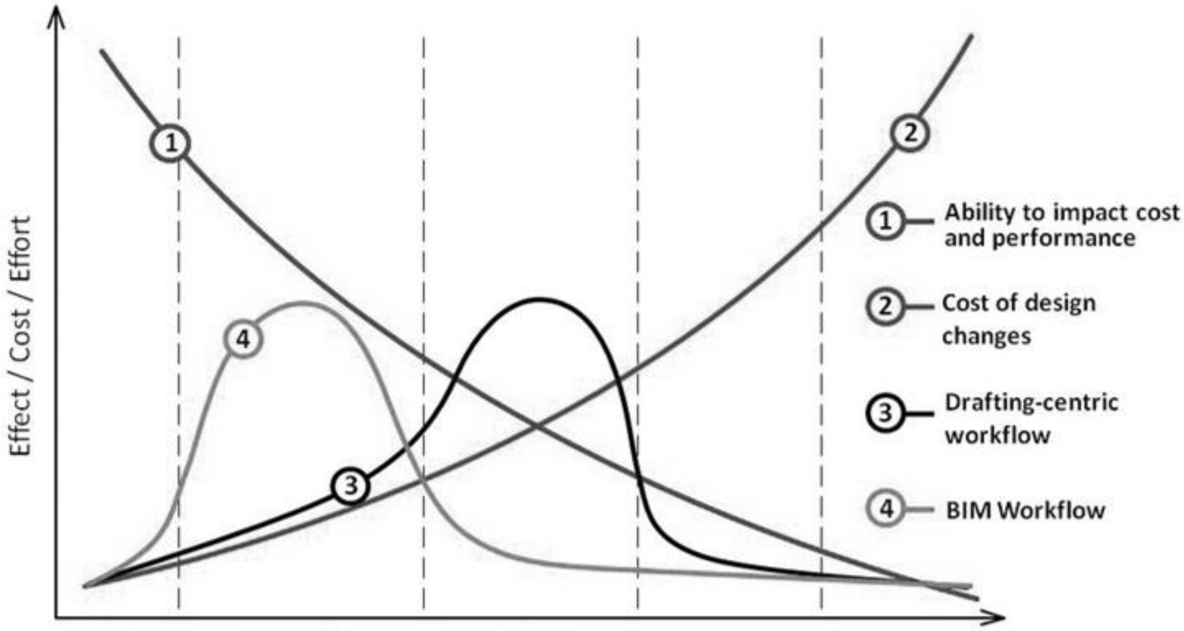


Figure 5: Macleamy curve traditional approach (line 3) vs BIM workflow (line 4) (Lu, 2014)

Various governments and companies recognize the benefits of BIM. For instance, Rijkwaterstaat where BIM is used in all the new design, build, finance and maintain projects (DBFM). The BIM program provides for the development and deployment of BIM within Rijkswaterstaat. It provides software tools, standards, models, testing, training and guidance for BIM in the form of manuals and tools (Rijkswaterstaat, 2017). Another example is Rijksgvastgoedbedrijf where BIM is used for current, relevant and reliable information to have sustainable, reliable information about the building stock (Rijksvastgoedbedrijf, 2017). In business collectives, like the “IPC voor Architecten”, are written. They have specified the level of detail (LOD) for each BIM phase (IPC voor architecten, 2012).

Level of detail	Phase	LOD Definitions
LOD 000	Demand specification	The Model Element may be graphically represented in the Model with a symbol or other generic representation, but does not satisfy the requirements for LOD 100. Information related to the Model Element (i.e. cost per square foot, tonnage of HVAC, etc.) can be derived from other Model Elements.
LOD 100	Demand specification and Functional design	The Model Element is graphically represented within the Model as a generic system, object, or assembly with approximate quantities, size, shape, location, and orientation.
LOD 200	Functional design	The Model Element is graphically represented within the Model as a specific system, object or assembly in terms of quantity, size, shape, location, and orientation.

LOD 300	Final design	The Model Element is graphically represented within the Model as a specific system, object, or assembly in terms of quantity, size, shape, location, orientation, and interfaces with other building systems.
LOD 400	Technical specification	The Model Element is graphically represented within the Model as a specific system, object or assembly in terms of size, shape, location, quantity, and orientation with detailing, fabrication, assembly, and installation information.
LOD 500	Delivery / use building	The Model Element is a field verified representation in terms of size, shape, location, quantity, and orientation.

Table 1: Phases and definitions of the Levels of Development – LOD's (IPC voor architecten, 2012) (BIMForum, 2016)

The level of development shows the progress in the design phase completion, Figure 6 shows a visualization of this progress.

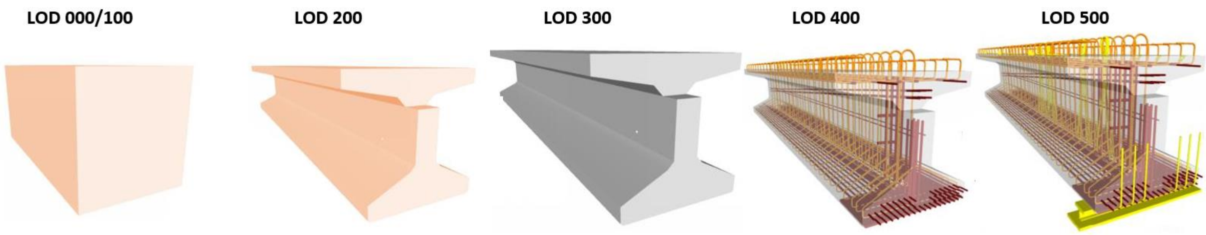


Figure 6: Example of Level of Development (adapted from: BIMForum, 2016)

2.4 Open standards

Historically, open standards have been the result of an agreement between technology suppliers, customers and regulatory authorities at a national or international level (Damiani, 2009). Open standers represent common agreements that enable information transfer (Krechmer, 2006). The emergence of open standards has been crucial to ensuring interoperability among different brands of software products or services.

All the basic standards according to BuildingSMART are shown in Table 2. Below all the standards are explained.

Name	Standard	Definition
IFC	ISO 16739	Transport data
IFD	ISO 12006-3	Mapping of terms
IDM	ISO 29481-1 ISO 29481-2	Describes processes
MVD	BuildingSMART MVD	Translated processes in exchange technical requirements

Table 2: The Basic Standards according to BuildingSMART (BuildingSMART, 2017)

IFC Industry Foundation Classes

IFC is a Data Standard developed and maintained by the buildingSMART organization (buildingsmart, 2017). IFC is the most widely spread ISO certified building component library in the building industry (Heidari, 2014) and can be used for the whole lifecycle management of a building project (Qin, 2011). IFC is used for data sharing in the construction and facility management industries (Galiano-Garrigos, 2017). BuildingSMART has developed a common data schema (IFC) that makes it possible to hold and exchange relevant data between different software applications.

IDM Information Delivery Manual

BuildingSMART processes (IDMs), see Figure 7, capture business process whilst at the same time providing detailed specifications of the information that a user fulfilling a particular role would need to provide at a particular point within a project. IDMs also propose a set of modular model functions that can be reused in the development of support for further user requirements (BuildingSMART, 2017). IDM is used as a framework, methodology and format (Galiano-Garrigos, 2017). IDM can be used to focus on the check of information in the model compared to a requirement (Hjelseth, 2010).

MVD Model View Definition

Model View Definitions (MVDs) define the subset of the IFC data model that is necessary to support the specific data exchange requirements of the AEC industry during the life-cycle of a construction project. A Model View Definition provides implementation guidance (or implementation agreements) for all IFC concepts (classes, attributes, relationships, property sets, quantity definitions, etc.) used within a particular subset. It thereby represents the software requirement specification for the implementation of an IFC interface to satisfy the exchange requirements (BuildingSMART, 2017).

IFD International Framework for Dictionaries

The Data Dictionary is one of the core components of the buildingSMART technology. The bSDD is a reference library based on the IFD standard and intended to support improved interoperability in the building and construction industry (BuildingSMART, 2017). IFD also organize information about construction work and is a framework for object-oriented information (Galiano-Garrigos, 2017). IFD is classification concept based on relevant products is mapped against a concept, e.g. a door. This concept, generic door, has attributes which make it possible to match this against real products (Hjelseth, 2010)

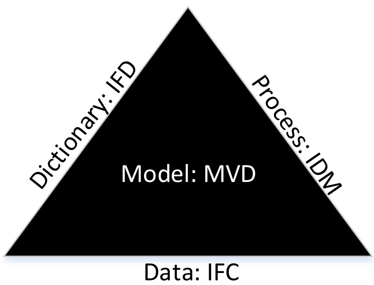


Figure 7: Basic methodology standards (adapted from: BuildingSMART, 2017)

2.5 Requirements management in BIM

Rule checking has been identified as potentially providing significant value to the AEC industry from both regulatory and industry perspectives (Solihin & Eastman, 2015). Model and requirements checking in BIM is normally done by use of standalone applications as Solibri Model Checker, SMARTcodes, ePlanCheck, AEC3 Compliance or EDM Model Server (Hjelseth, 2010). Each model checking concepts is based on its intentions. All concepts are based on an ontological foundation with a four-level taxonomy consisting of *Intention – Result – Rule set – Type of products*, illustrated in Figure 8 below.

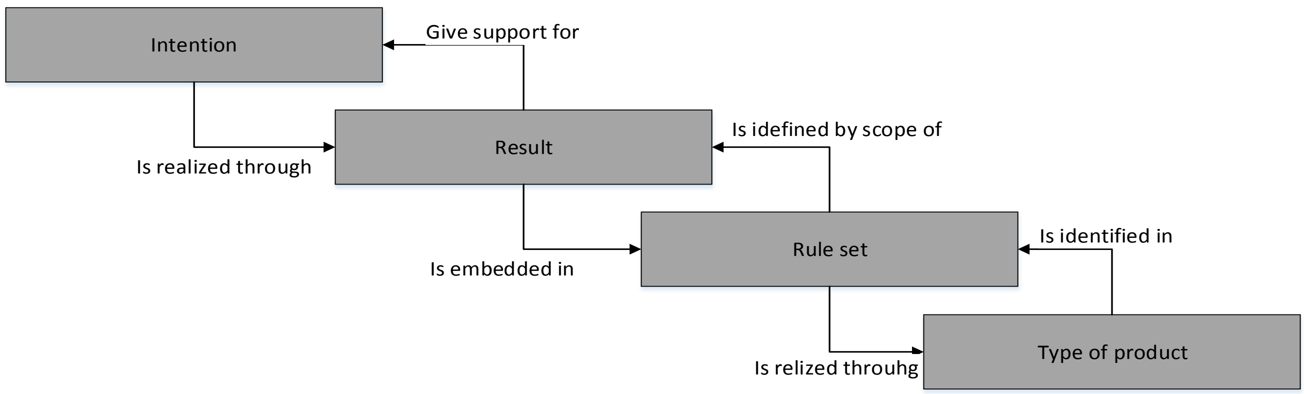


Figure 8: Ontology of model checking concepts (adapted from: Hjelseth, 2010)

Eastman (2009) suggested that besides building regulatory code-checking, more specialized types of rule checking such as client's requirements and requirements for specific building types are also emerging. In general, the scope of the rules falls into the following categories:

1. Checks for well-formedness of a building model
2. Building regulatory code checking

3. Specific client
4. Constructability and other contractor requirements
5. Safety and other rules with possible programmed corrective actions
6. Warrantee approvals
7. BIM data completeness for handover to the facilities management

Galiano-Garrigos (2017) conducted a study on that focusses on the degree of the automatic processing of digital rulesets. The outcome identified that 34% of requirements could be automatically checked, 13% partly checked automatically/manually, and 34% checked manually, whereas 19% of the requirements were not implemented as digital rules at all. This indicated that approximately half of the requirements can be checked automatically and verified, whereas the other half of the requirements have to be checked manually in a BIM, see Figure 9 (Galiano-Garrigos, 2017).

Figure 9: Distribution of processing BIM requirements (Galiano-Garrigos, 2017)

3 Systems Engineering

Systems Engineering (SE) as a work methodology in the Netherlands is best known in the infrastructure sector. Large infrastructure projects were designed and implemented with the use of this methodology. Rijkstwaterstaat and ProRail are encouraging the approach based on SE (Rijkswaterstaat, 2013). The term SE consists of the concepts 'Systems' and 'Engineering'. System is made up of elements that together perform the function of the system. Secondly, the concept SE is also formed by the term Engineering. SE is about the engineering activities throughout the entire lifecycle of the system (INCOSE, 2017).

The International Council on Systems Engineering (INCOSE) defines Systems Engineering as:

“Systems Engineering is an interdisciplinary approach and means to enable the realization of successful systems. It focuses on defining customer needs and required functionality early in the development cycle, documenting requirements, then proceeding with design synthesis and system validation while considering the complete problem: operations, cost and schedule, performance, training and support, test, manufacturing and disposal”.

The aim of this chapter is to provide answer to the first sub questions. In this chapter, the following sub-questions are addressed:

- What core concepts can be identified for SE?
- Which design phases can be identified in a SE process?
- How can requirements be formulated to be used automatically?

Goal of these sub questions is to get more insight about SE. This chapter starts with an introduction to SE with the general explanation of SE. It is continued by the application of SE in the construction sector. Furthermore, the standardization within the working method SE is discussed. At the end this chapter a section is provided with a sub-conclusion on BIM and SE. This chapter is also used as input for section 3.5 and chapter 5.

3.1 Introduction to Systems Engineering

The origin of SE can’t be traced back to a certain date in history. The Bible records that Noah’s Ark was built to a system specification and during the building of the pyramids systems engineering principles have been practiced at some level (Kossiakoff, 2011). The recognition of systems engineering as a separate activity is often redirected with the effects of World War II. The development of high-performance aircraft, military radar, the proximity fuse, the German VI and V2 missiles, and especially the atomic bomb required revolutionary progress in the application of energy, materials, and information. These systems were complex, combining multiple technical disciplines, and their development posed engineering challenges significantly beyond those that had been presented by their more conventional predecessors (Kossiakoff, 2011). Systems engineering as now known is formed in the 1950s and 1960s when textbooks were published that first identified systems engineering as a separate discipline and defined its place in the engineering of systems. The recognition of systems engineering as a unique activity developed as a necessary corollary to the rapid growth of technology, and its application to important military and commercial operations during the second half of the twentieth century (Blanchard, 2006).

The relationship between modern systems engineering to its origins can be best understood in terms of three basic factors: advancing technology, competition and specialization (Kossiakoff, 2011).

The 21st Century has been described as "The Systems Century" (Calvano, 2004). Systems engineering nowadays focuses on creating systems. A set of related elements defines these. It is a management and engineering effort throughout the lifecycle of a system. This effort requires the involvement of multiple disciplines in a continuous iterative process (see Figure 10). Different members of a multi-disciplinary engineering team represent multiple disciplines. To get an overview of systems engineering activities the entire product creation phase of the systems must be studied. This overview contains the technical system and the interaction of the engineering team members, i.e. how to act, know, discuss, decide and think (Moser, 2014).

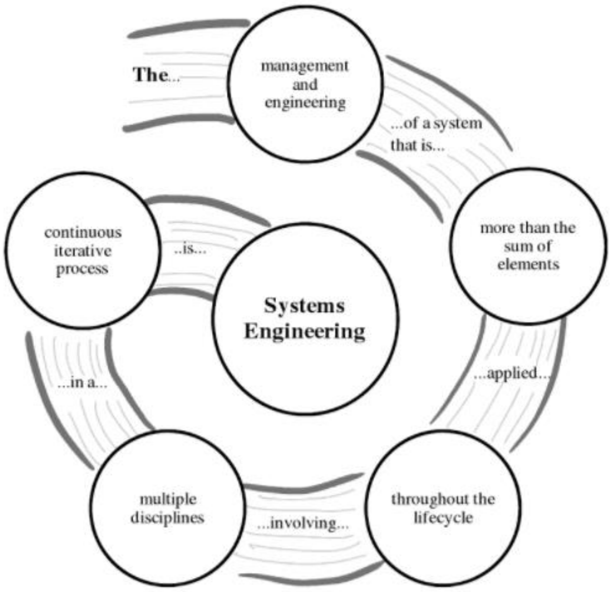


Figure 10: Basic five characteristics of systems engineering (Moser, 2014)

3.2 Application of Systems Engineering in the construction industry

The previous section explains what SE is, the history of SE, SE in the last decade, and what is known today as SE. This paragraph focuses on the application of SE in the construction industry. First, the intended goals of SE in general and in the Dutch construction sector are given. Secondly, the SE in the Dutch construction industry is elaborated through the definition, design, development and implementation lifecycle phases and the processes involved.

3.2.1 SE and IPM

Given the definition in paragraph 3.1 it follows that the goal of SE is to create a whole solution to a complex problem. According to Sheard (2009) complex systems are:

"Complex systems are systems that do not have a centralizing authority and are not designed from a known specification, but instead involve disparate stakeholders creating systems that

are functional for other purposes and are only brought together in the complex system because the individual "agents" of the system see such cooperation as being beneficial for them" (Sheard, 2009).

SE achieve this goal by focusing on defining customer needs and requested functionality early in development, capturing the requirements, design synthesis and system validation (ProRail, 2015).

According to Bar-Yam (2003) a systematic approach to complex systems development requires an evolutionary strategy where the individuals and the technology (hardware and software) are all part of the evolutionary process. Which is why ProRail created a guideline with principles that play an important role in SE:

- **System Thinking**: System thinking means that elements - which form part of the intended solution or interact with the need - are considered as one system;
- **The customer demand central**: The best solution is created for the system, based on customer demand, within the given solution area;
- **Optimization over the entire life cycle**: SE transcends the various phases of the life cycle and focuses on optimizing the system in all these phases, including interdependence;
- **Working explicitly**: Through explicit work, choices and information are traceable and transferable;
- **Applicable to any contract form**: SE is applicable in the construction sector for each contractual form and within each project.
- **Attention to competencies in attitude and behaviour**: SE is a method used by all throughout the project. The introduction of SE demands besides technical competencies but also certain competencies in attitude and behaviour.

SE is an integral (technical) project management. Projects in the construction sector continue to increase in complexity, dynamics and number of stakeholders; Hence the sector has been applying SE for nearly ten years (ProRail, 2015).

The intended goals of SE correspond to the goals of IPM. Figure 11 shows that Systems Engineering affects all the project components (ProRail, 2015). Like project management, SE deals with a variety of methods for designing and building a system that is largely independent of the domain itself (Eisner, 2008).

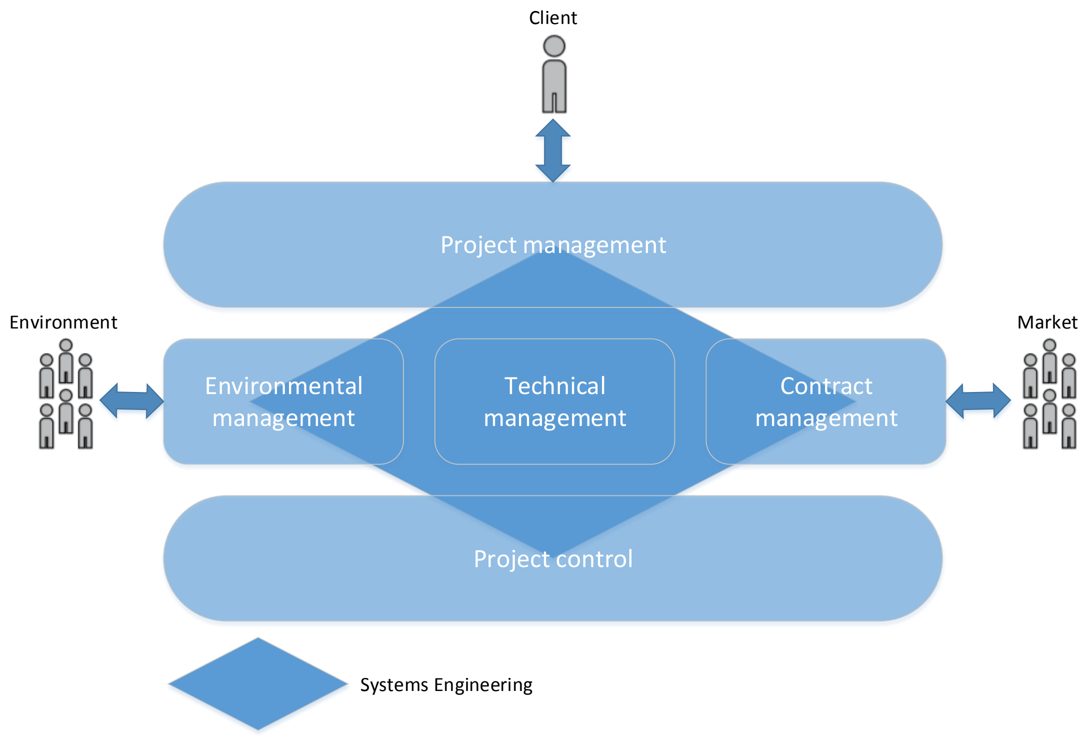


Figure 11: Relationship Systems Engineering and integrated project management (adapted from: ProRail, 2015)

3.2.2 v-model

The implementation of SE in the Dutch construction sector is an initiative of a collaboration between Prorail, Rijkswaterstaat, NL Ingenieurs, Bouwend Nederland, de Vereniging van Waterbouwers and Uneto VNI who created the "*Leidraad voor Systems Engineering binnen de GWW-sector*" (the SE guide). The SE guide provides a common framework with clear concepts and processes to the construction sector (Leidraadse, 2017).

According to the U.S. department of transportation federal highway administration there are seven lifecycle phases of development:

- **Phase -1** Regional Architecture
- **Phase 0** Concept Exploration
- **Phase 1** Project Planning & Concept of Operations
- **Phase 2** System Definition and Design
- **Phase 3** System Development & Implementation
- **Phase 4** Operations and Maintenance/ Changes & Upgrades
- **Phase 5** Retirement/ Replacement

Based on the phases they created a V-Model (see Figure 12). This model illustrates some key systems principles about the relationship of the early phases of the development to the end results of the project.

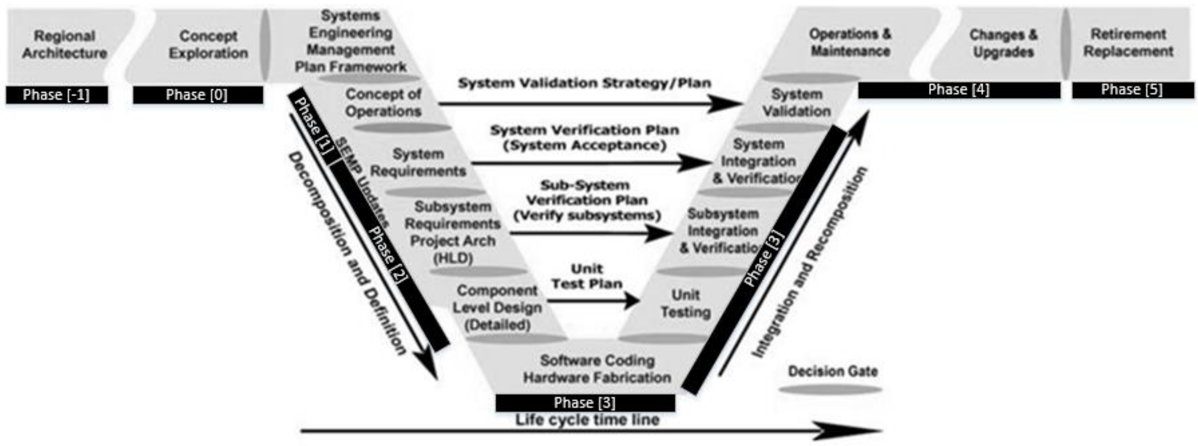


Figure 12: V - Model in the context of the life cycle framework (adapted from: U.S. department of transportation federal highway administration, 2017)

The SE guide also defines six lifecycle stages or phases that need to be followed to successfully implement SE within the entire lifecycle. These phases are: concept phase, development phase, execution phase, operational phase, maintenance and renewal phase and demolition phase. For each of the phases their underlying processes will be discussed.

Concept phase
Similar to phase -1 and 0 of Figure 12. During this phase, (new) needs of stakeholders are identified and possibilities are evaluated. The first customer requirements and solutions are determined here. The concept phase can lead to the initiative for developing and implementing a system (Rijkswaterstaat, 2013). This stage identifies the best business case project to move forward into development (U.S. department of transportation, 2017).

Development phase
Similar to phase 1 and 2 of Figure 12. During this phase, a system will be specified that meets the customer requirements. At the end of the development phase there is a design for the entire system. The definition of what the system is to do, how well it is to do it, and under what conditions is documented (U.S. department of transportation, 2017).

Developing a system can be conceived as a thinking, working and decision process, where information is gathered and edited. The development phase is iterative, goal-oriented and problem-solving, analyzing features and requirements and specifying the solution more and more in detail. The process of specification repeats until the level of detail is reached that covers the risks sufficient to achieve the realization of the system (Rijkswaterstaat, 2013).

In the construction sector, they regularly use the following terms combinations to indicate detail level in the development phase:

- Sketch - Preliminary design - Final design - Execution Design
- Functional design - Spatial design - Structural design

Specifying is an iterative process with a number of generic steps that are independent from the level of detail (see Figure 13):

- Analyse (solve problem and design solution);
- Structure and allocate (create overview);
- Design (capture choices and solve solutions).

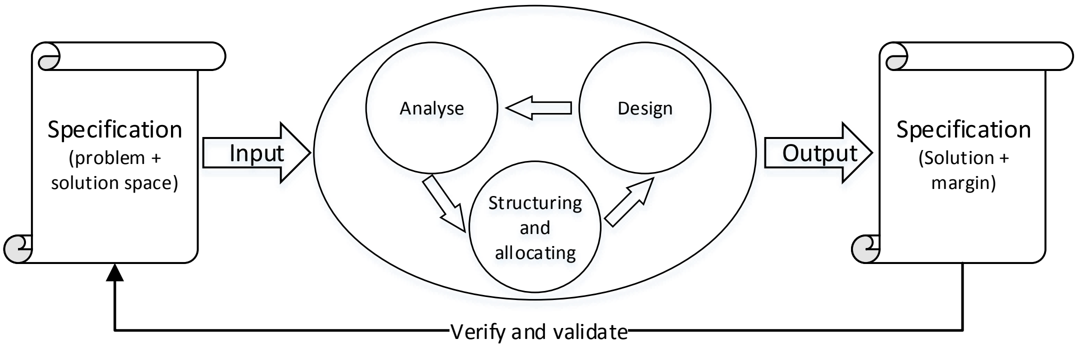


Figure 13: Iterative specification process (adapted from: Rijkswaterstaat, 2013)

The input a designer receives is often incomplete and not detailed enough for greater depth in the development of the solution. This is because this input describes the result of choices in an earlier phase at a higher level of detail. This makes a further analysis of the problem and the solution space required (Rijkswaterstaat, 2013).

Execution phase

Comparable to phase 3 of Figure 12. In this phase, the system is actually built. The realization of complex systems, like the development phase, takes place in a layered manner. System elements and subsystems are integrated into one whole. The execution phase consists of several activities: manufacturing and building, merging and integrating and verify and validate (inspecting and testing) (Rijkswaterstaat, 2013).

Operational phase

Comparable to phase 4 of Figure 12. At this stage, the system is being exploited. Here, the activities take place to use the system as intended (Rijkswaterstaat, 2013).

Maintenance and renewal phase

Comparable to phase 4 of Figure 12. During this phase, support activities are performed, which are necessary to keep the system in operation (Rijkswaterstaat, 2013).

Demolition phase

Comparable to phase 5 of Figure 12. This phase is intended to disable and remove a system with associated operational services and functions. (Rijkswaterstaat, 2013)

Upon completion of the phases, transmission of information between the involved parties takes place. It is important to transfer the necessary information transparently. As information loss can occur at transmission times, it is wise to avoid phasing and transferring at the same time (see Figure 14).

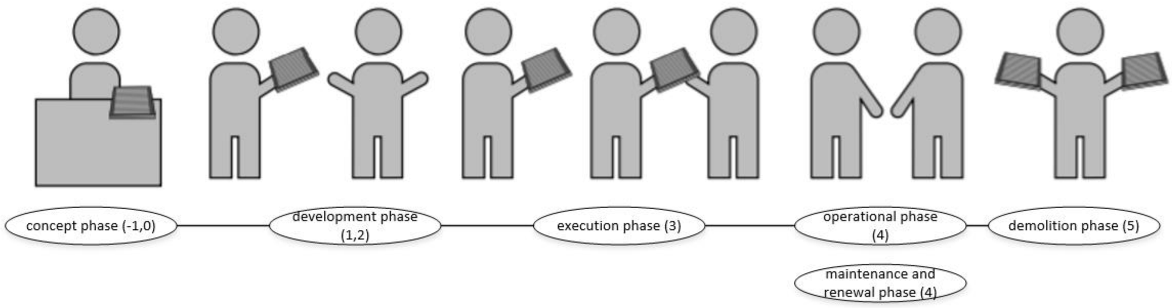


Figure 14: Information transfer in life cycle (adapted from: Leidraadse, 2017)

3.3 Requirements within System Engineering

The combination Hurks-Imtech has acquired the Design, Build & Maintain assignment for the Royal Cosun's new Food Technology Center in Dinteloord. The contract represents a value of more than 15 million euros for engineering, construction and fifteen years of maintenance (Hurks, 2017). This project has not fulfilled its objectives and expectations, and that for several reasons:

- The contractor could not describe and design how they want to build the building
- Two parallel processes on construction of the building and the System Engineering (System Engineering even happens afterward)
- Little review on the demands and requirements of the customer on the design and construction of the building

In these extensive collaboration forms, such as DBF(M)(O), the client/user is looking for a partner who can design, implement and operate an integral plan. Through collaboration between the client and the contractor, a client's project requirements can be achieved and this generates more added value compared to traditional construction projects.

The customer demand is the collection of requirements and preconditions of the customers regarding to the system. The first step in the development of a system is to specify the customer requirements. This starts with a problem analysis, environmental analysis and stakeholder analysis that capture customer needs. Customer needs are drawn up in the form of requirements and wishes. This information is captured by the Customer Requirements Specification (CRS) (Rijkswaterstaat, 2013).

According to Hull (2011), there must be an adequate basis for the development to proceed, so it is necessary to assess the input requirements. The assessment must answer the questions:

- Is the requirement complete? (no missing information)
- Is the requirement clear? (no lack of clarity – ambiguity, contradiction, confusion)
- Is the requirement implementable? (impossible to implement – no known solution)
- Is the qualification planning clear and acceptable?

A good system specification complies with the following characteristics (Rijkswaterstaat, 2013);

Complete. The specification is integral and runs across all disciplines and all the life stages of the system.
Actual. The specification fits the system as determined by the stakeholders and their interests at this time.
Clear. The specification is formulated clearly, the objects are defined and the borders are transparent. Designs and requirements are interconnected and this is demonstrated by the verifications. The design considerations should be documented and shared with all parties.
SMART. A good specification and/or requirement is: Specific (unambiguously defined), Measurable (when achieved in quality), Acceptable (for target and/or management), Realistic (achievable) and Time-bound (when the goal has to be achieved).

The review can be continued if a requirement and its qualification plan are acceptable the status can be set to agreed. If the requirement is not acceptable then an alternative form is sent to the customer (“wijzigingsverzoek”) and the onus passes to the customer, and the agreement state becomes “Customer assessing requirement from contractor”. If the customer is content with the alternative wording, he can set the state to ‘agreed’ (See Figure 15) (Hull, 2011).

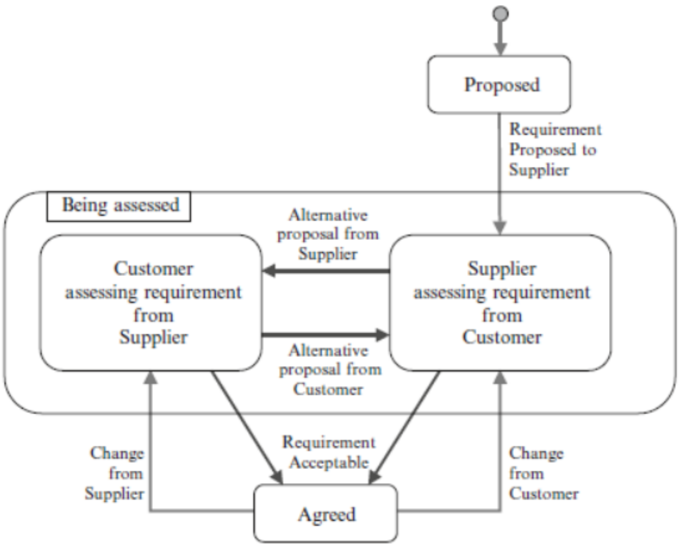


Figure 15: State chart for agreement requirement (Hull, 2011)

This review ensures well-written requirements. Benefits of these well-written requirements are (NASA , 2007):

- Well-written requirements establish the basis for agreement between the stakeholders and the developers on what the product is to do;
- Reduce the development effort because less rework is required to address poorly written, missing, and misunderstood requirements;
- Provide a basis for estimating costs and schedules;
- Provide a baseline for validation and verification;
- Facilitate transfer.

3.4 Formulation requirements

One of the most used SE tools in the Dutch construction sector is Relatics. During the Royal Cosun project, Hurks also used this tool. Relatics is for example used to manage project information within Rijkswaterstaat and for the development of the Gotthart tunnel, the widening of the A4, the Coentunnel and the Tweede Maasvlakte.

Relatics is a web-based application that enables to manage information within projects in the building sector. By the use of semantic technology and a requirement-centered approach Relatics can manage requirements, objects, spaces, activities, risks and verifications. With Relatics it can be defined what information should be managed (Relatics, 2017).

Relatics knows two kinds of users who can use the program, a functional designer who creates and configures a template and an end-user who uses the program. Before Relatics can be used a template needs to be configured for the end-user.

The flexibility of Relatics provides both an advantage and a disadvantage. The advantage of the flexibility of Relatics is that the information is transparent and collaboration between different disciplines can be created. The disadvantage of the flexibility of Relatics is that it requires extensive training before Relatics can be configured. So, it is the responsibility of the end user to formulate the requirements in the right way in Relatics.

To formulate the requirements in the right way ‘Bouw Informatie Raad (BIR) SE-BIM werkgroep’ (consisting of NL Ingenieurs, Vereniging van Waterbouwers, Rijkswaterstaat, Uneto Vni, Bouwend Nederland, CROW and ProRail) created the ‘SE uitwisselingsstandaard 2017-04-05 v1.0‘. This standard " Systems Engineering uitwisselingsstandaard voor de Nederlandse bouwketen" facilitates the exchange of information in systems between different parties over their entire life cycle; Such as development, production, use and demolition. It provides the formal language needed for acquiring and supplying systems. With this standard, a common "language" is established in the form of an SE exchange standard (Bouw Informatie Raad (BIR) SE-BIM werkgroep, 2017).

For the exchange of information between parties, an architecture has been laid out in layers by the BIR (see Figure 16). Each layer of architecture has certain functionalities and provides services above it and uses services of the layers below. A particular layer is independent from the details covered by underlying layers.

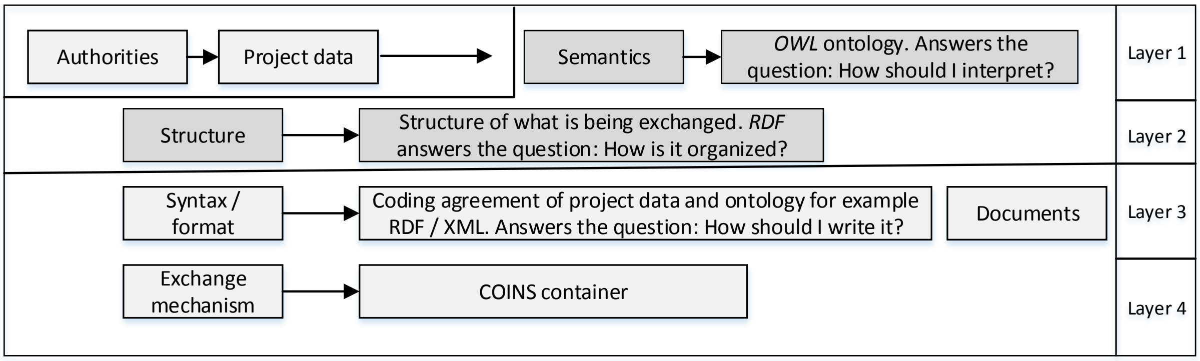


Figure 16: Architecture in layers, within the framework the "SE uitwisselingsstandaard" (layer 2) (adapted from: Bouw Informatie Raad (BIR) SE-BIM werkgroep, 2017)

Layer 1: The upper layer: The Instances - and semantics layer
Entities are the terms that capture information. An entity has a name and a definition, which makes it clear what concept is modeled with. They are the dictionary of the language used in the SE exchange standard. The entities are defined in a hierarchical specialization structure (taxonomy). Instants (project data) and semantics (meaning) are structured according to RDF. The meaning is recorded in a model. This model is called ontology. The language in which an ontology is described is OWL. OWL can explicitly express what we mean. The SE information model is an example of ontology.

Layer 2: Structure layer
The SE exchange standard is a formalized way of expressing sentences (language) explicitly. The sentences are transmitted according to a fixed structure (a model). The structure of exchanging SE information always has the form:

Concept - relationship - concept (a triple)

For example: requirement (concept) - relates to (relation) - artefact (concept). These senses can be processed by computers in a formal language.

Subject	Relatie-ID	Relatienaam	Name NL	Cardinality	Reverse name	Reverse name NL	Reverse cardinality	Object
name UID	Rel-00001	has name by literal	heeft lexicale naam	1:1	is by literal name of	is lexicale naam van	1:1	xsd: normalizedString
requirement UID	Rel-00002	is classified as by class	is geclassificeerd als volgens klasse	0:1	is classifier for	is classificatie voor	0:n	class of requirement type
requirement UID	Rel-00004	specifies	specificeert	0:n	is specified by	wordt gespecificeerd door	0:n	artefact UID
v&v activity UID	Rel-00006	has subject	heeft betrekking op	0:n	is subject of	is onderwerp van	0:n	requirement UID

Table 3: Example of how the triples are defined including cardinalities and their inverse (Bouw Informatie Raad (BIR) SE-BIM werkgroep, 2017)

A relationship is established (see Table 3):

- Subject
- Relationship name
- Object
- Cardinality (how often the relationship can be applied dominantly)
- Reverse Relationship Name
- Reverse cardinality (how often the relationship can be reversed)

Layer 3: Syntax / Format layer
The COINS container contains encoded SE information. This information is encoded in a certain format. This is preferably a format in which information is formally transmitted by a computer. RDF / XML, Turtle and JSON are some examples of such format.

Layer 4: The exchange mechanism
The bottom layer is one of the domains of COINS and about how specific project data is transferred between parties in a project. The mechanism for exchanging SE information includes the COINS container. This allows SE information, in various formats, to be exchanged in coherence.

3.5 Sub-conclusion relationship BIM-SE

In chapter two and three literature independently answers the sub-questions on BIM and SE. This paragraph is used to describe the relationship between SE and BIM (arrow 1 of Figure 2).

One of the first similarities between SE and BIM are the benefits which occur when applying these working methods. Both working methods aim for a better design, production quality, better customer service and access to lifecycle data. Another link between both working methods is the integral approach. Figure 4 shows the integrated workflow in a BIM where information is stored, accessed and adjusted in a common data environment. Figure 11 shows that Systems Engineering affects all the project components. Both working methods are integrated and assume a computer-based collaboration where team members are scattered across several locations but use shared databases.

The integrated approach to BIM and SE also provides a challenge. The integrated concept of BIM and SE blurs the level of responsibility so much that risk and liability are likely to be enhanced. Professional groups, such as the AIA and AGC, are developing guidelines for contractual language to cover issues raised by the use of BIM technology (Eastman et al., 2011). The guidance “Leidraad voor SE” indicates that SE is suitable for each contract form but must be used in the draft and preparation of the contract to reduce risks.

The phasing between the BIM and SE working method is also a link between the two approaches. Table 1 indicates the phasing of a BIM based on LODs. Figure 12 indicates the phasing of the construction process based on system thinking. Between the BIM and SE phases, a link can be generated by coupling each phase of the construction process to LODs.

For both work methods, open standards have been created. Figure 16 is a section of the “SE uitwisselingsstandaard” for the exchange of SE information between parties. Table 2 gives an overview of BIM standards according to buildingSMART. For the exchange of information in a BIM, an IFC is needed based on the ISO 16739. These open standards ensure common agreements that enable information transfer (Krechmer, 2006). The “SE uitwisselingsstandaard” and IFC will be used to develop the tool in chapter 6.

4 Quality Assurance law

The Dutch regulation regarding the quality of construction projects has been transforming in recent years with legislation changes taking place into the civil code. The most prominent (as well as most recent) change that impacts on-site quality is the Dutch quality assurance directive: "*Wet kwalitietsborging voor het bouwen*". This strengthens the position of the private and business consumer. Due to the increasing complexity in construction, revision of the current quality assurance system is necessary (Eerste Kamer der Staten-Generaal, 2017).

In this chapter, the following sub-question is addressed:

- How does the new quality assurance law affect the relationship between BIM and SE?

Goal of these chapter is to get more insight about QAL. This chapter starts with an introduction to QAL with the history about the QAL. It is continued by the application of QAL in the current construction sector. This chapter is also used as input for and chapter 5 to provide an overall conclusion on the literature review.

4.1 Introduction to Quality Assurance law

The quality assurance law regulates the introduction of a new quality assurance system for the construction sector. This strengthens the position of the private and business consumers. Due to the increasing complexity in construction, revision of the current quality assurance system is necessary (Eerste Kamer der Staten-Generaal, 2017).

Figure 17 shows the timeline for the quality assurance law. The development of the law started in 1997, when the workgroup MDW (market forces, deregulation and legislative quality) reported to simplify the licensing process (Egmond, 2017).

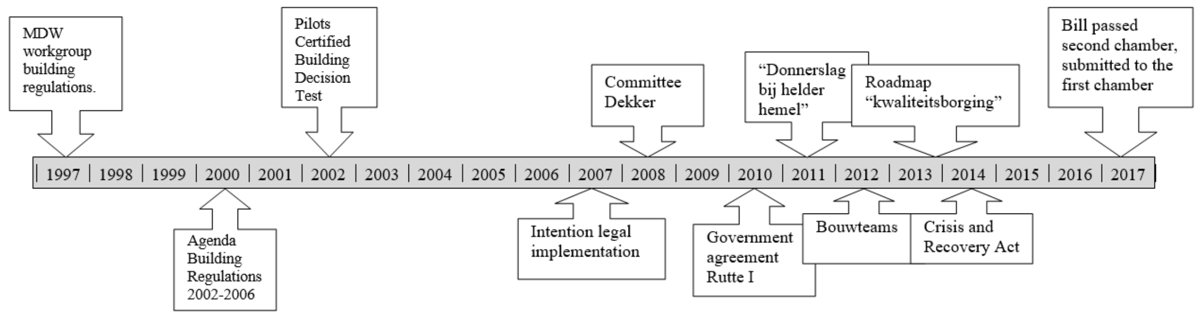


Figure 17: Timeline bill quality assurance law (adapted from: Woningborg, 2017)

One of the focal point during the "Agenda Building Regulations 2002-2006" was to move the relocate the responsibility of the building permit into the market and to ease the work of the municipalities. (Egmond, 2017). During the "Agenda Building Regulations 2002-2006", the first concepts of the Quality Assurance Law were devised, which was adopted by the second chamber on February 2017.

Quality control in the new Quality Assurance Law will be based on approved instruments (transparent, reproducible, independent) in which an authorization organization supervises the system (Egmond, 2017).

According to Koning (2016) the future construction process ensures more certainty, an expansion of construction, shift to private entitled quality agencies and quality impact. Below is an overview of both methods for quality assurance are compared to each other:

Phase	Current construction process	Future construction process
Application permit	• Initiator requires environmental permits for the building at the municipality or the Olo (Omgevingsloket online). • Initiator provides a complete detailed plan for construction	• Applicant chooses recognized quality assurance instrument and contracts an entitled person who guarantees the quality • Initiator requires environmental permits for the building at the municipality or the Olo
Disapprove or approve building permit by municipality	• The municipality reviews the application for the environmental permit for spatial planning, building regulations and well-being requirements by using external parties	• The municipality tests quality instrument and looks at whether the application complies with the spatial planning, building regulations and well-being requirements (no construction testing)
Construction	• After granting permission, the construction starts • Many adjustments to the building plan during construction • Contractor incur costs for quality assurance • Risk-based review by municipality on construction	• After granting permission, the construction starts • Dossier-based testing using instrumentation on construction quality and control by the entitled person who guarantees the quality • Capture documentation by contractor
Completion	• After completion of construction phase, the construction is reported complete and put into operation	• Signature declaration by the entitled person • Send declaration, receive and process declaration by municipalities

Table 4: Overview of the current and future construction process (Koning, 2016)

A law only has value to the people of a society if its problem-solving benefit is greater than its costs and other burdens (Quality of Laws, 2017). Mr. J.M. Schouwenaar (member of the VVD in the Senate) assumed there were three problems in the current quality assurance law:

- The contractor's responsibility stops when the project is completed, which is very It is difficult for many people.
- There was no overview. It is not clear who is responsible and liable. The new quality assurance law ensures that the contractor is liable.
- With the new quality assurance law, the market will be responsible for supervision. The municipalities did not properly implement this task.

Upon completion of the construction, the contractor must demonstrate that the regulations have been met. The law ensures that the market is aware of compliance of the building regulations (Egmond, 2017). When it appears that a building has not been built according to the regulations and agreements made, clients get better opportunities to encourage the contractor to repair work (Eerste Kamer der Staten-Generaal, 2017).

The most important changes to this law are (Woningborg, 2017):

- The public system of quality supervision changes into a combined public-private system
- Mandatory hiring of a private quality supervision by the contractor / licensee
- Compulsory declaration of the quality supervision on the constructed construction as built (instead of as planned as in the current system) as a condition for commissioning
- Information obligation to consumers and indicates how the contractor is insured
- The definition of the hidden defect is adjusted to the benefit of the consumer, which makes the contractor more liable
- The contractor hands a mandatory delivery file to the consumer

At the request of the Interior Ministry, the Economic Institute for the Construction (EIB) performed a social cost-benefit analysis of the Quality Assurance Law. The current work that the municipality now performs as part of the environmental permit for the construction test will decrease. In total, it is a municipal effort of € 1060 million, which will no longer be implemented in the new situation. Applicants also have to provide less information in the new situation by submitting the environmental permit. This results in a cost saving of € 190 million. The total balance is a saving of €1.7 billion. On an annual basis, the cost saving is an average amount of more than €100 million. The results are summarized in Table 5 (Koning, 2016).

Process acceleration and more certainty	€840
- Cost reduction by speeding lead time	€670
- More certainty	€170
Building code free work	€790
Shift testing to private parties	€100
- Less work by permit application	€190
- Less work by municipalities	€1.060
- Higher cost private parties	€-1.370
- Extra quality through intensive testing	€420

- Provide data when ready	€-30
- Organizational costs	€-140
- Training and discharge costs	€-30
Balance	€1730

Table 5: Overview NPV in million € (2014 price level) (Koning, 2016)

4.2 Sub-conclusion relationship Quality Assurance law on BIM and SE

In chapter four literature independently answers the sub-questions on the quality assurance act. This paragraph is used to describe the relationship of the quality assurance act on the relationship between SE and BIM (arrow 2 of Figure 2).

SE has become the new method to design and prepare projects. SE starts with recording of the functional design based on the wishes of the client. A second important aspect is that integral design is used as starting point. The coordination between the different components of the design is essential. Working systematically from coarse to fine is a feature of SE. The application of SE would connect very good to effectually and efficiently secure quality for the new quality assurance law.

SE and BIM are systemic thinking, a total approach, of the early definition or customer requirements and the technical integral approach. The Quality Assurance law can easily be implemented within SE and BIM and the Quality Assurance law can be applied in Dutch construction with minimal costs (see Table 5) and a cost saving of more than €100 million (Koning, 2016). The task at hand for construction industry is to improve (expand) their workflow and, even further down the line, transform their workflow into the principles of SE and BIM.

5 Conclusion BIM, System Engineering and the Quality assurance law

BIM is one of the most promising developments in the AEC industries. BIM requires a different way of collaboration between stakeholders. Collaboration on construction projects is closely linked with communications and seamless information exchange among stakeholders. The rising interest in BIM can be seen in conjunction with new project management frameworks, such as Integrated Project Delivery (IPD), which increases the need for closer collaboration and more effective communication (Bryde, 2013).

BIM is not just a technology change, but also a process change. By enabling a building to be represented by intelligent objects that carry detailed information about themselves and have links and relationships with other objects in the building model, BIM not only changes how building drawings and visualizations are created but also dramatically alters all the key processes involved in putting a building together (Eastman et al., 2011).

SE focusses on defining customer needs and requested functionality early in development, capturing the requirements, design synthesis and system validation (ProRail, 2015). SE start with identifying the (new) needs of stakeholders and evaluating the possibilities. Based on the customer requirements a system will be specified. After the system is actually built, it is exploited. Support activities are performed, which are necessary to keep the system in operation. The last phase is intended to disable and remove a system with associated operational services and functions. Thus, SE is about the engineering activities throughout the entire lifecycle of the system (INCOSE, 2017).

One of the first similarities between SE and BIM are the benefits which occur when applying these working methods. Both working methods aim for a better design, production quality, better customer service and access to lifecycle data. Another link between both working methods is the integral approach. The phasing between the BIM and SE working method is also a link between the two approaches. Between the BIM and SE phases, a link can be generated by coupling each phase of the construction process to LODs. The integrated approach to BIM and SE also provides a challenge. The integrated concept of BIM and SE blurs the level of responsibility so much that risk and liability are likely to be enhanced. For both work methods, open standards have been created. These open standards ensure common agreements that enable information transfer (Krechmer, 2006).

A law only has value to the people of a society if its problem-solving benefit is greater than its costs and other burdens (Quality of Laws, 2017). The Quality Assurance law can easily be implemented within SE and BIM and the Quality Assurance law can be applied in Dutch construction with minimal costs (see Table 5) and a cost saving of more than €100 million (Koning, 2016).

6 Methodology

As the complexity level of the design and construction processes is increasing, traditional information medium such as paper-based documents cannot satisfy the required integrity, precision and timeliness (Zhang, 2015). The concept of Building Information Modeling (BIM), Systems Engineering (SE) and the Quality Assurance Law (QAL) are contribute to achieve this.

In this chapter the tool, based on the concepts BIM, SE and the QAL, is developed. In this chapter, the following sub-question is addressed:

- How can the project's requirements be verified based on BIM, SE and the QAL?
- How can the project's requirements be presented based on BIM, SE and the QAL?

First step in this chapter is to determine the requirements the tool should comply to. The tool should connect BIM, SE and the QAL. Tools connecting BIM and SE (requirement checkers) will be used as basis to develop the tool. Based on these requirements, a founded decision for a validation tool can be made. Thereafter, a detailed description of this tool is provided.

In this chapter a distinction is made between how the tool works and how the tool should be used. How the tool works is described in the thesis on a detailed level. How the tool should be used is described in an appendix, though a short summary of the usage of the tool is provided.

6.1. Introduction

The American Society of Civil Engineers defined quality in construction as meeting established requirements as follows: "Quality in constructed project is achieved if the completed project conforms to the stated requirements of the principal participants (owner, design professionals, contractors) while conforming to applicable codes, safety requirements and regulations" (Low, 2014). Further, it is reckoned that a successful contractor is one who recognises the importance of quality to its activities, understands the need for the proactive management of quality and puts in place the mechanisms to ensure that quality management is undertaken systematically, rigorously and continuously. This indicates that the performance of the contractor and the quality of the building are the most distinguished differentiating characteristics in the construction industry (Ng, 2005).

Quality checking is a way to share and utilize knowledge and cannot be interpreted, when validation passed, as a good design/model. It presents a way to validate regulations and can, therefore, rule out the possibility of a bad design/model.

With respect to raising the quality of the built environment, contractors are constantly challenged to improve their workmanship quality, and hence, they have to be driven to find better ways of undertaking the quality management process. Quality control (QC) primarily deals with issues relating to conformance to the plans and specifications. This means that all the materials, systems and workmanship applied to the project must be designed to conform to the requirements set forth in the contract documents (Low, 2014). Quality management (QM) is what an organization does to ensure that its products conform to the customer's requirements (Natee, 2016)).

An average contractor is estimated to spend 5–10 % of the project cost doing things wrong and rectifying them as they often do not plan work properly the first time and ensure that the required workmanship standard can be achieved in order to avoid the price of non-conformance (Kaynak, 2003). Kaynak (2003) also mentioned a "Ten Time" rule, which means that the cost of putting right quality problems at the construction phase is ten times higher as it does in the design phase and it costs ten times as much again to wait to resolve these quality problems once the product is in the commissioning phase as compared to if it is put right in the construction phase.

A substantial time and cost-saving can be realized if the contractor puts inadequate investment to plan and control quality. The cost of initiating a proper quality management system is in the range of 0.1–0.5 % of the total project cost, and this must be monitored closely so that it is within the overall construction and company budget (Sullivan, 2014). From Sullivan's (2014) experience, this will trigger savings of at least 0.5–3 % of project cost, a return of more than five times the investment.

6.2. Method

6.2.1 Four classes of functionality Eastman (2009)

According to Eastman (2009) there are four classes needed in the software processes a working requirement-based checking system. These classes are used to develop tool to connect BIM and SE. This method will be used as basis to develop the tool presented in chapter 6.4. These four classes of capabilities are diagrammed in Figure 18.

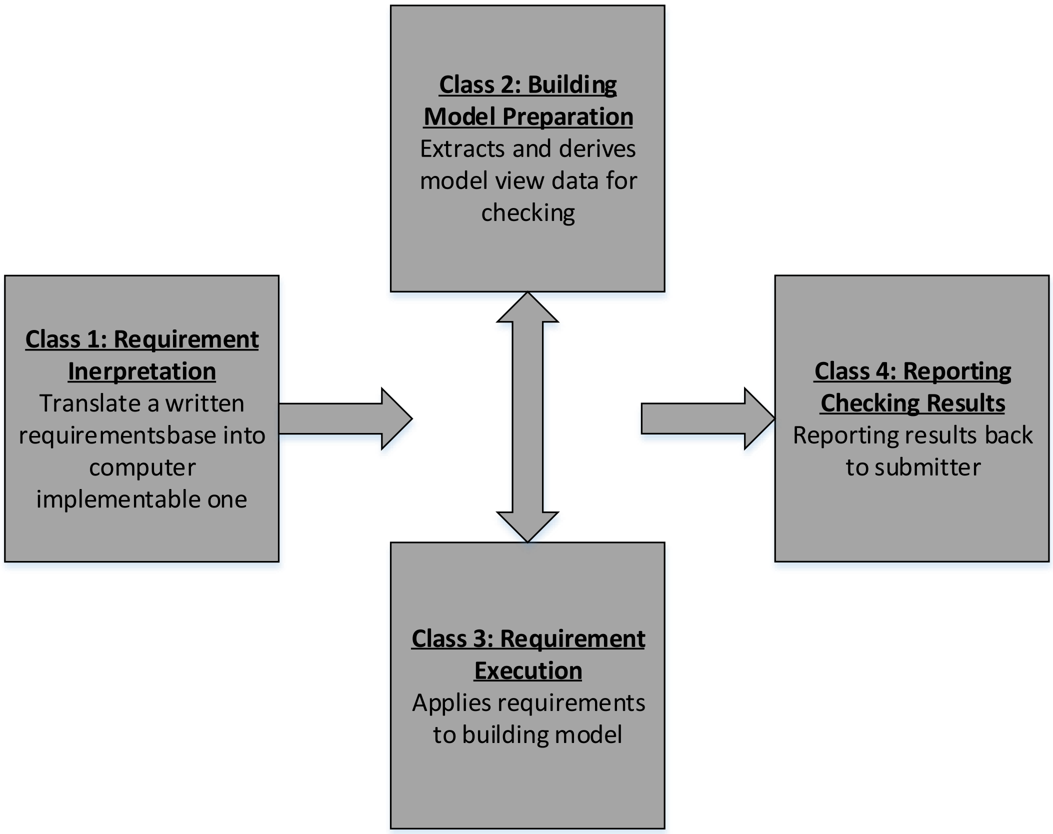


Figure 18: The four classes of functionality a requirement checking system should support: Requirement derivation, building model preparation, requirement execution, and requirement reporting (Adopted from: Eastman, 2009)

Class of functionality 1 Requirement interpretation: Requirements for building design are first defined by people and represented in human language formats, typically written text, tables and possibly equations. In building codes, these requirements have legal status. How can the interpretation of these requirement into a machine-processable format be done, in a manner that the implementation can be validated as consistent with the written requirement? The designed tool will use SE exchange standard to (see chapter 3.4) to the interpretation of requirements.

Class of functionality 2 Building model preparation: In traditional computer drafting practice, the objective was being to lay out 2D drawing representations that people could interpret for building information. The primary requirement in this earlier process was that the drawings must “look visually correct” and to contain the varied information needed for requirement checking. Today, with object-based building models, the requirements have changed. Objects being checked now have a type and properties. Thus, the requirements of a building model adequate for requirements checking are stricter than earlier drafting requirements. This information must then be properly encoded in IFC by the software developers to allow proper translation and testing. If users are asked to explicitly enter complex derived properties, the issue of erroneous data that is not consistent with the building model arises. The tool will depend on the delivered data and the previously made agreements in the project. If the elements in the IFC and the requirements in a SE software package are provided with the correct coding, the tool will be more transparent and easier to manage.

Class of functionality 3 Requirement execution: The execution phase brings together the prepared building model with the requirements that apply to it. Execution issues largely deal with the management of this the review process. In the tool, the data of the IFC elements and requirements from the SE software package will be ready to be managed when they are imported in the tool.

Class of functionality 4 Requirement check reporting: The last step in requirement checking reports the results. Design conditions that are satisfactory—those that PASS—need to be reported as part of an audit trial that validates the completeness of the check. One can envision various situations where the identification of instance conditions that pass a requirement would provide valuable knowledge. The loaded requirements (which are linked to IFC elements) can be managed by selecting whether they are complete, modified or open (not achieved). The client will be provided with account (log-in data) to be able to view (and not to adjust) the current status of the project.

6.2.2 Requirements checking platforms

Model checking is a way to share and utilize knowledge and cannot be interpreted, when validation passed, as a good design. It presents a way to validate regulations and can, therefore, rule out the possibility of a bad design. Model checking is a general term for several types of checking but always performed on a model and the information it contains.

A detailed review of these applications can be found in Eastman (2009).

Solibri model checker (SMC):

The SMC is a java-based application that evaluates an IFC model regarding predefined rule-set libraries such as object existence, relations, fire code exits, path distance checking, and space program checking (Lee, 2015).

Rules can be parametrically varied through table-set control parameters. However, entirely new rules are added in Java using the SMC application programming interface (API). The API interface is not publicly available, restricting the rules to be checked to those supplied by Solibri (Eastman, 2009).

Jotne EDModelChecker (EDM):

Jotne EDModelChecker provides an object database and supports the open development of rule checking using the EXPRESS language, which is the language in which the IFC model schema is written. New model views can be developed using EXPRESS and EXPRESS-X, which is a language for mapping instance data from one EXPRESS schema to another and supports extensive queries and reports. These facilities make EDM open to sophisticated user extensions. EDM also provides textual reporting and server services. It is supported by EDM Model Server, an object-based backend database server, that allows EDM to deal with building models and potentially several of them at a time (Eastman, 2009).

FORNAX:

The Singapore CORENET effort developed its own platform, called FORNAX, developed by novaCITYNETS Pte. Ltd on top of EDM Model Checker (Khemiani, 2005). FORNAXt is a C++ object library that derives new data and generates extended views of IFC data. FORNAX objects carry rules for assessing themselves, providing object-based modularity. FORNAX has been reviewed by a number of other building code efforts as a possible platform including the Norwegian Selvaag Group, who applied it to fire exit assessment (Eastman, 2009).

SMARTcodes:

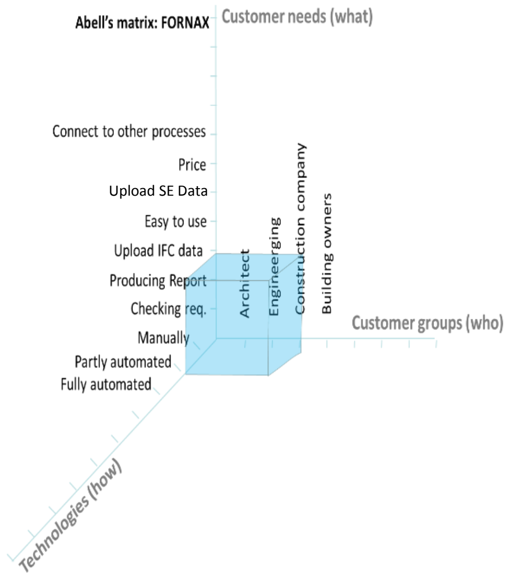
A platform for rule checking is being developed by ICC, called SMARTcodes. It provides methods of translation from written language rules to computer code, using a dictionary of domain-specific terms and semi-formal mapping methods. SMARTcodes also provides methods to access the relevant data in an IFC model and report on results. SMARTcodes has been developed by AEC3 and Digital Alchemy (Eastman, 2009).

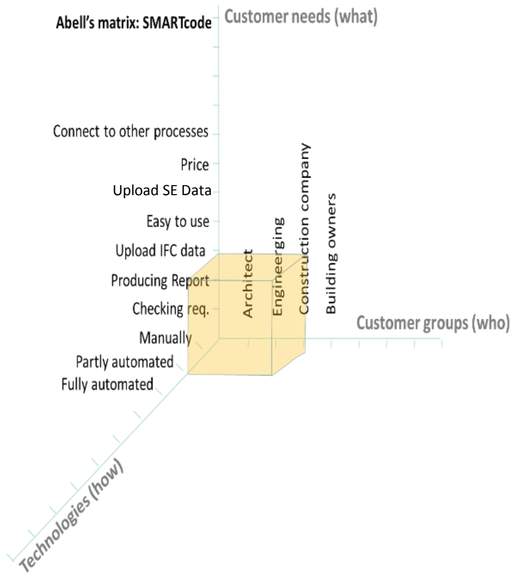
IFC mvdXML checker:

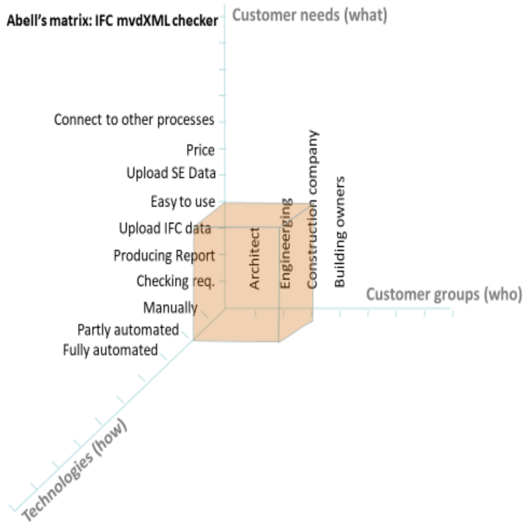
This checker is developed based on the open standards mvdXML as the format for structuring validation rules and the BIM Collaboration Format (BCF) to issue reports as a result of the checking process. The checker is implemented on top of the open source bimserver.org framework (Zhang, 2015).

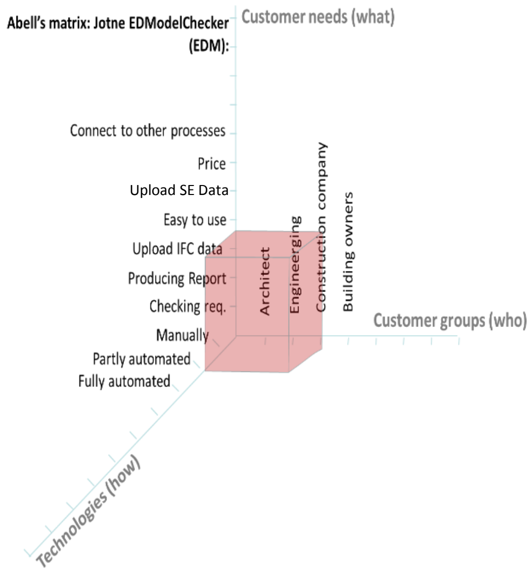
6.2.3 Comapere rule checking platforms with Abell's model

Abell's model illustrates an effectual approach in a three-dimensional model. The model is used to analyse the scope of operation of a business. This is done by including areas such as technologies and products a business operates in, and the market audience that it targets. The three dimensions of the business are '*customer groups'* (who will be served in the business), '*customer needs'* (what are the needs of the customer) and '*technology'* (how are these needs are going to be met). By defining these dimensions, the tool helps to define a business by the scope and make the target segment visible, which is the figure formed between the dimensions (Nijssen, 2014). Figure 19 presents the Abell's models of the requirement checking systems. The customer groups are the different parties who could use a requirement checking system: Architect, engineering, construction company and building owners. The technology for a requirement checking system could be manual, party automated and fully automated. The customer needs, which can be fulfilled by a requirement checking system, are: checking requirements, producing a report, uploading IFC data, easy to use (available tutorials), uploading SE data, low price and a connection to other (work) processes in the company business (is the tool flexible/can the tool be adjust by the user?).









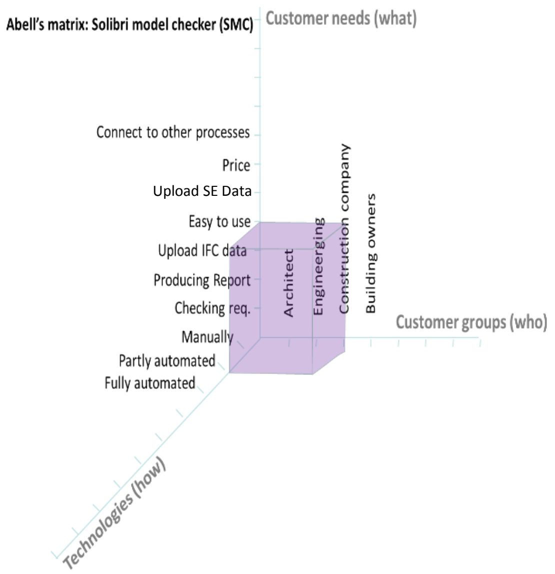


Figure 19: Overview Abell's matric for FORNAX, SMARTcode, EDM, SMC and mvdXML

Based on Figure 19, it can be concluded that the current tools used to link BIM and SE have a very similar scope of operation.

6.3. Data collection

The construction of programs is probably easier in visual programming language than in textual languages (Green, 1996). Visual programming is a programming paradigm that models a computer program as a directed graph. In this graph the data flows over the edges from one node to the next node. Where each node can perform operations to the data (Aerle, 2015).

Visual programming is a concept that is already being used in the AEC sector. It is implemented on top of two existing CAD packages, Grasshopper and Revit, by two different vendors. Both projects are actively developed and can be extended by plug-ins to provide for new functionality (Aerle, 2015). Grasshopper 3D and Dynamo are visual programmes used by designers. They utilize the same framework of formalization; however, they define the instructions and relationships of their program through a graphical (or "Visual") user interface. Instead of typing text bound by syntax, they connect pre-packaged nodes together. They require no knowledge of programming or scripting, but still allows designers to build form generators.

Visual programming introduced a new way of creating robust and scalable Internet applications. With a new technology called the Internet Information Server (liS) application, developers can use programming language for writing applications that glue together all the elements of an Internet application (Kurniawan, 2000).

For visual programming, the computer software Mendix is used to develop the tool. Mendix is a platform that enables enterprises to transform how their organizations compete with applications. The platform is recognized as a Leader in Gartner's 2017 High Productivity Application Platform as a Service (HpaPaaS) (Paul Vincent, 2017) Magic Quadrant, a Leader in Gartner's 2017 Mobile Application Development Platform Magic Quadrant (Jason Wong, 2017) and a Leader in Forrester's 2017 Wave for Mobile Low-Code Development Platform (Hammond, 2017).

To assess the state of the development platform market and see how the vendors stack up against each other, Hammond (2017) evaluated the strengths and weaknesses of top vendors in the category. After examining past research, user need assessments, and vendor and expert interviews, he developed a comprehensive set of evaluation criteria. He evaluated vendors against 24 criteria, which he grouped into three high-level buckets: current offering, strategy and market presence. The results are visualised in Figure 20, Mendix is one of the leaders with a strong strategy and strong current offering.

Figure 20: Development Platforms (Hammond, 2017)

6.3.1 Domain model

The domain model is a data model that describes the information in the tool in an abstract way. It is central to the architecture of the tool. The domain model consists of entities and their relations represented by associations.

Figure 21 illustrates the domain model of the tool. The domain model defines the management of requirements. The line between them is an association. The words 'ManagementRequirements', 'Requirement', 'BimElement' and 'Assignee' are the names of the entities. An instance of an entity is called an object. The words below the entity names are the attributes of the entities. The properties or features of an entity are described using attributes. An attribute represents a small piece of information about an entity, such as the name or birth date of a person. The entity 'BimElement' consists of an attribute 'Name' and the entity 'Requirement' consists of the attributes 'Name', 'Subject', 'RelationshipName', 'Object', 'Cardinality', 'ReverseRelationshipname' and 'ReverseCardinality' (based on SE exchange standard (Bouw Informatie Raad (BIR) SE-BIM werkgroep, 2017)).

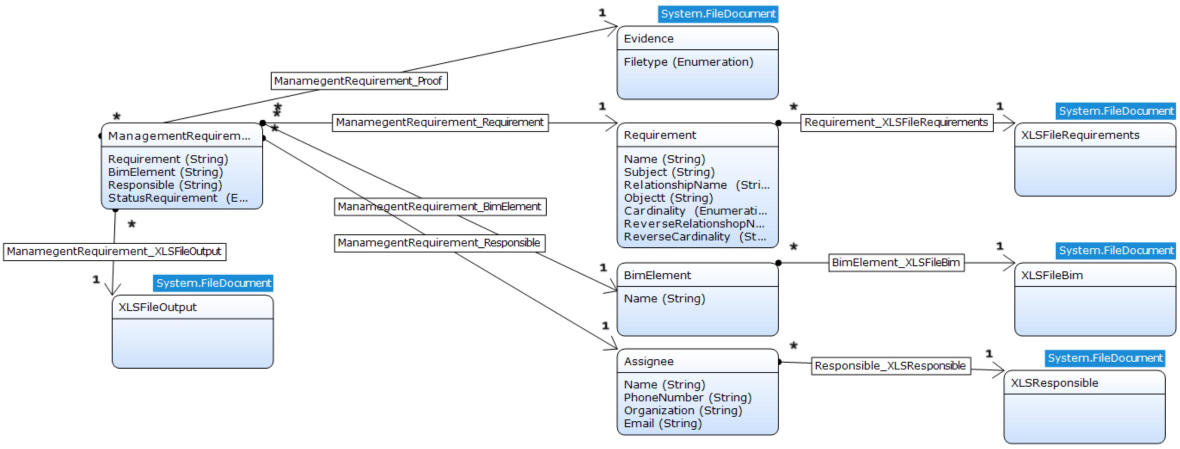


Figure 21: Domain model

An association describes a relation between entities. In the domain model, an association is represented by a line or arrow between two entities.

In XML, instances of these entities and their association are shown in Figure 22.

```
< Assignee id="101">
        <Name>Nisam_Shami</number>
        <PhoneNumber>06XXXXXXXX</PhoneNumber >
        <Organization>Hurks_Bouw_en_Vastgoedontwikkeling</Organization>
        <Email>n.shami@hurks.nl</Email>
< Assignee_ManagementRequirement>id_201</Assignee_ManagementRequirment>
</Assignee>
< Assignee_ManagementRequirement id="201">
        <Requirement>Requirement1</Requirement>
        <BimElement>BimElement1</BimElement>
        <Assignee>Nisam_Shami</Assignee>
        <StatusRequirement>completed</StatusRequirement>
</ManagementRequirement>
```

Figure 22: Example XML Assignee and Management Requirement

The XLS-entities in the domain model are used to import data in the tool. Paragraph 6.3.2. will discuss how data will be imported in the tool.

6.3.2 Import Data

In IFC, objects are assembled in BIM to define the building representations and for transferring of data and semantics among applications (Qin, 2011).

The data from the project Royal Cosun is used to import data in the tool. The IFC-file is a rich data model that can be used for reuiqrement checking and made use of open standard. That's why the tool uses IFC and Relatics data. However, all software that can output excel data is suitable for the tool. The basis for the implementation of data import in the tool are the Excel sheets from a IFC-file and SE-package (Relatics) as shown in Figure 23. This data is

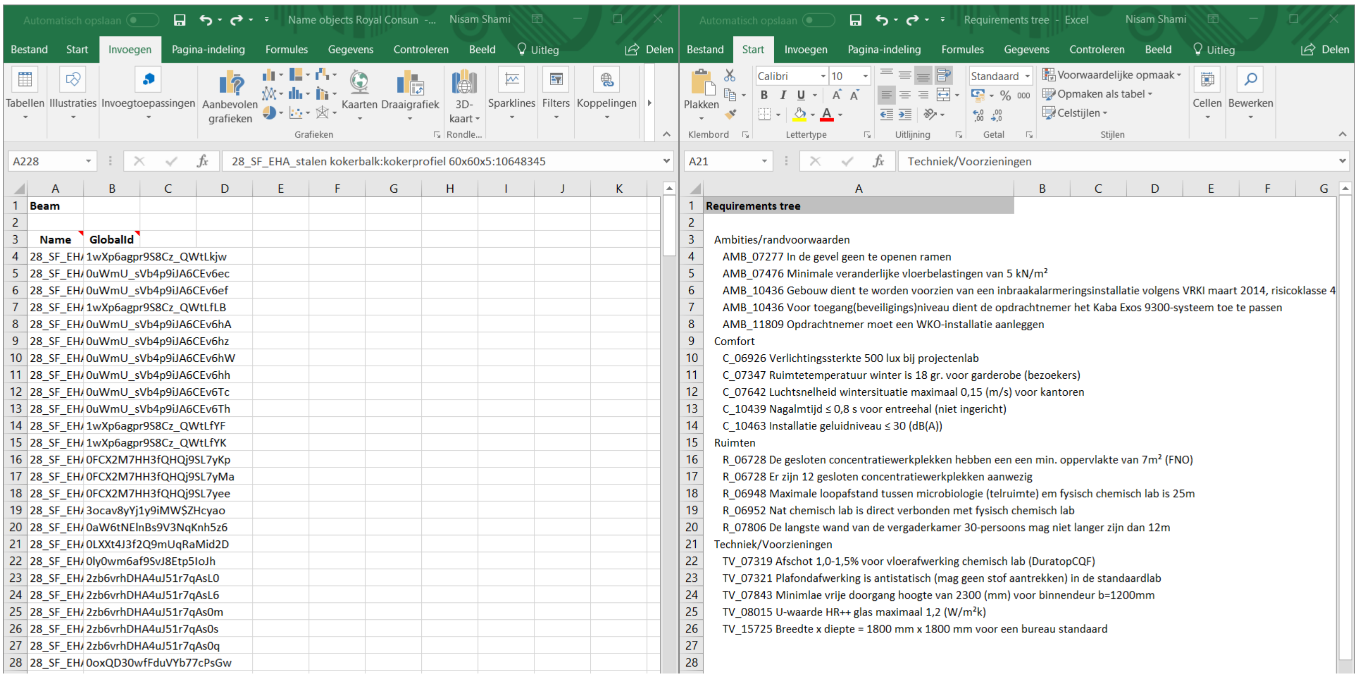


Figure 23: Data from IFC-file and SE package

generated by the use of “Tutorial from IFC data to an Excel file (Appendix B)” and “Tutorial from Relatics template to an Excel file (Appendix C)”. The IFC-file consists of 26 sheets of information on elements (4450 elements) and the Relatics-file consists of 1 sheet of requirements.

The status of each requirement in the tool can be ‘open’, ‘completed’ or ‘modified’. Figure 24 shows the microflow which is used to program this option.

Figure 24: Microflow “Status Requirement”

The end event of this microflow is shown in Figure 25.

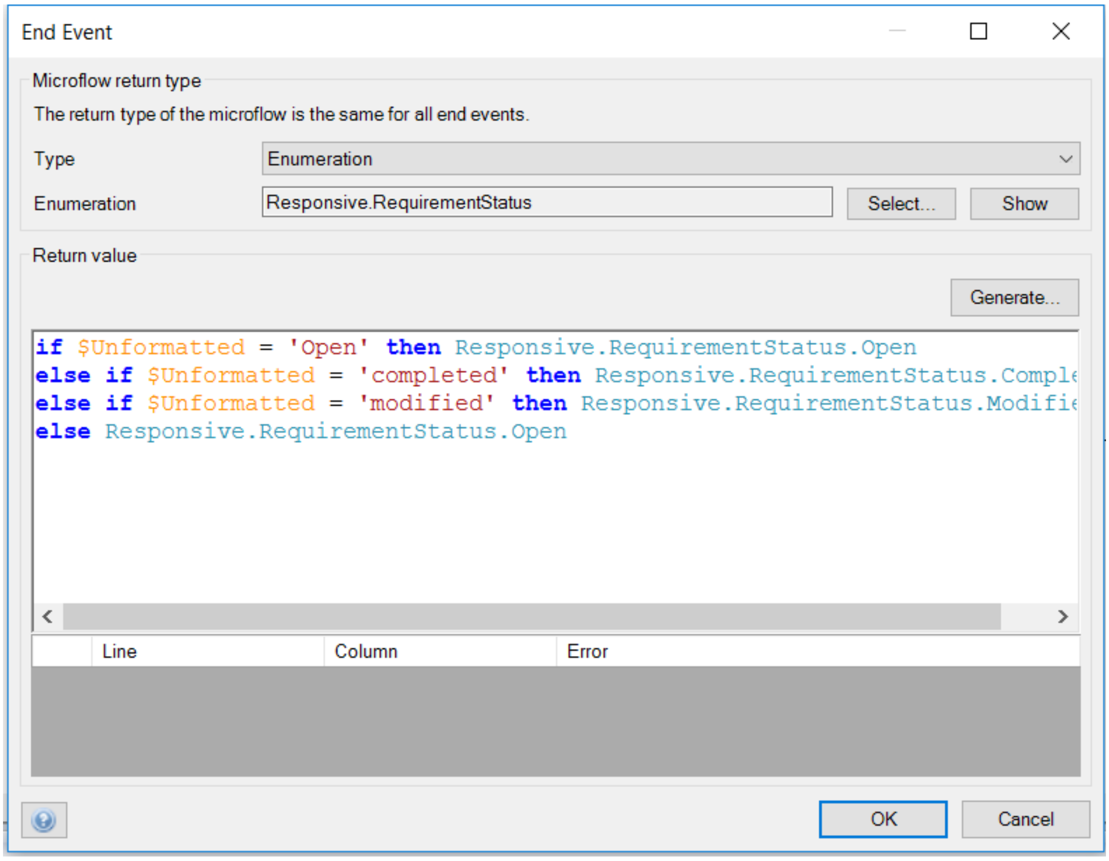


Figure 25: End even of the microflow "Status requirement"

For each sheet of information, a template is needed to import the data in the tool. The IFC-file consist of 26 sheets and the Relatics-file consists of 1 sheet. This provides a total of 27 templates needed.

The templates for the IFC-data and Relatics-data needed to be imported to ensure each template delivers data from the Excel file in the tool.

After each template are imported, the data is ready to be used in the tool. The data of the project Royal Cosun proves 4450 IFC-elements 24 requirements from Relatics to be used.

6.3.3 Data exchange

Appendix F provides a BPMN-diagram of the data exchange within the. The data exchange starts with the wishes of the customer. The contractor need to convert these wishes into measurable requirements (see chapter 3.3). Based on these measurable requirements a design is developed. After extracting data from the requirements (SE) and IFC-file (BIM), the data is ready to be uploaded in the tool. To comply with the quality assurance law, the assignee and evidence is uploaded to proof each requirement. The tool will depend on the delivered data and the previously made agreements in the project. If the elements in the IFC and the requirements in a SE software package are provided with the correct coding, the tool will be more transparent and easier to manage. The requirements are ready to be managed by selecting the corresponding IFC-element, assignee and evidence. Finally, a private account will be provided to all end users to log in and use the tool.

6.4. Results

The results of the literature study are shown in chapter 5. The literature review gives understanding to the relationship between BIM and System Engineering and the effect of the new Quality Assurance law on the relationship between BIM and System Engineering. This chapter provides the results of the tool which connects BIM, SE and the QAL.

Based on the four classes of functionality a requirement checking system should support from Eastman (2009) a data integration platform is developed. All parts of the tool are discussed and explained below.

The page "Project Overview" provides an overview of all ongoing project in the organization. As shown in Figure 26, each project consists of specific data for a specific project.

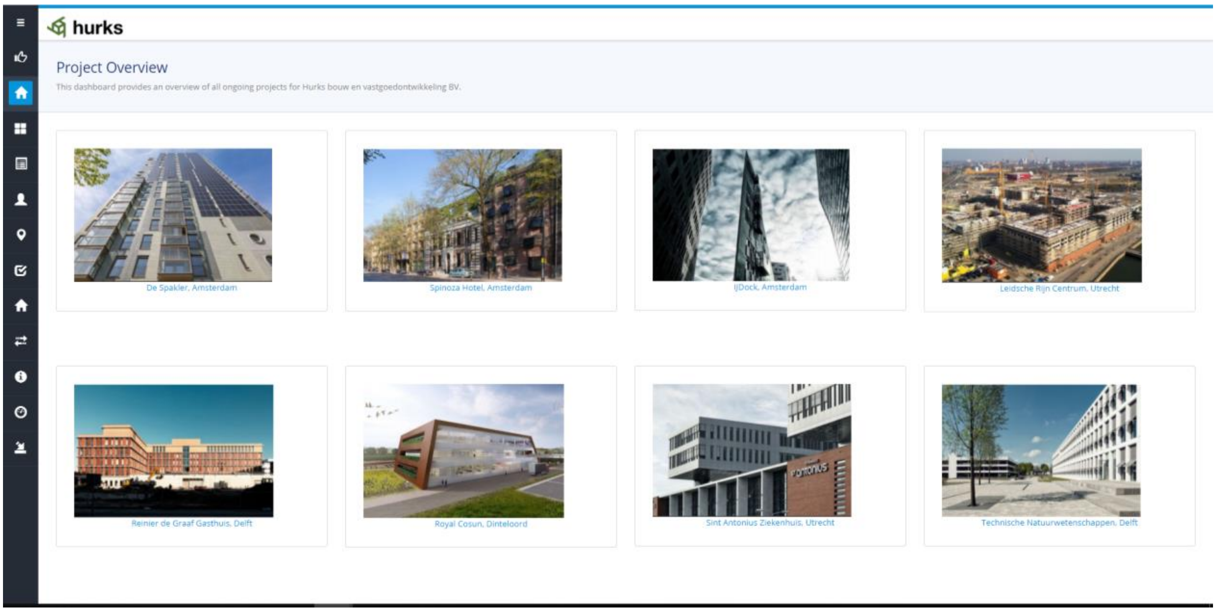


Figure 26: Home – Project Overview in the tool

A dashboard is an overview that can host a collection of widgets, see Figure 27. A dashboard allows the user to organize these widgets. The user can view information in the widget "Projectdetails" and "How-to?", add information in the widgets "Assignee" and "Evidence" and upload information in the widgets "Requirements" and "BIM-elements". The added and uploaded information can be managed in the widget "Mange requirements".

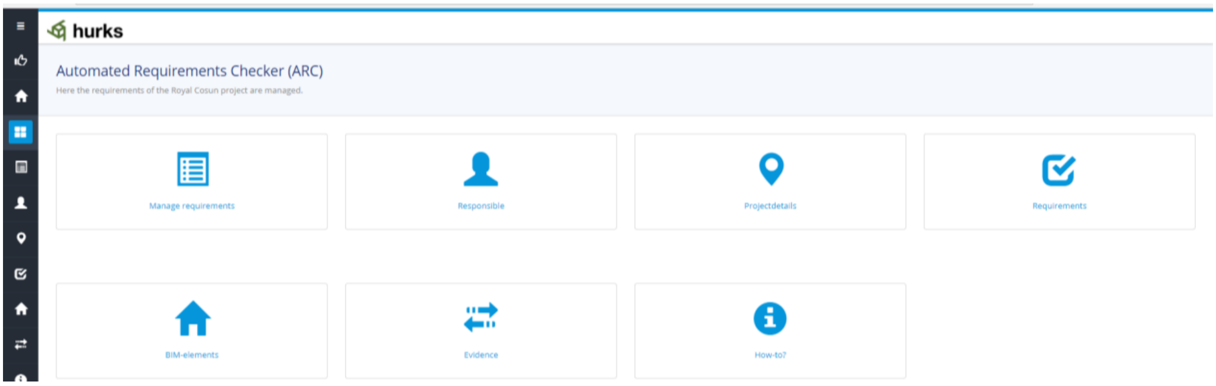


Figure 27: Dashboard in the tool

The added an uploaded data come together on the page “Manage Requirements”. Here the requirements of the project are managed. The page shows an overview of all requirements with the corresponding (uploaded) elements, (added) assignee and (added) evidence as illustrated in Figure 28.

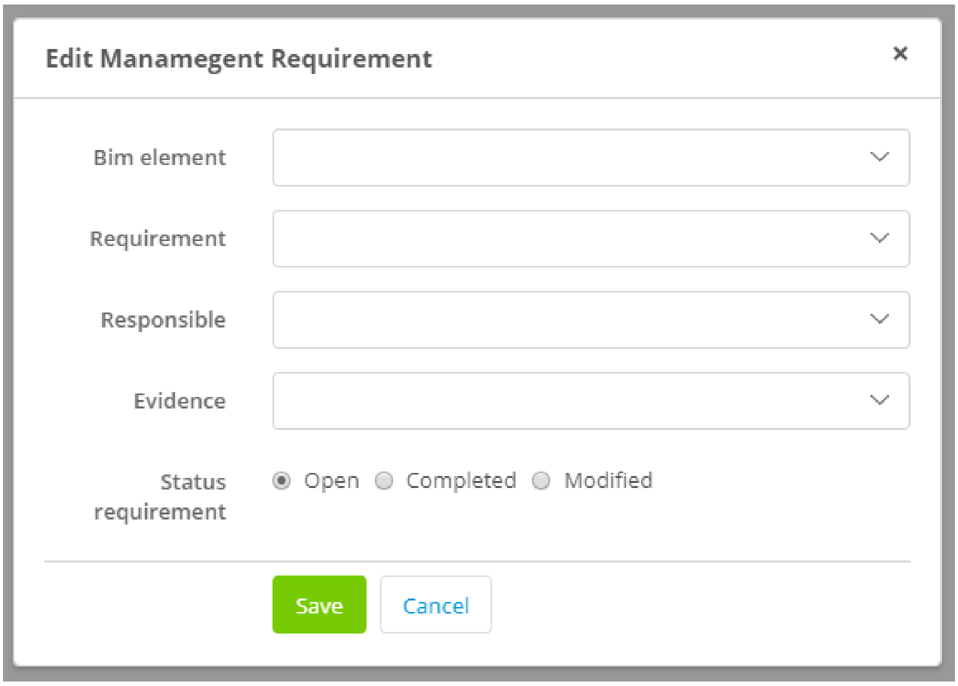


Figure 28: Management Requirements in the tool

The page “Assignee” presents an overview of people who are responsible for the unique requirement. The name, phone number, organization and e-mail of each assignee is will be uploaded.

The page “Project details” offers details about the unique project, in this case the project Royal Cosun. Details are given about the place, contacts and contract etc. (see Figure 29).

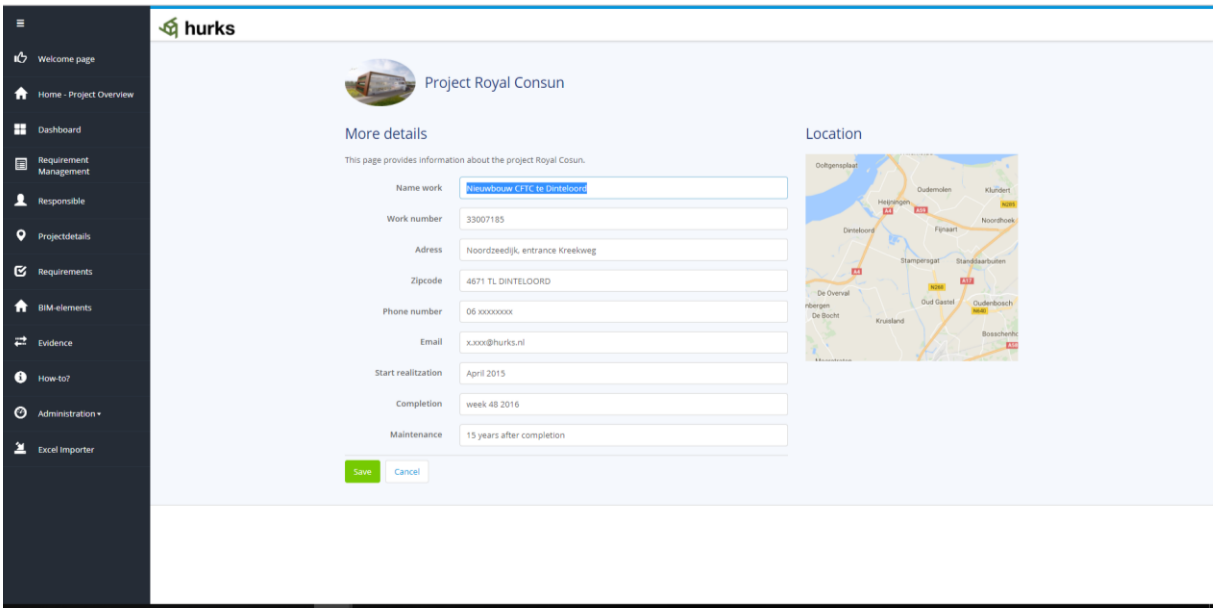


Figure 29: Project details in the tool (Royal Cosun)

Imported requirements are shown on the page “Requirements”. The page offers an overview of the imported data from Relatics. The imported data will be shown as a drop-down option in the page “Manage Requirements”.

The page “BIM-elements” presents an overview of the imported data from the IFC-file. The elements are shown as a drop-down option to manage the requirements.

Each individual requirement must be proven. In the page “Evidence” an overview of the evidence to prove the unique requirements are shown (see Figure 30). The evidence can be uploaded in the filetype .pdf, .wrd, .xls, .rvt, .ifc and .dwg. The quality assurance law is here represented. This shows the contractor that the building is compliant with the regulations.

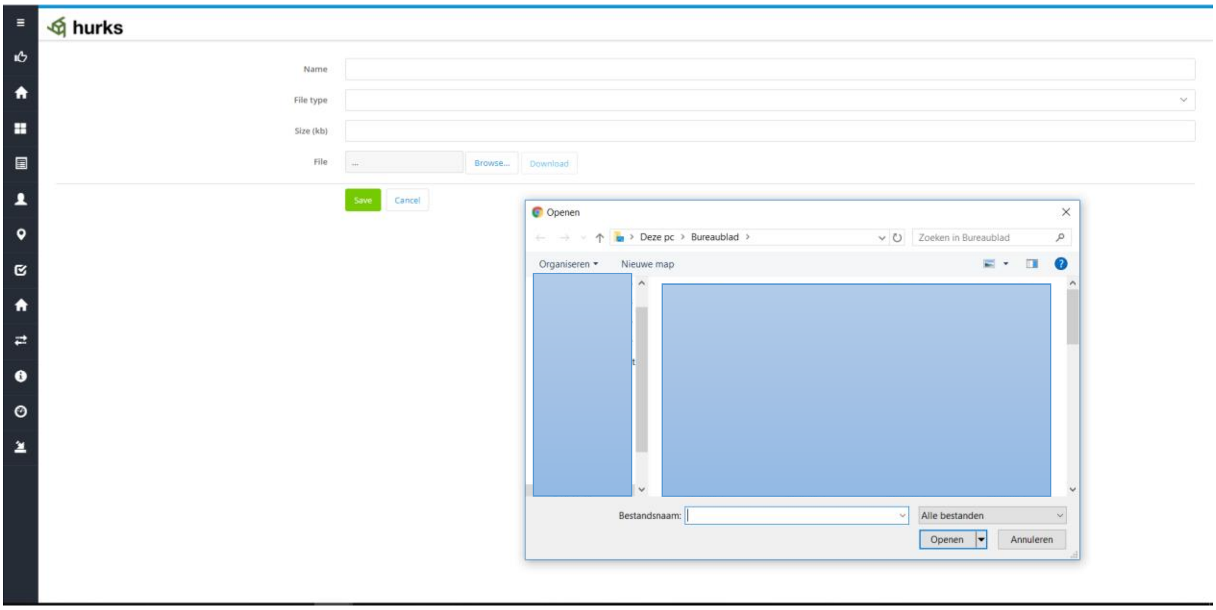


Figure 30: Adding evidence in the tool

The tool has a page to show how to generate date from IFC and Relatis files (Figure 31). These help pages will always be available to the user. If other IFC tools and SE tools are used to generate data, these tutorials will also be added

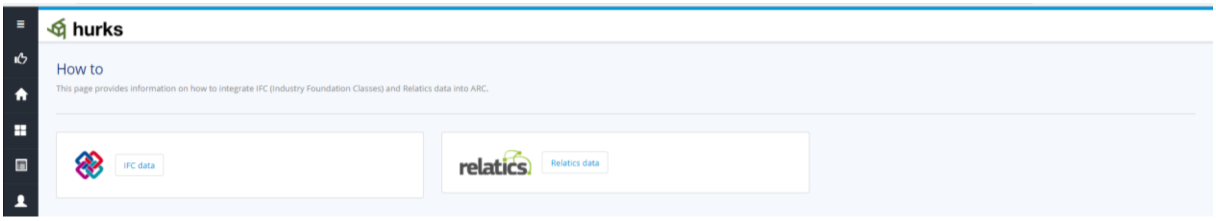


Figure 31: How-to? in the tool

The IFC to Excel tutorial explains in four steps, shown in Figure 32, how to select the right properties and generate the needed Excel-file.

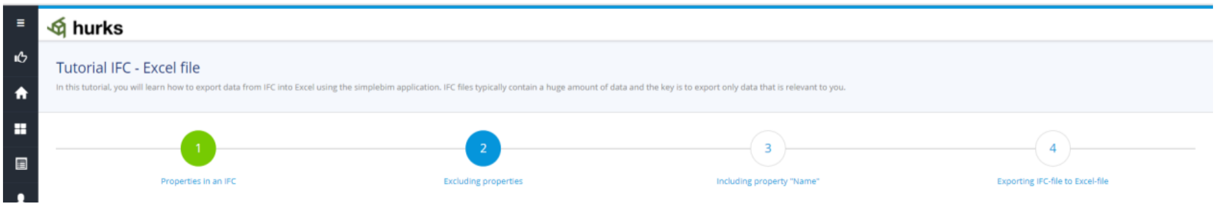


Figure 32: Tutorial IFC - Excel file in the tool

The Relatics to Excel tutorial explains in three steps, illustrated in Figure 33, how to select the right workspace and output the needed Excel-file.

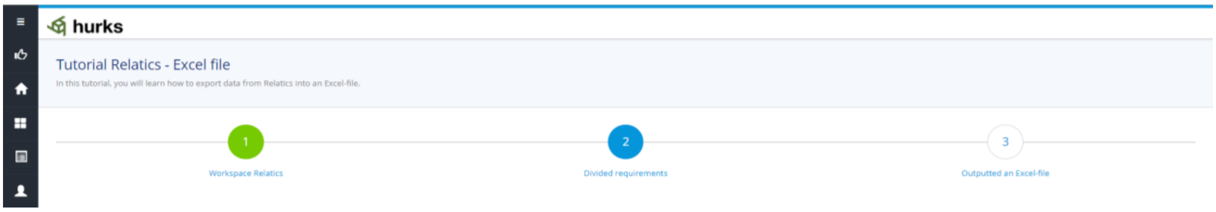


Figure 33: Tutorial Relatics - Excel file in the tool

The tool provides an option to create new users and to make unique accounts for users and administrators (based on the input from the interview from Appendix E). As shown in Figure 34, the tool provides the option to add a new local user, give the account and a user role (user or administrator) and a log of the adjustments and log-in times are kept.

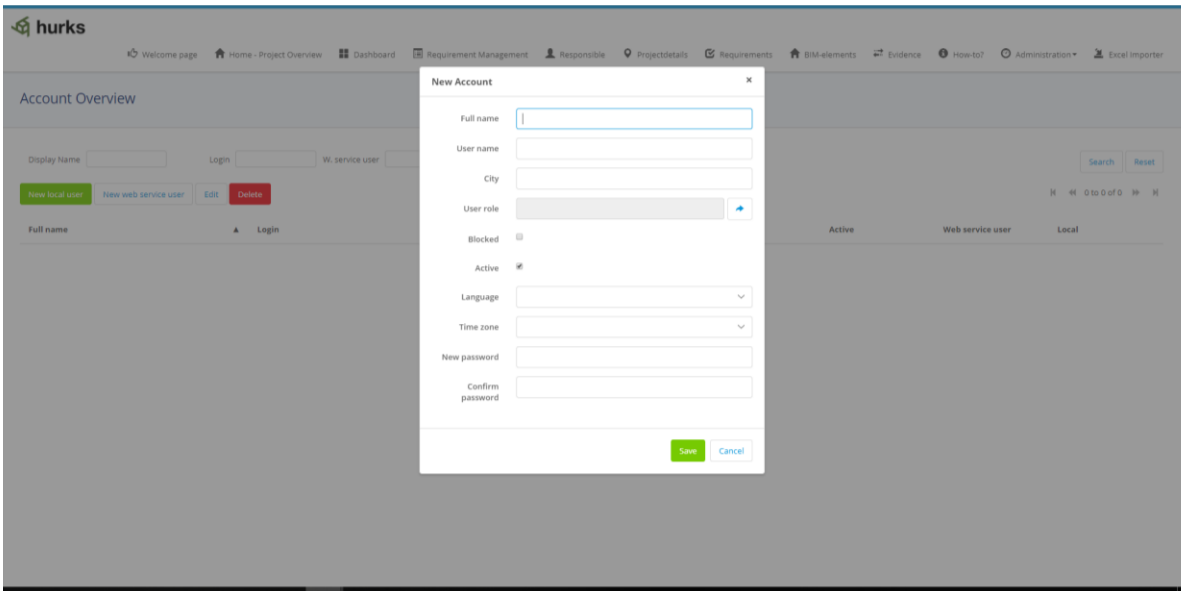


Figure 34: Administration in the tool (adding a new account and user)

There is a difference in the accounts user and administrator. The user doesn't have access to all the pages (overview of all projects and import of data) and the user doesn't have the option to adjust the tool. He/she just have the option to view pages in the tool.

The tool can be used on desktop, tablet and phone as shown in Figure 35. This ensures that the tool is always at hand and can be used at the construction site (with a tablet) and on the go (with a telephone).

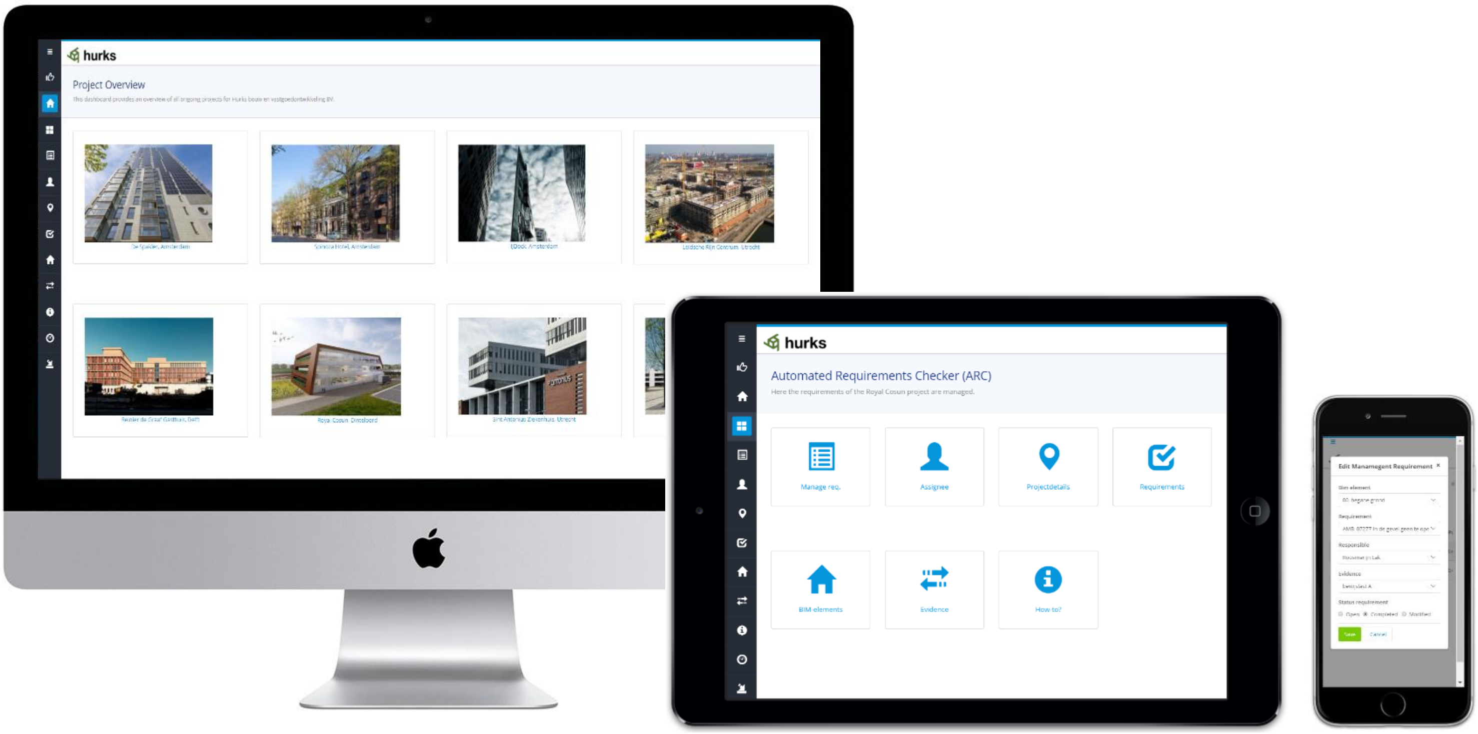


Figure 35: The tool presented on desktop, tablet and phone

7. Conclusion

The main subject of the thesis is a tool based on BIM, SE and the QAL, within this subject the thesis is focused on the exchange of data. This chapter presents the conclusions on the results and findings of the research. The needed information gathered by performing a literature review, interview and visual programming to create the tool. The information is used to answer the main question and sub questions of this research.

Construction projects are becoming increasingly complex and customers are demanding more, but there are concerns about the poor performance of the construction industry. A solution to this problem is a tool based on the concept of Building Information Modeling, Systems Engineering and the Quality Assurance Law.

This problem definition resulted into the following main research question:

> *"How can the validation and verification of requirements for construction works be visualized in phase 2 and 3 of the System Engineering process (definition/design/ development/implementation), based on open standards and software (visual programming)? And how can this be documented based on the Quality Assurance act?"*

In order to be able to answer this question the research has provided answers to the research questions. The conclusions of the research and answers to the individual research questions (see 1.3) are respectively found in Chapter 3.5 (question 1, 2, 4, 5), Chapter 4.2 (question 3), Chapter 6.2 (question 6) and Chapter 6.4 (question 7 and 8).

BIM can be seen as a form of collaboration between multiple organizations, representing different disciplines. Each discipline is supported by its own software applications, therefore, shared data platforms based on open standards are required to enable communication amongst stakeholders. System Engineering is an interdisciplinary approach and suitable to support BIM in each contract form and collaboration between different disciplines. SE and BIM are systemic thinking, a total approach, of the early definition of customer requirements and the technical integral approach. The Quality Assurance law can easily be implemented within SE and BIM and the Quality Assurance law can be applied in Dutch construction with minimal costs and a cost saving. The task at hand for the construction industry is to improve (expand) their workflow and, even further down the line, transform their workflow into the principles of SE, BIM and the QAL.

The literature review identified various methods to verify the validation and verification of requirements for construction works. However, but this has not yet resulted in an easy-to-use outcome for practice which is based on BIM, SE and the QAL.

Therefore, a data integration platform is developed. The method should be user friendly, verify the completeness of objects on instance level and make use of open standards. Standardized formats, such as a SE uitwisselingsstandaard, can be used to describe the requirements of the BIM. The tool enables users to upload IFC and SE data (all software that can output excel data is suitable for the tool) into the tool. All parties are kept informed by creating a user account with unique login details within the tool.

7.2 Scientific relevance

According to the theory, the advantages of applying BIM and SE is huge. But on the other hand, there is resistant against the implementation of BIM and SE. The developed platform could be used for the connection between practice and theory. Stakeholders (see Appendix D) from company has assessed, based on the tutorial, that the developed tool is user-friendly.

7.3 Societal relevance

The findings of this study are useful for all parties involved in the definition, design, development and implementation phase of the project lifecycle.

For contracting/construction companies, it provides interesting new possibilities in dealing with one of the many construction topics that are monitored on a daily basis. According to J.M. Schouwenaar (see Appendix A) the quality assurance law will require contractors to proactively ensure the quality of their work. End-users should be able to verify specified requirements with the use of the elements of BIM. Contractors are struggling on how to deal with the QAL. The tool offers possibilities to deal with the burden of proof and to meet the QAL.

Clients and project developers have also an interest in the possible implications of this study, since the quality assurance law, ensure that the client's requirements have been met and allow for a smoother hand over process transitioning into the operation and maintenance phase of the project lifecycle.

The findings are also important to software developers and SE and BIM experts, encouraging them to consider further solution development to BIM and SE software.

7.4 Recommendation and future research

The tool should be further developed in the future. Firstly, a limitation of the tool is limited use of valuable data in an IFC-file. The tool now uses a limited amount of valuable information from an IFC file. Valuable information such as linked data and relations between the various objects in an IFC file should make the tool better in the future. In addition, an opportunity for development the tool is to make the generic tool more specific for use. It is possible to create microflows (similar to rulesets in Solibri) for requirements that often occur. Each administrator/company can develop a standard set of microflows.

Companies that will use the tool will have to take into account the applied coding within the company and in cooperation with other parties. Users of the tool will benefit from similar coding in the BIM process (IFC-file) and SE process (requirements).

In addition, contractors are reluctant to support the quality management system (investment in understanding and learning staff). Human behavioral attributes should be considered when implementing and maintaining a quality management system for effective total quality management (Natee, 2016). This thesis creates more awareness for quality management systems in general, by providing a tool to support the quality management systems and meet the regulations (QAL).

References

Aerle, M. L. (2015). *IFC Dataflow - An open framework for connecting BIM web services.* Eindhoven.

Azhar, S. (2011). Building information modeling (BIM): Trends, benefits, risks, and challenges for the AEC industry. *Leadership and management in engineering*, 241-252.

Barlow, J. (2000). *Innovation and learning in complex offshore construction projects.* Research Policy, 29(7), 973-989.

Bar-Yam, Y. (2003). When systems engineering fails - toward complex systems engineering. *Ieee International Conference on Systems Man and Cybernetics*, pp. 2021-2028.

BIMForum. (2016). *Level of development specification.*

Blanchard, B. S. (2006). *Systems engineering and analysis.* Englewood Cliffs: Prentice Hall.

Bouw Informatie Raad (BIR) SE-BIM werkgroep. (2017). *Systems Engineering uitwisselingsstandaard voor de Nederlandse bouwketen.*

Bryde, D. B. (2013). The project benefits of building information modelling (BIM). *International Journal of Project Management*, 31(7), 971-980.

Building Smart. (2018, januari 2). Retrieved from http://www.buildingsmart-tech.org/.

Buildingsmart. (2017, september 17). *IFC Introduction*. Retrieved from http://www.buildingsmart.org/about/what-is-openbim/ifc-introduction/

BuildingSMART. (2017, September 15). *Open Standards - the basics*. Retrieved from http://www.buildingsmart.org/standards/technical-vision/open-standards/

Calvano, C. &. (2004). Systems engineering in an age of complexity. *Ieee Engineering Management Review*, pp. 29-38.

Cobouw. (2017, Juli 4). *Bizar bouwdebat in Eerste Kamer: 'privaat' bouwtoezicht terug bij af*. Retrieved from https://www.cobouw.nl/bouwbreed/nieuws/2017/7/bizar-bouwdebat-eerste-kamer-privaat-bouwtoezicht-terug-bij-af-101250413

Cobouw. (2017, februari 15). *NVM: kosten nieuwbouwwoning stijgen door nieuwe bouwwet*. Retrieved from https://www.cobouw.nl/woningbouw/nieuws/2017/2/nvm-kosten-nieuwbouwwoning-stijgen-door-nieuwe-bouwwet-101172426

Damiani, E. A. (2009). *Open source systems security certification.* New York: Springer.

Eadie, R. B. (2013). BIM implementation throughout the UK construction project lifecycle: An analysis. *Automation in Construction*, 145-151.

Eastman, C., Lee, J., Jeong, Y., & Lee, J. (2009). Automatic rule-based checking of building designs. *Automation in Construction, 18*(8), 1011-1033.

Eastman (2011). BIM handbook : A guide to building information modeling for owners, managers, designers, engineers and contractors (2nd ed. ed.). Hoboken, NJ: Wiley.

Eerste Kamer der Staten-Generaal. (2017, Juni 29). Retrieved from Wet kwaliteitsborging voor het bouwen: https://www.eerstekamer.nl/wetsvoorstel/34453_wet_kwaliteitsborging_voor#p1

EersteKamer. (2017, april). *eerstekamer*. Retrieved from https://www.eerstekamer.nl/wetsvoorstel/34453_wet_kwaliteitsborging_voor

Egmond, H. v. (2017). *Wet Kwaliteitsborging voor het bouwen - De stand van zaken...* Instituut bouwkwaliteit.

Eisner, H. (. (2008). *Essentials of Project and Systems Engineering Management (Vol. 3th).* John Wiley & sons, Inc.

Fricke, E. G. (2000). Coping with changes: Causes, findings, and strategies. *Systems Engineering*, 169-179.

Galiano-Garrigos, A. M. (2017). *Building Information Modelling (BIM) in Design, Construction and Operations II.* WIT Press.

Gemeente Den Haag. (2017). *Private kwaliteitsborging in Den Haag: nadelig voor bewoners.* Den Haag.

Green, T. R. (1996). Usability analysis of visual programming environments: a 'cognitive dimensions' framework. *Journal of Visual Languages & Computing 7.2*, 131-174.

Hammond, J. S. (2017). *The Forrester Wave™: Mobile Low-Code Development Platforms, Q1 2017.* Forrester.

Hardin, B. (2015). *BIM and construction management : Proven tools, methods, and workflows (Second edition/ed.).* Indianapolis: John Wiley.

He, Q. W. (2017). Mapping the managerial areas of building information modeling (BIM) using scientometric analysis. *International Journal of Project Management*, 35(4), 670-685.

Heidari, M. A. (2014). Smart-BIM virtual prototype implementation. *Automation in Construction, 39*, 134-144.

Hjelseth, E. &. (2010). Overview of concepts for model checking. *In Proceedings of the CIB W*, Vol. 78, p. 2010.

Huijnen, C. (2014). *Systems Engineering at Minicipalities with Relatics.* Faculty of Civil Engineering and Geosciences: Delft University of Technology.

Hull, E. J. (2011). *Requirements engineering (3rd ed. ed.).* London Springer.

Hurks, B. (2017). Retrieved from http://www.hurks.nl: http://www.hurks.nl/nl/over-ons/nieuws/hurks-imtech-bouwt-nieuw-cosun-food-technology-centre

INCOSE. (2017). *Wat is Systems Engineering?* Retrieved from https://www.incose.nl/

IPC voor architecten. (2012). *Detailniveau BIM per fase.* Woudrichem.

Jason Wong, V. L. (2017). *Magic Quadrant for Mobile App Development Platforms.* Gartner.

Kaynak, H. (2003). The relationship between total quality management practices and their effects on firm performance. *Journal of operations management, 21(4)*, 405-435.

Khemlani, L. (. (2005). CORENET e-PlanCheck: Singapore ' s Automated Code Checking System. *AECbytes, Building the Future*, 1–8.

Koning, E. S. (2016). MKBA wetsvoorstel kwaliteitsborging voor het bouwen. *Economisch Instituut voor de Bouw*.

Koorneef, S. (2014). *Samenwerking in DBFMO-projecten: Een onderzoek naar de samenwerking opdrachtgever en opdrachtnemer in DBFMO-projecten.*

Kossiakoff, A. S. (2011). *Systems engineering principles and practice (Vol. 83).* John Wiley & Sons.

Koutsos, T. M. (2016). *A novel method for assessing and mapping multiple impacts due to a technical construction project.* Landscape and Ecological Engineering.

Krechmer, K. (2006). *Open standards requirements - Advanced topics in information technology standards and standardization research.*

Kurniawan, B. (2000). *Internet programming with visual basic (Books for professionals by professionals).* Berkeley: Calif Apress. doi:10.1007/978-1-4302-1144-0.

Latiffi, A. A. (2014). The development of Building Information Modeling (BIM) definition. *Applied Mechanics and Materials*, 625-630.

Lee, Y. E. (2015). Validations for ensuring the interoperability of data exchange of a building information model. *Automation in Construction, 58*, 176-195.

Leidraadse. (2017). *Leidraad voor Systems Engineering binnen de GWW-sector*. Retrieved from https://www.leidraadse.nl/

Low, S. (2014). *Project quality management : Critical success factors for buildings.* Singapore: Springer.

Lu, W. F. (2014). Cost-benefit analysis of building information modeling implementation in building projects through demystification of time-effort distribution curves. *Building and Environment*, 317-327.

Migilinskas, D. P. (2013). The benefits, obstacles and problems of practical bim implementation. *Procedia Engineering*, 767-774.

Moser, H. A. (2014). *Systems Engineering, Systems Thinking, and Learning: A Case Study in Space Industry.* Springer.

NASA . (2007). *Systems Engineering Handbook.* Hanover.

Natee, S. L. (2016). *Quality function deployment for buildable and sustainable construction.* Singapore: Springer.

National Institute of Building Sciences. (2017, Juni 29). *Frequently askes questions about the naional BIM standard-United States*. Retrieved from https://www.nationalbimstandard.org/faqs#faq1

Ng, S. (2005). Performance of engineering consultants in iSO 9000-based quality management systems implementation. *Engineering, Construction and Architectural Management, 12(6)*, 519-532.

Nieman, S. L. (2016). *Quality assurance in the building process: The consequences of the new quality assurance act for the building process in relation to SE and BIM.* Eindhoven: Technische Universiteit Eindhoven.

Nijssen, E. (2014). *Entrepreneurial Marketing: An Effectual Approach.* Routledge.

Omgevingsweb. (2017, Juli 4). *Wet kwaliteitsborging voor het bouwen gaat in 2018 niet door. Moet vrijwel zeker aangepast worden en terug naar Tweede Kamer.* Retrieved from http://www.omgevingsweb.nl/nieuws/wet-kwaliteitsborging-voor-het-bouwen-gaat-in-2018-niet-door-moet-vrijwel-zeker-aangepast-worden-en-terug-naar-tweede-kamer

Oraee, M. H. (2017). Collaboration in bIM-based construction networks: A bibliometric-qualitative literature review. *International Journal of Project Management*, 1288-1301.

Paul Vincent, V. L. (2017). *Magic Quadrant for Enterprise High-Productivity Application Platform as a Service.* Gartner.

ProRail. (2015). *Handboek Systems Engineering (SE) Overzicht in processen, informatie en technieken.*

Qin, L. D. (2011). Industry foundation classes based integration of architectural design and structural analysis. *Journal of Shanghai Jiaotong University (science)*, 83-90.

Quality of Laws. (2017, september 20). *Quality assurance programs for laws*. Retrieved from http://www.qualityoflaws.com/elements-of-a-solution/quality-assurance.aspx

Relatics. (2017, augustus 20). Retrieved from Information is yours: https://www.relatics.com/product/

Rijksvastgoedbedrijf. (2017, september 8). Retrieved from RVB BIM Norm: https://www.rijksvastgoedbedrijf.nl/expertise-en-diensten/b/building-information-modelling/rvb-bim-norm

Rijkswaterstaat. (2013). *Leidraad voor Systems Engineering binnen de GWW-sector (versie 3).* Grafisch Bedrijf Bokhorst, Nunspeet.

Rijkswaterstaat. (2017, september 8). Retrieved from Bouwwerk Informatie Management: https://www.rijkswaterstaat.nl/zakelijk/werken-aan-infrastructuur/efficienter-werken/bouwwerk-informatie-model/index.aspx

Royal Consun. (2017, november 8). Retrieved from https://www.cosun.nl/Over-Cosun.aspx

Sbrcurnet. (2017, september 6). *Bim*. Retrieved from http://www.sbrcurnet.nl/bim

Sheard, S. (2009). Principles of complex systems for systems engineering. *Systems Engineering*, 295-311.

Solihin, W. E. (2015). Toward robust and quantifiable automated iFC quality validation. *Advanced Engineering Informatics, 29(3)*, 739-756.

Solihin, W., & Eastman, C. (2015). Classification of rules for automated bIM rule checking development. *Automation in Construction, 53(8)*, 69-82.

Sullivan, K. (2014). Quality management programs in the construction industry: best value compared pared with other methodologies. *Journal of Management in Engineering, 27(4)*, 210–219.

Teicholz, P. (2013). *BIM for facility managers.* John Wiley & Sons.

The International Council on Systems Engineering (INCOSE). (2017, juni 29). *What is Systems Engineering?* Retrieved from http://www.incose.org/AboutSE/WhatIsSE

U.S. department of transportation federal highway administration. (2017). *Description of the Life cycle Model*. Retrieved from https://www.fhwa.dot.gov/cadiv/segb/views/document/sections/section3/3_1_1.cfm

van Gulijk, S. (2015). Laat verwachtingen geen bron voor teleurstellingen zijn. *Nederlands Juristenblad*, 552-559.

Weerink, J. J. (2016). *Verifying the completeness of building information models: Enhancing information completeness and control over BIM development processes.* Eindhoven: Technische Universiteit Eindhoven.

Werf, R. v. (2015). *Projectplan - Project Nieuwbouw CFTC – Royal Cosun.*

Woningborg, T. e. (2017). *Kwaliteitsborging - De toegevoegde waarde van Woningborg Toetsing en Toezicht.* Gouda.

Zhang, C. B. (2015). Interoperable validation for IFC building models using open standards. *ournal of Information Technology in Construction (ITcon)*, 24-39.

Appendix A: Interview Mr. J.M. Schouwenaar

Technische Universiteit Eindhoven, Graduation research
Interview: invloed Wet kwaliteitsborging voor het bouwen (34.453)
Interviewer: Nisam Shami
Naam geïnterviewde: Mr. J.M. Schouwenaar (VVD) (lid van de VVD-fractie in de Eerste Kamer)
Datum afname: 18-07-2017
Locatie: Pastoor Petersstraat 3, 5612 WB Eindhoven (interview werd afgenomen via telefoon)

Hoofdvragen:

1. **Waarom is deze wet volgens u nodig?**

In deze Kamer worden wij opgevoed met ons af te vragen of er een probleem is of niet. Hierin waren wij (VVD) van mening dat er toch een probleem is, omdat het voor heel veel mensen lastig is dat de verantwoordelijkheid van de aannemer op het moment van oplevering ophoudt. Mensen hadden geen verhaal en konden achteraf moeilijk aantonen waar het fout was, aangezien alles bijvoorbeeld is dichtgemetseld. De aannemer wordt daarom scherper gehouden en moet beter zijn best doen. Een ander probleem, los van de oplevering, is dat het overzicht een beetje weg is. Hierin is niet duidelijk wie waarvoor aansprakelijk is. Als iets fout gaat dan wijst iedereen naar iedereen. Bijvoorbeeld een project in Middelburg, waar de damwanden het begaven. Daarom is het goed dat er een iemand (de aannemer) aansprakelijk is en hij het geld verhaalt op de onderaannemer via regresrecht. En het grootste verbeterpunt in ons ogen is dat de gemeentelijk bouw en woningtoezicht niks meer deden en dit nu wordt overgedragen aan de markt. De gemeenten brengen wel dure leges in rekening, nu komt de kwaliteitsborger (als onafhankelijk figuur) tijdens het bouwtoezicht houden. Dat was eerst formeel de opdracht van de gemeentelijke bouw en toezicht, maar die deden dat niet. Deze drie punten (vroeg stoppen aansprakelijkheid aannemer, iedereen wijst naar iedereen en gebrekkige controle gemeente) worden door deze wet aangepakt.

2. **Senator Bikker (ChristenUnie) stelde dat het borgen van kwaliteit en veiligheid een publiek belang is. De senator vroeg waarom niet is gekozen voor optimalisering van het huidige publieke stelsel in plaats van een hybride privaat/publiek toezicht mechanisme** (Omgevingsweb, 2017)**. Wat is uw antwoord daarop?**

Dit vergt veel ingrijpen van het Rijk bij de gemeentes. De Rijk zou hierdoor te veel op de stoel van de gemeente zitten. De Rijk kan de gemeentes ook niet dwingen om het geld aan bouwtoezicht te besteden.

3. **De Vereniging van Nederlandse Gemeenten vooralsnog kritisch en vindt het onuitvoerbaar voor gemeenten. Zij vinden bijvoorbeeld dat gemeenten moeten handhaven op zaken waarop zij niet langer toezicht houden, omdat ze wel verantwoordelijk blijven voor de gehele vergunning. Wat vindt u hiervan?**

Ik denk dat je doelt op de veiligheid. Zodra er iets fout gaat qua veiligheid kijkt iedereen naar de gemeente (zie Londen, Eindhoven of Middelburg). Zij vinden dat ze de verantwoordelijkheid hebben, maar niet de capaciteit of de knowhow om alles te checken en te controleren en in de gaten te houden. Dat is ten deel waar, want als het om bevoegdheden en veiligheid gaat hebben de gemeenten alle bevoegdheden die ze voor deze wet ook hadden. Ze blijven de mogelijkheid hebben om informatie op te vragen. Dit vind ik dus een onjuist geformuleerd argument.

4. **Het CDA vindt dat de wet veel te makkelijk allerlei aansprakelijkheidsrisico's op het bordje legt van bouwbedrijven. Vooral als bouwers te maken hebben met professionele opdrachtgevers** (Cobouw, 2017)**. Wat vindt u hiervan? Moet er hierin bijvoorbeeld een scheiding komen tussen professionele en niet-professionele opdrachtgevers?**

Daar ben ik het niet helemaal mee eens, want het gaat niet om een professionele opdrachtgever (bijvoorbeeld woningcorporatie of ziekenhuisbestuur) het gaat om de gebruiker (bijvoorbeeld patiënt of leerling). Die heeft de gevolgen daarvan als het werk niet in orde is en niet het bestuur van een corporatie of ziekenhuis. Een onderscheid maken in afnemer waren wij (VVD) het niet mee eens en dat amendement is ook verworpen in de Tweede Kamer en wat ons betreft terecht.

5. **Welke aanpassingen zijn er volgens u nodig om deze wet wel door te voeren? Hoe het aangepaste wetsvoorstel eruit gaat zien?**

Voor mij hoeft er niks veranderd te worden, wat mij betreft mogen de drie amendementen van Albert de Vries van de PVDA eruit. Deze drie zijn geschreven om ervoor te zorgen dat de gemeenten nog wat te zeggen heeft. Of het zover komt weten we niet. Links vindt het woord "privatisering" heel beangstigend. Het betreft geen privatisering, wat het is niet iets wat functioneert wordt overgedragen aan de markt. De overheid houdt namelijk nu geen toezicht en wat er niet is kan je ook niet privatiseren. Die markt gaat nu doen wat de overheid tientallen jaren had moeten doen.

6. **De Nederlandse Vereniging van Makelaars (NVM) is bezorgd over mogelijke extra kosten voor een nieuwbouwwoning als gevolg van de nieuwe Bouwkwaliteitswet. Uit onderzoek in de gemeente Voorst blijkt dat de leges voor een gemiddelde woning van € 4.000,- naar € 3.500,- zijn gedaald, terwijl de private kwaliteitscontrole kopers duizenden euro's extra kost** (Cobouw, 2017)**. Wat vindt u van het standpunt van de Nederlandse verenging van makelaars en wat denkt u dat nodig is om dit te voorkomen?**

De consument betaalt meer, maar krijgt ook meer. Eerst betaalde hij leges en daar kreeg hij geen toezicht voor (lichtelijk overdreven). En nu betaalt hij meer, maar krijgt hij ook wat. En vervolgens zouden de leges niet van €4000,- naar €3500,- moeten, maar wat mij betreft naar €0.-. Dat rechtvaardigt in mijn ogen een kostenstijging die overigens te niet gedaan zou moeten worden door een veel grotere legesdaling dan nu. De gemeentes zijn zeer terughoudend wat betreft legesverlaging.

7. **De conclusie van de gemeente Den Haag luidt: "Het uit elkaar trekken van ruimtelijke ordening en techniek in de vergunning leidt tot onduidelijkheid en daardoor tot een toename van trilling schade en illegale bouw"** (gemeente Den Haag, 2017)**. Wat vindt u hiervan?**

Ik weet niks van trilling schade of illegale bouw. Wat ik wel weet is dat één pilot in de gemeente Den Haag doorslaggevend is voor het wel of niet accepteren van deze wet. De gemeente Den haag is heel belangrijk, maar maken niet de dienst uit in het land. Er zijn nog 400 andere gemeenten die verenigd zijn in de VNG. Daarnaast zijn pilots juist bedoeld om te controleren wat er fout kan gaan en wat er ervan kunnen leren.

Appendix B: Tutorial from IFC data to an Excel file

In this tutorial, you will learn how to export data from IFC into Excel using the Simplebim application. IFC files typically contain a huge amount of data and the key is to export only data that is relevant to you.

A certain wall has 22 rows of information, see Figure 36. Figure 37 shows that each object has a lot of properties which produce a lot of information for example each wall.

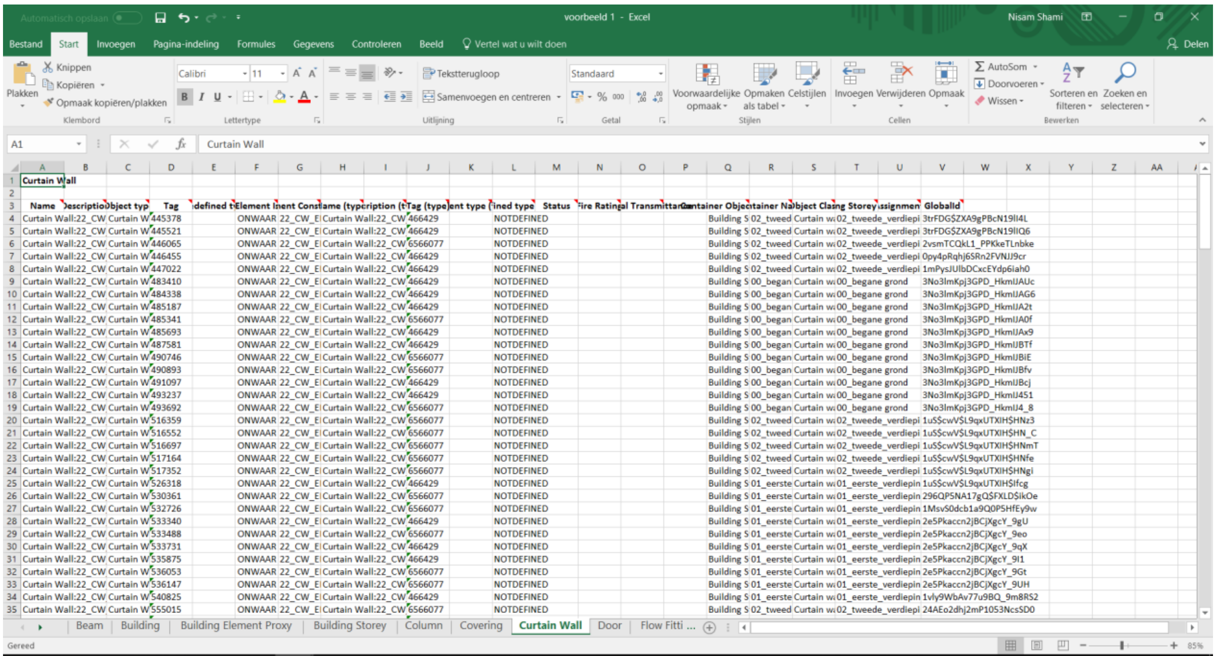


Figure 36: Huge amount of data in an IFC

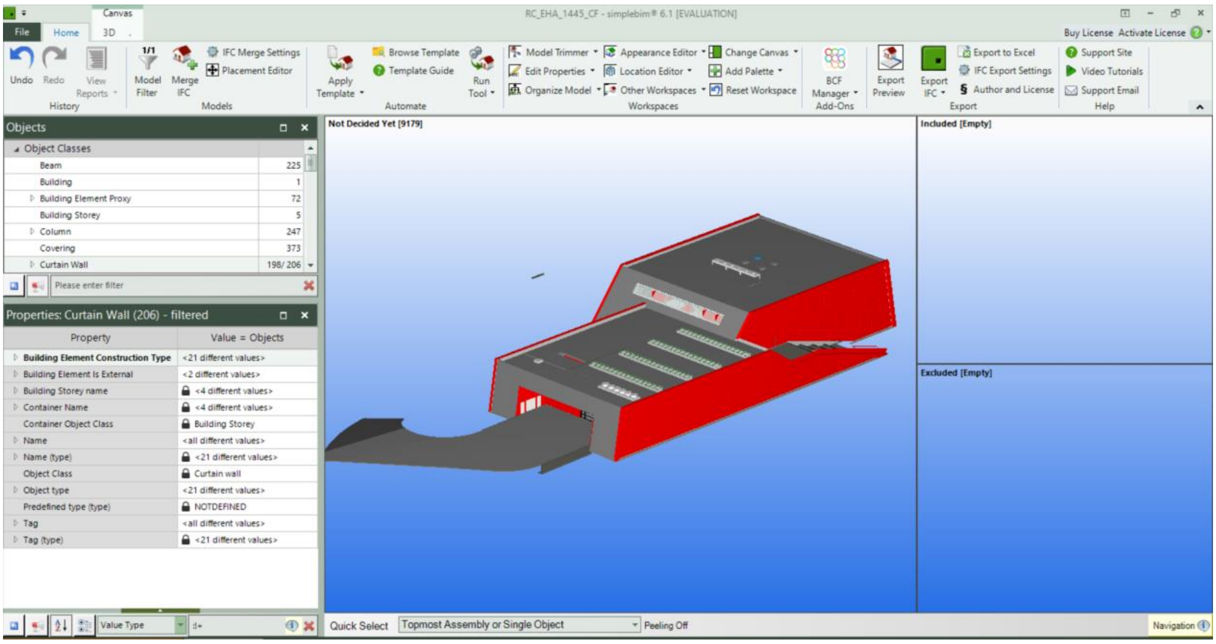


Figure 37: Properties from the objects in an IFC

To make sure to export only data that is relevant, all the properties need to be excluded (see Figure 38).

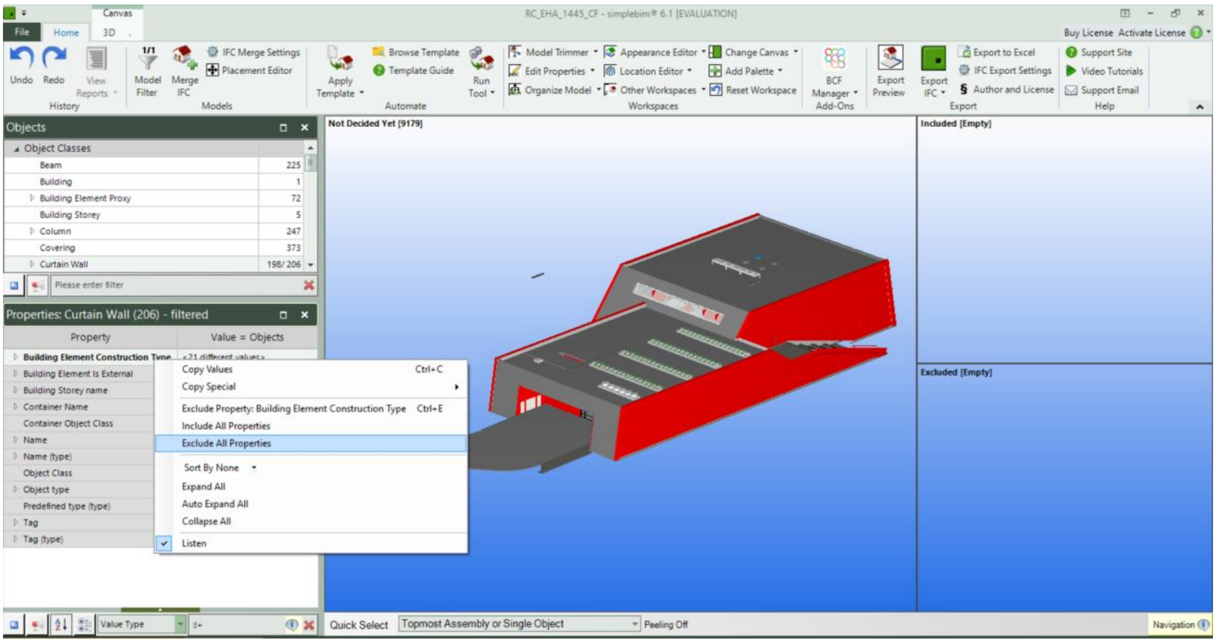


Figure 38: Excluding all properties from objects

Include the relevant properties which will be used, in this example include the property "Name" as shown in Figure 39.

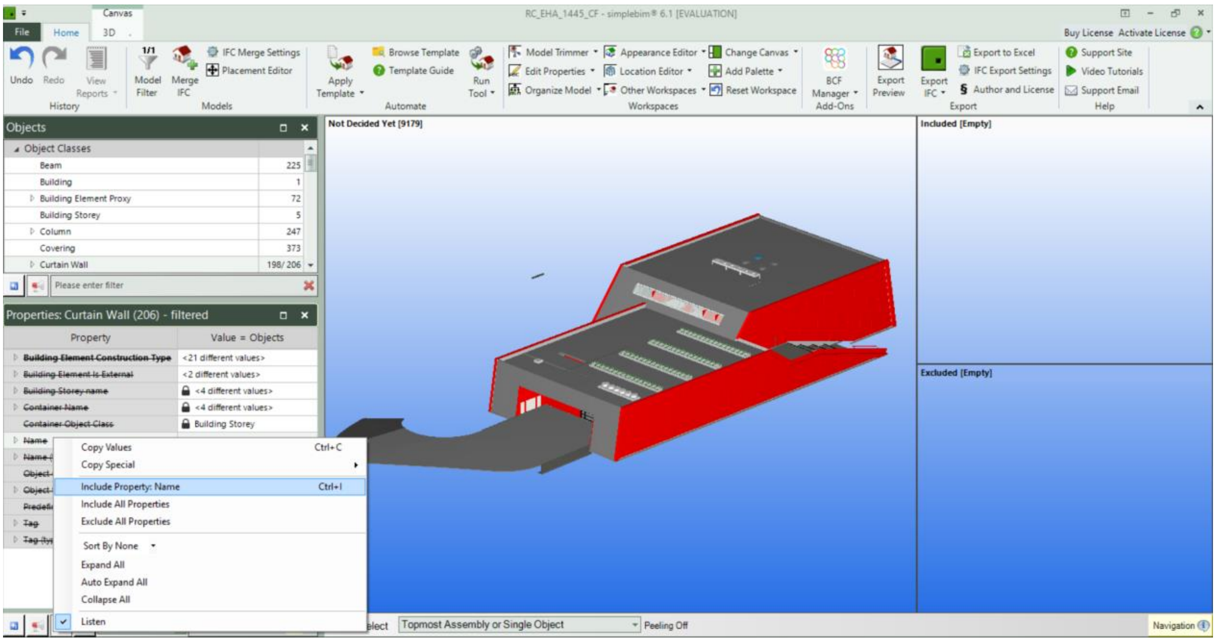


Figure 39: Including property "Name"

After selecting the right properties, the IFC-file needed to be export to an Excel-file (see red square in Figure 40). This creates a new Excel-file containing all included objects and properties. Each object class becomes a worksheet in Excel, each property a column and each object a row.

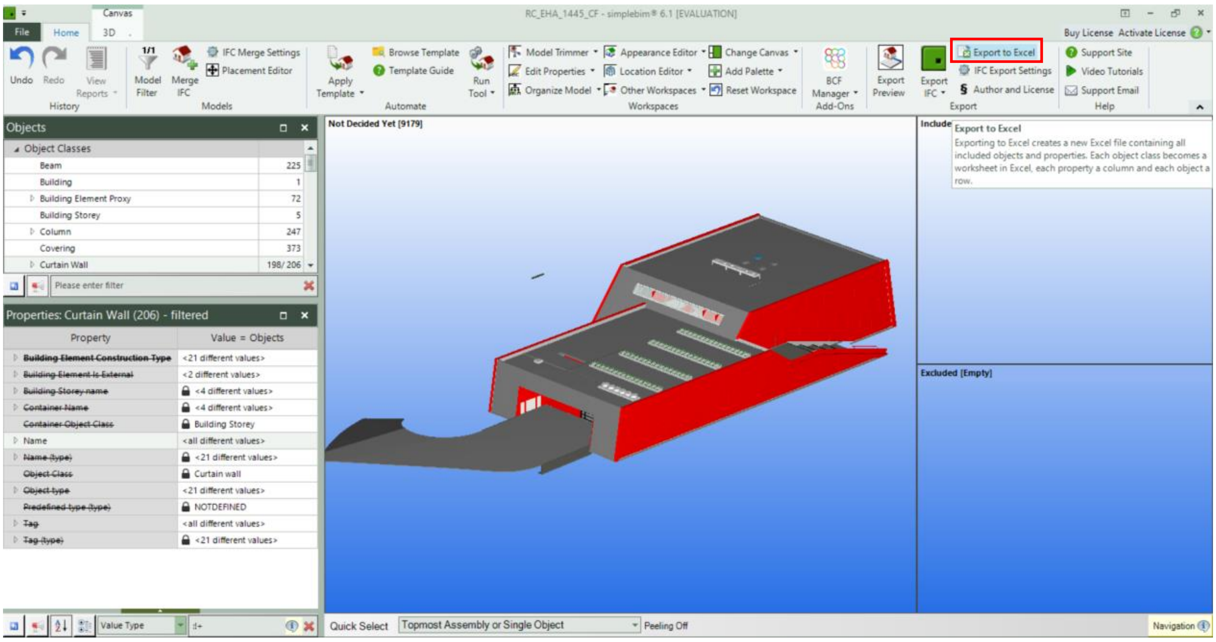


Figure 40: Exporting IFC-file to Excel-file

This results in an Excel-file with only the relevant data (see Figure 41).

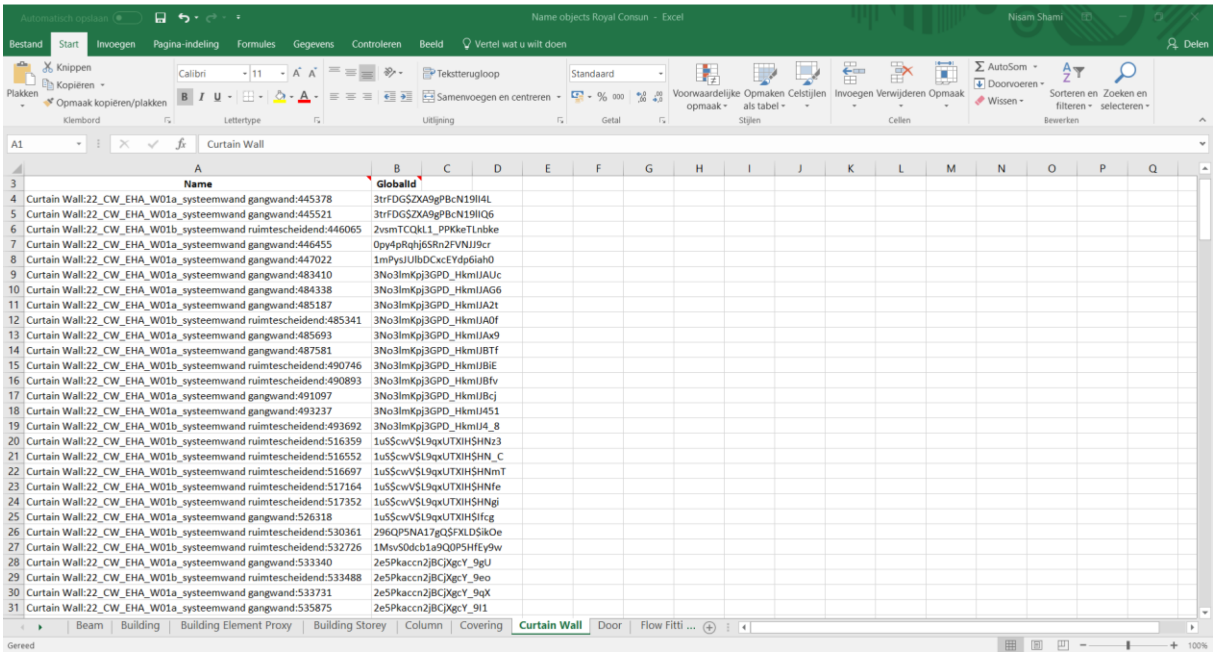


Figure 41: End result from IFC to Excel

Appendix C: Tutorial from Relatics template to an Excel file

This workspace will be used to test the automated validation and verification of requirements for construction works in a BIM using the requirements from the project Royal Cosun.
In this workspace, you can keep track of your project using system engineering techniques (see Figure 42).

In this workspace, you can document and manage your:

1. Function Breakdown Structure (FBS)
2. Organization Breakdown Structure (OBS)
3. Work Breakdown Structure (WBS)
4. System Breakdown Structure (SBS)
5. Meetings
6. Documents
7. Requirements

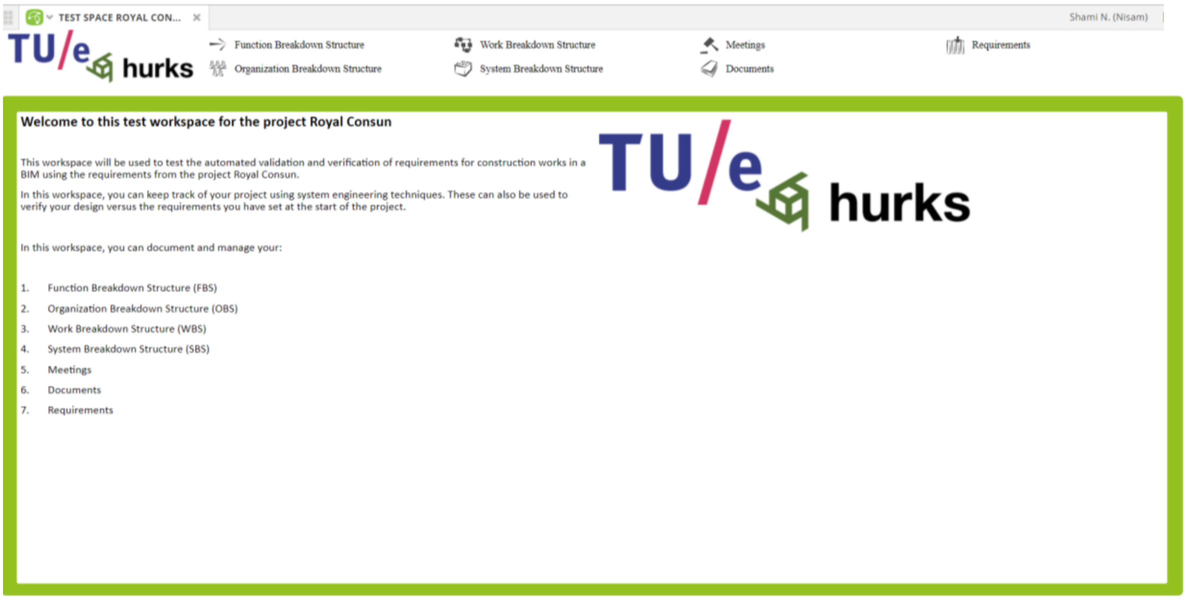


Figure 42: Home screen Relatics template for the projet Royal Cosun

During this project, the client divided all the requirements under the following chapters, as shown in Figure 43:
1. Ambitions / conditions
2. Rooms
3. Technology / Facilities
4. Comfort

Each requirement starts with AMB_, R_, TV_, C_ and followed by a specific number.

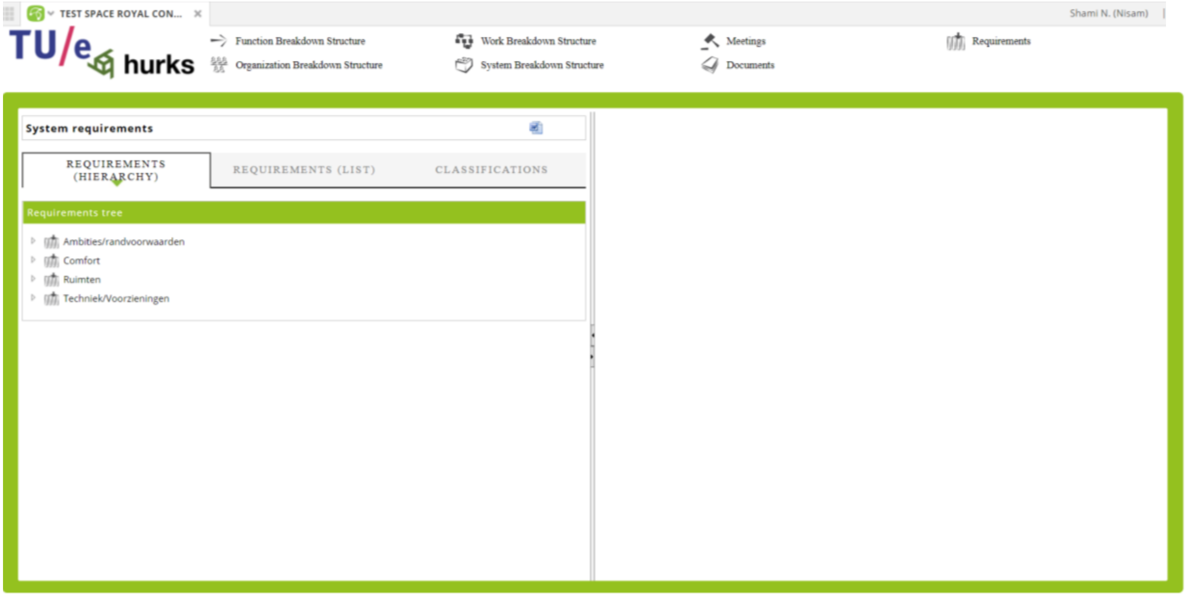


Figure 43: Distribution of all requirements in chapters

The requirements can be outputted to an Excel-file by right clicking the requirements tree and download the requirements tree as an "Excel web page (.xls)", see Figure 44.

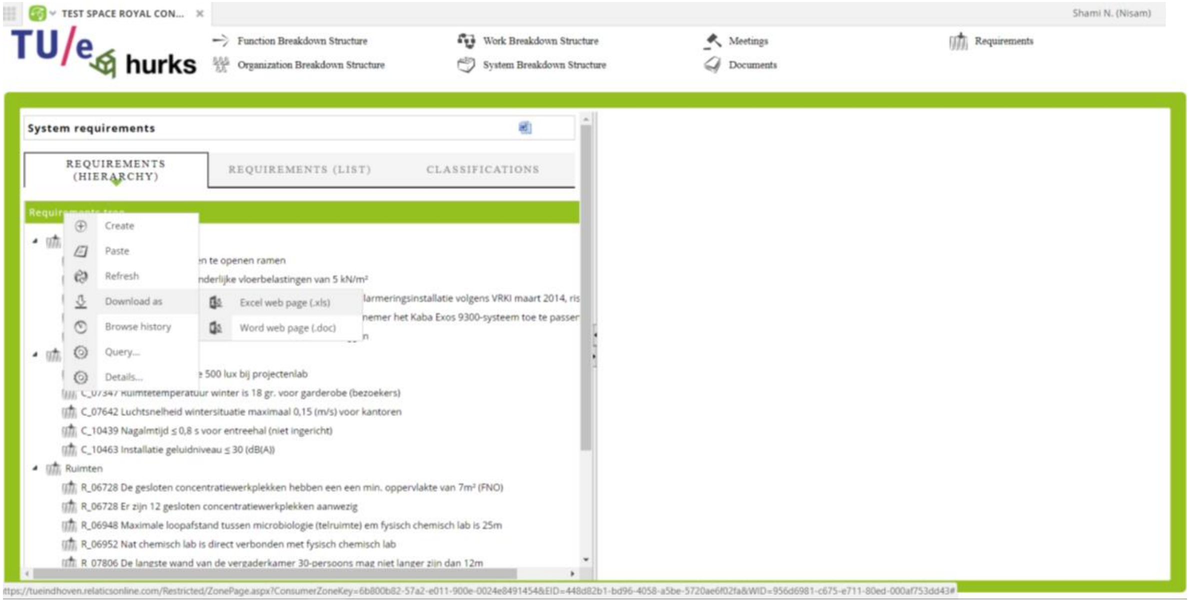


Figure 44: Download the requirements in Relatics into an Excel-file

The outcome (see Figure 45) is an Excel-file with all the requirements under their specific chapter.

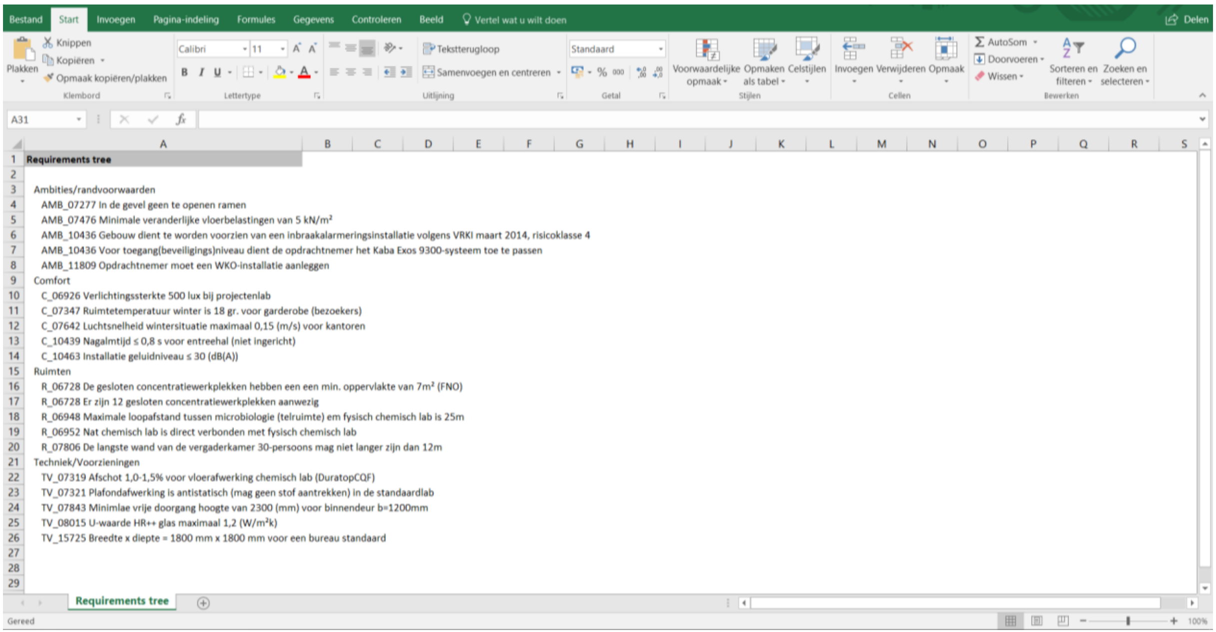


Figure 45: Outcome of requirements in an Excel-file

Appendix D: Interview R. Lak

Technische Universiteit Eindhoven, Graduation research
Interview: invloed Wet kwaliteitsborging voor het bouwen (34.453)
Interviewer: Nisam Shami
Naam geïnterviewde: Mvr. R. Lak (System Engineer/Planontwikkelaar Hurks bouw en vastgoedontwikkeling)
Datum afname: 07-12-2017
Locatie: Pastoor Petersstraat 3, 5612 WB Eindhoven

Het doel is om de te voorzien van gegevens en deze gereed te maken voor gebruik. Daartoe worden gegevens (IFC-model en eisen in Relatics) van het project Royal Cosun gebruikt.
Tijdens deze tutorial zal R. Lak dienen als een system engineer (de persoon die de tool voorbereidt) en als eindgebruiker. R. Lak zal eerst gegevens genereren van het IFC-model en Relatics, vervolgens de gegevens in de tool controleren en implementeren, voorbereiden op gebruik en uiteindelijk de tool als eindgebruiker gebruiken.

Hoofdvragen:

1. **Vond u de bijbehorende tutorial duidelijk?**

De tutorial was zeer goed te volgen en gaf genoeg ondersteuning voor een leek als ik. Graag zou ik willen zien dat er wat meer informatie wordt gegeven over waarom ik een handeling moet verrichten. Het is mogelijk om aan de hand van de tutorial de gewenste uitkomsten te verwezenlijken.

2. **Zou u de tool toepassen in een project?**

Indien deze werkwijze vanaf het begin van een project (contractueel) wordt vastgelegd, zou ik graag willen dat tool gebruikt word in toekomstige project van Hurks Bouw en Vastgoedontwikkeling.

3. **Welke aanpassingen ziet u graag?**

Graag zou ik willen dat er een onderscheid gemaakt wordt tussen de verschillende gebruikers van de tool. Ik als System Engineer zou graag meer bevoegdheden willen hebben dan neven/onderaannemer.

The goal is to provide the de tool with data and make it ready for use. To this end, data (IFC model and requirements in Relatics) of the project Royal Cosun is used.
During this tutorial R. Lak will serve as a System Engineer (the person who prepares the tool) and as an end user. R. Lak will first generate data from the IFC model and Relatics, then check and implement data in the tool, prepare it for use and finally use the tool as an end user.

Questions:

1. **Was the tutorial clear?**

The tutorial was very easy to follow and gave enough support for a layman like me. I would like to see that there is some more information about why I have to perform an action. It is possible to realize the desired results based on the tutorial.

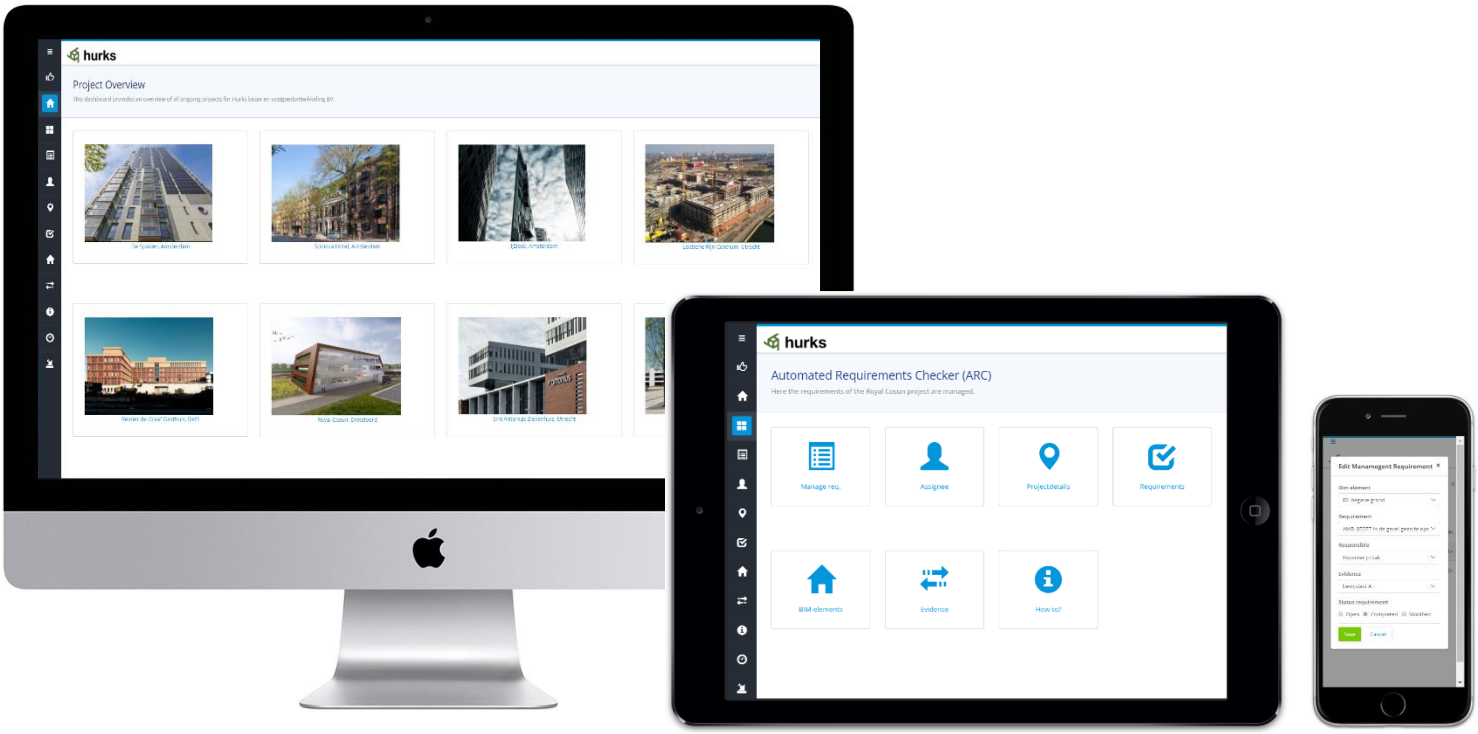
2. **Would you apply the tool in a project?**

If this method is (contractually) established from the start of a project, I would like the tool to be used in the future projects of Hurks Bouw en Vastgoedontwikkeling.

3. **What changes do you like to see in the tool?**

I would like to see a distinction made between the different users of the tool. I as a System Engineer would like to have more authorizations compared to subcontractor.

Appendix E: Tutorial Tool



The goal today is to provide the tool with data and make it ready for use. To this end, data (IFC model and requirements in Relatics) of the project Royal Cosun is used.

During this tutorial you will serve as a System Engineer (the person who prepares the tool) and as an end user. The steps are shown in bold and the actions are in italics.

You will first generate data from the IFC model and Relatics, then check and implement data in the tool, prepare it for use and finally use the tool as an end user. Good luck!

1. Generate data from the IFC model and Relatics

1.1 Generate data from IFC model

In this tutorial, you will learn how to export data from IFC into Excel using the Simplebim application. IFC files typically contain a huge amount of data and the key is to export only data that is relevant to you.

A certain wall has 22 rows of information, see Figure 46. Figure 47 shows that each object has a lot of properties which produce a lot of information for example each wall.

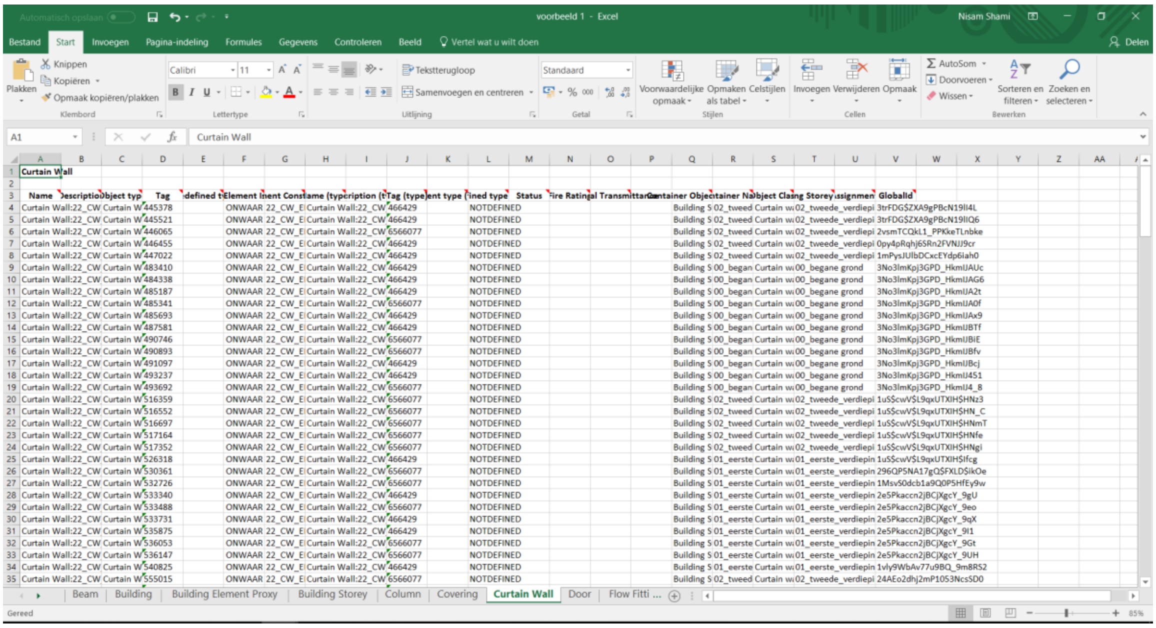


Figure 46: Huge amount of data in an IFC

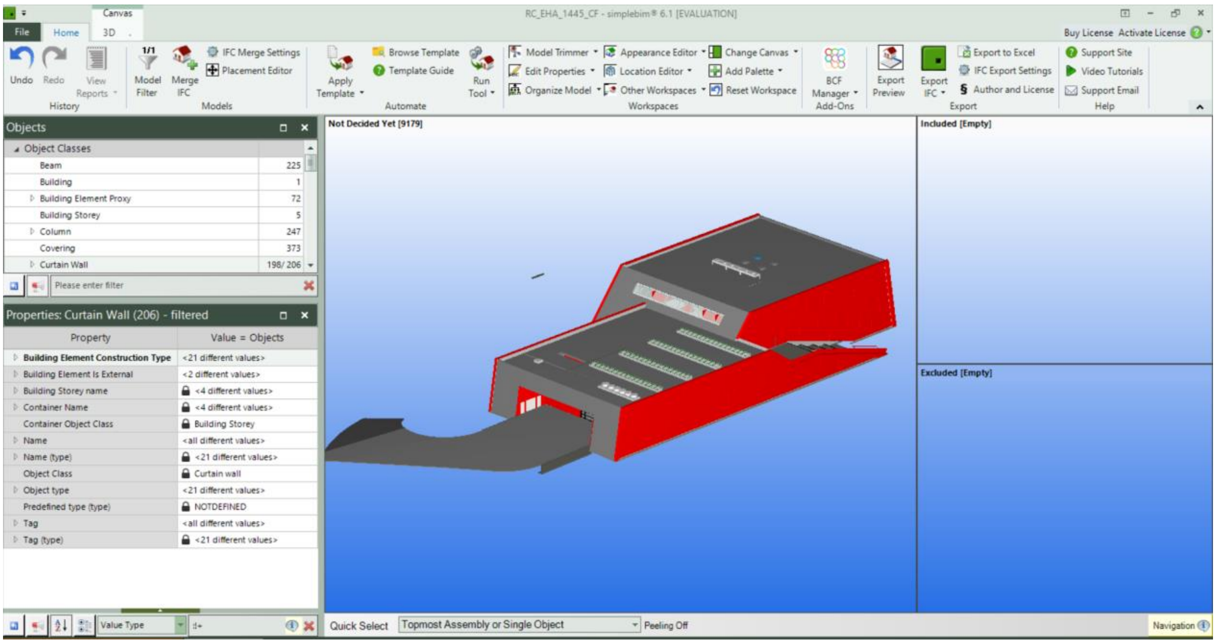


Figure 47: Properties from the objects in an IFC

Step 1: Open simplebim and the IFC-file of Royal Cosun

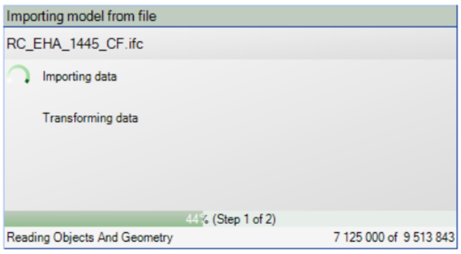


Figure 48: Importing IFC-model Royal Cosun

Step 2: Excluding all properties

The IFC-model of Royal Cosun consists of 26 objects. Each object consists of their own properties.

Click on the object "Curtain Wall"

Right klick on the "Properties"

Select "Exclude All Properties"

To make sure to export only data that is relevant, all the properties need to be excluded (see Figure 49).

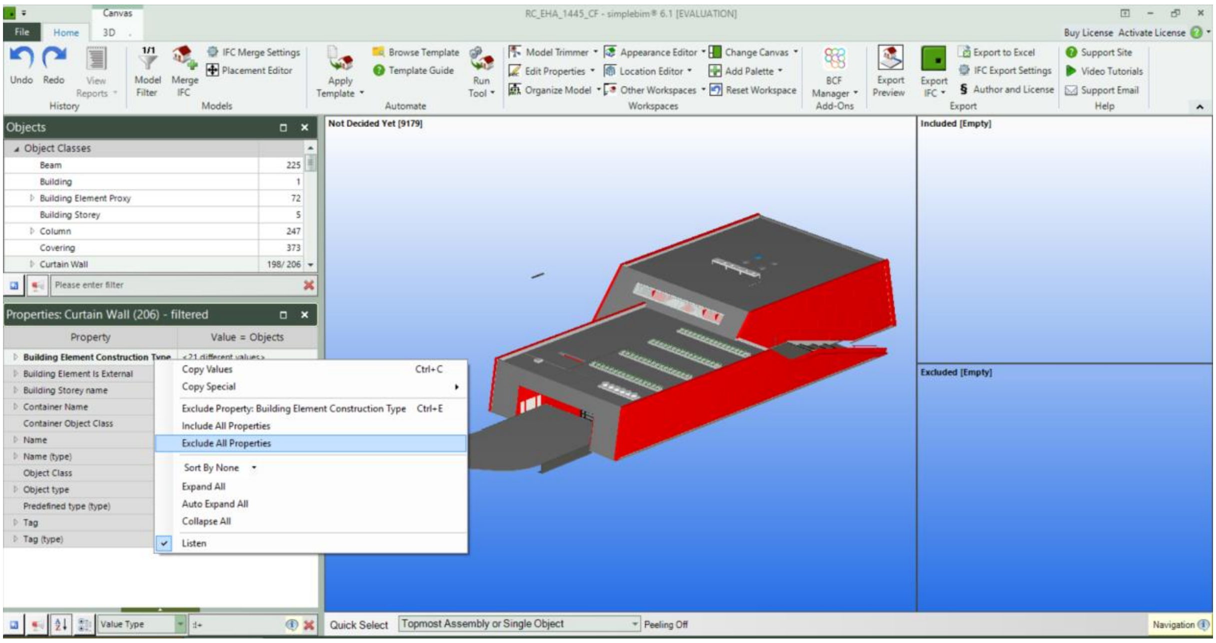


Figure 49: Excluding all properties from objects

Step 3: Including "Name"

Right-click on the "Properties"

Click on "Include Property: Name"

Include the relevant properties which will be used, in this example include the property "Name" as shown in Figure 50.

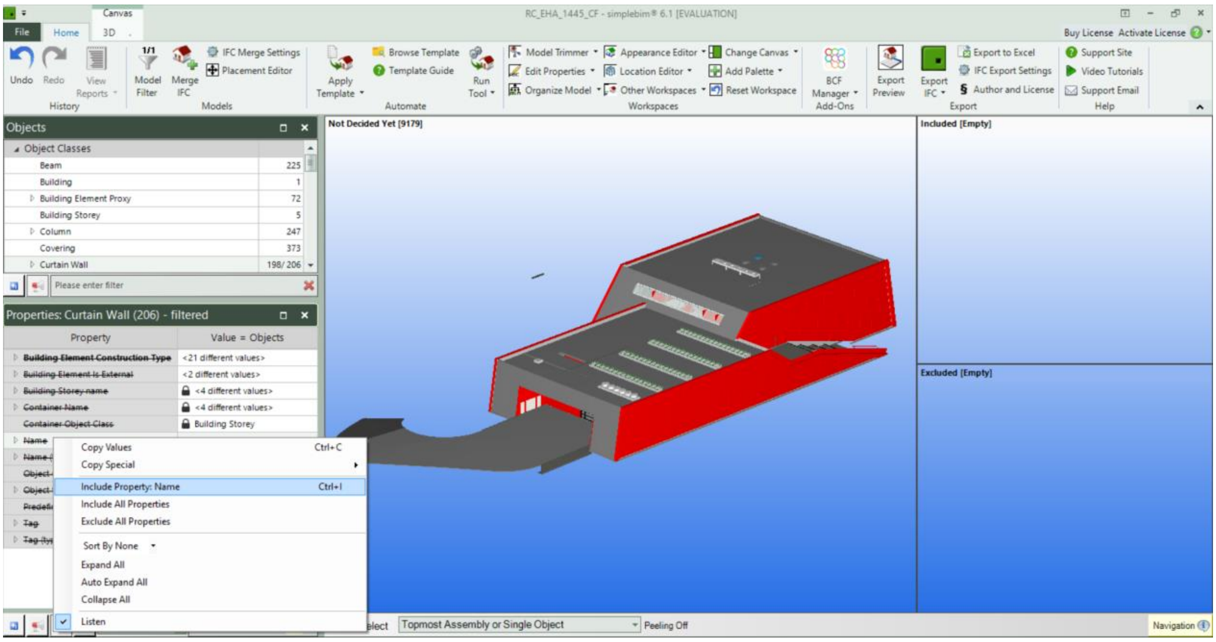


Figure 50: Including property "Name"

Step 4: Exporting Excel

After selecting the right properties, the IFC-file needed to be export to an Excel-file (see the red square in Figure 51). This creates a new Excel-file containing all included objects and properties. Each object class becomes a worksheet in Excel, each property a column and each object a row.

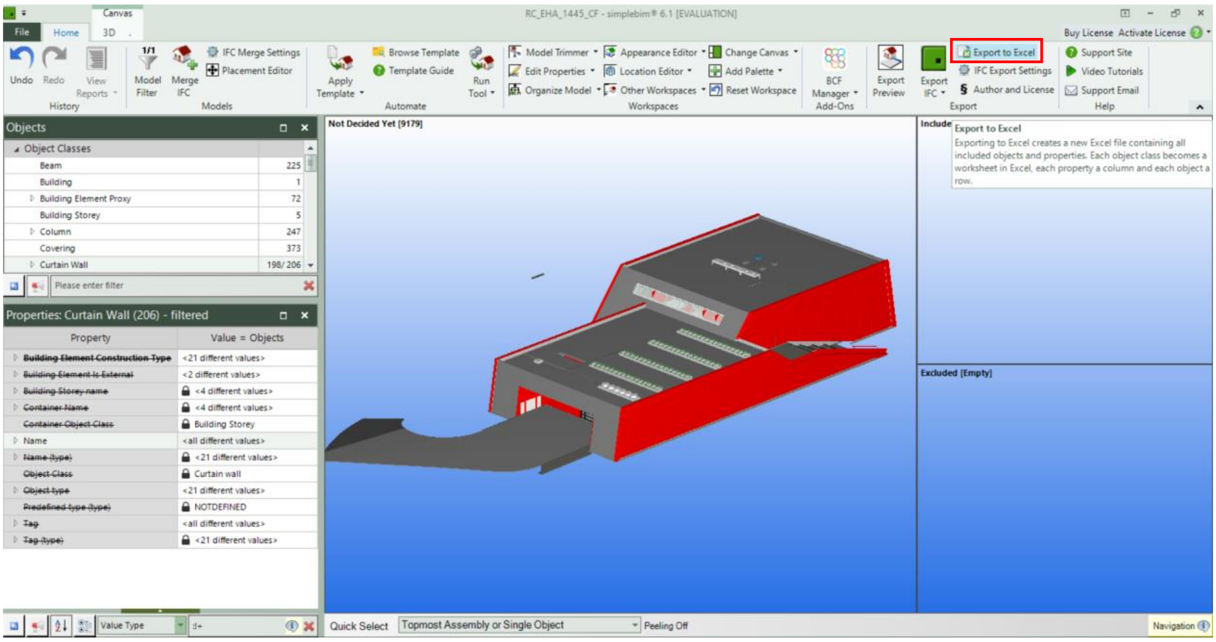


Figure 51: Exporting IFC-file to Excel-file

This results in an Excel-file with only the relevant data (see Figure 52).

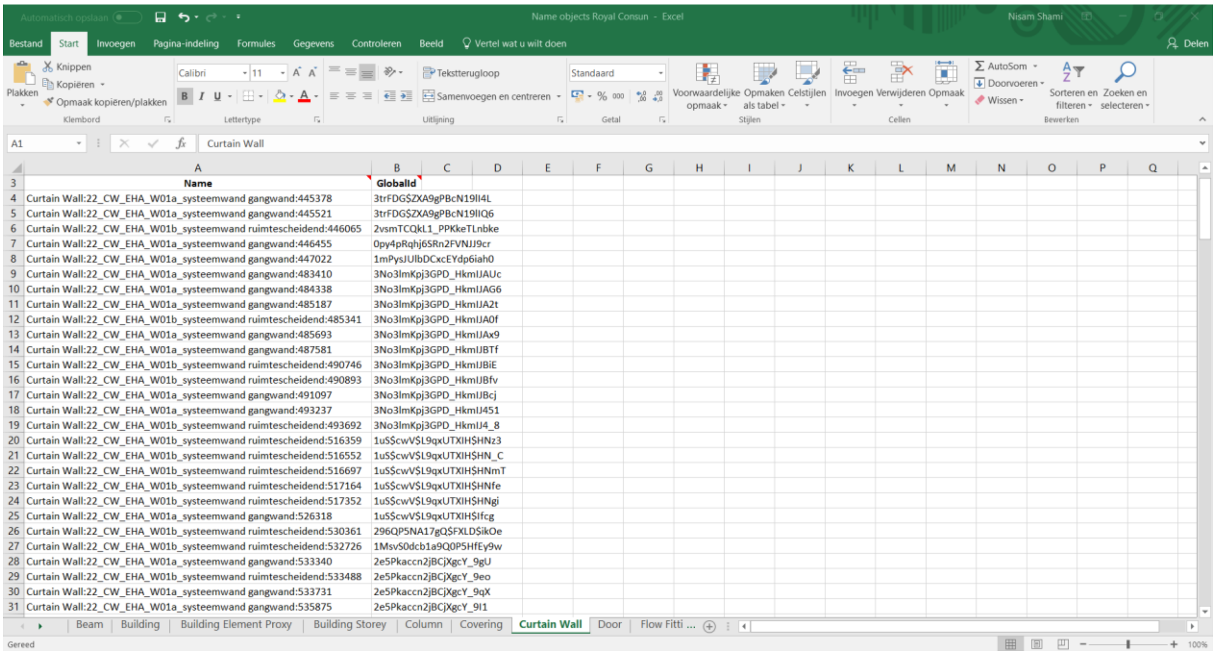


Figure 52: End result from IFC to Excel

Save file

1.2 Generate date from Relatics

Step 1: Opening Relatics

Go to: https://tueindhoven.relaticsonline.com/ and open the space "test workspace for the project Royal Cosun

This workspace will be used to test the automated validation and verification of requirements for construction works in a BIM using the requirements from the project Royal Cosun.
In this workspace, you can keep track of your project using system engineering techniques (see Figure 53).

In this workspace, you can document and manage your:

1. Function Breakdown Structure (FBS)
2. Organization Breakdown Structure (OBS)
3. Work Breakdown Structure (WBS)
4. System Breakdown Structure (SBS)
5. Meetings
6. Documents
7. Requirements

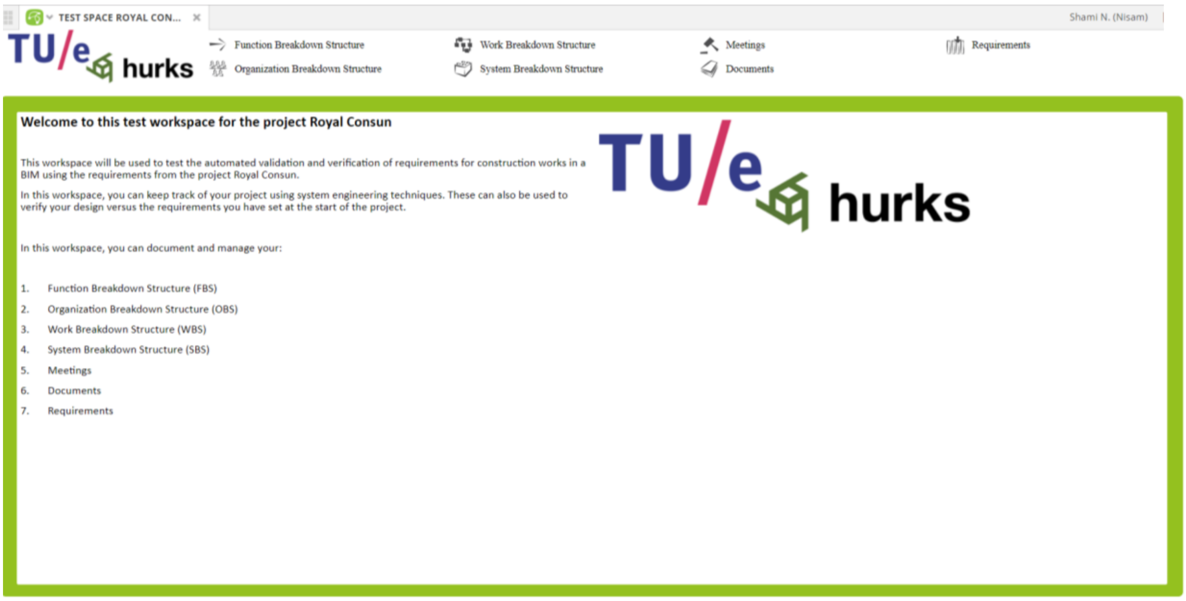


Figure 53: Home screen Relatics template for the projet Royal Cosun

During this project, the client divided all the requirements into the following chapters, as shown in Figure 54:
1. Ambitions / conditions
2. Rooms
3. Technology / Facilities
4. Comfort

Step 2: Opening Requirements

Klick on “Requirements” (see red square)

Each requirement starts with AMB_, R_, TV_, C_ and followed by a specific number.

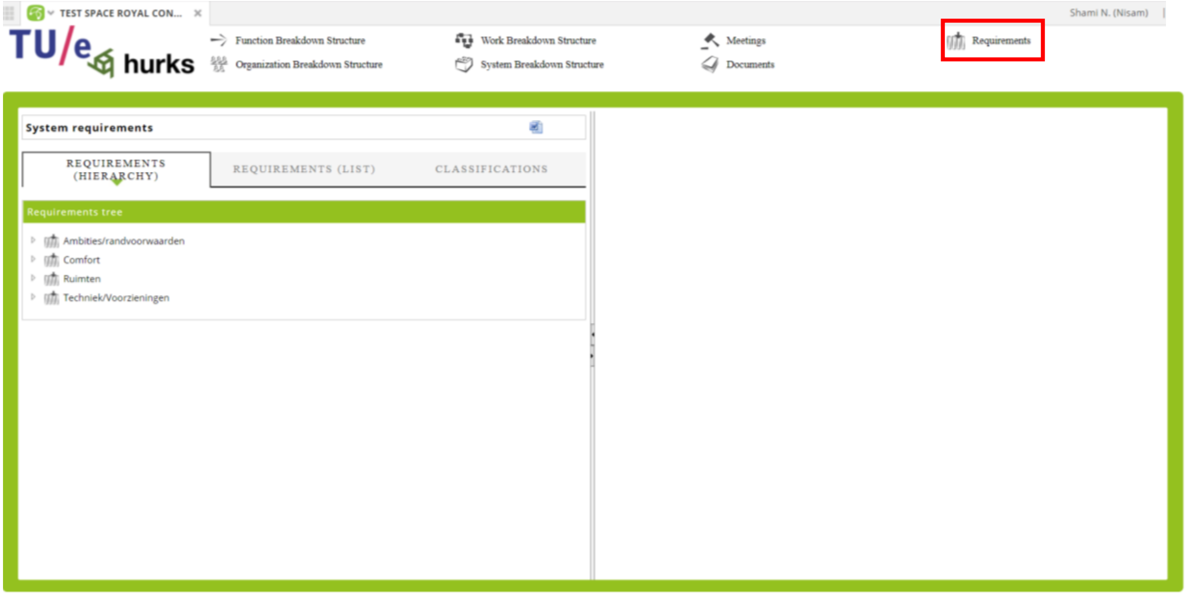


Figure 54: Distribution of all requirements in chapters

Step 2: Outputting Excel-file

Right-click on “Requirements tree”

Select Download as

Select “Excel web page (.xls)”

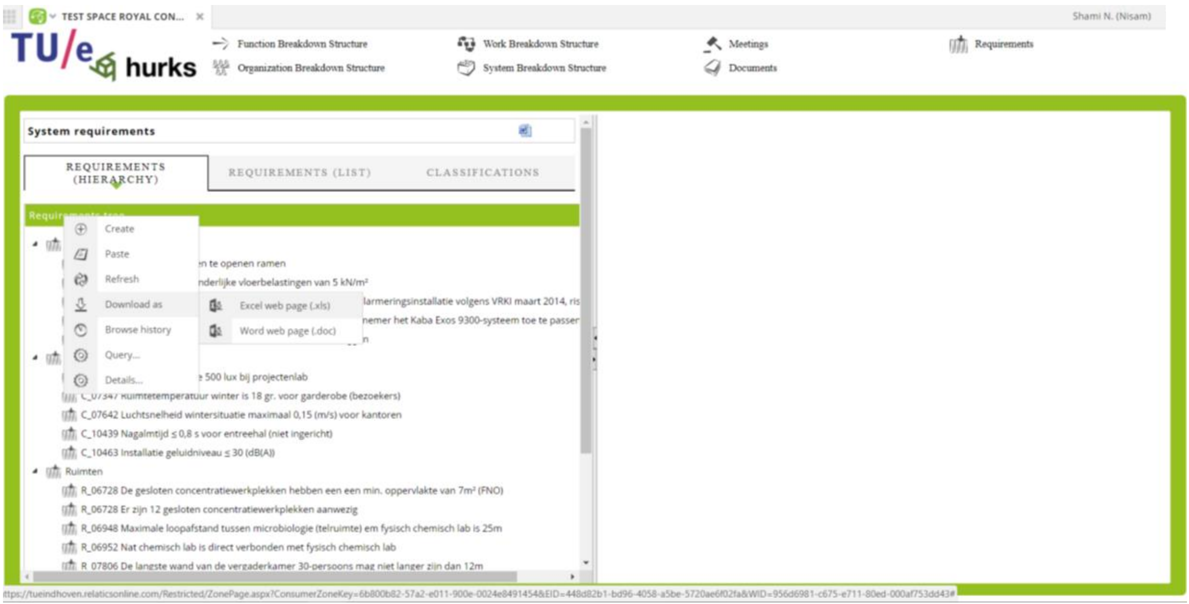


Figure 55: Download the requirements in Relatics into an Excel-file

The outcome (see Figure 56) is an Excel-file with all the requirements under their specific chapter.

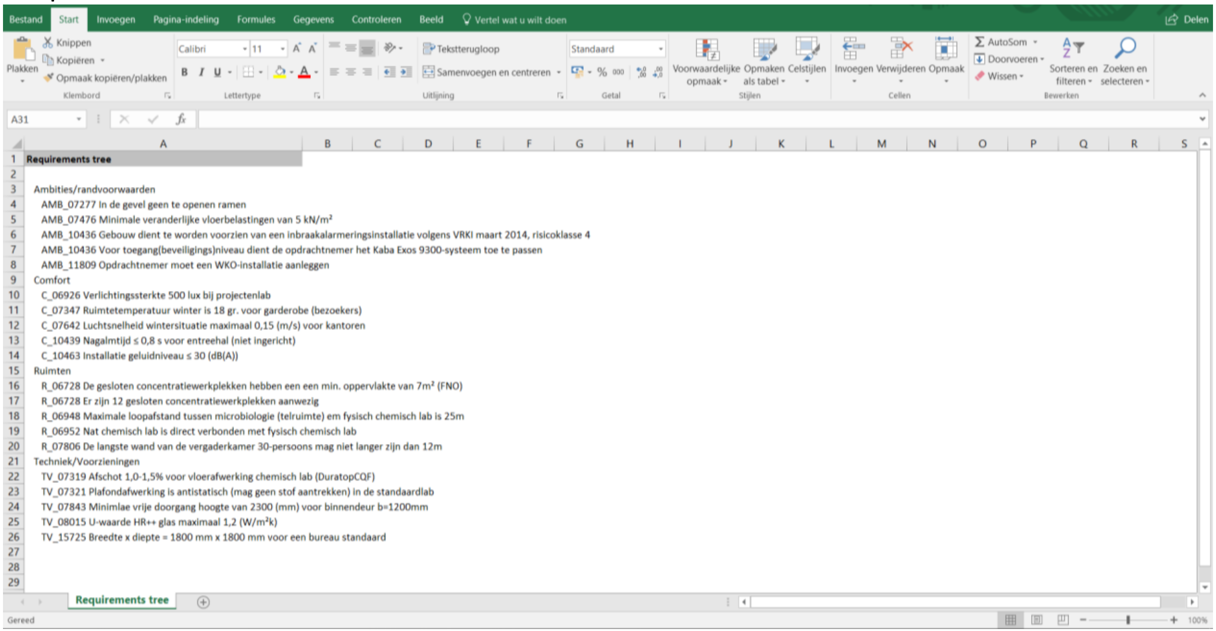


Figure 56: Outcome of requirements in an Excel-file

Save file

2. Check and implement data in the tool

The generated data should now be loaded into the tool. The generated Excel files consist of 26 sheets of IFC data and 1 sheet of Relatics data. The tool is programmed so that every form of Excel file can be uploaded with the right settings.

Open Mendix 7.8.0 and select the tool (see Figure 57*)*

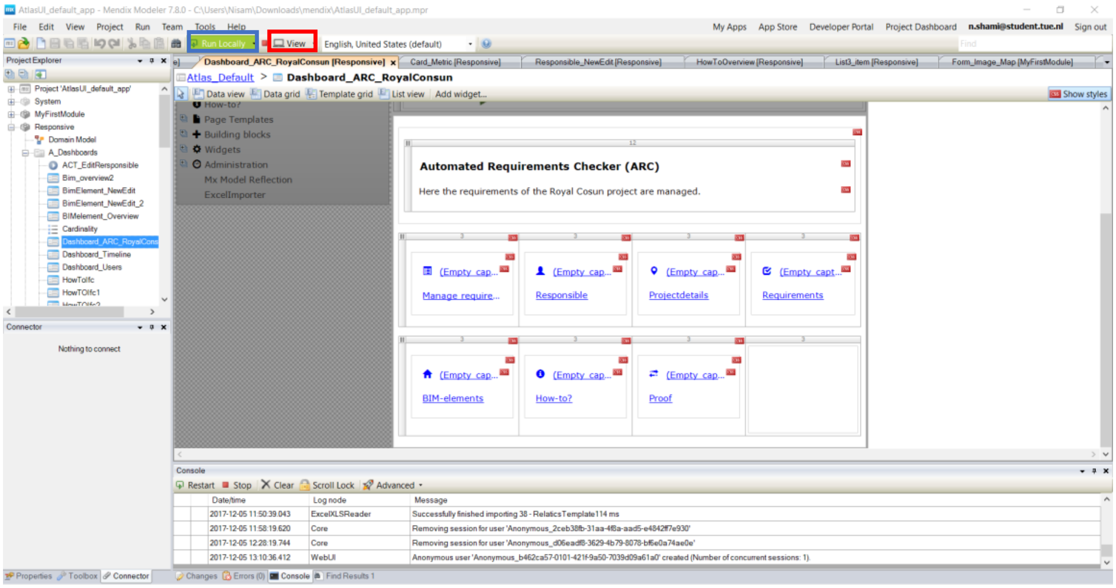


Figure 57: Mendix version of the tool

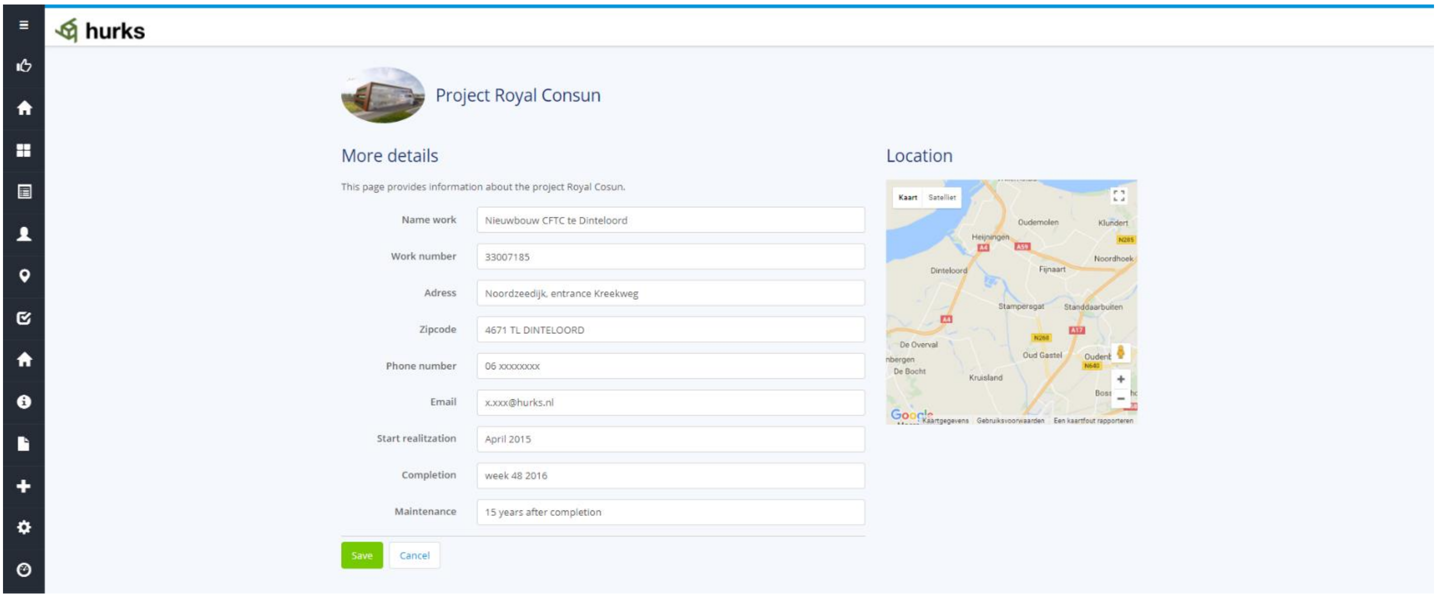
Klick on "Run Locally" (see blue square Figure 57)

After Mendix has loaded the tool it is possible to run the tool (is there is no error) in the desktop version, tablet version and phone version.

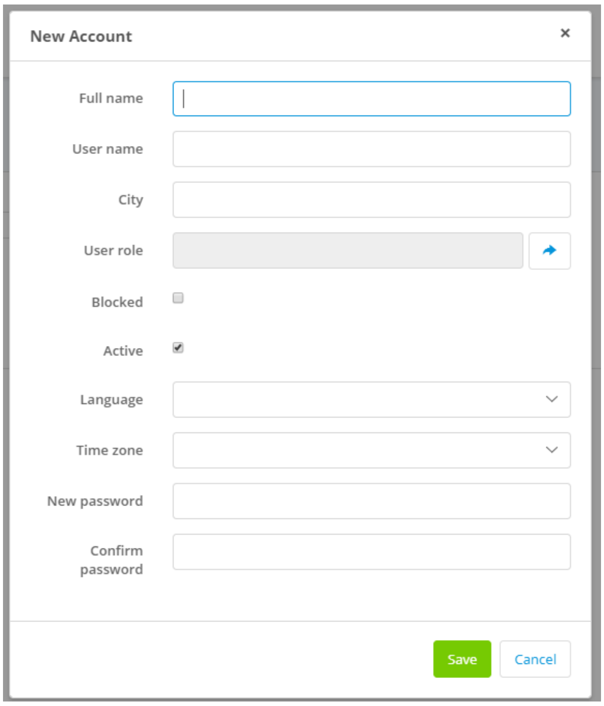
Click on "View" to open the desktop version (see red square Figure 57) or press F9

The tool consist of the following index:

- "Welcome page" - in this the user is greeted
- "Home – Project overview" - an overview of all current projects within Hurks bouw en vastgoedontwikkeling. This is also the home page of the tool. This page is only visible to the System Engineer and designated persons within the organization.
- Dashboard - Home screen of a user. It shows all possibilities of the tool to manage the requirements.
- Requirement Management - An overview where all requirements and elements come together. Each requirement can be linked to an element and an assignee and organization. In addition, it shows per requirement whether it is open, modified or complete.
- Project details – Page provides information about the project Royal Cosun.



- Requirements - Overview of all requirements generated from Relatics
- BIM-elements - Overview of all requirements generated from IFC
- How-to? – Tutorials how IFC and Relatics data can be converted to Excel files to become usable for the tool
- Proof – overview of all supporting documents
- Assignee – overview of people who are responsible
- Administration - An overview of all active accounts. Administration has the ability to create accounts for individual end users.



- Excel Importer - This option allows you to import Excel data into the tool

For every sheet of information an import template must be created in the tool (27 in total). these templates must be created in "Excel Importer". A sheet can be created and duplicated.

Klick on "Excel Importer"

Klick on "IFCtemplateBeam"

Make sure the correct settings apply to this template (see Figure 58)

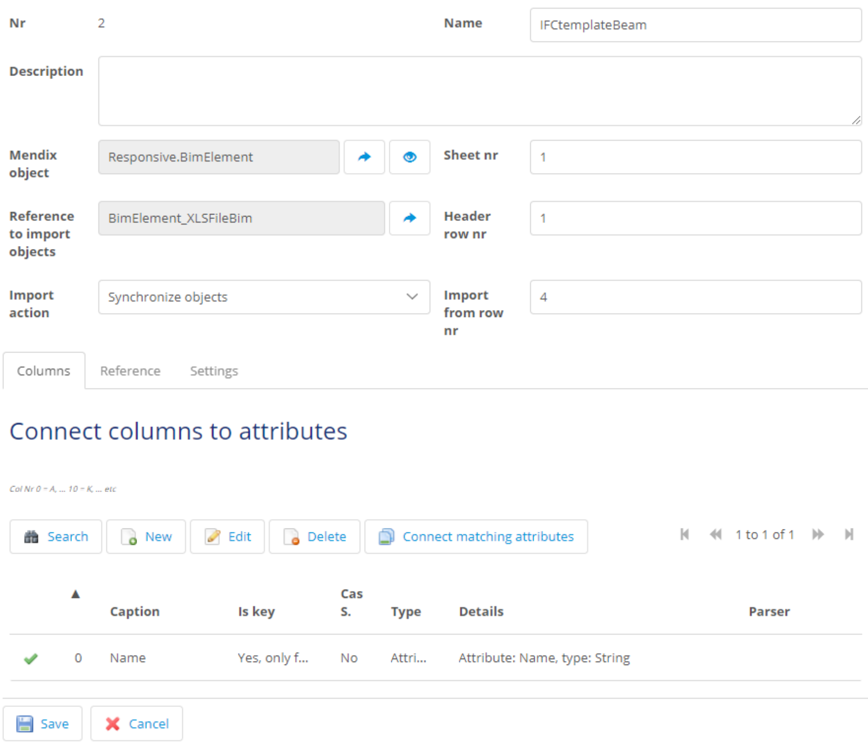


Figure 58: Settings Import template

Check if the Excel-file matches the settings of this template (see Figure 58)

Are the beams located on sheet number 1?
Are the names of the beams located on row number 1?
Does the tool need to import data from row number 4?
Is the import action synchronize objects? (changes in the main file immediately cause changes in the tool)

Is so, save the template

Click import files, select the “IFCtemplateBeam” (see red square Figure 59)

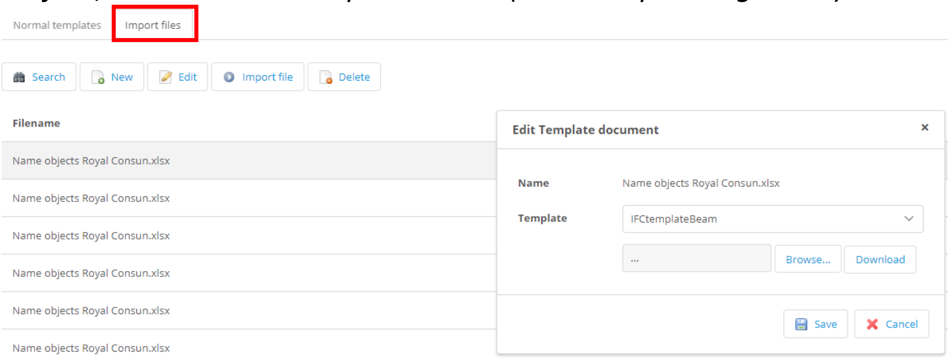


Figure 59: Overview Import files

Browse to the saved Excel-file of IFC-elements

Select the file

Klick “Save” to save the file

Klick “Import file” to import the beams into the tool (see red square Figure 60*). Import the other template to make sure the tool contains all the generated information.*

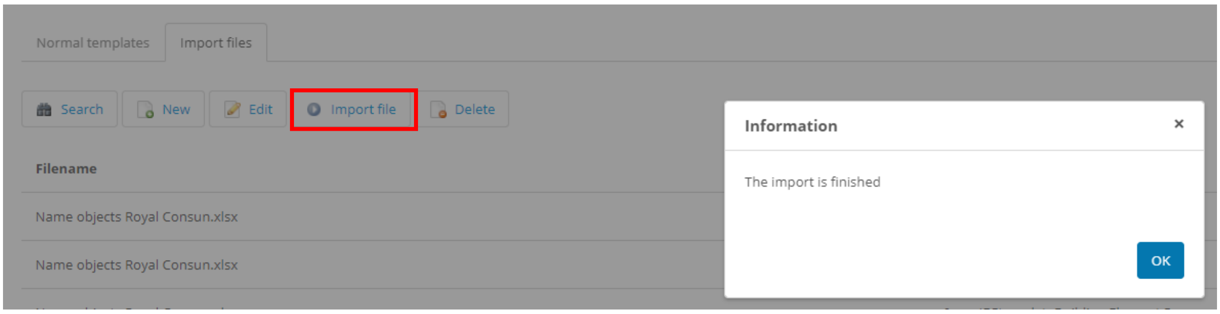


Figure 60: Import Excel-file

Click on the BIM-elements and Requirements in the menu to see if the data is imported (4450 IFC-elements and 20 requirements).

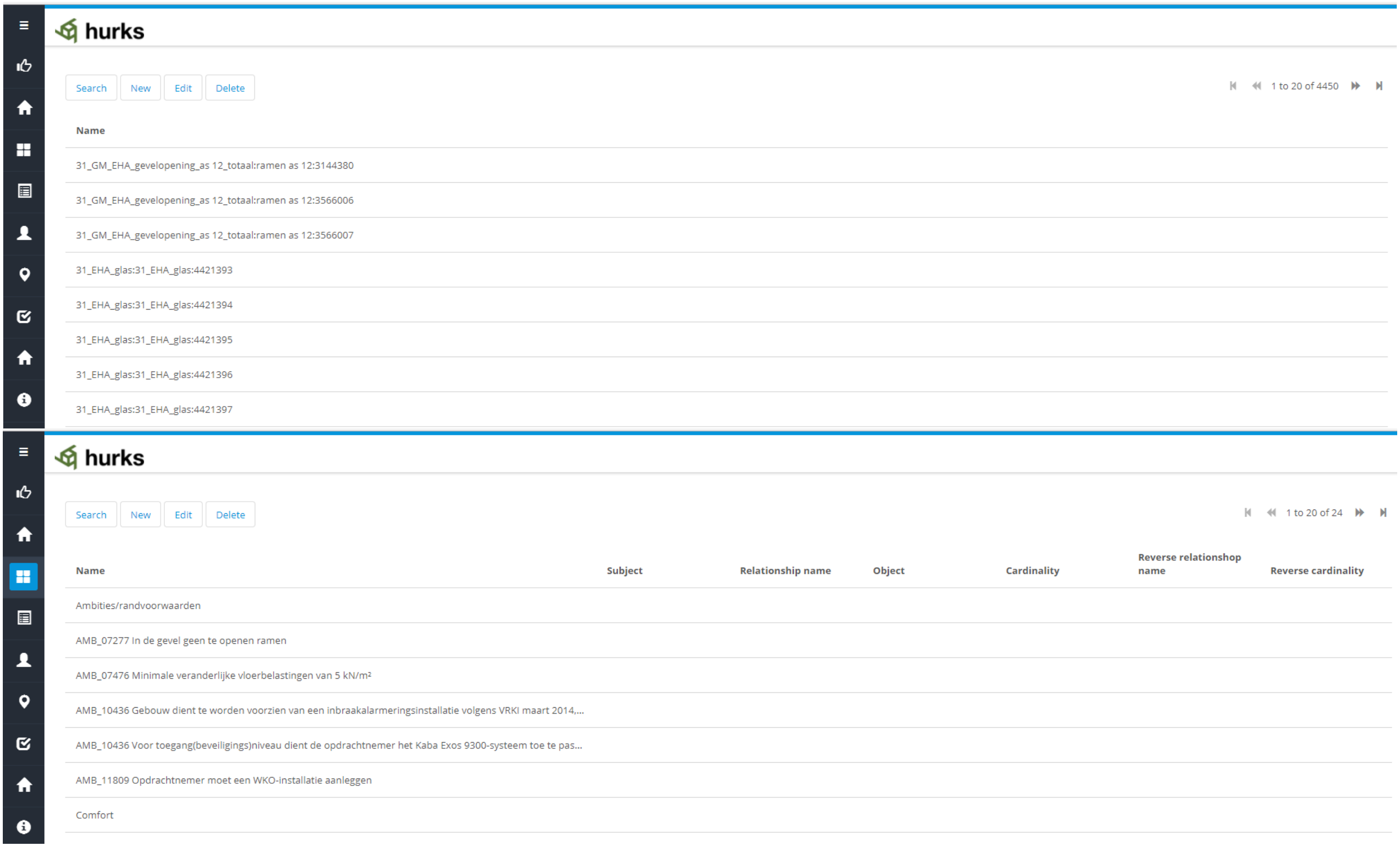


Figure 61: Overview of imported data (IFC-elements and requirements) in the tool

3. The tool as an end user

Step 1: Add Assignee

Click "Assignee" to see the responsible overview (see red squares Figure 62). Klick on "new" to add yourself as an assignee (see Figure 63).

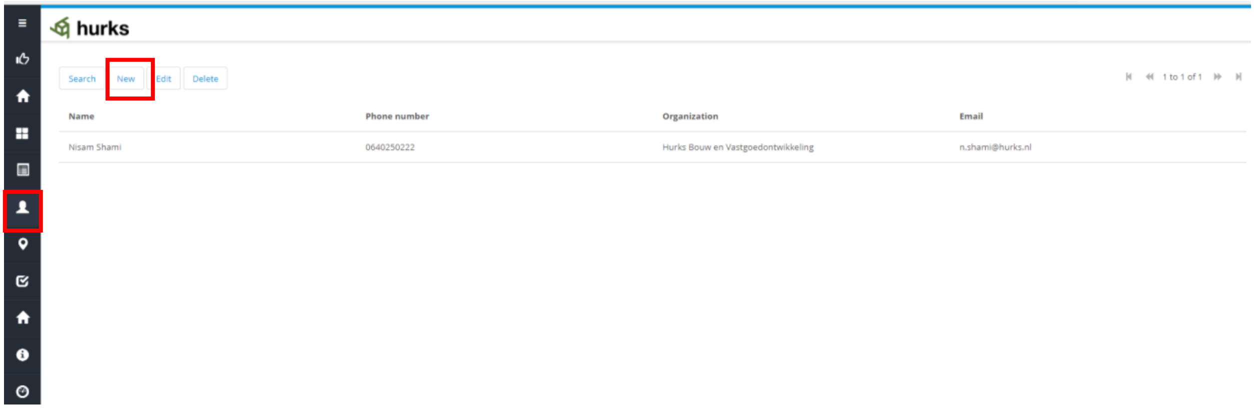


Figure 62: Assignee overview

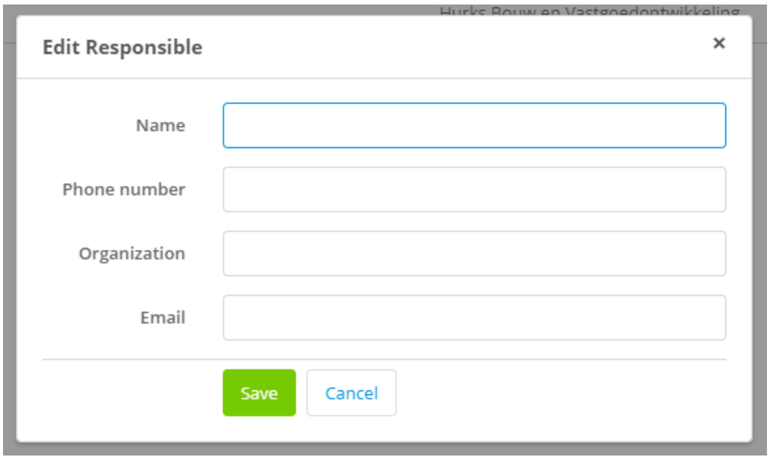


Figure 63: New Assignee

Step 2: Uploading Evidence

Open the page "Evidence"

Select "New" (see Figure 64)

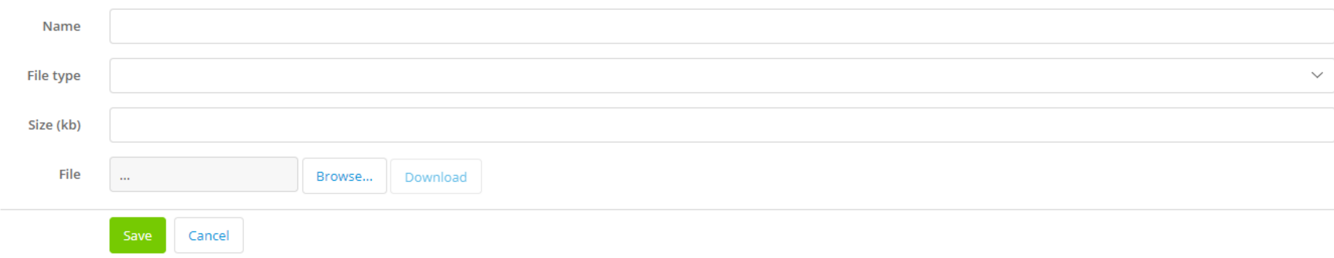


Figure 64: Uploading evidence

Fill in:

Name: Bewijs materiaal A

File type: .pdf

Size: 150

File: (browse and upload Bewijs materiaal A)

Step 3: Managing Requirements

Open the page "Management requirements"

Select "New" (see Figure 65*)*

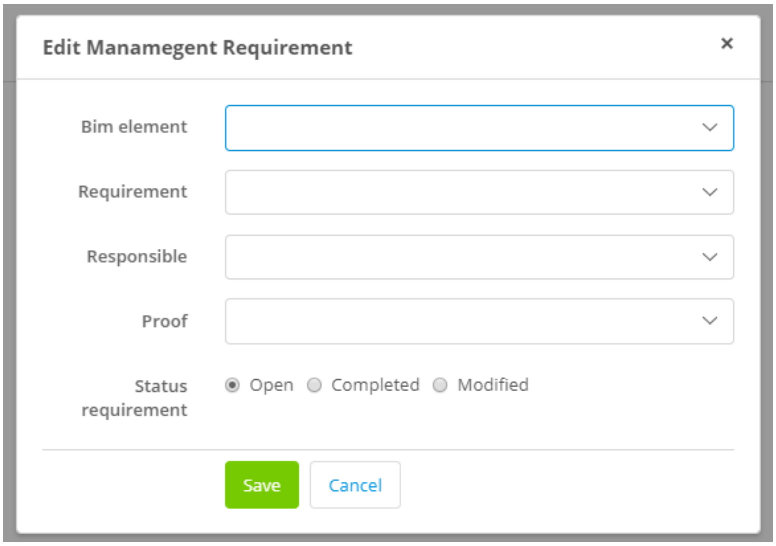


Figure 65: New "Managing requirements"

Select the following:

Bim element: 00_begane grond

Requirement: AMB_07277 In de gevel geen te openen ramen

Assignee: Yourself

Evidence: Bewijsmateriaal A

Status requirement: Completed

Klick "Save"

Go to Mendix and open the tablet version and phone version of the tool by pressing Ctrl + Shift + F9 and Ctrl + F9

You are now ready to manage all the requirements within the project and to combine Systems Engineering, BIM and the Quality Assurance

Appendix F: BPMN-diagram data exchange within the tool