Building smart: Digital rule checkers

- A tool for improving the building industry

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BY:

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SUMMARY:

The purpose of the thesis is to evaluate how digital rule checkers can be implemented as a tool for improving building information modelling. It describes principles and methods of how to develop digital building rules, exemplified with a transformation of the ISO/DIS 21542 standard regarding universal design.

The building industry is the largest industry in the world. While other industries have revolutionized their efficiency and capacity by utilizing the information technology during the last 40 years, the building industry has not changed much.

The thesis gives a short overview of the traditional building process and the potential of BIM. Additionaly it presents how universal design can be incorporated in the new way of managing information. Further, the principles of digital rule checkers are described, and different methods of how to develop digital building rules are presented.

Using a case study, the process of how to develop digital building rules by initiating the transformation of ISO/DIS 21542, an international standard regarding universal design, is exemplified.

The thesis concludes that digital rule checkers might be a good tool for improving the building industry. The technology is available and processes have been described for how to develop the concept further. What stands left is testing in a larger scale and better documentation.

RESPONSIBLE TEACHER: Professor Tor G. Syvertsen

SUPERVISOR(S) Eilifh Hjelseth (Standard Norway)

CARRIED OUT AT: the department of structural engineering

Department of structural engineering

NTNU – Norwegian University of Science and Technology.

Master Thesis 2010

for

Stud. techn. Anders Kristensen

BuildingSMART: Digital Rule Checkers

BuildingSMART: Digitale regelsjekkere

The dissertation will describe principles and methods of how to develop building rules that can be implemented in building information models.

As a case study it will look deeper into universal design and the possibilities and challenges building information modeling faces in this sector.

Key issues:

1. How do you translate a national standard into a digital version?
2. How do you make sure a digital version has the same quality as an original standard?
3. What do you do with those rules that are not easy translatable/needs human interpretation?
4. How does digital code checkers work with the IFC format?
5. How could universal design be implemented in building information modeling?

The thesis should be prepared as a digital report and handed in to the Department of Structural Engineering no later than Monday, 14. June 2010.

Supervisor: Prof. Tor G. Syvertsen (torgsyv@gmail.com)

Co-Supervisor at Standard Norway: Eilif Hjelseth (EHj@standard.no)

Preface

This report is made as a master thesis at the department of structural engineering at NTNU the spring of 2010. The report constitute 20 weeks of work, corresponding to 30 credits.

The scope of building information modelling implies both how things are done today and how thing can be done in the future, consequently my thesis is addressing both how digital rule checkers works today and concepts of how they can work in the future. The language of conceptual texts tends to have more of a vocal tone than the language of pure scientific texts. I have tried to write as scientific as possible, however, it must be mentioned that my underlying enthusiasm and interest in the future of building information modelling, might be present in some parts of the text.

The readers of the thesis are both people who know this field of technology quite well, and readers who are not as familiar with it. My purpose is to write an informal text that creates enthusiasm and awakens interest in the field, as I have experienced through withing, rather than a text that just informs readers with facts about how the technology of building information modelling works.

The master thesis is made as an indivudial work with guidance from Tor G. Syvertsen from the institution of construction technique, NTNU and Eilif Hjelseth from Standard Norway. I would like to thank them for inputs and help throughout the workprocess.

In addition I would like to thank Nick Nisbeth for guidance regarding the work of AEC3 and Gunn Kristensen and Kristina Spilde for help and support throughout the process.

Bergen, June 2010

Anders Kristensen

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Abbreviations

BIM: Building Information Model/Modelling

IFC: Information Foundation Classes

IFD: International Framework for Dictionaries

IDM: Information Delivery Manual

CAD: Computer aided design

DWG: 2D drawing format

Summary

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Content

Appendix A is an XML sheet in an external file.

1.0 Introduction

There have been huge developments within the building sector from ancient times until today. The information technology is growing exponentially and involves more and more of the world as we know it. However, before the digital world took its role in society, the tools used, when designing and building buildings, were drawings.

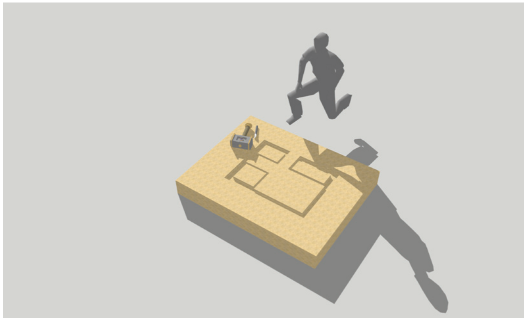
Figure 1: Stone drawing board

The first building drawing known of is a temple plan inscripted on a stone drawing board from the 3rd millennium BC in the city of Lagash in Babylon. The process of changing and improving the design was naturally hard. The ancient Egypt invented the papyrus, which made the process of changing the design easier. New geometric methods where developed when the ancient Greek period started. Compass and triangles where developed to assist designers, and the drawings became more accurate. They mostly used papyrus and parchment from animal skin when they drew, but they still had plans carved out in stone. An example is a construction plan found in the marble inside the temple of Apollo. When the Roman period began, elevation drawings, and some form of perspective drawings to communicate more efficient were developed. The modern architectural drawing came into being at the time when gothic construction began to decline. In the 15th century the geometrical method of perspective drawing that is still used among architects today was presented and in the early 19th century, the isometric drawing was introduced. The process of communicate via these drawings, were still hard. First they made a master drawing, and then the technical drawers had to draw copies of this for the builders to use. If the master drawing had some errors, every copy of the drawing had to be handed in, and new one had to be drawn. [1]

In 1840 the blueprint was invented. This new invention changed the communication drastically. The blueprint is a copying process which uses the sun to bleach a certain type of blue paper through a tracing paper. The process takes from two minutes to one hour depending on the weather, and the result is a blue drawing with white marks. The copying speed was improved, but the master drawing still had to be drawn by hand, and if an error was found, all the blueprints needed to be remade. This technique was used until the nineteen forties when the white print came into the marked. This was a similar process. The technique was cheaper, but they still had the same problem with one master drawing which needed to be drawn by hand. [2]

In 1963, Ivan Sutherland, who worked at MIT (Massachusetts Institute of Technology) developed a tool called sketchpad. This is known as the first program that had an interactive communication with a computer via a graphical user interface. In simple terms, you could draw with a light pen on a light sensitive screen. The lines were saved as codes in an object model, and the first digital drawings were made. [3]


Figure 2: Ivan Sutherland and sketchpad [4]

The next step happened in the end of the nineteen eighties. Both the computers and the graphical user interface had improved with an astonishing speed since 1963 and now computer aided drawings (CAD) programs could be used on normal computers. The cost of the software was nevertheless so high, that only the largest companies could afford them. The cost made a large amount of small companies bankrupt, while the large companies got even bigger. [5]

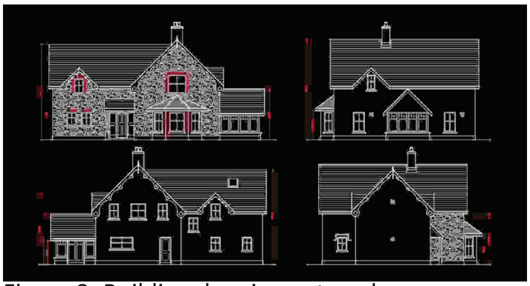
Figure 3: Building drawing autocad

CAD changed the medium of communication within the building sector fundamentally. It was possible to draw in both 2D and 3D, and as the time went by, geometrical information models came into being. Soon after, building information models (BIM) was created by linking properties to the geometry.

A BIM is a digital version of an original building. It is used when communicating the building ideas between the different designers, builders, users and authorities. Basically, it describes the process of making and managing the building information of an existing or future building.

The objective of and the philosophy behind BIM is that a better flow of information in the building industry will lead to better buildings with fewer errors, and a more efficient building process. [6]

1.1 Aims

The aim of the thesis is to describe and discuss the process of how to implement rules into BIM. A case study is used to exemplify the concept by analyzing a universal design standard (ISO/DIS 21542) and discussing how it can be interpreted into a digital rule checker.

The philosophy behind the concept of digital rule checkers is that the efficiency and quality of the building industry will be significantly improved with the usage of automated quality tests of digital building models. However, there is also a possibility of implying rules within the design program itself.

It does exist building laws and regulations that contain rules within energy usage, loads, universal design, reinforcement, dimensioning and so on. A method of checking the digital building model for these requirements would be valuable. Instead of having people working for the government, using a lot of time going through a project, checking each plan, and sections according to the requirements, a rule checker can, in theory, do it automatically while the building is being designed.

The informative part is based in a literature study combined with meetings and feedback from the authors' tutors. In chapter two, universal design is introduced and discussed in a general matter. Chapter three explains how building information modelling and digital code checkers can improve the traditional information management. Chapter four defines what a digital rule checker is, how it could be able to function in accordance with BIM and discusses possible advantages and disadvantages with the use of digital code checkers. In chapter five, the result from the case study is presented and discussed.

2.0 Universal design

This chapter of the thesis gives a general introduction to universal design. The following questions are discussed:

- *what* is universal design?
- *why* use universal design?
- *which* buildings should be designed universal?
- *how* apply universal design?
- *who* is responsible for universal design?

Universal design is an international strategy. In this chapter the functionality of the strategy is narrowed to how it is incorporated in Norway, with respect to the built environment.

2.1 *What* is universal design?

The definition of universal design is:

A broad-spectrum solution that produces buildings, products and environments that are usable and effective for everyone, not just people with disabilities [7]

The purpose of universal design is to define how the built environment should be designed, constructed and managed to enable people of all abilities to approach, enter, use, egress from and evacuate a building independently, in an equitable and dignified manner and the greatest extent possible. [8]

When fully implemented universal design is expected to be of benefit to all people, including people with hearing-, vision-, mobility-, cognitive-, and hidden impairments (such as strength, stamina and dexterity) and people with diversities in age and stature(including frail old people, children etc.) [8]

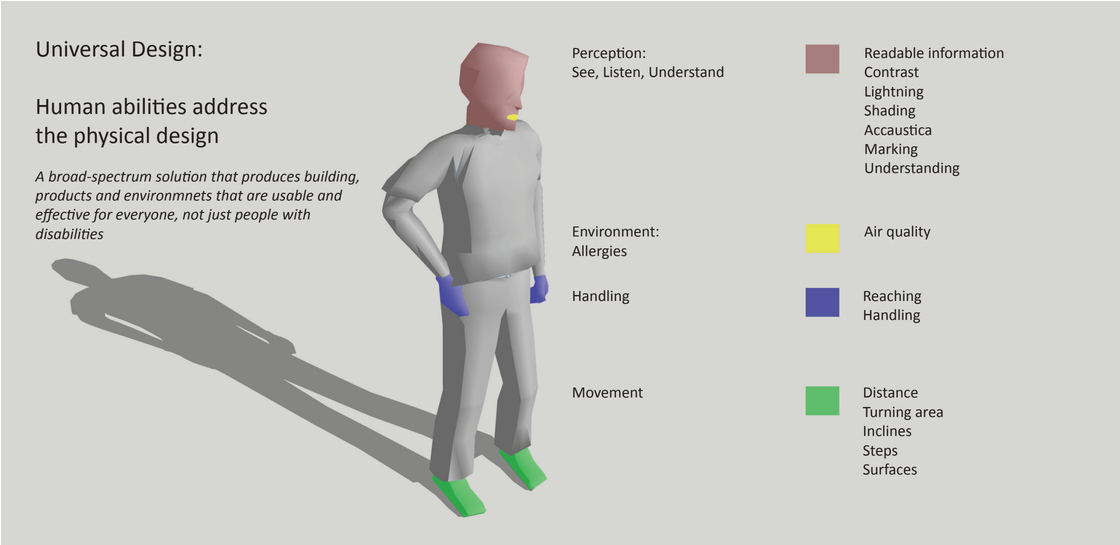

Figure 4: What universal design is [9]

2.2 *Why* design universal?

As life expectancy rises there is a growing interest in universal design. Modern medicine has increased the survival rate of those with significant injuries, illnesses and birth defect and it is important to consider those individuals when future environmental requirements are made. The aims is a society where all people have the possibility to access and use the environment.

2.3 *Which* buildings shall be designed universal?

The UN established a convention about the rights to humans with disabilities December 13th 2006. The purpose was to secure humans with disabilities full and equal rights to realize their human rights. It establishes that the states in the UN are obliged to carry out necessary actions to secure that humans with disabilities have access to the environment, transportation, information and communication together with other offers and services which are open or offered to the general public. [10]

Norway signed this convention in 2007 and, as a consequence, a Norwegian law was established January 1st 2009. It is illegal to discriminate humans with disabilities. The law involves an obligation to universally design the built environment that is meant to be used by the general public. [10]

The law does not include specification about what discrimination of humans means. However, a framework for how to design universal, which will be included in the Norwegian building and planning law, is under development. Every public space and private space meant to be used by the public, will be required to be built according to this framework. There has also been made an action plan for how to make the existing public space universally designed by 2025. [10]

Regarding private building project, there are no laws or regulations that constrain the usage of universal design in Norway. However, the government have established an organization called the house bank.   The entrepreneur can get an additional loan from this bank if they choose to build their buildings according to universal design, or within the range of energy requirements. Changes will take place in the future and severe requirements regarding universal design will replace the existing requirements. [11]

2.4 *How* should universal design be applied?

A normative framework for specifying the qualities of the products and environment are in development. The Norwegian ministry of the Environment made a report in 2007 to clarify the concept of universal design:

"Universal design is a strategic approach to planning and design of products and environments in a fashion that promotes an inclusive society that ensures full equality and participation for all. The universal design strategy is normative, providing a framework for specifying the qualities of products and environment such that these may be used by all members of society on an equal footing. It is to be incorporated as an integral part of cohesive design activity." [12]

The primary aim is to ensure full participation in society for all individuals; this will be done by removing existing disabling barriers and preventing new ones from emerging. The focus incorporates a stronger focus on equality than what is implied earlier, and it encompasses a broad field of work processes; community planning, land use, architecture, construction, activity, product development and more. [12]

A key feature of the universal design strategy is its focus on seeking even better solutions. A dynamic tool that reflects the need for ongoing consideration of new means of minimising limitations is the aim of the framework in development. [12]

There is also the possibility that universal design strategy may come into conflict with other areas of regulations, such as conservation and safety considerations. In such cases an effort should be made to seek solutions that satisfy universal design requirements to the greatest possible degree. [12]

The design is supposed to be made without the need for adaption or specialized design. The solutions should not in any way signify that it has been specifically designed for persons with functional impairments. Consistent attention to aesthetic perspectives is important to make products and facilities attractive, and may help to ensure that accessibility and usability features are seen as a natural, integral component of design. This aspect of universal design will, however, not be present in a normative framework since aesthetic is a subjective field and cannot be implemented and understood by a computer. Universal design in practice requires great accuracy in terms of design, operations and maintenance needs. [12]

The laws and requirements that have been made regarding buildings in general, all descends from common sense. The Standard Norway organization is working on making a Norwegian Standard for universal design. A Norwegian standard is not the same as a law, and has more severe requirements than what the Norwegian law states. If a standard is used when designing, the quality of the building will accord to the law. [13]

The international standard organization (ISO) is also developing a standard(ISO 21542) concerning universal design. This standard is the most developed standard available in this field today [14] and will be used as the case study in chapter five.

2.5 *Who* is responsible for universal design?

The highest responsibility regarding universal design in Norway is the Norwegian parliament. They establish the laws in Norway and one of these laws is the planning and building law. Universal design will be implemented in this law when the normative framework has been made.

Below the Norwegian parliament is the ministry department and local authorities. Ministry department can make regulations to the laws. Regulations give supplementary rules and detailed description to the laws that already exist. The local authorities can make bye-laws. These are rules with a local character, which makes it possible to have special considerations in each district. If universal design are in conflict with other areas of regulations, bye-laws can be made to incorporate special considerations. [15]

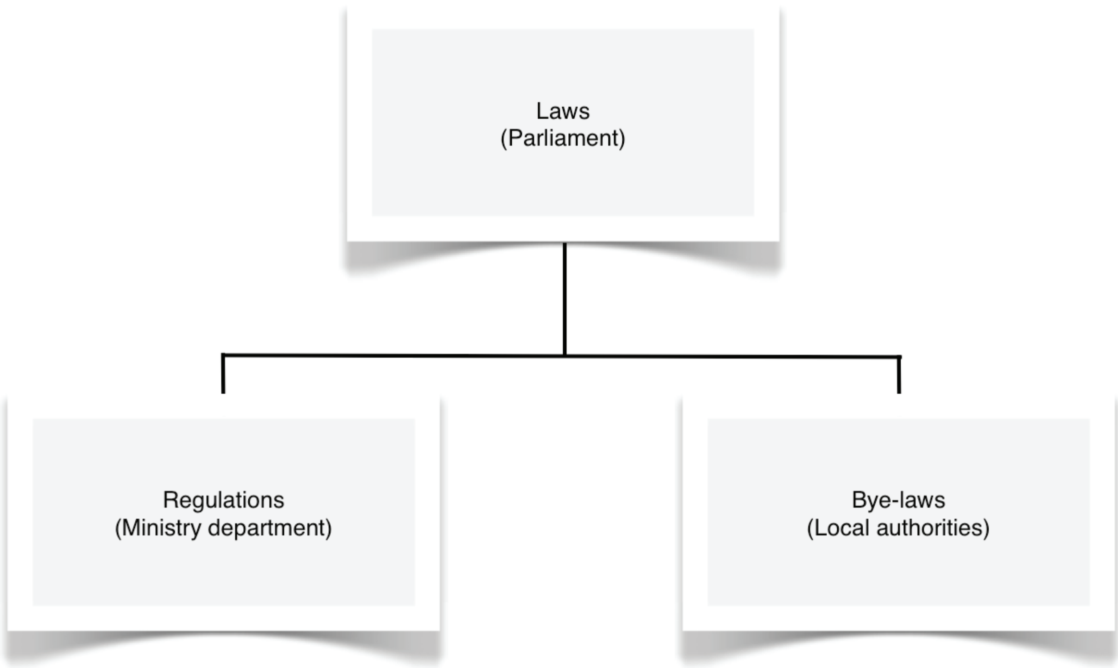

Figure 5: Laws and relations [15]

The planning and building law has no requirements when it comes to private buildings. The entrepreneur is responsible for making the building program that describes the content of the building and its functioning requirements. The entrepreneur is also responsible for designing buildings universal or not. If the entrepreneur decides to have a building which is universal designed, it is the project managers responsibility to figure out how to transfer this into a workable solution. The standard that is under development will then be used as a reference tool for how the solutions shall be made. [16]

3.0 Building processes and information management

The BIM consists of geometrical information. Points that are attached to each other form lines, lines that are attached to each other form surfaces and surfaces that are attached to each other form volumes. Each volume has a specific position and dimension, and can be linked together. Properties are linked to the volumes and in this way the volumes are divided into floors, walls, ceiling, et cetera. Each volume also has information linked to them as what type of material they consist of and so on. The purpose of the information model is to resemble the original building, or the future original building, as much as possible.

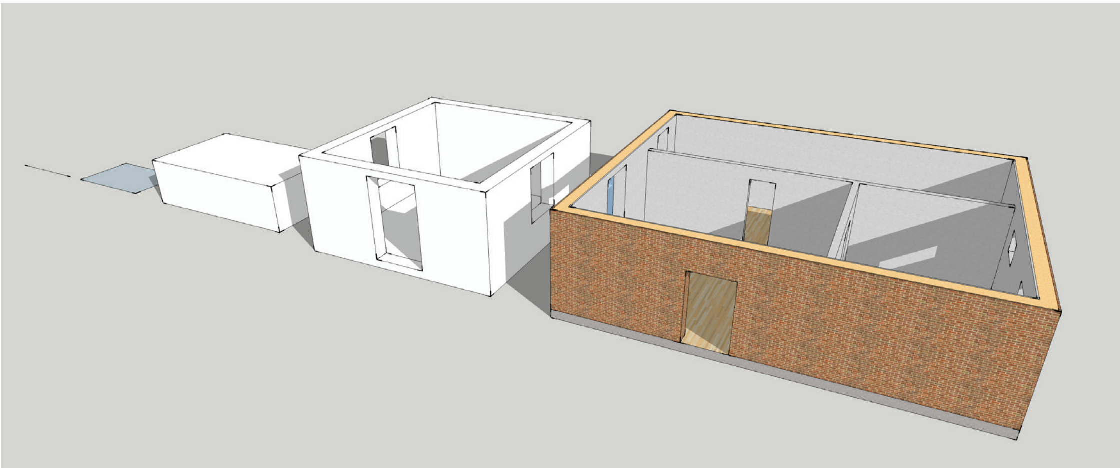

Figure 6: Visual BIM structure

What you see on the screen when working in BIM software is known as a graphical user interface. [17] The underlying logical design of the program is a structured system of information. Databases are linked together and the relationships between them form the structure of the system. The system design can be visualized through an object model, which consists of objects, links and properties. [18]

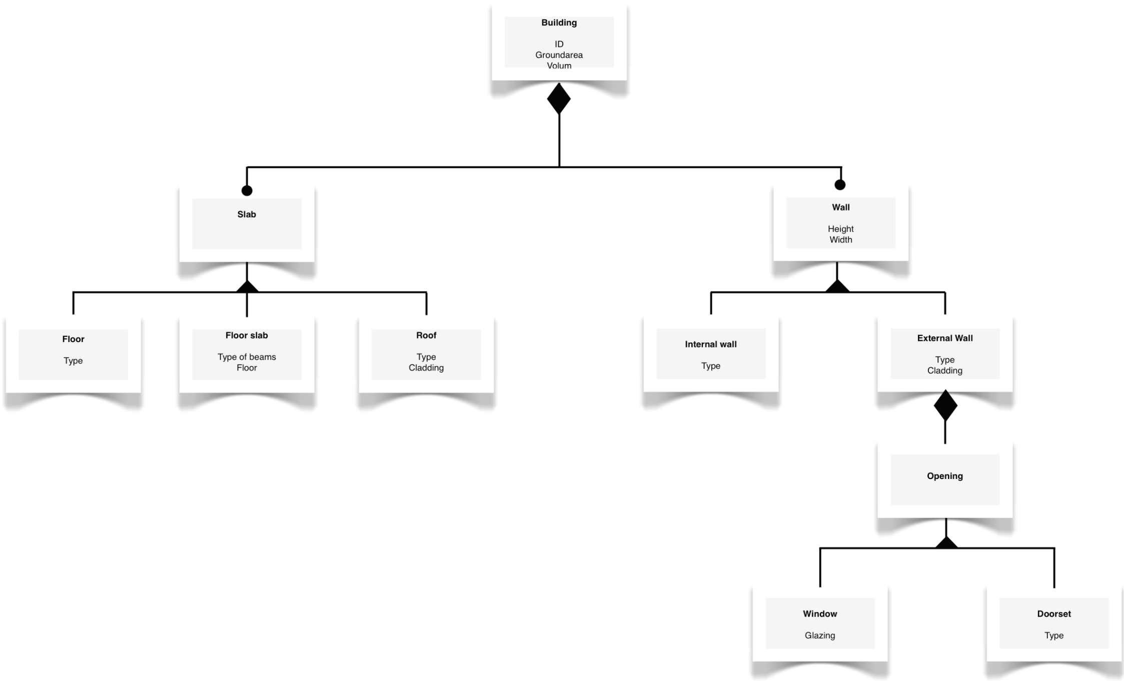

Figure 7: Object model

The most important aspect of BIM is information management. The structured system of information, that is made when designing a BIM, can improve the traditional way of managing information significantly.

In this chapter the traditional information management and the BIM way of managing information will be compared. At last implementation of universal design into the building processes by use of BIM, will be discussed.

3.1 Traditional information management in the building process

The building sector is known as “the 40 % sector”. Fourty percent of the total amount of energy the world uses derives from the building sector [19], 40% of the waste derives from the building sector [20] and 40 % of the material resources derive from the building sector. In addition 10% of the building costs are directly linked to building errors, due to insufficient communication in the design phase. [21]

In the oil and production industries, information technology has revolutionized the marked with the result that economy, quality and efficiency have dramatically improved. In the building sector, not much has happened the last 40 years. The information technology has not been implemented in the same way.

The traditional information management in the building sector is sequential. [22] There is a difference in how many phases a building process has and what the phases consists of. However, the process can generally be divided into 4 different phases [23];

-The idea phase: The aims and framework for the project are set. The architect developes ideas of how the buildings should be made.

-The design phase: The architects develop the building in cooperation with expert consultants.

-The building phase: The building is created and documented.

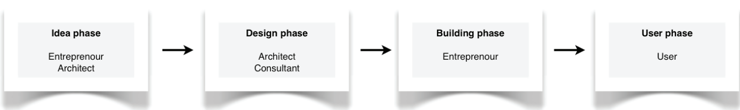

Figure 8: 4 sequential phases [23]

-The user phase: The users move into the building and utilize the space.
A division into six phases can also be seen. The idea phase is then divided into a pro-

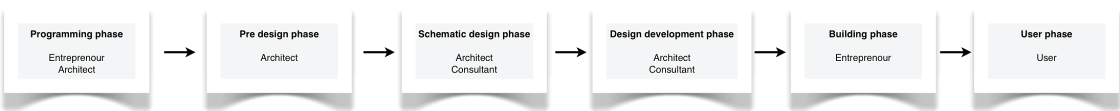

Figure 9: 6 sequential phases [22]

gramming phase and a pre design phase, and the design phase is divided into a schematic design phase and a design developement phase. [23]
One problem with the sequential program is the transmission of information between the different phases. The sequential information management has a lack of flexibility. When one phase is finished it is hard to go back to an earlier process and change any decisions made at that stage. The reason is that all other decision made in later phases has to be re-evaluated. In the traditional information management, the framework for the building is normally made in the programming/idea phase, with an existence of a small amount of knowledge. The chance for those decisions to be ideal

is small, and the result is bad solutions, both in economical terms, timeline and quality.
At the same time as the sequential phases are taking place, building processes are developed. Eikeland [24] has divided those processes into three main groups:

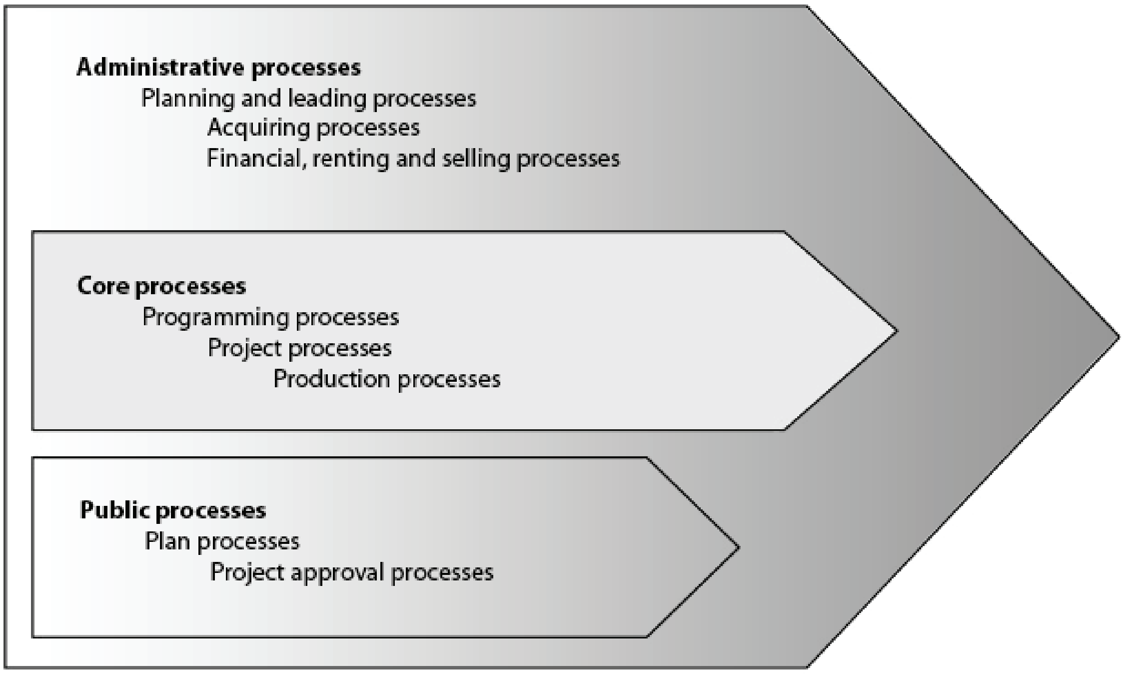

Figure 10: Building processes [24]

The core processes deal with the development and production of the building. The administrative processes facilitate the planning and controlling of the core processes. They should also manage and control the building process as one unit. The public processes provide that the building process accords with valid laws and regulations.
The different processes are running parallel with the building phases.

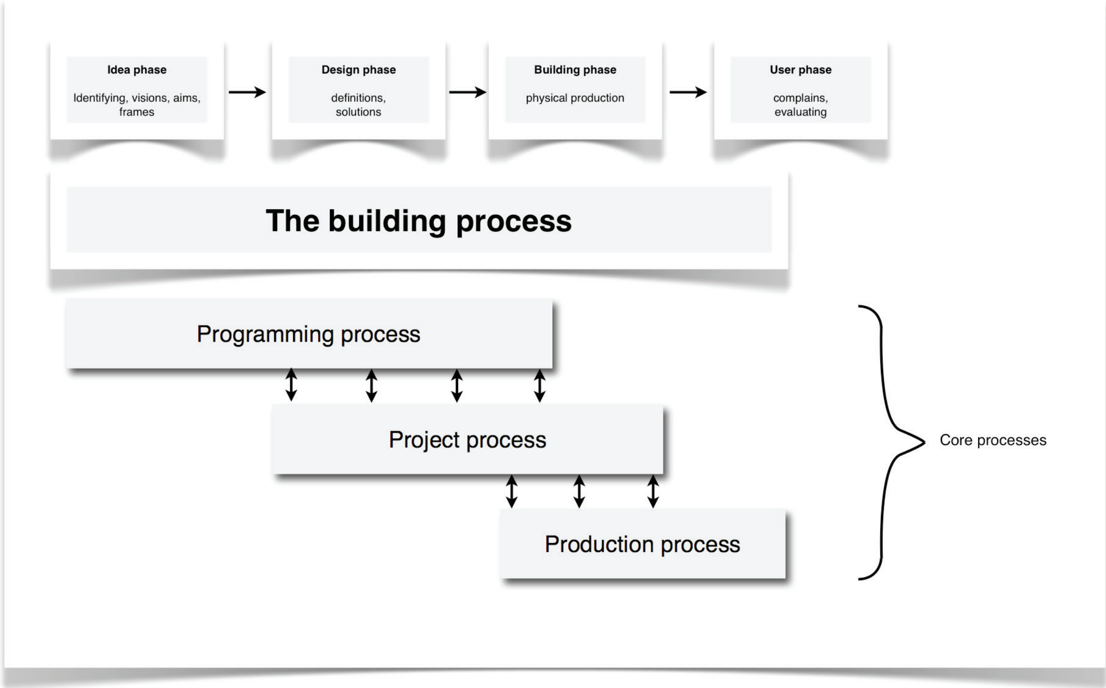

Figure 11: Phases and processes [23]

3.2 Information management with BIM

The key aspect of improving the building processes is better information management. Regarding this, two problems were identified in the traditional information management:

1. There is a lack of flexibility in the sequential building process
2. Decisions are taken at an early stage with a small amount of knowledge.

The obvious solutions for the first problem would be to make the building process more flexible. A BIM process has a great advantage when it comes to flexibility. Instead of working with sections, elevation and plans in 2D, everything is connected in a 3D model. If a structural engineer decides that the cross sections of the columns in a building are too small, he can go into the 3D model and change the cross section for the object columns. Every plan, elevation and section will be changed automatically. It is possible to digitally visualize the model in the graphical user interface, check different details and overview everything before it is built. In that way, errors that occur can be fixed before they are physically built. This makes it easier to make changes to the design in later stages of the building process. The sequences will be more interactive and it is easier to achieve an optimized solution.

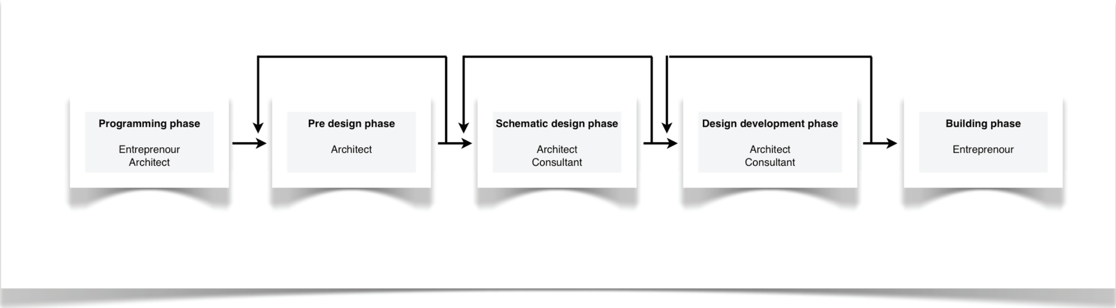

Figure 12: Iterative phases (25)

The solution to the second problem is either to make the decision at a later stage, or take the decision at an early stage, but with a larger amount of knowledge. Due to the flexibility of a BIM process, it is possible to delay the final decisions and expand the design phase. The decisions made in the early phase of the project might have a large impact on the result of the project in later stages. Therefore the efficient information available in the early stage is critical for the project.

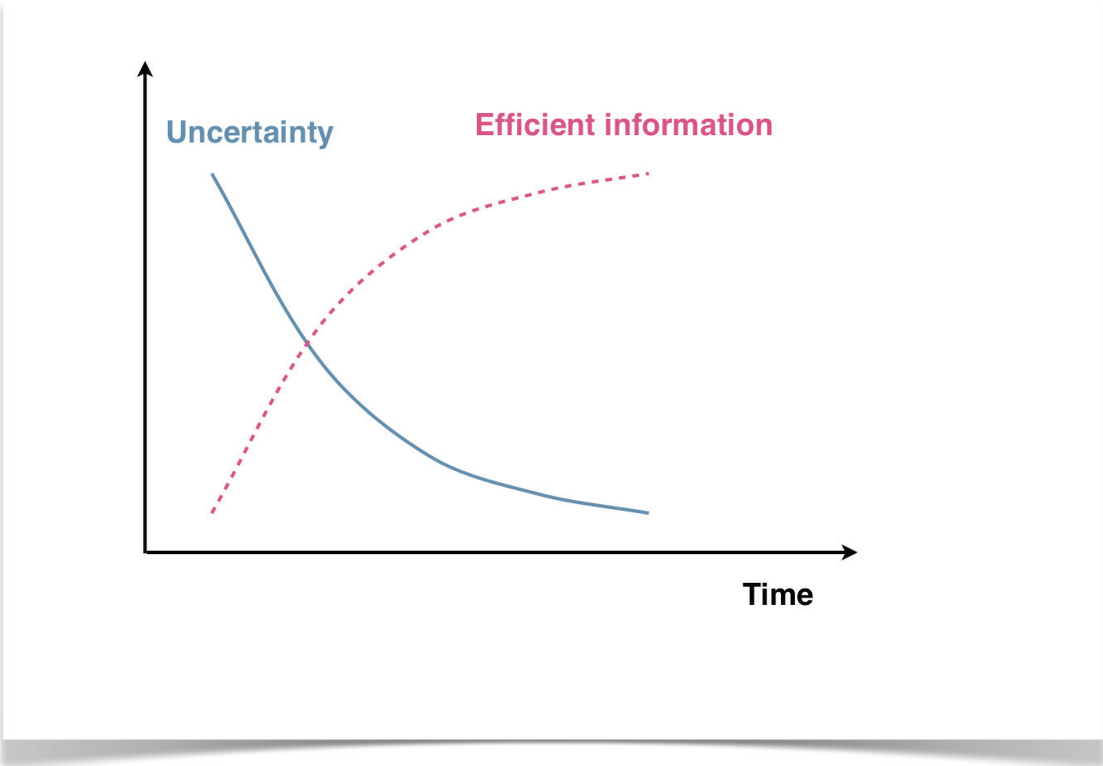

Figure 13: Uncertainty, time and effiecient information (26)

Trends, where the building companies expand their design phase of projects, have been seen in Norway in later years. The idea is that by including more expertise from different fields of the building sector in an earlier stage, the amount of efficient information will increase, the uncertainty in a project will decrease and better decision will be taken.

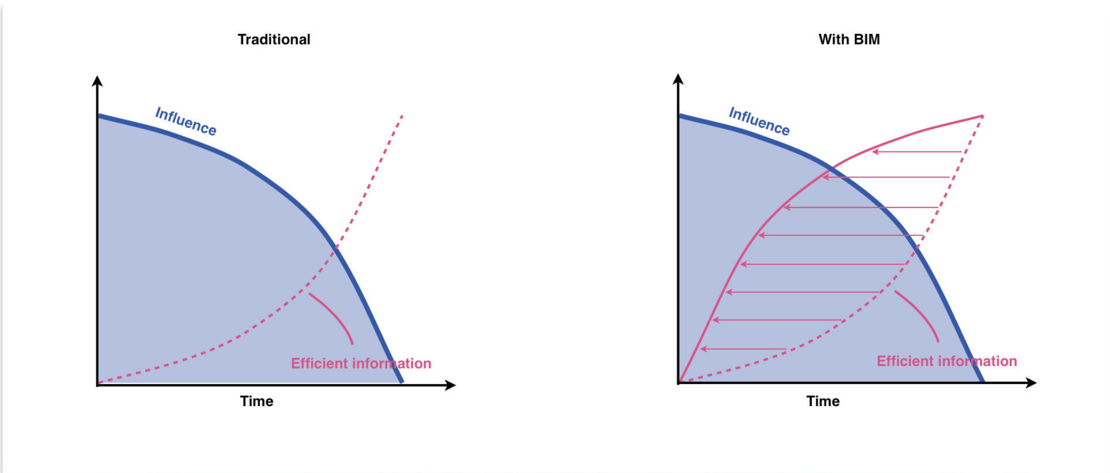

Figure 14: Influence, time and efficient information (27)

The same concept can be directly transferred to the utilization of BIM. By using BIM, the different areas of experts will contribute to the project by putting their information directly in to the BIM model.

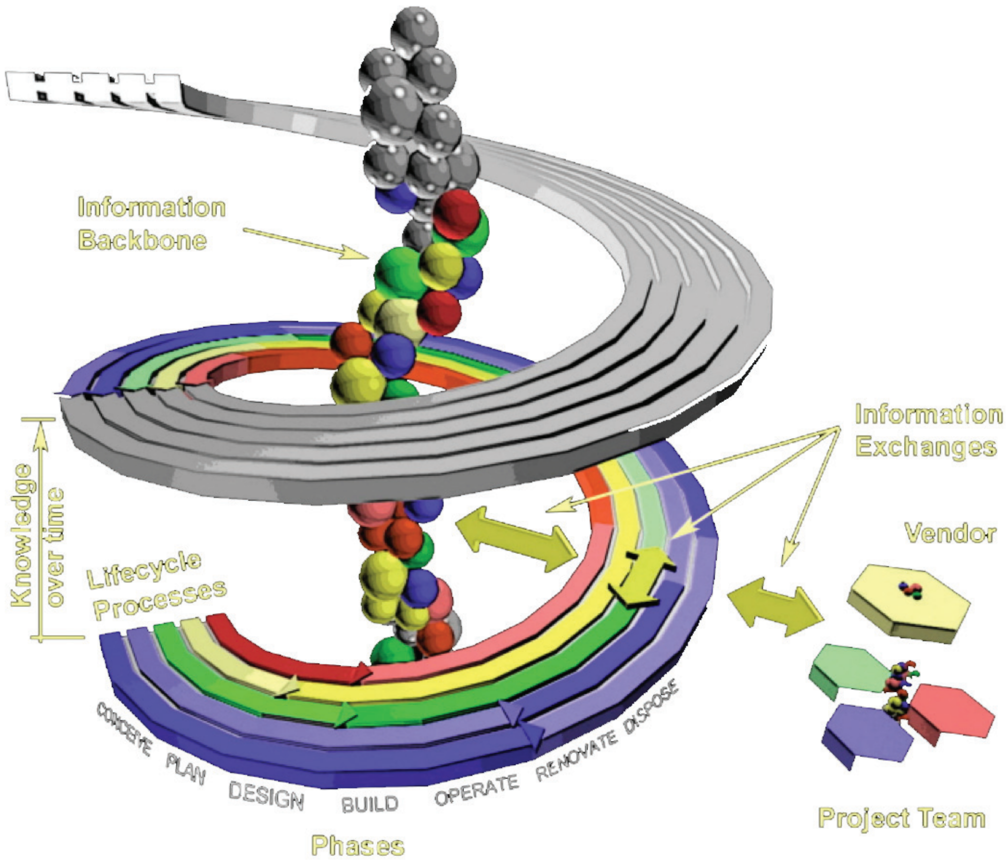

Figure 15: Utilization of BIM (28)

There is a risk to this concept. When increasing the amount of information in the BIM, there is also a need for a system that is able to manage and structure the information. The term, efficient information, is important. If every group of experts within a specific field puts their knowledge into the BIM without any ulterior motive, the result will be a mess of information where none of it can be used in a reasonable matter.

3.3 Buildingsmart - Concept

Buildingsmart is an organization that works with the development of effective building information management. So far, something they call the BIM triangle has been established. To be able to manage the information in an effective way there are three different key elements needed [29];

- A format (IFC)
- A terminology (IFD)
- A process. (IDM)

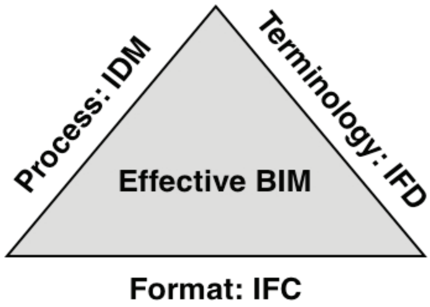

Figure 16: Buildingsmart triangle

3.3.1 IFC

The format is called IFC. The abbreviation means industry foundation classes, and it is best described as an open source format for building models, with some structure. As the DWG format from AutoCAD has been used as the exchange format for 2D drawings, the IFC format aims to be the main exchange format for building information models. The different models from the architects, structural engineers, pipe engineers and electric engineers can all be joined into the IFC, and the IFC can be used as a structured base of information where all the different actors can use, take and develop what information they need. [30]

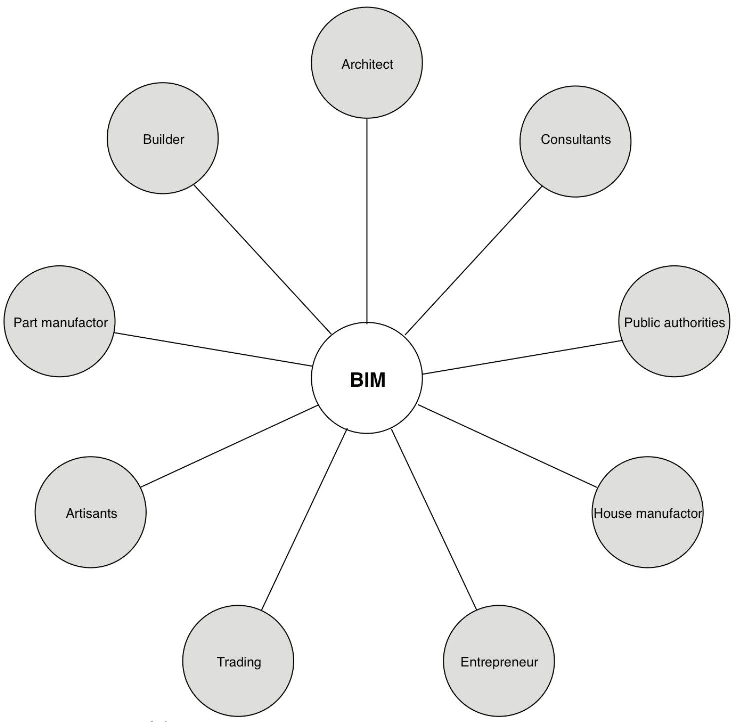

Figure 17: Buildingsmart concept

3.3.2 IFD

After they established the format, they determined that a joint terminology was needed. They established the IFD, meaning International Framework for Dictionaries. The dictionary is object based and every object in the dictionary has a unique code. The problem with national standards is that the same thing is called upon with similar words, making it hard to translate the meaning into a computerized language. With an object based dictionary one of the challenges with the makings of digital code checkers will be solved. [30]

3.3.3 IDM

They decided they needed some sort of process map to control the flow of information, and linking the IFC and IFD together. They established the IDM, an abbreviation which means Information Delivery Manual. This is still under development and it aims to describe relevant business processes as planning, building and user-processes. This means it has to describe;

- Who shall deliver
- What specific information in the joint BIM
- To which object shall this be delivered
- To which people that needs the information for their modelling
- When shall the different phases happen

The IFC contains information about the sectors that are involved in a project and the life cycle phases in the project. Due to the amount of information in the IFC, the IDM clarifies which information shall be exchanged and linking this to a time schedule of when it shall be exchanged. [31]

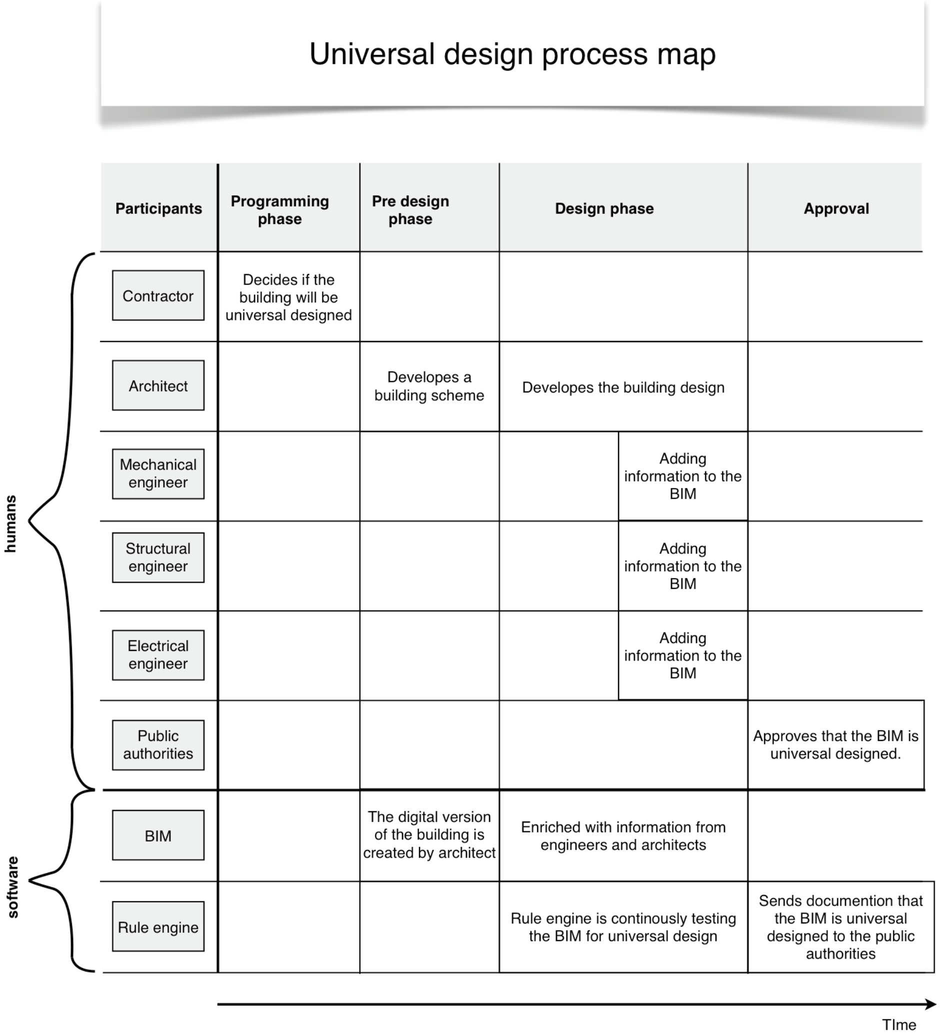

Figure 18: Prebuilding process map, universal design

More information can be found on their website; www.buildingsmart.com

3.4 Buildingsmart - Today

For an inexperienced person, the Buildingsmart concept can look chaotic. There are many abbreviations, and the ideas are still in development. The ideas are however, based on important and crucial facts. The building information needs to be organized and a structure of the different processes needs to be in place before the usage of BIM can be efficient.

3.4.1 Positive experiences

When all the different models are joined together in one IFC model, the IFC viewer is useful for visualization. It is possbile for builders to use models directly when they build. They bring computers to work and can visualize the rooms before they build them. Dimensions and positions on the different elements can be checked without confronting the building chief.

The use of the IFC has also proved to be useful when it comes to tests of the information quality. When all the different models are joined together in one IFC model, a model checker called 'Clash Detection' has been developed [32]. The Clash Detection searches the IFC model looking for overlapping elements. If for example a load bearing wall collides with pipes or the pipes and electric system over crosses, this will be revealed in this test. Instead of fixing it when the building is made or worse not be able to fix it, it is now possible to fix the digital model directly.

The IFD they have developed might become a valuable tool. Both rule checkers and economical processes have in theory the possibility to take advantage of the IFD.
The IFC is developed as a free open source format. Everyone can use it, and the development is not bounded by economical limitations.

3.4.2 Challenges

This thesis will not focus on the limitations of the Buildingsmart concept, but focus on the possibilities of the concept in future developments. Nevertheless, there are some limitations at present.

The IFC is developed as an exchange format and not a format which is meant to be used directly. [33] This means that each sector still has to build their model with their own software and then import everything into IFC. A perfect BIM program is a program where information can be developed, shared and used in one structured platform to make the flow of information work better. When designers from each field of the sector use their own platform, and then afterwards share their information, the BIM idea is not used directly, and the flow of information is not as efficient as it can be. In a future scenario it is likely that a perfect BIM will exist where every sector build their part of the building within the same program. The use of the IFC will then be unnecessary.

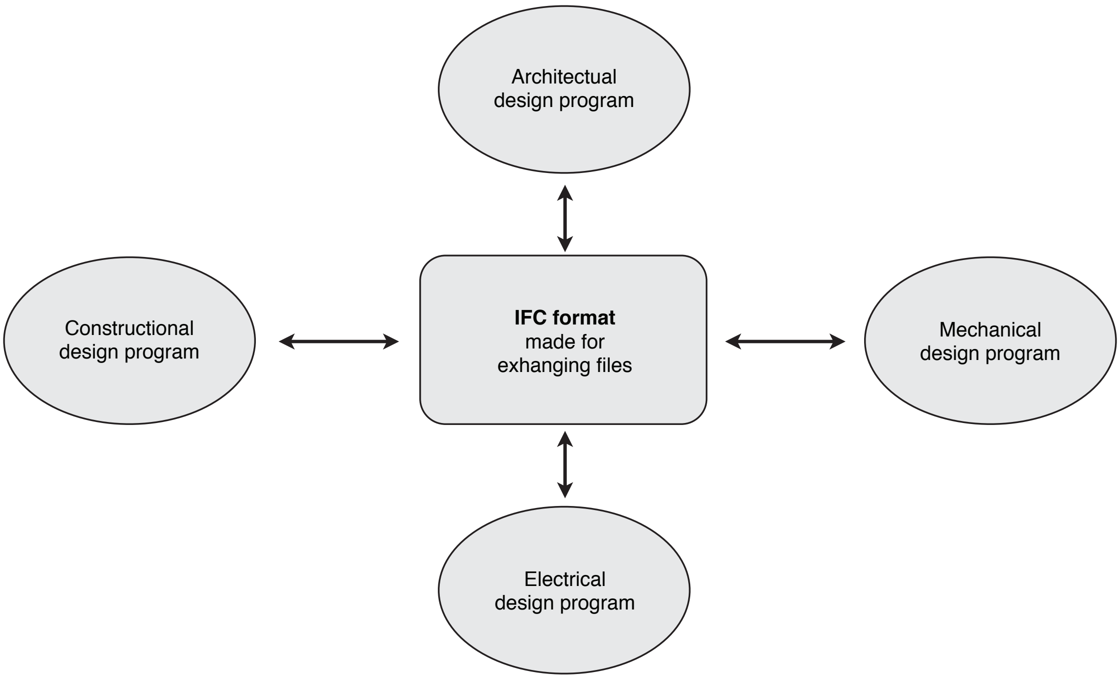

Figure 19: The consept of IFC

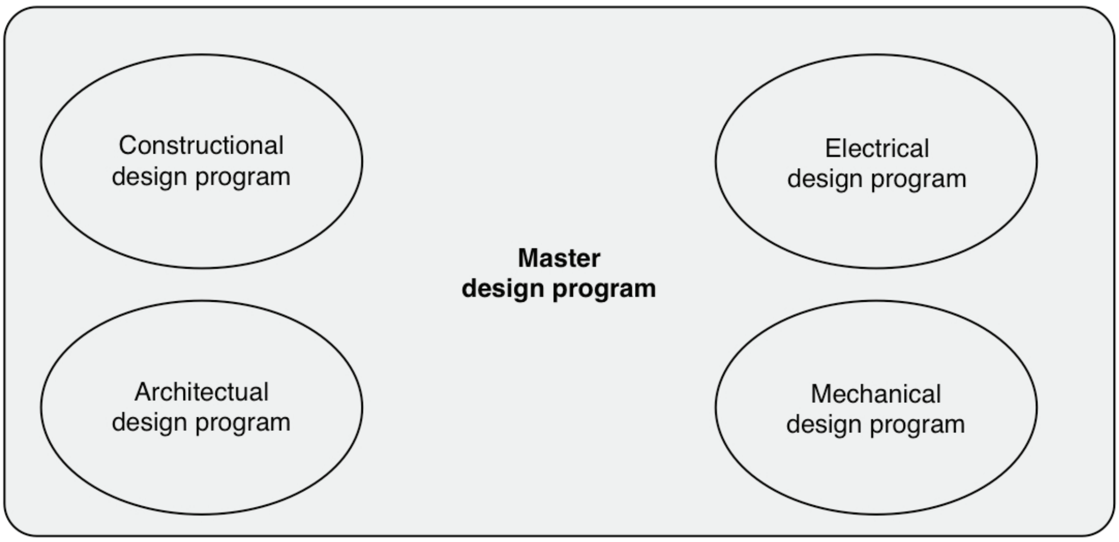

Figure 20: The consept of a perfect BIM

Being an exchange format has some limitations when it comes to usability. The IFC is designed as a quite flat and flexible platform, while the designer's own software is more rigid and structured [source]. This is due to the fact that the IFC is an open source format which imports and exports from other file types. In a more rigid and structured format it is easier to design and implement rules and constraints, than in a flexible format [kilde]. When implementing rules and constrains in a flexible version more links and rules are necessary than the case would be for a rigid version. This is explained thoroughly in chapter four.

The import and export of the IFC does not work well enough. If an architect decides to design a special window or door that is not in the IFD library, there as a chance that the IFC format not will recognize these objects as doors or windows. This is only one of many import and export issues. Export and import requirements for IFC are set to a low standard. The more software that have the possibility to export and import to IFC, the better the chance for Buildingsmart to get the IFC recognized as an ISO format. In the future the requirements must be severed, to make the import and export work fluent. [34]

Yet, the structure of the processes is not well enough developed. If the IDM are being implemented properly in projects, the information should be at such a high level of accuracy that:

- Every object has a responsible builder,
- Are linked to a time table of when it shall be delivered,
- Shows clearly what specific information the BIM and each object needs
- Shows which people this information should be addressed to. [source]

Many of the limitations in the Buildingsmart concept are in development and their way of dealing with the information management is improving. Compared to the traditional way of managing information, results can already be seen.

Positive experiences	Challenges
The information quality tests have a high standard and is definitely a useful tool in the building processes per date.	The IFC is an exhange format. In a future scenario, there might be a program that have the possibility to design all the BIM in one program. Than the use of IFC will be unnecessary
The IFD can become a unique and valuable tool in constraining the BIM. Economical processes might also take adantage of the IFD.	The IFC is developed as an exhange format. It is not ideal for operations conserning code checkers.
The IFC viewer is useful for visualization.	Export and import requirements for IFC are set to a low standard.
IFC is developed as an open source format.	The structure of the processes is not developed enough.

Table 1: Buildingsmart, positive experiences and challenges

3.5 Implementing universal design into the building phases

A building goes through several different phases during its lifetime. This part of the thesis will explain and discuss how BIM, exemplified with implementing universal design in the building processes, can be utilized in the different phases. The phases in a BIM project is more interactive than in a traditional project, consequently the boarders between each phase is more fluent, and changes are more easily adopted.

3.5.1 Idea phase

The aims, visions and framework for the buildings are identified in the idea phase. The entrepreneur decides whether he wants a universal designed building or not.

The architect has only a vague idea of how the building will be and experiments with sketches and models. Lightning, textures, space and the integration with the landscape are important factors for the architect in this phase.

BIM can be utilized to explore spaces and visualize the ideas. There is no point in testing the building for a normative universal design framework. However, if the building is meant to be designed universal, the concept of universal design should be addressed already in this phase. Main elements within the building such as stairs and doors should have proper dimensions and floors should be made without difference in levels.

3.5.2 Design phase

The next phase in the buildings life is the design phase. The design is tested and changed in numerous ways. The architect is cooperating with different fields of expertise to create a building which accords to regulations and laws. If the building should have a universal design, it is important that this is integrated in the design phase.

The architect works constantly with improving the design of the building. Utilization of code checkers that can test if the design is universal would be valuable. Instead of consulting a specialist or manually look into a standard to check whether the design is universal or not, he/she can press a button that says “check for universal design” and the design is automatically checked. The elements of the building that is not designed universal can be changed. When the design is finished, it can automatically be validated by the authorities, instead of going into the slow process of planning approval that exist today. Time and efficiency of the process will improve and better buildings will be made.

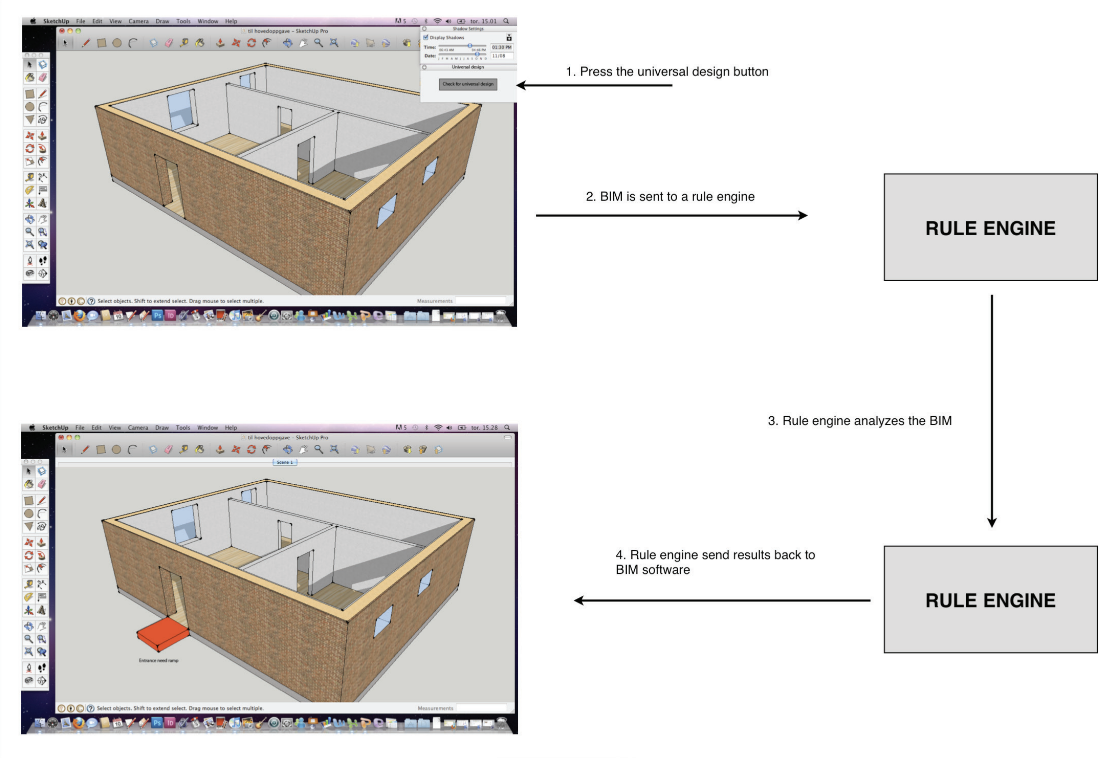

Figure 21: Rule checking consept

The making of a code checker is explained and discussed in chapter four and exemplified in chapter five.

In some cases, the ideas the architects have and what the code checker tells them to do might collide with each other. The use of light, textures and colours are for example quite specified in the standard and may be colliding with the idea some architects have regarding the use of shadows and lights to create certain impacts. [35] However, the architect of the building is not only an artist, but has a responsibility when it comes to the use of the building. In many cases the architects will prefer to know the framework of which they are designing during the process, instead of being told to change their design in a later stage. In that way BIM can better the design phase and the use of universal design.

On the other side, it is important to let the architect have their freedom when they are experimenting with design, and too many restrictions might limit the creativity. A future scenario, where the humans decide the program of a building and computers thereafter make a digital version of it is not desirable.

Computers have some limitations when it comes to design compared to humans. They are by no means intelligent. The software of a computer consists of two types of systems. A structured system that stores information and a rule based system that controls the information. It works by collecting one and one instruction from the storage, carries out a instruction and saves the result another place. These instructions are very basic and it requires a large amount of instruction to do complex operations. [36]

When humans design, they are using their creative ability. That involves not just taking rational decisions, but also being able to reflect, discuss and change in order to create a good design. [35] A perfect solution for a building given a site and a program does not exist. A computer works trough a line of instructions, and the result is only one solution. A computer is able either to say yes or no, but not good or bad. If computers where designing buildings the result would be too much similarity and the diversity of the cultural landscape would cease to exist.

The design should be finished after this phase and accord to every valid laws and regulations. Any later changes in the design will be of a high cost or not possible, a BIM project is however more flexible than a traditional project, consequently changes will be easier adopted also in a later phase of the project.

3.5.3 Building phase

After the design phase, the project evolves into the building phase. Each room is built sequential, but since a building consists of several rooms, the phase is interactive. The focus is to transfer the design into reality with as high quality as possible, as fluent as possible, with as low cost as possible, and as fast as possible. However, high quality and low costs and speed might be challenging to unify. Communication, clarity and a comprehensive building schedule are key aspects of making a success.

The building schedule must be as detailed as necessary, and should also have a dynamic profile to maintain the fluentness of the project [37]. In other words, if a delay is happening at one place, for example that the builders are slower than the schedule, the building schedule should automatically develop its scheme so that the plumbers or electricians that are doing the next work on that place, not have to stay at the site, waiting for the builders to finish. This is a subject that lies beyond this thesis, so it will not be described any further here. However, there have been interesting approaches to solve this and further reading can be found on http://www.edr.no/.

Another interesting question regarding the building phase is how much guidelines the workers need. A bathroom can be used as an example. According to regulations, the floor shall have a fall on 1 to 100 against the sink [38]. To be able to make a rule checker compliable to check this, we need to define the regulation mathematically. An equation that defines the surface and the direction of the fall need to be in place. After that, two controls have to be established. That the fall, or in other words, the maximum angle difference between the horizontal surface and the bathroom surface, is more than 1 to 100, and that the fall vector is directed against the sink. To find the maximum angle and direction requires derivation with thought of both X and Y of the surface equation. To be able to define this rule in a rule checker is, in other word, a heavy and complicated task. The same goes to the graphic visualisation of it.

The result after this task is a BIM which shows the correct fall on the floor. The workers that builds bathroom already knows that the floor needs this fall, so the code checkers approval of this will have no influence of the work they do. Consequently time and money has been used on something that in reality did not have any effect.

At one aspect, the use of BIM in the building phase might have a great advantage. Today, the builders tend to use 2D drafts as the information source when they are building. 2D drawings have less information available than 3D models and building errors do occur due to this fact. Builders can start to bring computers with 3D models along on the work. This enables them to visualize what they are building when they are building it and thereby reduces the amount of errors in this phase which will reduce the costs.

If we look at possibilities in the future the process of how designers communicate with builders can be changed completely. At the doorstep to common knowledge is a term called augmented reality(AR). By using a smart phone you can see the real world trough the screen of the phone, but with additional information about the elements you see. [39]

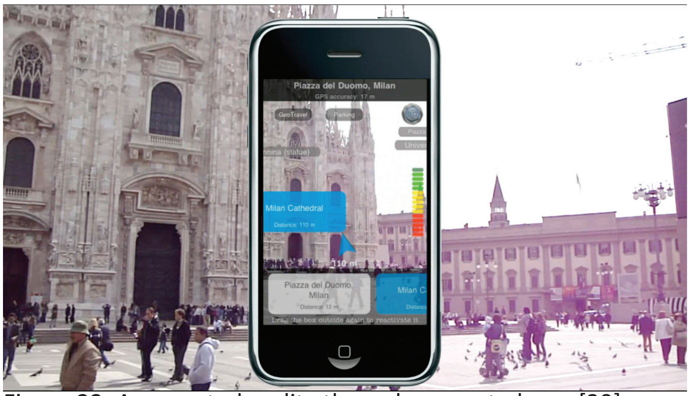

Figure 22: Augmented reality through a smart phone [39]

Due to the current speed of the technological development there is assumed that this technology also would be implied in glasses and even lenses in some years. If the builders can use lenses with the capability of the augmented reality viewing, the building phase will be revolutionized. If each worker has the building information model implied in their lenses they can see what the buildings will look like when finished, while they are building it. By implementing different layers in this BIM viewer the builders can choose between what they want to see depending on how far they have come in the building process. The accuracy of the building will be increased greatly and the building errors will be reduced. The use of paper in the building industry will also cease to exist.

3.5.4 User phase

After the building is finished the user phase of the building starts. This is the important phase of universal design. Whether it is designed universal or not, start to have an effect from this point and forward.

A distinction can be made between two types of users; users with disabilities and users without disabilities. Each group has their individual needs. In buildings especially made for the elderly, hospitals or similar, the main type will be the users with disadvantages. For the rest of the public environment, the main type of user will be the ones without disabilities.

Looking at the type of user which does not have any disabilities, there is one important aspect which needs to be considered. There should not be any disadvantages for this user when the building is universal designed. In some cases unfortunately there will. Universal design is a framework of rules which comes with many requirements and limitations. A space where everything is painted in a dull colour, where there is warning signs wherever there is a possibility of hazard and where there are no shadows is a result. For private building projects this is not optimal. The possibility of creating a building which is not designed universal, but which is easy to transform in a later phase, should be considered. In a previous plan, the Norwegian government included this possibility. In the last plan they have removed this possibility. The reason is that it creates a separation between users with or without disabilities. In that way it could be seen as a discriminating law, which has never been the intention of introducing universal design.

When it comes to the utilization of BIM, the user phase will be completely changed. As mentioned earlier the building sector is known as the 40% sector, due to the fact that buildings are responsible for 40% of the energy usage in the world. The main part of this energy usage happens in the user phase of the buildings life cycle. To reduce this in the future a BIM will be linked to each building that is created. A computer that is controlling the energy use of the building is connected to the BIM and a low energy profile will automatically be implemented in the building. The Norwegian Defence estates agency has already implemented this in their new buildings with positive results. [40]

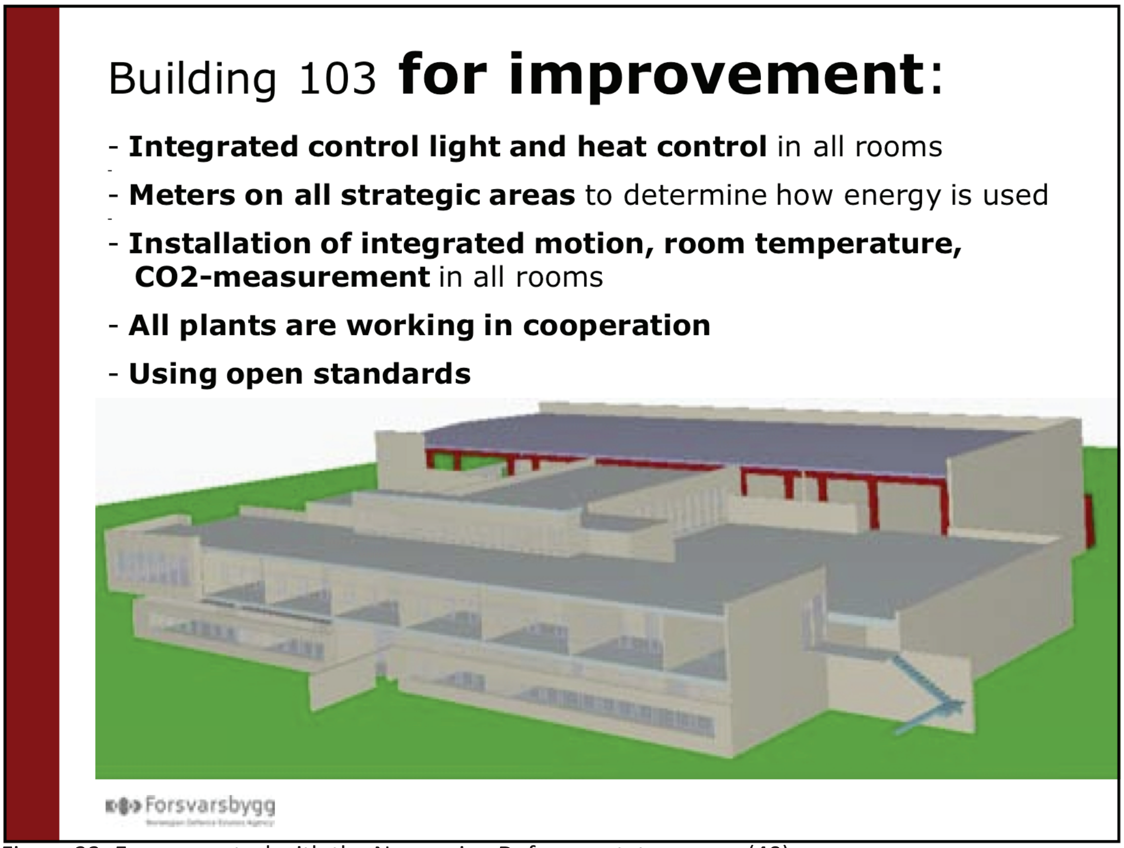

Figure 23: Energy control with the Norwegian Defence estate agency (40)

4.0 Digital rule checkers

A rule checker is a program that is able to check if other programs are following rules they are meant to follow. For example does rule checkers exist within the usage of the html language, the code language that is being used when making internet pages. The rule checker checks if the html language is following the rules which are given in html coding. By that it is predicting whether the internet page the html language is making will work or not, and also what the reason for any malfunction will be [41]. There are many other examples as well. As this thesis is being written it is constantly also being checked by another rule checker; the spell check.

For the building sector and BIM the intention is that a rule checker should be able to test the quality of the digital model. This can be differentiated into two main types of "qualities" that can be tested.

The first type is a test of information quality. As mentioned in the previous chapter, the building is per date being built in several different softwares, before being imported into a main base of information (IFC). The basic idea behind an information quality test is to test if the basics of the building have been built equal in all the previous software. Consequently to test if all the columns, walls and openings are at the place they shall be and if there exist any collisions between the different services. (loadbearing wall and pipes and electricians)

The second type is a test of the building quality. In other words; to check whether the building information models are being built according to valid regulations and laws. Today it exist a numerous amount of laws a building has to accord to. A single rule checker will not be able to check if the building follows all those laws, but instead focusing on single areas as energy and universal design as will be discussed further in this chapter.

A future scenario might be that rule checkers is able to check every knowable law. The research on the area is however still in an early phase, so this scenario still has many years to come. It must be evaluated if a rule checker has the possibility to check all valid laws, and what laws are necessary for a rule checker to check.

Information quality test	Building quality test
Test of the unanimity of the different building models, consequently if all the columns, walls and openings are at the place they shall be in all the previous software	To test whether the BIM are according to valid laws and regulations.

Table 2: Comparing the two different quality test

This chapter will give an introduction to how a rule checker for BIM works, describe the different rule checkers that exists within BIM today, and look deeper into how the future of rule checking can be.

4.1 How does a rule checker work?

A rule checker is software which is made to control other softwares behavior. This can be done in different ways.

The inside of a computer consist mainly of three parts, a calculation unit (CPU), a memory and a permanent storage of information. The memory and the permanent storage of information contain different types of software which is a term used for digital storage of data [36]. The structure of this data is often referred to as the system design [18]. The information can be understood as instructions, numbers or letters. Constrains can be given to the information by relating an instruction telling them how to behave [36].

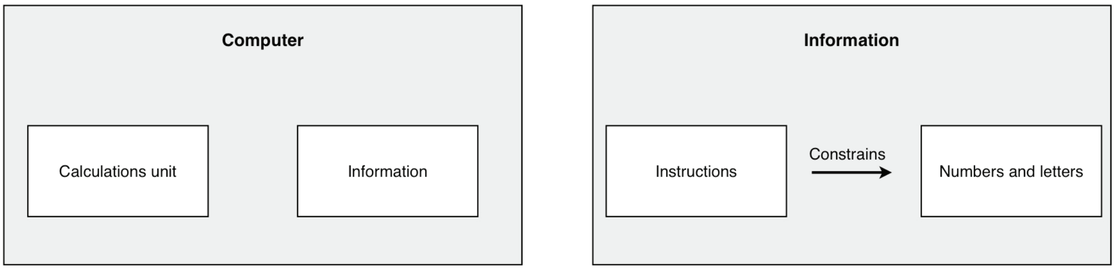

Figure 24: Basics of a computer and types of information

Object modeling language is a modeling language based on a standardized set of symbols and ways of arranging them to model a system design. The language is visual and at a higher level of abstraction than a code and is often used to communicate the design ideas [42]. It consists of objects with relations between the different types of objects. Properties are given to both the objects and the relations. Rules can be implemented to the object models by implementing constrain to the properties.

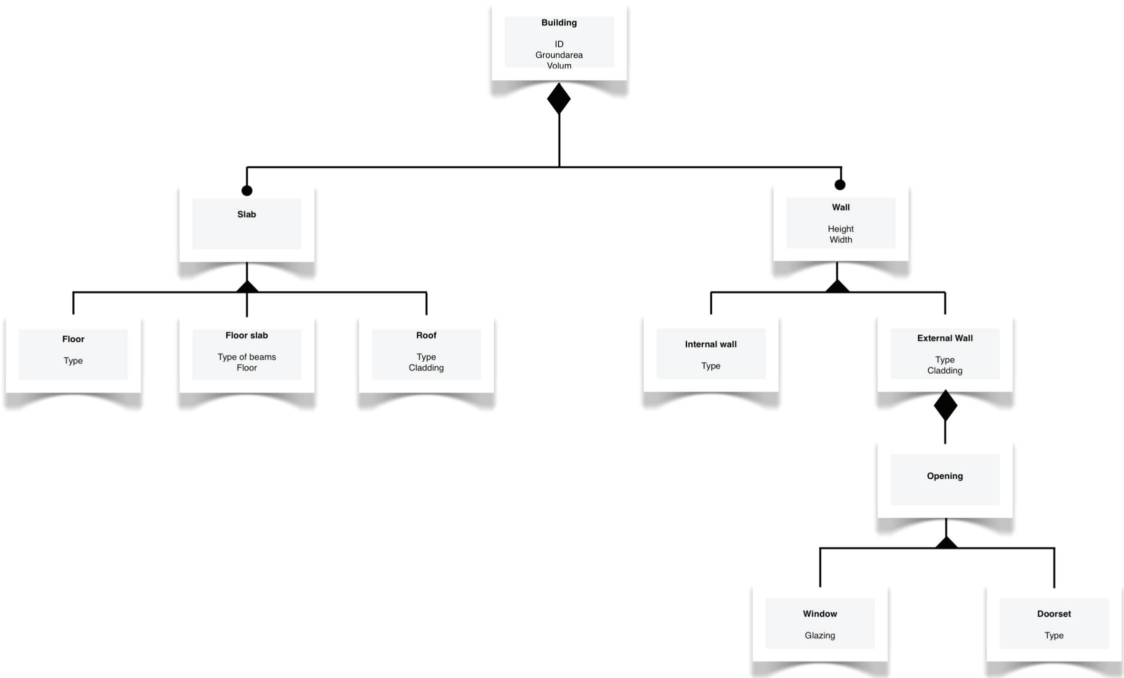

Figure 25: Structured object model

As seen from the diagram, objects can have sub-objects. The sub-objects inherit all the properties belonging to the object. By having an hierarchical structure of the system with many grades of sub-objects the amount of rules needed to constrain the system will be greatly reduced. Succeeding this, a simpler rule engine with fewer rules can be used to constrain the design.

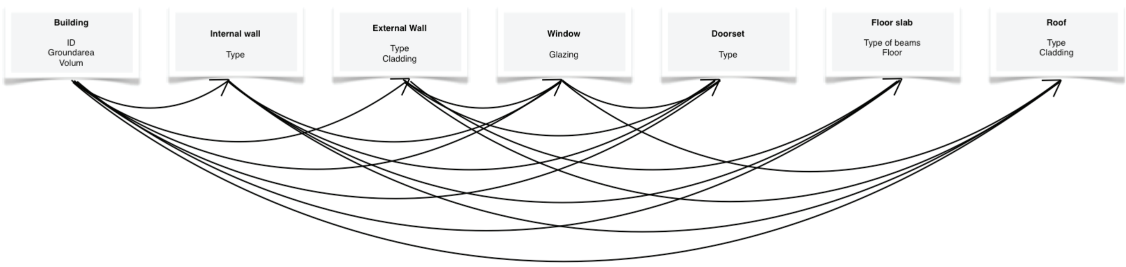

Figure 26: Flat object model

Constrains can either be implied within the software or by an external software.

4.2 Implementing rules <u>within</u> software

In BIM rules can be implemented directly within a software by constraining the design phase. A window can for example not be created in Archicad, without being attached to a wall or a roof. The rule ‘windows need to be attached to walls or roofs’ are then automatically implemented. Archicad also uses an object library in the design phase (similar, but narrower than the IFD library). When creating objects you can choose between a variety of standard solutions that are within normal laws and regulations. There is also the possibility of adding new object sets that accord to specific laws or regulations. (The objects can however manually be changed by the designer in a later stage.) The objects created do not need a rule check since they already are valid when they are created. This way of making sure a design is built according to certain rules is an example of implementation of constrains within software. [43]

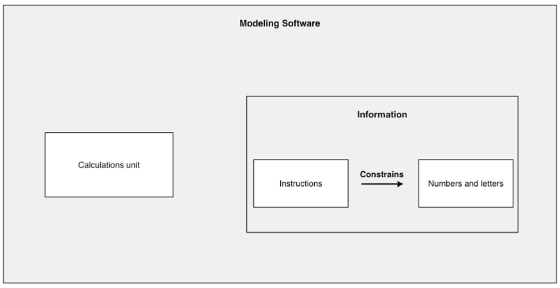

Figure 27: Implementing rules within software

4.3 Implementing rules by external software

Rules can also be implemented by external software. In those cases the designer can build the design without any constrains. In a later phase he/she sends the design to an external rule checking software that analyses the design. After the analysis the rule checking program sends the results back to the designer. The analysis process will be discussed later.

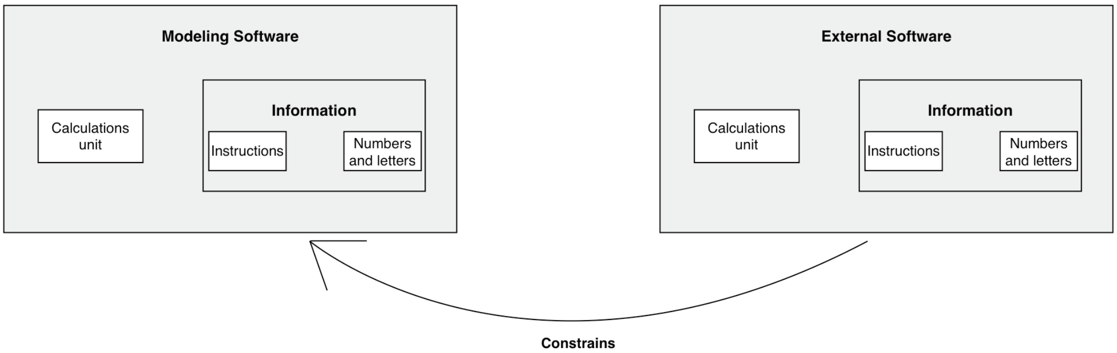

Figure 28: Implementing rules by external software

4.3.1 Making a digital building code

The external software needs a digital building code as a compliance base when analyzing the design. This is done by interpreting an original building code into a formalized rule set. There have been different approaches the last years in doing this [44]. They normally derive in a process that contains three main steps:

1. Define the scope of the original building code.
2. Structure the original building code
3. Create the computable rules
4. Validating the digital building code

This is a highly iterative process and the sequence of the two first steps can be changed without having any effect on the final digital building code.

4.3.1.1 The scope of the original building code

Defining the scope of the original building code is a step where the original building code is being prepared for formalization. A computer sees the world as black and white and not in grey scales as humans do. In this step the code will be translated into a precise language and regarding this two different challenges need to be thoroughly solved:

1. Some codes are not directly translatable.
2. The natural language is imprecise.

Handling of the codes that are not directly translatable

The original building codes are made by humans and are meant to be understood by humans and not computers. They consist of both numerical constrains, as for example the clear width of doorways, and presence of special qualities, as for example, adequate lightning in functional rooms. A study in 2005 found that 30 % of the rules in building laws are numerical and the 70 % remaining consist of a presence of special qualities [45]. Special quality rules are rules that are not directly understood by computers, but there is, per date, three logical ways of dealing with those rules. This can be demonstrated by looking at the adequate lightning rule. Adequate is adjective that is imprecise, a computer does not understand such an adjective.

The first way of dealing with this is to translate the building codes that are not understandable. In this example it is done by translating 'adequate' into a known illumination value. The building information model must have information regarding the illumination in each room and by having limit values in the digital building code the problem is solved.

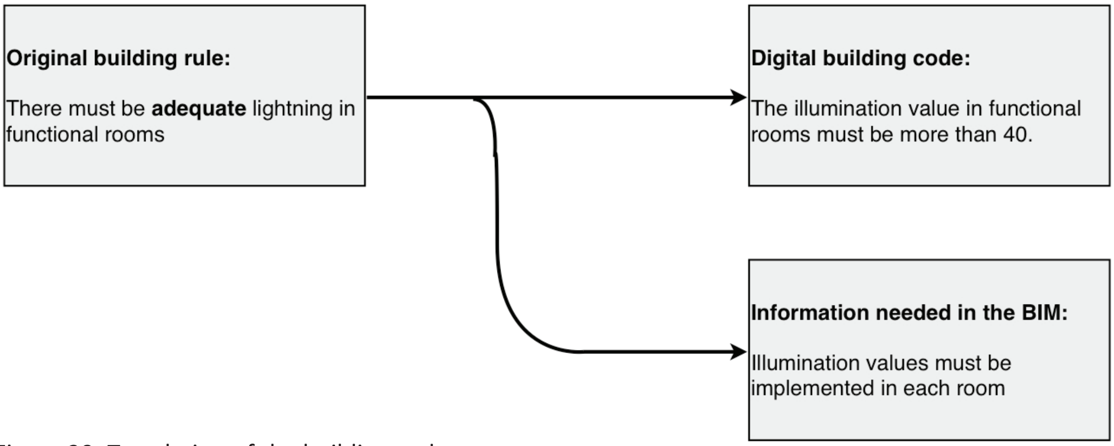

Figure 29: Translation of the building codes

The second way of solving this problem is to enrich the BIM directly with illumination information in each room as sufficient or not sufficient.

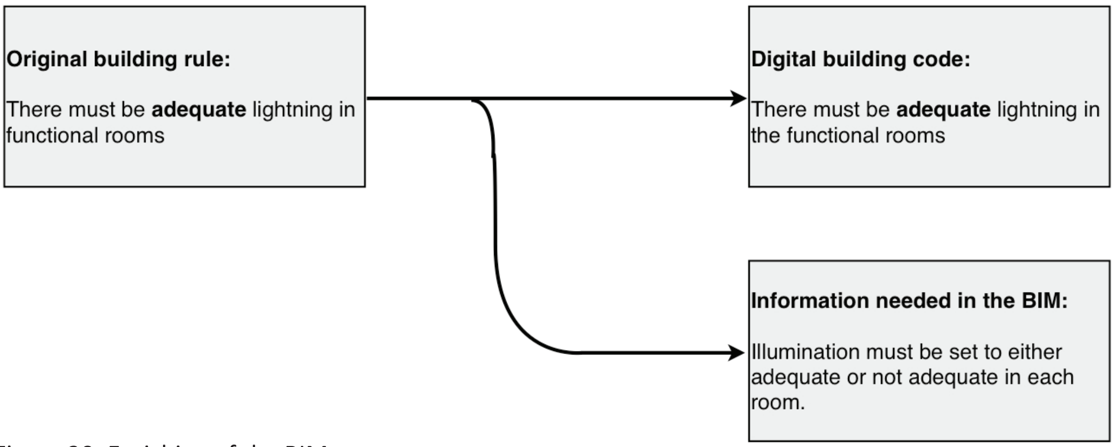

Figure 30: Enriching of the BIM

The third solution is similar, but instead of enriching the BIM model, the digital building codes can have checkmarks schemes with the rules the computer is not able to solve. These can manually be checked by humans in a later phase.

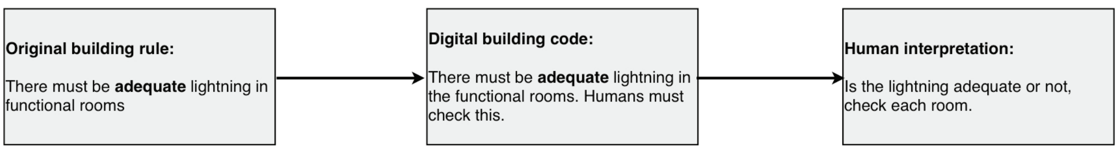

Figure 31: Human interpretation

Natural language and formal language
A problem that also comes into play when translating rules is the imprecision of the natural language. A computer does not understand the natural language, so it has to be interpreted to a language a computer can understand. A computer can only understand solid truths and untruths and are not able to handle discussions which the natural language is full of. The natural language is therefore translated into a formal language. This can be understood as a standardized rule format, which is capable of giving a computer a set of instructions [46]. When translating the natural language the uncertainty and the impreciseness will disappear. In the table below some of the differences between a natural language and a formal language can be seen.

	Natural language	**Formal Language**
Content	Complex and inaccurate	Simple and accurate
Meaning	Vague discussions	Truths and untruths
Structure	None	Object oriented
Has objects	Yes	Yes
Relations between objects	Adjectives	Mathematichal signs
	Larger than	>
	Less then	<
	or	V
	and	U
Words with several meanings	Yes	No

Table 3: Natural language and formal language

The formal language contains all the objects the natural language have, the difference is that relations and links between subjects are showed with the help of mathematical signs as >, <, V, U and so on.

The natural language also contains words that have several meanings. This cannot be present in a formal language. The implementation of the IFD library in the building-sector will solve this problem.

When some of the present rule checkers gets information that is wrong or lacking due to missing information in the models, they tend to choose to interpret these as good enough [47]. The reason for this is to smooth the running of the programs. The intention with a rule checker is to make a program that is 100% trustworthy and if the result is uncertain, the validity of the rule checker disappears.

4.3.1.2 Structure of the digital building code

After the language has been formalized the output is a list of all the different rules descending from the original building code. These rules now have to be structured. The process is similar to creating software with the object modeling language; Create object and relations between the object, properties are then added to the objects and relations, and rules are constraining the properties.

The structure will look different depending on how your objects and relations are linked to each other.

Han, Kunz and Law recommend the structure to be as equal as possible to the structure of the building information model. By having a similar build up it is possible to directly test the compliance by mapping the two models to each other and the rule engine can be built in a simple manner [48].

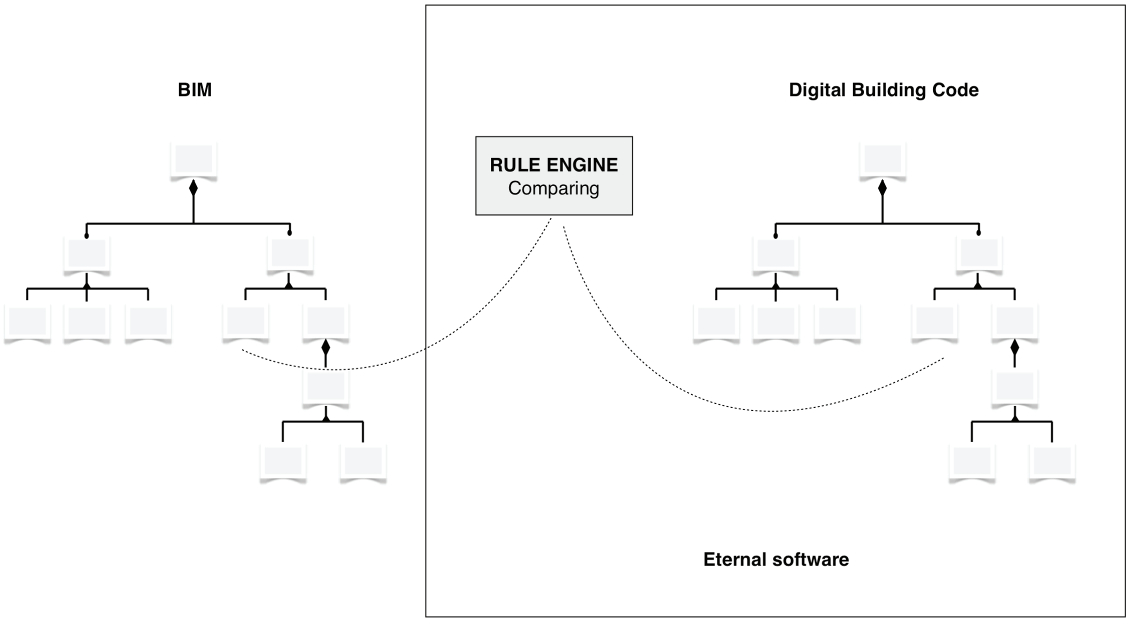

Figure 32: Structure of the rule, example 1

AEC3 is a company that developed another way to structure the digital building code. They made an explicit rule set for each chapter in the building code. Since each BIM is made up of objects and spaces, the BIM passes the test by making sure every element passes each rule. The first question in such a rule is then if a certain element applies to this rule. This makes it easier to develop digital building codes; the codes are made by using an automatic mark-up language directly marking up the original building code and the structure of the building code do not need to have any similarity to the BIM. The digital building codes made can in principle work with any building information model that consists of object and spaces. [49]

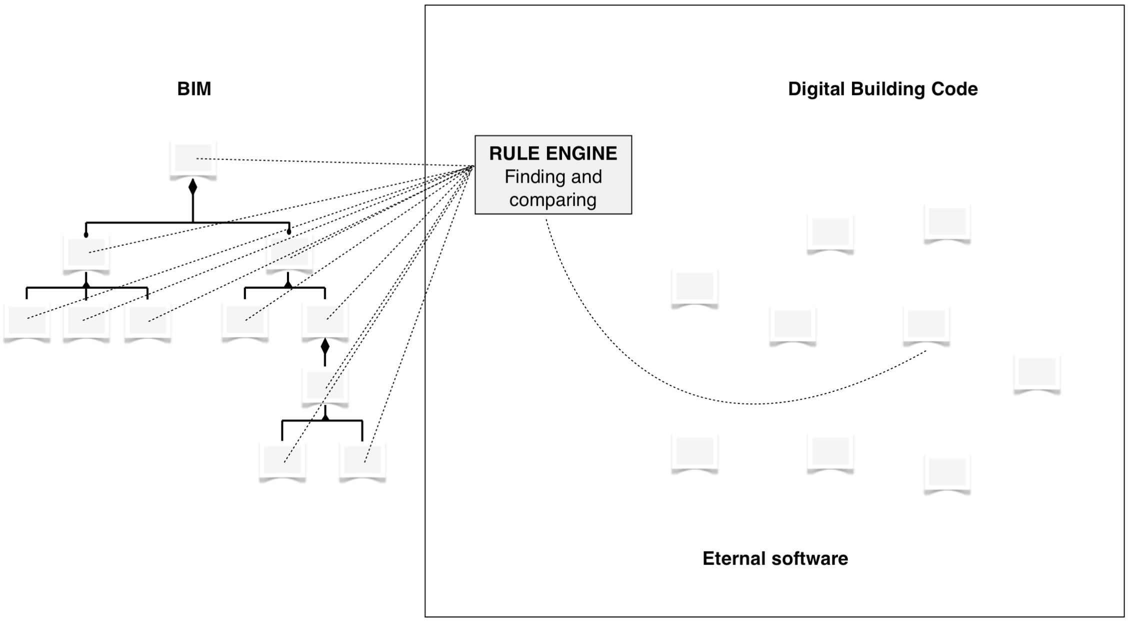

Figure 33: Structure of the rule, example 2

Everything shall be as simple as possible, but not simpler. The two approaches above both tries to follow this principle. The first approach tries to make a system that is as simple as possible; this derives in a rule engine that can be made as simple as possible. The second approach tries to make the approach as simple as possible; the digital building code is easier to make and the result is a digital rule checker that can work with any building information model consisting of objects and spaces.

4.3.1.3 Create the computable rules

After the rules have been structured, one has to create the computable rules. This can either be done manually be IT experts, writing each formal rule into a computable rule, or this can be done automatically be expert systems. The algorithm SMARTcode uses to translate the markup language into computable rules, are a good example on the last approach.

4.3.1.4 Validating the digital building code

When making a digital building code it is of great importance that every part of the original building code is implemented in the digital version. If not, the digital version will not be valid and not usable for the usage they are meant to; automatic code checking. One has to be aware of the dangers from the rules that are not directly computable, and make sure a system that also is able to cope with those rules is present. There are examples on code checkers today that have been made by implementing only the easy interpretative rules [47]. There is also a general lack of documentation when it comes to which part of the original codes they have implemented and which part is left out. In the future making of code checking a process that makes sure every part of the original version are present has to be developed. Bell, Bjørkhaug and Hjelseth made a report in 2009 that indicated a seven step process of how this can be done [44].

Stage	Description	Deliverable	Actors
1	Scope, define the rule source, assumptions and terminology	Document defining sources, scope, assumptions and terminology	Rule experts, appointed by rule owners
2	Structure the rule source according to logic and terminology	Document defining the rule source clearly according to document from first stage	Rule experts in collaboration with computable rule experts
3	Create the computable rules, possibly build upon existing rules	Computable rules on standardized format	Rule experts and computable rule experts
4	Verify the computable rules	Report with verification results	Computable rule experts with rule experts, different from makers of the computable rules
5	Implement the computable rules	Running rule checking software	Software developers
6	Test the computable rules	Test results	Rule experts
7	Certify implementations	Certified software	Certification authorities

Table 4: Seven step process of the making of a rule checker. (44)

The digital code checkers functionality is dependent on the level of information in the BIM and how those two bound together. If the BIM does not have the information asked for by the code checker, there must be a warning system implemented in the code checker telling what type of information is missing for the code checker to do a valid run through.

4.3.2 The functionality of a rule engine

A rule engines functionality is similar to a client-server relationship. The rule engine is the client and the BIM model is the server. It works by asking simple binary question to a BIM model that responds (yes or no). Depending on the answers it continues its chain of instructions until it is finish [48].

To further clarify how an analysis process works, two different examples are presented. The first one descends from a report by Han, Kunz and Laws from 1998 regarding testing accessibility for handicapped, and the second one descends from a report from Tan, Hammad and Fazio in 2009 about how to solve complex building regulations.

4.3.2.1 Example one

Han, Kunz and Law made a framework for how a rule engine can work for the testing of handicapped accessibility in 1998. The rule engine worked with an IFC file of a building and therefore had the same structure as the IFC hierarchy [48].

First it checked whether the rules where relevant to the project under considerations. Next it looked at specific building, specific floors, and then specific spaces. Finally it determined if a set of rules is relevant to the specific building components associated with a specific space. [48]

The rule checking program initially labeled a space as either required or not required for accessibility. Then, it determined which building components were associated with a specific space that was in a required state. After that the it determined whether an individual building component that was contained in a required space was relevant for the overall code-compliance of the building design. For example does not all water closets in a space need to be accessible. [48]

Once all the relations where established it examined all the building components. After examination the program resolved whether an individual building component within an accessible space is required to comply with the accessibility code. If one of the toilets passed the accessibility tests, the other toilets on the same floor were set to not required. If there are no toilets in the accessible space that comply with the accessibility code, the code-checking program marks all the toilets in the space as required. [48]

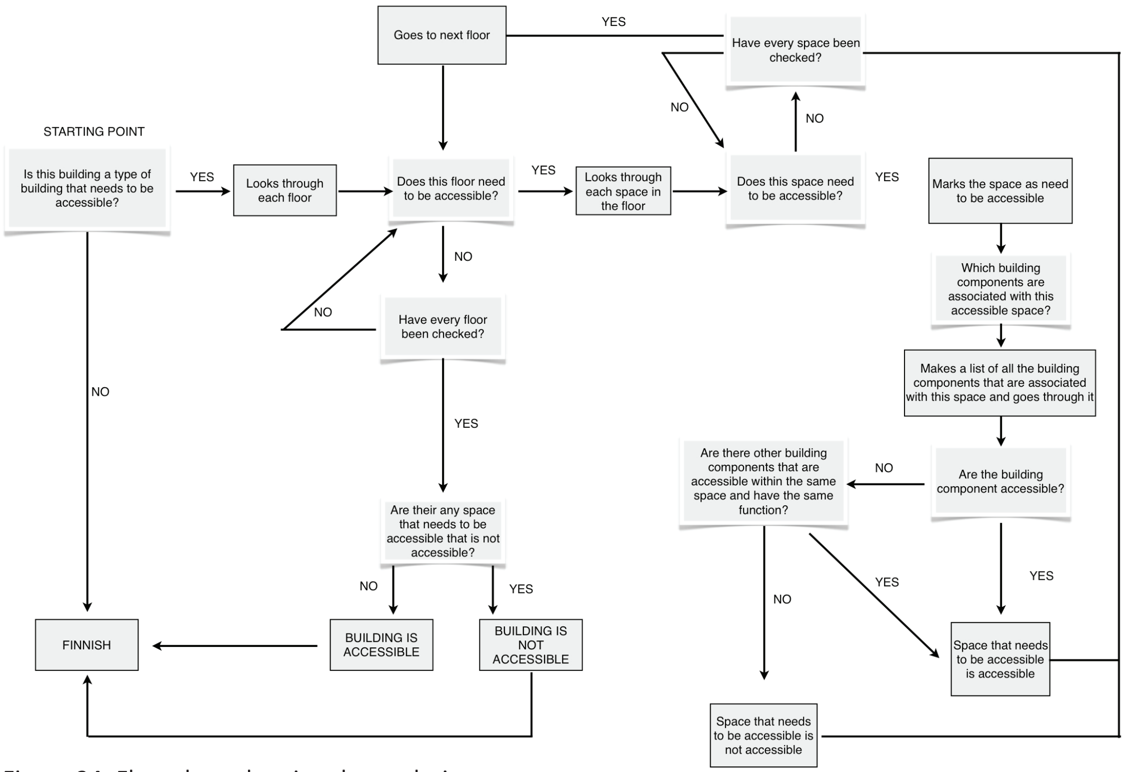

Figure 34: Flow chart showing the analyzing process

The flow chart is made to visualize the analyzis process. It has some flaws, however, the flow chart presents a good example of how a rule engine works by asking binary questions.

If the analyzis goes through the first building component in the list of building components, and finds that it is not accessible, it will automatically mark the building as not accessible, even if later components in the lists of building components have the same functionality and are accessible. A better way of doing it would be to first make a list of what functionalities that is required for an accessible space, and later search through the components to check if the requirements are fulfilled or not.

4.3.2.2 Example two

For more complex building regulations as for example energy regulations the BIM may lack information to be able to directly do a pass / fail compliance test. Tan, Hammad and Fazio therefore proposed a new way of dealing with this problem march/april 2010. They are introducing an extended building information model (EBIM), which also includes results from simulations regarding heat, moisture, air, sound, fire on so on. To deal with the extent of variety in digital building codes they introduces an extended building code (EBC), by implementing a decision table that is defining the logic of design regulations and their dependency within a standard building code. The result is that future changes in the building codes can be implied within the decision tables, which do not need the intervention of IT specialists. The EBIM and EBC is complied in a normal rule engine (Rete algorithm), and the assessment result is thereafter being sent back to designers [50].

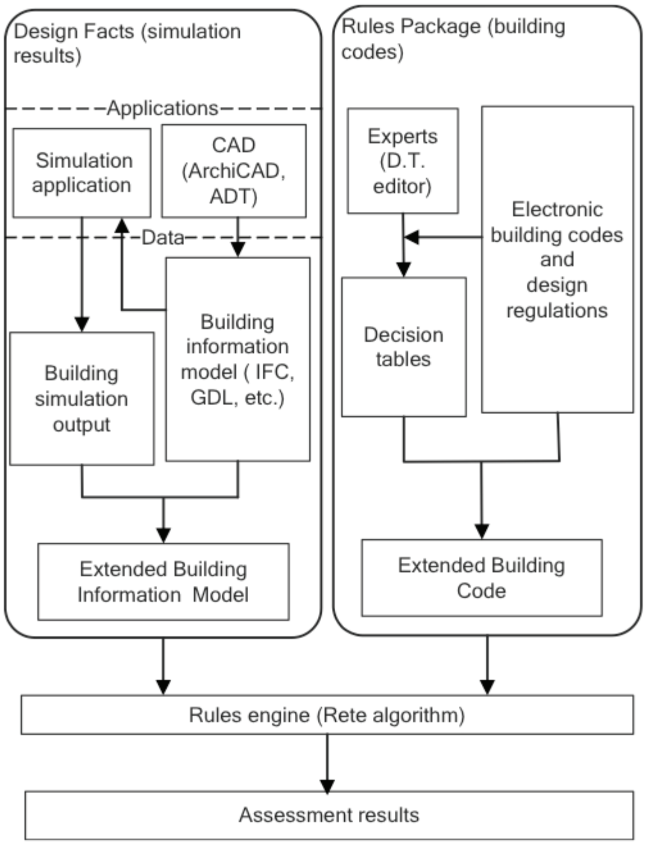

Figure 35: Constraining more complex regulations (50)

4.4 Summary

In this chapter the basics of how rules can be applied within BIM is shown.

There are two type of qualities that can be tested; information quality and building quality.

Rules are implied in the process either by constraining the design phase directly, or by testing the model in an external software.

When testing the model by external software, a digital building code is necessary as a compliance base.

The digital building code is made by interpreting an original building code. This is done in a sequential process; a translation of the original rules into formalized rules, a structuring of the formalized rules, an implementation of the system into a rule engine and a validation of the rule engine made.

To clarify the functionality of a rule engine two different examples are shown.

Type	Sub-type	Rule engine	Advantages	Disadvantages
Within software		Not needed	No need for any rule checker since the rules are followed when objects are made	Limits the creativity and possibility of the designer
By external software	Structure similar to BIM (example 1)	Comparing	Rule engine can be built in a simple manner	Time consuming to make
	Structure similar to original standard (SmartCode)	Finding and comparing	Easy to make digital versions of standards	A slower working digital rule checker.
	Extended building code (example 2)	Comparing	Possibility to implement changes	A more complex system

Table 5: Advantages and disadvantages for different ways of implementing rules into BIM

Another aspect that must be further investigated is how a digital code checker can be changed according to all the different regulations and laws that exist and are being developed. When making a digital building code regarding universal design, it should have the possibility of being adapted to the different places it is meant to be used. To make a new digital code checker in each new place where there is a small difference in laws and regulations is far too inconvenient and not in accordance with any BIM philosophy. Tan, Hammad and Fazio have an interesting approach regarding how to deal with that aspect.

5.0 Case study

In this chapter the process of transforming an original building code into a digital building code will be exemplified by initiating the transformation of ISO/DIS 21542.

The case study is limited to what an expert on the original building code can do. To make a functional digital building code, collaboration with computable rule experts is necessary.

5.1 Background

The process of making a digital building code is discussed in chapter four.

5.1.1 The SmartCode approach

The SmartCode approach of making digital building codes is a semantic approach. It is based on using a mark-up pen to mark the words in the building codes as either verbs, objects, constrains or meaning. Then an expert system automatically transforms the mark up words into a digital building code.

5.1.2 The Standard

The ISO/DIS 21542 is an object based standard. It consists of 36 different chapters containing rules that can be transformed (clause 5- clause 41), where as the rest of the standard is informative. Each of the rules contains chapters relating to one specific object. This makes it favourable for a transformation into a digital building code.

The standard uses figures that describe the rules that are mentioned in a clear way. However, a law is not allowed to contain figures, nor is a computer able to directly understand a figure.

The ISO standards are meant as guidelines or recommendations, and are not used as established laws or regulations. However, in Norway parts of the building and planning law is directly relating to the Norwegian standard, saying this or similar approaches must be used. The ISO standard can be regarded as a similar approach. In general the ISO standards are known to have a high quality, and many national standards are based upon the work from the international standard organization.

The ISO/DIS 21542 is a standard that is still under development. The abbreviation DIS means draft international standard.

5.2 Method

Based on the semantic approach of the SmartCode concept by AEC3, the original standard is decomposed into a list of rules. The rules are structured into the objects and sub-objects properties, based on the original structure of the standard. This to make sure every part of the standard is transformed.

The method used in the case study will not create the most fluent digital building code. The priority has been to make sure every part of the original standard is transformed.

The SmartCode concept is based on a process with the usage of a mark-up language directly in the original standard to automatically create the digital building codes. The tools they have used have not been available during this case, and therefore a similar manual method is chosen. The formalization of the natural language should be done by experts in computable rules and not by a rule expert. The list of rules is therefore still written in a natural language.

5.3 Result

Excel is used as the tool for visualizing the structure of the rules. The total sheet can be seen in appendix A.

5.3.1 Overview

Chapter	Object
Clause 5	Approach to building
Clause 6	Designated accessible parking space
Clause 7	Path to the building
Clause 8	Ramps
Clause 9	Guards
Clause 10	Entrances
Clause 11	Internal space
Clause 12	Vertical circulation
Clause 13	Stairs
Clause 14	Handrails
Clause 15	Lifts
Clause 16	Platform lifts
Clause 17	Escalators and travelators
Clause 18	Doors and windows
Clause 19	Reception areas
Clause 20	Cloak rooms
Clause 21	Large seating areas
Clause 22	Meeting rooms
Clause 23	Viewing spaces
Clause 24	Bars, pus and restaurants
Clause 25	Terraces, verandas and balconies
Clause 26	Toilet rooms and sanitary rooms
Clause 27	Accessible bedrooms
Clause 28	Kitchen areas
Clause 29	Storage areas
Clause 30	Facilities for guide dogs
Clause 31	Floor and wall surfaces
Clause 32	Acoustic environment
Clause 33	Lightning
Clause 34	Fire emergency warning systems
Clause 35	Visual contrast
Clause 36	Operating controls and devices
Clause 37	Furniture
Clause 38	Fire safety
Clause 39	Orientation
Clause 40	Signage
Clause 41	Symbols

Table 6: Overview of the chapter decomposed into rulelists

5.3.2 Example from excel

Clause 18, doors and windows

Object	**Sub-object**	**Property the rule regards to**	**Rule**	**Type**
Doors and windows (openings) (18)	**Doorset**	General	General requirements for entrance doorways; see 10.5	Informal, referring
		Width	Clear width of doors shall be minimum 800mm, 850mm or more is recommended	Translatable
		Height	Clear height of doors shall be at least 2000mm	Translatable
		Threshold	A level treshold is recommended for internal and external doors	Recommendation
			Where a raised threshold is/exists/provided/necessary, it shall have a maximum height of 15mm, be beveled when higher than 5mm and have visual contrast	Translatable
		Surrounding space	Shall have a level manoevring area on either side of a door	Translatable
			If any door is opening towards a descending stair, the minimum safe distance for maneuvering should be 2000mm	Translatable
			A maneuvering space of not less than 600mm shall be provided between the leading edge of a door and a wall that is perpendicular to the doorway.	Translatable
		Door leaf	The maximum distance from the handle of the door leaf to the wall surface shall not exceed 250mm	Translatable
		Operating force	When the operating force needed to open the door is greater than 30N at 0 degrees and 20N at 30 degrees opening, an automatic opening door is recommanded	Recommendation
			The operating force should be adjusted to less than 30 N at 0 degrees and 20 N at 30 degrees openings.	Recommendation
			Building for public use should preferable have sliding automatic doors with dual powered controlled door opening and closing and a hold-open device.	Recommendation
		Visual indicators	Glazed walls and fully glazed doors shall be clearly marked with visual indicators	Translatable
			The visual indicators shall be uninterrupted and of at least 75mm height	Translatable

			The visual indicators shall have a difference in light reflectance values of minimum 60 to the background and shall be places at a height of 900-1000mm and 1300-1400mm above floor level	Translatable
			An additional visual indicator placed at a height of 100mm – 300mm is recommended	Recommendation
			Visual indicators made consisting of two separate colors with a minimum difference in LRV of 30 points are recommended	Recommendation
		Viewing panels	The lower edge of the glazed panel shall be not more than 1000mm above the finished floor	Translatable
			The upper edge of the glazed panel shall be not less than 1600mm above the finished floor.	Translatable
			In width, the glazed panel shall start not more than 200mm from the latch edge of the door, and the glazing be not less than 150mm wide	Translatable
			The glazed panel may be subdivided by narrow construction cross sections, if sight is not restricted	Not a rule
		Visual contrast	Doors forming part of an accessible path of travel shall have a difference in light reflectance value to doorframe and the surrounding wall of not less than 30 points.	Translatable
			The minimum width of the area of visual contrast shall be 50mm.	Translatable
			At least a marking of 50mm width, with a visual contrast from the wall – with a minimum difference in LRV of not less than 30 points – shall surround the door.	Translatable
		Automatic opening door	The minimum width shall be at least 800mm, width 850 mm as recommended value	Translatable
			All automatic doors should be capable of remaining totally open(at least 90 degrees in the case of hinged doors) without manual support	Translatable
		Powered swing door	There shall be suitable detection devices that is set to ensure that a person approaching or leaving the door do not come into contact with the door during the opening and closing phases.	Translatable
			Shall be fitted with a return delay mechanism that allows sufficient time for safe	Translatable

			passage and for detecting the presence of a person laying on the floor within the door closing area.	
			Shall be capable of being used manually in the event of electrical or mechanical failure.	Translatable
		Revolving door	Where a revolving door or turnstile is installed, a hinged or sliding door shall be provided as an alternative alongside	Translatable
			Shall be large enough to allow safe passage and accommodation for a wheelchair user and a companion,	Need to be interpreted
			An automatic revolving door shall be equipped with a means to slow it or to stop it if it is subjected to pressure or resistance	Translatable
		Automatic sliding or folding door	An automatic sliding or folding door shall be equipped with a means to slow it or to stop it if it is subjected to pressure or resistance	Translatable
			Doors should not obstruct the flow of people or create a collision hazard.	Recommandation
			The door shall never obstruct the escape route	Need to be interpreted
		Door hardware	Door locks or other devices to open the doors shall be reachable and operable	Need to be interpreted
			Door hardware shall be located between 800mm and 1000mm in height	Translatable
			Adequate clear passage spaces shall be available on either side of the doors to enable people in wheelchair to access the door controls and pass through	Need to be interpreted
		Fire resistance	Special consideration should be given to the choice of closing device for a fire resisting doorset	Need to be interpreted
			The door leaf should always be easy, intuitive and obvious for everyone to open, whatever its configuration, dimensions or ironmongery	Need to be interpreted
			Also see 13.1	Referring
	Wall	Glazed walls, visual indicators	Glazed walls shall be clearly marked with visual indicators	Translatable
			Uninterrupted visual indicators of at least 75mm height	Translatable
			With a difference in light reflectance values of minimum 60 to the background shall be places at height of 900-1000mm and 1300-1400mm above	Translatable

			floor level	
			An additional visual indicator placed at a height of 100-300mm is recommended	Recommendation
			Visual indicators made consisting of two separate colors with a minimum difference in LRV of 30 points are recommended	Recommendation
	Windows	Position	Opening windows shall not project into pedestrian areas below a height of 2100m	Translatable
			Windows should be easy to open and close. They should be possible to open and close with only one hand.	Recommendation, need to be interpreted
		Hardware switchers	Hardware shutters and switches for remote control should be places between 800mm and 1000mm above the floor	Recommendation
		Height	To enable wheelchair users to see through a window, the glazing should be no higher than 1100mm from the floor	Recommendation
		Visual indicators	Glazed walls and fully glazed doors shall be clearly marked with visual indicators	Translatable
			Uninterrupted visual indicators of at least 75mm height	Translatable
			Width a difference in light reflectance values of minimum 60 to the background shall be placed at a height of 900-1000mm and 1300-1400mm above floor level	Translatable
			An additional visual indicator placed at a height of 100-300mm is recommended	Recommendation
			Visual indicators made consisting of two separate colors with a minimum difference in LRV of 30 points are recommended	Recommendation
			Consider requirements in clause 35	Referring

Table 7: Example, doors and windows

The example above shows the list of rules regarding doors and windows structured into different objects, sub-objects and the properties they relate to. The left column is defining what type of rule it is. There has been a subdivision into five different kinds of rules.

Translatable:	Rules that is directly translatable into a rule checker. Note that the BIM must be enriched with necessary information regarding the objects to make those rule checkers work in a proper way.
Recommendation:	Rules that are meant only as recommendations and not requirements. They contain the verbs *should be* or *is recommended* instead of *shall*.
Referring:	Rules that only refers to other parts of the standard.
Need to be interpreted:	Rules that have insufficient information to be understood be a computer. A further clarifying is necessary.
Not a rule:	Rules that contains the verb may be. They have no requirements or recommendations and are therefore not rules.

5.4 Discussion

5.4.1 Experiences

There is a clear connection between the number of standards a BIM will be able to check against and the amount of information necessary in a BIM. Universal design is a relatively new concept and so far BIM has not been fully researched regarding this concept. It is expected that BIM will need to be enriched to be able to implement this concept properly. When it comes to other structural areas the information needed in the BIM should already be quite clear.

The rules in the standard are mostly constraining the BIM on a visual level. The need for using IFC instead of an architectural design program cannot be seen.

A problem with a digital rule checker is that it does not clarify whether the model is good or bad, only if it follows the rules that are supplied in the rule checker. A searching digital building code, as the SmartCode approach produces, would not say anything about a corridor being to narrow, if the BIM does not contain an object called corridor. The first rule in a digital building code should be whether the BIM model has the objects and properties needed to do a proper check of the BIM.

There is a large amount of information, which needs to be translated in the process of interpreting a digital building code. A process that clearly indicates what has been done and what has not been done at any given time, is crucial.

The IFD library would be of great help when transforming the natural language into a formalized language.

The rule set made in this example is not ideal. The structure of the system will make the rules work over each other, or in other words, the digital building code will ask the BIM the same question several times during a run through. This will slow the rule checker down when doing larger operations. A different way of building a rule checker would be to look at the objects and properties mentioned, and make a rule set of each object. Then afterwards look at what links exists between the objects, and make a rule set of each link. This approach will secure that the rules mentioned will be asked only once. However, this process is more time consuming, and the risk of loosing information when translating the original standard into a digital building code is larger.

Some work still remains with regards to the quality of the rules in the standard. Some need to be clarified and some are contradictory. For example:

The main horizontal circulation design shall be level on each storey in order to ensure that the building is accessible to all people. Horizontal circulation shall be without steps. Where differences in level cannot be avoided, ramps, lifts or platform lifts shall be provided.

A rule cannot say that the horizontal circulation shall be level, and than afterwards say, were difference in level cannot be avoided. The solution is to change the first verb shall, to should. In the future standards should be developed in colaboration with computabel rule experts.

The rules can be seen as quite restricting when it comes to the design process. Solutions that can be easily changed to fit into the universal design code in a later period of life should be considered. The possibility of implementing rules into a library should also be considered. Instead of having 200 rules that says something about how an accessible toilet should be designed, there is a possibility of having three different standard accessible toilets in the library that the designer can choose between. However, this will as well limit the freedom for the designers.

The rules regarding universal design exist due to the rules of human abilities. These rules could be called meta rules, since they are the ones that defines the other rules. The possibility of making a framework of meta rules that automatically defines the other rules via simulation tests could be explored.

5.4.2 Further work

If compared to the IFC format, a different structure of each object is recommended. This structure should be made is similar as possible to the original structure of the objects in the IFC format.

Creating databases with objects and relations would be the next logical step. By doing this, the structure and relations are physically created instead of just visualizing it in a sheet. A formalization of the natural language is also necessary. Experts in computable rules must do this.

The SmartCode method will only result in a BIM that is either universal designed or not universal designed. It will not say anything about what level of universal design the BIM has. A leveling of the BIM can be done in two ways.

- By making two different rule checkers, one that controls all the translatable rules and one that controls the recommending rules. The universal design can then be subdivided into two levels.

- By adding weight point to the rules regarding their importance. Universal design can then be divided into several levels depending on how many percent of the rules the BIM have passed.

Future research on this field is recommended.

5.4.3 Future perspectives

There may exist another way of finding the errors of a BIM regards to universal design. One possibility is to use knowledge experienced through the creation of computer games. Today, there exists computer games were it is possible to walk around in a digital world in the same way as persons can do in real life. (World of Warcraft, Counterstrike, Quake and more).

There are two significant differences between BIM and computer games. The technology of computer games is much further developed, and they are focusing on dynamic objects reacting to each other and the environment, instead of static objects that exist within a BIM.

The digital world that exist in computer games could be exhanged with the built environemt that is to be tested. By doing automatic simulations of the people with disabilities, the same errors as a digital building code for universal design finds, should, in theory, be found. This is done without the amount of rules that is necessary with the normative framework that is incorporated today. To imply changes to the rules would also be easier, since it can be done by changing the properties to the people with disabilities.

This possibility needs to be clarified with experts in creation of computer games before taken any further. However, it is important to be aware of that there are other areas of expertise that has done significantly more work and has more experience within the usage of information technology.

6.0 Conclusion

In this thesis the concept of digital rule checkers has been described and discussed. The purpose is to have digital rule checkers that are valid and standardized, and comprice all current laws and regulations. Today, there are several commercial digital rule checkers on the market. However, the usability is limited due to the poor documentation of their validity(i.e. what do they include and what do they not include?) Digital rule checkers might be a good tool for improving the building industry. The technology is available and processes have been described for how to develop the concept further. What stands left is testing in a larger scale and better documentation.

It is easy to visualize ideal solutions. The IFC, introduced by the Buildingsmart concept, is not a perfect solution for a master platform. It is, however, important to start the development from where we are today. Therefore, the implementation of digital rule checkers linked to the IFC could be one way to continue the development.

The concept of implying rules within software instead of implying rules by external software should not be forgotten. The rules are then unnecessary since the objects are valid from the moment they are created. This will however limit the creativity of designers.

To learn from other fields of expertise are important. When it comes to information technology, there are fields that have been developed further than the building industry. Dynamic objects that form the rules of the static environment through simulation tests is an intriguing thought, even though further research has to be done. Interaction within several fields of interest might be crucial for the benefit of the implementation of digital rule checkers within BIM.

I would like to end this thesis by a quote from the famous scientist Albert Einstein:

"Imagination is more important than knowledge. For knowledge is limited to all we now know and understand, while imagination embraces the entire world, and all there ever will be to know and understand."

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