Fire protection engineering in a BIM environment

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SBUF
SVENSKA BYGGBRANSCHENS UTVECKLINGSFOND
The development fund of the Swedish construction industry

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Summary: This report summarizes the project 'Fire Protection Engineering in a BIM Environment'. The aim of the project is to survey the current state of knowledge of fire safety design in a BIM environment, as well as to study, develop and test work methods processes in order to implement fire-related requirements and functions in a BIM environment. The project was carried out by Briab Brand & Riskingenjörerna AB, NCC Building Sverige and DeBrand Sverige AB. The project received funding from SBUF – Svenska Byggbranschens Utvecklingsfond (the Swedish construction industry's organization for research and development).

Briab R&D, Malmö, March 2018.

Preface

BUF – Svenska Byggbranschens Utvecklingsfond, the financer of the project, commissioned Briab Brand & Riskingenjörerna AB, NCC Building Sverige AB and DeBrand AB to survey the current state of knowledge of fire safety design in a BIM environment, to study, develop and test work methods and work processes needed to implement fire-related requirements and functions in a BIM environment. The project members were Johan Norén, Fredrik Nystedt, Michael Strömgren and Robert Möllard from Briab Brand & Riskingenjörerna AB, Ulf Larsson and Thomas Järphag from NCC Building Sverige AB, and Mattias Delin from Debrand Sverige AB. The applicant in relation to SBUF was NCC Building Sverige AB through Thomas Järphag, and the project ran from November 2016 to March 2018.

The work was conducted in collaboration with a reference group consisting of representatives from various parts of the building industry. The following individuals made up the reference group throughout, or during part of, the project:

- Mårten Lindström, BIM Alliance
- Thomas Järphag, NCC Buildings Sverige AB
- Andreas Furenberg, Peab Sverige AB
- Max Bergström, Peab Sverige AB
- Emil Hagman, Skanska
- Michael Thydell, Sweco Architects AB
- Mattias Näll, Sweco Architects AB
- Johan Stribeck, Tikab strukturmekanik AB

The reference group's expertise, networks and good suggestions have been invaluable. Its firm belief in the project made it possible to interview key players in the building industry, to field-test proposed work processes, and to spread news of the project in various forums.

In addition to the reference group, we would like to thank the people who took part in the in-depth interviews: Adam Mohammadi (Skanska), Marcus Bengtsson (Locum), Magnus Ljung (Swedavia), Ulf Larsson (NCC Building Sverige AB) and Mårten Lindström (BIM Alliance). During the evaluation, additional interviews were held with Annamaj Larsson (Peab Sverige AB) and (Johanna Fredhsdotter Lager NCC Building Sverige AB). These stakeholders' experience, thoughts and ideas laid the foundation for developing the proposed work processes and for making fire protection engineering a part of BIM in the future.

Malmö, March 23, 2018

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Summary

BIM is a multi-facetted concept that has gained increasing recognition in recent years. More and more actors are working to incorporate BIM in their processes, which in turn means considerable changes to both work process and requirement setting.

The strength of BIM is that all concerned parties gain access to the right information at the right time and are able to collaborate on a common platform. However, the building industry perceives the differing levels of digitalization between actors as a problem, and when all the consultant disciplines don't work using models, the considerable benefits of BIM are not realized. Unfortunately, fire protection engineering is one of the disciplines that has not kept up-to-date with developments and has not taken its responsibility of following digital developments in the building industry.

In an SBUF-funded project, Briab Brand & Riskingenjörerna AB, NCC Building Sverige AB and DeBrand Sverige AB have tried to change this. The project's aim was to survey the current state of knowledge of fire protection in a BIM environment, and to study, develop and test work methods and work processes in order to implement fire-related requirements and functions in a BIM environment.

The goal of the project was to enable fire protection engineering to be done in a BIM environment, and to pave the way for a future standardization of developed work processes, proposals for parameters and data management.

The work comprised an initial literature study and in-depth interview with various building industry actors, in order to collect national and international experiences relating to BIM and fire protection. Then various work processes, depending on the maturity levels of BIM, were defined, field-tested and evaluated. When developing work processes, the focus was on the decentralized information flow, corresponding to BIM level 2, and on a more integrated, real-time-driven information flow, corresponding to BIM level 3.

For each work process, critical steps were identified and proposals for handling them were presented, relating to existing technical, organizational and responsibility-related prerequisites. The various work processes focused on securing functioning design flows and information flows for technical fire protection information. This was so that fire-related information, in the form of parameters and associated parametric information/value, and visual rendering of various fire-protection related features can be communicated within a project. Depending on the design phase, proposals at various levels of information were defined. Based on control variables and different requirement parameters with specific values (e.g. EI 60), the current fire protection requirements for a building or facility based on current protection levels are clarified.

Relating to the development of various work processes, the study has investigated and described in short, the different functions for control and review, as well as automated regulation control, in relation to the work processes.

Projects at BIM level 2 (a decentralized information flow) require a high level of coordination between disciplines, and that fire protection designers are allowed to specify fire-protection-related parameters in the models of the various disciplines. In order to render visual information such as fire compartment boundaries, escape routes and location of e.g. fire extinguishers, one must create a separate fire model with up-to-date graphics display (equivalent to 2D rendering), that can be linked to other disciplines' models or be part of a coordination model.

For projects at BIM level 3 (an integrated, real-time-driven information flow), design takes place via a cloud-based database and in a shared model. Fire-protection-related information and requirements are defined as parameters in the model and as information in a shared database. In the common model, fire-related graphics displays fire extinguishers, emergency lighting and fire compartment boundaries are defined. A work flow via a shared database and model allows for a better information flow with information updated in real time, and better possibilities for future development of functions for control and review.

To keep developments moving forward, and to succeed with implementation, critical success factors and future development needs have been identified. In many respects these are vital to the entire building industry. The most critical factors are:

- The need for increased knowledge in the fire protection consultancy industry about BIM as a concept and about model-based design
- A great need for standardized terminology, processes and data management throughout the building industry, especially in fire protection
- That future versions of IFC include a "*Model View Definition*" linked to fire protection, in order to have a software-neutral data exchange format. This is so that fire-related information in the form of control parameters and analysis results can be communicated independent of the software being used
- A need for new business models that consider quality and effectivization, and that offer a win-win perspective for all involved parties in a project
- Clearer collaboration and allocation of responsibility between different actors, and that legal aspects keep up with digitalization for all actors in a project
- Future building regulations are revised, based on structure, content and format, in order to increase logic and so it is possible to make executed code of the fire protection regulations

Based on this initial project on fire protection engineering in a BIM environment, our hope and conviction are that the discipline of fire protection will become a natural part of BIM. This would create further opportunities for achieving the considerable benefits that BIM offers the entire building industry.

Contents

1 Introduction

1.1 Background

BIM is a multi-facetted term that has gained increasing recognition since around the year 2000. Ideas about what BIM is and how it can be used vary between different actors. BIM is about creating and using digital models of buildings in urban planning, which means that BIM has two meanings:

- Building Information Models – the digital models that are created
- Building Information Modeling – the work method where digital information is used and shared

In recent years, several state and industry initiatives have created more order, and increasingly, clients are demanding that design is done in a BIM environment, in order to create better understanding, increase collaboration and productivity, and improve preconditions for future phases. If the building process is to benefit fully from all the opportunities BIM offers, all parties have to work in or understand this work process. As a discipline, fire protection is still marginalized, and the documents that are supplied don't make use of available digital information to any great degree. This approach creates unnecessary delays, obstructs collaboration and reduces the capacity to conduct effective controls. With digital information that is available to and shareable with all interested parties, BIM adds value that a more analog process can't.

In recent years, BIM has gained increasing impact in the industry. More and more actors are working to incorporate BIM in their processes, which in turn means considerable changes to both work process and requirement setting. The strength of BIM is that all concerned parties gain access to the right information at the right time and are able to collaborate on a common platform. Sweden has not progressed as far as other countries; for instance, public sector projects in Finland, Hong Kong, Norway, Singapore, Great Britain and South Korea all have requirements on the use of BIM.

Smart Built Environment, a long-term Swedish strategic innovation program aimed at improving urban planning processes with digitalization as a key driver, has been underway since 2016. Within the framework of this program, several initiatives for digitalized urban planning are in progress – from municipal comprehensive plans and local plans to building projects and management.

BIM makes it possible to streamline design and production, with fewer mistakes. By using BIM for visualization, calculation, clash detection, production planning, building planning, analyses and during management, one can improve a building's quality through its entire life cycle. With BIM everyone involved can collaborate with greater clarity, throughout the building's life cycle. (see Figure 1.1).

Several consultant disciplines have increasingly transitioned to model-based deliverables, but the industry sees the difference in digitalization level between designers as a problem.

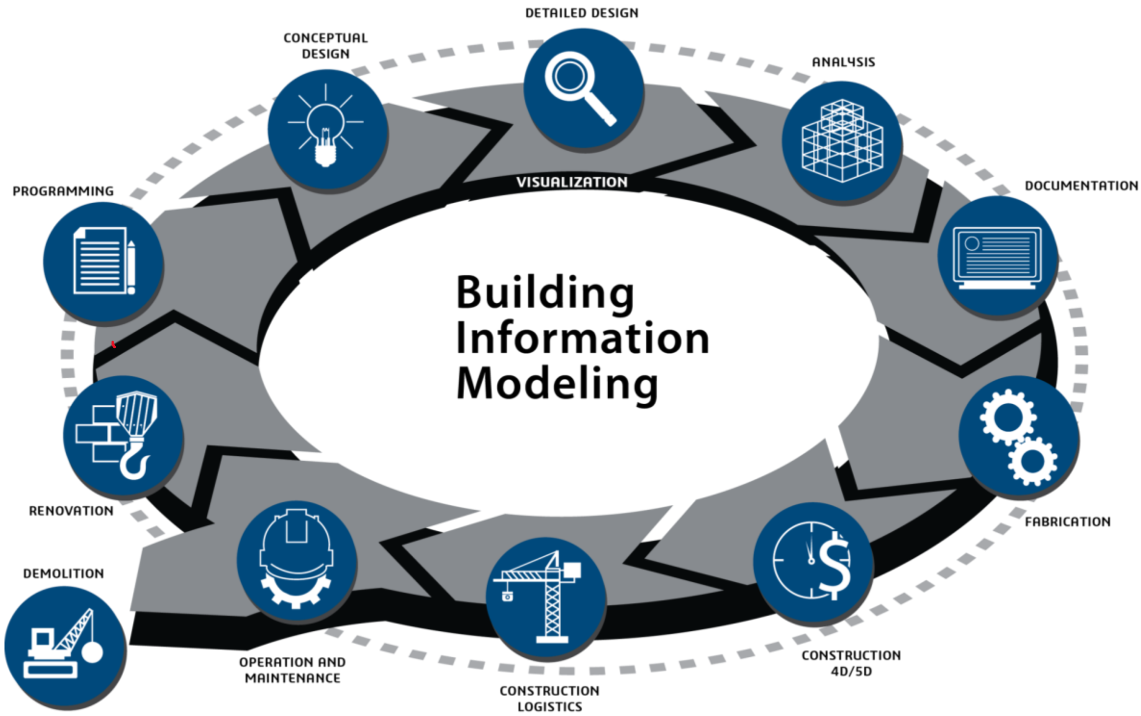

Figure 1.1 *BIM is a process for creating and using digital models of buildings, for their entire life cycle – from design to management.*

Today, fire protection designers normally supply design documentation in the form of a technical specification, which is visualized partly in the form of simple sketches or, at most, drawings for each discipline, which must then insert the information into their BIM models. The technical specification is normally called a fire protection documentation, and today it is a mix of regulation texts taken straight from the Building Regulations by the Swedish National Board of Housing, Building and Planning; the European construction standards (ECS); and descriptions of the building and design in question, so that the building can be designed with satisfactory fire safety. The fire protection specifications are relatively difficult for other designers to interpret, and the other designers have a difficult time finding the requirements that concern them, interpreting these requirements, and ensuring that they have been managed within their own design process.

The way critical fire safety information is currently handled opens the door for communication failures, since the fire protection designer lacks the knowledge and control of how different fire safety measures are presented. The shortcomings in communication and understanding increase the risk of mistakes, and can generate high costs, which can be reduced if there is a standardized work process that integrates fire protection design in the processes of other disciplines in BIM modeling. To be a more natural part of the building process, the discipline of fire protection needs not only to find a way to become an integrated actor and discipline, it also needs to improve communication and create collaborations across discipline boundaries. And if the discipline can create and implement a methodology that enables a model-based way of working with its information, it can improve control, quality and efficiency through the entire building process.

1.2 Aims and objectives

The aim of the project is to survey the current state of knowledge of fire safety design in a BIM environment, to study, develop and test work methods and work processes needed to implement fire-related requirements and functions in a BIM environment.

Additionally, the project aims to investigate the possibility to define a systematic and efficient review and control function, in order to reduce errors and deviations, and to deliver higher quality during design.

The objective of the project is to determine and to propose how the fire protection discipline can become a natural actor in a BIM environment, in order to work and deliver information via models. The purpose of this is to increase awareness of the role of fire protection in the building process, to reduce errors in production and to ensure better communication flows among the design group and between different phases of the building process, in order to enable a future standardization of the workflow.

1.3 Target group

The target group for the project is the entire building industry, since fire protection is a central part of the life cycle of a building. Requirements on fire safety play a role, right from the initial ideas phase and local plan, through design, construction and management phases.

The project's results, however, are intended mainly for actors who are well initiated with BIM and who work model-based on a daily basis. The project report is written to increase understanding of BIM as a concept among the fire protection consultancy industry, to describe the challenges and benefits of including fire protection in existing processes, and how current fire protection engineering can be part of BIM.

1.4 Implementation

The first part of the project was focused on information gathering, and a part that investigated process development.

The information gathering phase comprised a literature study, in order to learn how fire protection has been included in a BIM environment internationally and over time; and interviews with various clients, designers, builders and fire protection designers. The purpose of the interviews was to find out the needs and wishes of the building industry, and to identify critical success factors for the development of work processes for BIM and fire protection during the design of a building or facility.

Based on the literature study, the interviews and the project group's knowledge of fire protection engineering, control and BIM modeling, work processes were developed based on various levels of BIM maturity and proposals for control and review have been studied in connection to the work processes. In order to evaluate the work processes, these have been field-tested in various ongoing projects.

2 Information gathering

Below we present an extended summary of the information gathering that was conducted for the project. Using searches in literature databases and in-depth interviews with various actors in the building process, such as clients, designers and property managers, we surveyed the current state of knowledge of BIM as a process and the need for information. The knowledge level regarding BIM and fire protection was studied in greater depth, to get an overall idea of the current state of knowledge and the desired future developments, in order to understand the need, and the opportunities and challenges that face the implementation of fire protection as a discipline in BIM.

The focus of the information gathering was the benefits of BIM, critical success factors and ongoing national initiatives for better and clearer information management, the information requirements in various phases of the building process, and collaboration, clash detection and automated control and review.

2.1 Perceived benefits and early lessons learned

Several studies show the possibilities of BIM, and how it can be used for a more efficient design process. A study by Bosch et al. (2016) shows that visualization, information sharing and clash detection are the features that are perceived as the greatest benefits of BIM, and that are the main drivers for implementing BIM in one's own operations. Even if there are many drivers for BIM, there are also some obstacles. Bosch et al. also show that the greatest perceived obstacle was the lack of clear client requirements regarding BIM, and that partners don't work fully in BIM. Heavy investments in software and hardware were also seen as big obstacles. Even if most respondents didn't view BIM as strategically important, they felt that they had to implement BIM to show that they are keeping up with technical advancements.

The definition of BIM includes the model of the building and the process where various actors collaborate in order to share information about the building with each other. If a BIM model is going to be more than simply a 3-D visualization of the building, the model must also include information about the building and the construction process. This would enable the BIM model to be used to make calculations and timetables. In these contexts, people talk about 4D and 5D models, meaning that the model also includes the dimension of time and the dimension of cost, respectively.

Several benefits of BIM, relating to time, quality and economy, were identified at an early stage (Jongeling 2008). Thanks to high-quality information, the design process becomes clearer, more integrated and more efficient, while it is also perceived as more inspiring and attractive. The visualization option makes for faster and simpler decision-making processes and sales processes. But the greatest benefit is in the coordination process. Fewer misunderstandings and greater participation can significantly reduce the number of mistakes. The workload for design in a BIM environment is very different from design in a mainly 2-D tool, as Figure 2.1 illustrates. One reason why the initial phase is more work-intensive in BIM is that the BIM tools are more complex, and because of the need to make project-specific information available at an early phase of the project.

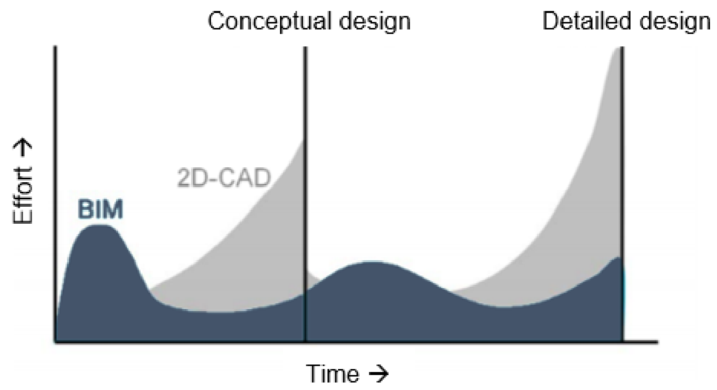

Figure 2.1 Difference in workload for design with BIM tools (Jongeling, 2008).

Holzer (2016) cites several examples of inadequate application of BIM, in order to learn from the most common mistakes. Working in BIM is a process, where it's important to highlight the good-news stories as well as the less successful examples of BIM implementation. After interviewing some 40 BIM managers, Holzer can present both pitfalls and a proposal for procedures ensuring a successful BIM implementation. A common challenge is a pseudo use of BIM, which means that a traditional CAD workflow is used for deliverables, but the practitioners state that they used BIM, possibly to impress the client or to fulfill government requirements. BIM is much more than creating a 3-D model in the final phase of a project. The BIM-based work process involves a higher degree of cooperation and information sharing throughout the planning process, which delivering a 3-D model can give the impression of. However, the benefits that working in BIM has on the deliverables are lost.

Another pitfall is that the various disciplines don't share information with each other to a sufficient extent. Initially, the transition to a BIM-based work method involves extra work, and possibly reduced efficiency for the disciplines. A short-term prioritization of one's own profits at the expense of the project is not directly favorable for the client. Therefore, it is extra important that within the project there are client-driven incentives, functioning business models and a well-considered, well-accepted BIM manual. An additional pitfall is if the models are filled with too much data, which makes them heavy and difficult to share and coordinate. The BIM manual should specify the detail level that applies in the various project stages.

2.2 Critical success factors

A successful implementation of BIM requires an industry-wide, multi-level approach, based on process, technical, policy, and people and skills (EUBIM Taskgroup, 2017). Figure 2.2 shows examples of factors of which there must be a general agreement on if a BIM-based work method is to be introduced successfully.

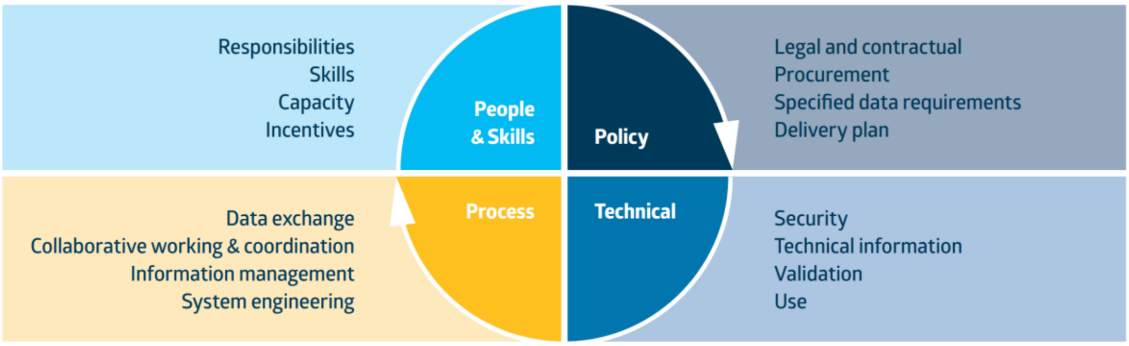

Figure 2.2 *Implementation of BIM requires agreement on issues relating to policy, technical, process, and the skills that those involved must possess (EUBIM Taskgroup, 2017).*

'Policy' concerns mainly administrative and legal preconditions relating to BIM deliverables. This can be about standards, national provisions and attachments or industry-wide regulations on consultancy services and contracting. In order to standardize, systemize and improve the information flow, the building industry manages various projects, such as CoClass (see section 2.2.1) and BIP – Building Information Properties (see section 2.2.2). At the same time as the building industry standardizes and develops systems for more efficient information management, Boverket (the Swedish National Board of Housing, Building and Planning) is working on concepts for documentation systems for building products (See section 2.2.3).

As for 'Technical', it is a matter of creating a system that is neutral in relation to the software that is used. In this respect, IFC (Industry Foundation Classes) is very important, in the form of a standardized, neutral and open file format which enables joint review of multiple models, independent of the software they were created in (Forbes & Ahmed, 2010).

Another key factor is the actual work process. How and when should information be exchanged? Should information be available in a cloud structure where the update is available for all parties in real time? Or should information sharing take place at predetermined times? Processes for coordination, clash detection and review should be specified and cleared with all parties early in a project. Finally, successful implementation of BIM requires that new skills are developed, as well as new roles such as BIM manager and BIM coordinator. The Swedish Association of Local Authorities and Regions, SALAR (Sveriges Kommuner och Landsting), (2017), is further developing these aspects, with a focus on digitalization in public-owned property organizations.

Access to updated content libraries that can be added to the model as graphics display is another vital factor in successful BIM implementation. Today there is no standardized format for BIM content, which is an obstacle to collaboration and productivity. True, one can get digital information from manufacturers, but Candela, (2015) argues that it quickly becomes outdated. As technology develops, cloud services should be increasingly used, to ensure that the right information is used in every BIM deliverable, and to secure the information flow through the building's life cycle.

2.2.1 CoClasses

Since the 1970s, Sweden has used the BSAB system (from Byggandets Samordning AB). From 2016 the system has been successively replaced by the new classification system CoClass (Svensk Byggtjänst, 2016), which was developed for implementation in the increasingly digitalized urban planning sector.

The CoClass system is based on BSAB and is a system concept for catalogization and structuring of building components and systems, where everything that is part of the built environment is represented. The aim of the system is to enable effectivizations in the project, by making communication easier and clearer. Using the CoClass names, content other than the visual can be expressed, such as the building components and their relations, qualities, contents, environmental and energy characteristics, fire protection performance and maintenance requirements (Svensk Byggtjänst, 2016).

In 2017 the Swedish Transport Administration (Trafikverket (2018)) successively began the implementation of CoClass as a support in their action plan for BIM, with the aim of securing information management throughout the life cycle of a facility. CoClass was built to be internationally compatible and is expected to aid in the development of international classification systems. To the extent that this is possible, CoClass follows the classes in the international IFC system. CoClass will also be available in English. Since CoClass was developed to cover all the different phases of a construction project, it will be a common language that lasts over time.

In practice, CoClass means that both information flows and names will be standardized. When the same names are used by different disciplines and parts of the industry, there will be less risk of interpretation difficulties and miscommunication. The concepts follow a hierarchy and consist of system-wide objects from building down to component level. Non-visual concepts such as properties, functional systems and spaces will also be represented.

Hence, for fire protection it is possible to use existing concept structures, and to apply specific professional concepts in the fire protection field.

2.2.2 Building Information Properties

Building Information Properties, BIP[1], is a system for managing names and properties of building objects. It is related to the codes in BSAB for building components and production results. Like CoClass, BIP is based on the international IFC format. The project in which BIP was developed was initiated by BIM Alliance (Bipkoder, n.d.).

The difference between CoClass and BIP is among other things that CoClass is more generic and can be used throughout the life cycle. BIP is more focused on specific phases, such as design, production or management. The names in BIP have more variation in how they are constructed, while CoClass has a clearer system. Because BIP uses type codes and type, objects with the same characteristics can be grouped, even if they belong to different classes in the CoClass system.

For instance, for the fire protection field, it could be the case that windows and doors that are in different classes according to CoClass are in the same type according to BIP, with regard to fire rating.

2.2.3 National Board of Housing, Building and Planning's digitalization work

At the same time as the urban planning sector is investing and developing systems for more efficient information management, the National Board of Housing, Building and Planning and other government bodies are working to facilitate digitalization. For building products, there will be requirements that information on the building products that are included in the building are retained over time (Boverket, 2015). Data management of building products and their characteristics is called a log book (Regeringen - Näringsdepartementet, 2017a) which must be kept over time. The timing for implementation of the log book requirement has not been finalized, but the Board will present the assignment to the Swedish government in the summer of 2018. Initially, only larger buildings will be included, but the requirement will subsequently be extended, which places a lot of demands on standardized information management and systems to ensure observance throughout the life cycle of the building.

The Board has also got an assignment that runs from 2018 to 2020, which is about facilitating digitalization in the urban planning sector (Regeringen - Näringsdepartementet, 2017b). Part of the assignment is that the Board will work to ensure that the requirements in the building regulations can be managed digitally in the various phases of the building process. The entire building process is affected by the assignment, and here the Board, together with the Swedish Mapping, Cadastral and Land Registration Authority, will work to make the process more efficient and to facilitate uniform application.

[1] http://www.bipkoder.se

2.3 Good practice

When design is to take place in a BIM environment, there is a need for new professional roles, such as BIM strategist and BIM coordinator (Westerlund, 2013). A BIM strategist works with strategic, over-arching matters early in a project, and develops the project's BIM strategy, advises in BIM-related issues, decides which BIM skills are required, and ensures that there is a clear requirements specification ahead of the procurement phase.

It is the BIM strategist's job to recommend which BIM level should be applied in the project, based on what is contained in the available technology, what can bring benefits and how the project can be optimized. Different levels of BIM are based on the maturity level of the project relative to BIM and aim to create a common requirement level regarding technology, data management and collaboration. The BIM coordinator's duties begin when the targets and strategy are finalized. The BIM coordinator gets the programs to work on a tactical and methodical level, coordinates the models and leads the BIM coordination meetings. Figure 2.3 shows an overall view of the activities that concern the BIM strategist and the BIM coordinator in the design phase.

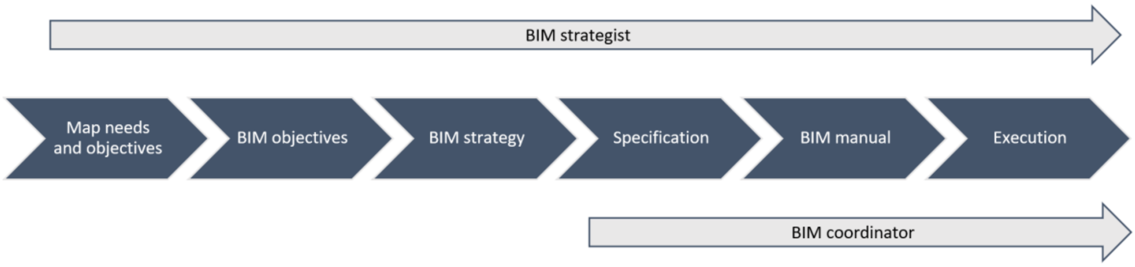

Figure 2.3 Illustration of the BIM strategist's and BIM coordinator's activities to secure the benefits of BIM (Westerlund, 2013).

The BIM strategist and the BIM coordinator work together to develop the BIM manual, which contains guidelines for BIM modeling, project management and project phases, architectural design, technical design and analyses, construction, quality control, quantifying and calculations, environmental and energy calculations, BIM for property management etc. When new actors become part of BIM, it is vital that strategists and coordinators understand the working methods and processes of the new disciplines.

2.4 Information in BIM deliverables

LoD – Level of Development is a key concept in BIM, and is used to describe the model's detail level, related to the geometry of an object. Figure 2.4 shows different LoDs for a steel column.

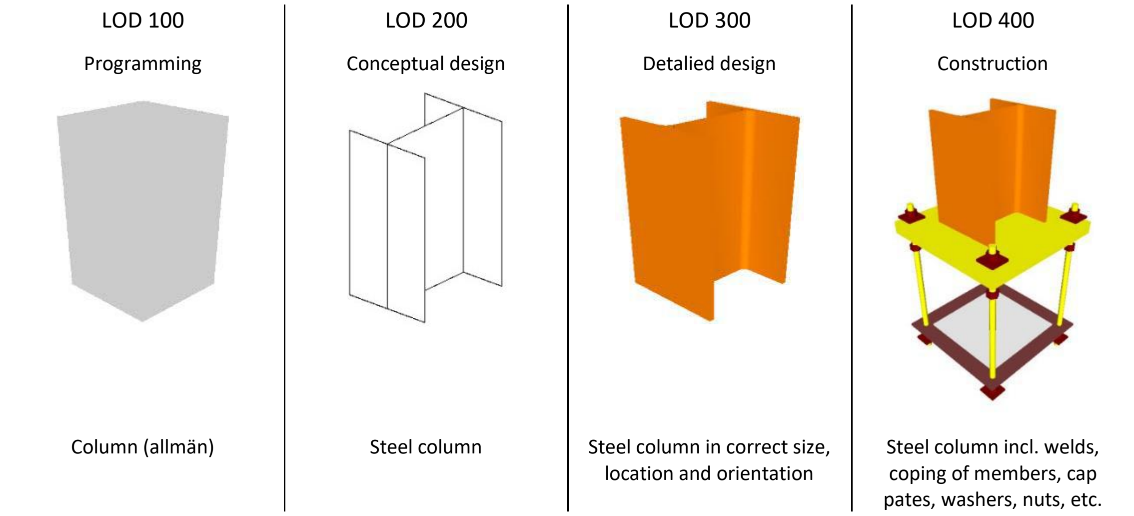

Figure 2.4 Illustration of LOD – Level of Development for a steel column in a BIM model, (BIMforum, 2017), modified.

From a life cycle perspective, LoD has a limited application. This is why Jongeling and Nordberg (2017) propose that the Swedish concept 'bestämningsgrad' (degree of determination/description) is used in Sweden to define information volumes in information deliverables in the life cycle of the built environment. An information volume is information that can be shared and stored digitally. It can consist of a document, a database or a model. The degree of determination/description is directly related to a particular information volume, and it describes the level of detail in relation to its location in the building's life cycle. Jongeling and Nordberg also propose that the degree of determination/description is made up of combinations of life cycle phases, information levels and aspects where the various life cycle phases referred to are planning, design, production, operation and demolition. Information levels can be made up of functional system, constructive system, component, placement, dimension and details, which relate more to LoD (see Figure 2.4). The conceptual model presented by Jongeling and Nordberg describes information volumes in BIM deliverables as different functional or constructive systems that are structured with the help of properties. From the start, BIM deliverables contain just a few systems, which are described by a few properties. With time the complexity increases, and BIM deliverables contain increasingly large information amounts, see Figure 2.5.

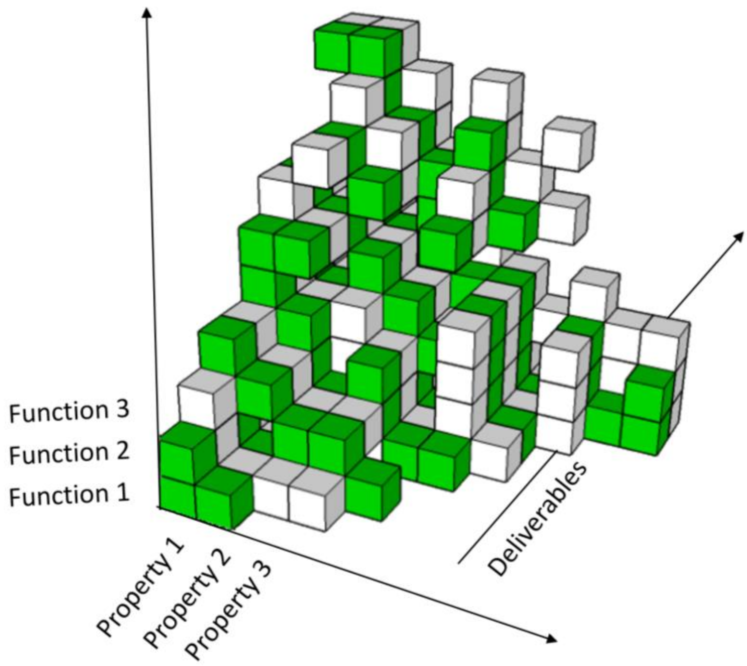

Figure 2.5 Conceptual model for information volumes in BIM deliverables (Jongeling & Norberg, 2017), modified.

Jongeling and Nordberg exemplify the conceptual model with a BIM deliverable for the foundation of an elevator shaft which describes the degree of determination/description for two functions and two properties, see Table 2.1.

Table 2.1 Examples of functions and properties in a BIM deliverable.

Function	Property
Pre-cast concrete walls	Weight
In-situ concrete walls	Length

The complexity increases as more functions and properties are specified in various phases of the life cycle. The requirements can be supplemented with physical locations (in the model) and who is responsible for them. However, each BIM deliverable follows the main principle, that the functions (the objects) are classified and defined by various properties.

McConahey & Lyzun (2013) illustrate similar thinking in Figure 2.6, which visualizes the difference in level of detail between conceptual and detailed design. In the conceptual design phase it is necessary to check that there is room for the installations, and how much space they take up. Pipework should be shown with necessary clearance, but not details like flanges and valves. Once the solution is chosen, specific data is taken from the manufacturer and the level of detail of the model increases considerably. It is often not until this stage that joint review and clash detection can be completed.

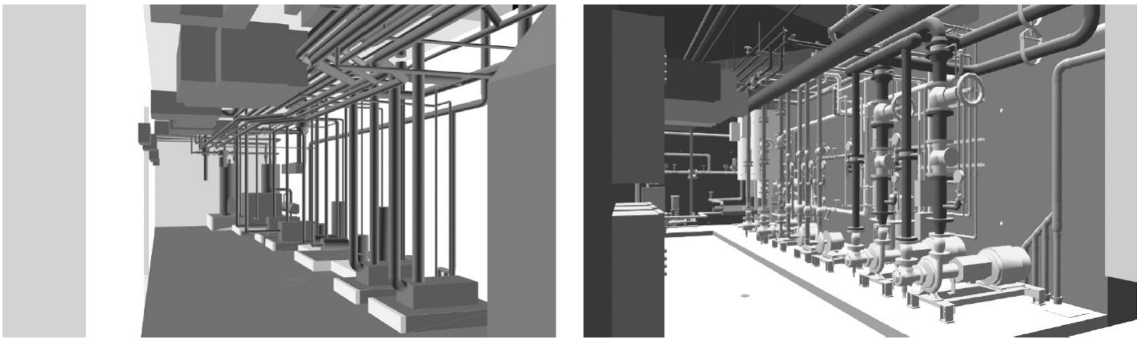

Figure 2.6 *Illustration of difference in level of detail between construction document and selected design. (McConahey & Lyzun (2013).*

2.5 Joint review and clash detection

The capability for efficient coordination, joint review and clash detection are some of the biggest advantages of BIM. Clashes can be divided into three groups:

- Hard clashes, where building elements and installations are located in the same volume in the physical world.
- Soft clashes, where design errors result in a lack of space for other parts, e.g. access, fire protection and insulation.
- Scheduling clashes, where production plan is not matched to staff supply, equipment, purchasing, etc.

Clash detection normally focuses on hard collisions and deficiencies in coordination between architect/designer and the technical disciplines of electricity, plumbing and HVAC during the design phase. But Wang et al. (2014) show that a large number of errors occur during later stages, when detailed design has been finalized. It is mainly when coordination occurs continuously, from conceptual design document to production, that the benefits are maximized in a model-based work process. Wang et al. (2014) present a framework for clash detection that can be used during design and production. The framework consists of four stages:

- Programming. Coordination based on various requirements and budget.
- Conceptual design document. Coordination of space and location requirements.
- Detailed design document. Coordination of buildability.
- Production plan. Coordination of actual construction.

In a case study of a large hospital project in Shanghai, Wang m.fl. (2014) showed that the largest number of clashes are discovered during joint review of detailed design documents (71%), which far exceeds the number of clashes discovered up to the project planning document (20%). It is important that continual joint review, especially after construction document and procurement, can bring considerable cost savings. It is also important to ensure that requirements are met during the various project phases, in particular at completion. From a fire protection perspective, one must be able to demonstrate that all requirements defined by society are met, so the building or facility can be commissioned.

2.6 Automated control and review

Several countries have tried to develop a system for automated control of code compliance in a BIM model (Ismail et al., 2017). The reviewed literature contains a presentation of various systems which are all based on the same fundamental structure, according to Ismail et al. (2017). The interpretation of code compliance is done either in a programming language or using logic. The difficulty is not creating the code, but in translating the building regulations to executable code.

The building regulations have a structure and use concepts that are often difficult to lift from their context. Also, they only have a small degree of generalization and a high degree of detail, with several selections that guide the design. For instance, Swedish building regulations have roughly ten options regarding numbers of occupants, which each affects the requirements that apply.

Lee et al. (2016) describe how South Korea's building regulations have been translated to rule-based executable code. The process is described in Figure 2.7.

1. Original wording

An owner of a building (except for some buildings as per special paragraph) that has six or more stories and a total floor area of 2,000 sq. m. or more must be fitted an elevator. Where applicable, the elevator's size and design are specified by the Ministry of the Interior and Safety.

2. Simplified wording

A building with six or more stories and a total floor area of 2,000 sq. m. or more must be fitted an elevator.

3. Translated simplified wording

TAS 1 (state): A building with six or more stories and a total floor area of 2,000 sq. m. or more
TAS 2 (content): A building must have an elevator fitted

4. Configuration

TAS 1 (state): Number of stories (6 or more)
Total floor area (2,000 sq. m. or more)
TAS 2 (state): Fit (Elevator)

5. Logical unit

getBuildingFloor() ≥ 6,
getTotalFloorArea() ≥ 2000 m^2
isExist(Elevator)

6. Script

```
IF (getBuildingStoriesCound () >= 6
   AND getBuildingArea () >= 2000)
         isExist (Elevator) = TRUE
END IF
```

Figure 2.7 Process for creation of executable code of the South Korean building regulations (Lee et al., 2016)

Lee et al. went through more than 15,000 wordings in the South Korean building legislation, filtered and classified them, in order to create the executable code – a time-consuming chore and a challenge for the government body in question. Solihin & Eastman (2015) reach similar conclusions, stating that in future a completely different type of regulation wording will be required, in order to facilitate automatic control.

Dimyadi et al. (2014) and Choi et al. (2014) show how a computerized system can be developed to support the fire protection designer and to a degree, to automate compliance. All the authors show that the technology exists for automated compliance; the difficulty is in translating the building regulations into programming language.

2.7 Fire protection in BIM

SFPE – the Society of Fire Protection Engineers has developed a position statement to show how the discipline of fire protection engineering can benefit from BIM (Society of Fire Protection Engineers (SFPE), 2011). SFPE concludes that BIM is a dynamic and powerful tool that can be used in all phases of a building's life cycle. SFPE identifies some principle areas where fire protection can be integrated with BIM.

SFPE pointed out especially that the information traditionally shown on fire protection drawings can be added to the model, e.g. fire compartment boundaries, evacuation routes, emergency lighting, occupant numbers, fire extinguishers, etc. Particular software for the design of e.g. sprinklers and fire alarms can also be developed.

Such software can make direct use of the information in the model, and be updated in real time, as changes are made. Here, BIM enables effective controls, to identify clashes between various installations and building elements. Moreover, tools for analytical design, e.g. analysis of the spread of smoke, and evacuation are integrated in the model, without the need to build separate geometries.

However recent development has not focused on, or integrated technical fire protection to any great extent. Rather, it has concerned installations and how the disciplines of ventilation, electricity and heat/sanitation can integrate their design in BIM. Fire protection in the form of fire alarms and extinguishers are examples of installations that have been dealt with (Shino, 2013). However, fire protection has primarily been managed as an installation discipline, equivalent to electricity, plumbing or HVAC.

Design and presentation of fire-protection-related information such as fire compartment boundaries, escape routes, access routes, etc. is relatively uncommon, even if Shino points to considerable quality benefits if this information is made available as properties in BIM deliverables. In a joint review, any deviations from fire protection requirements could be seen as soft clashes. Shino (2013) exemplifies a possible future benefit of fire-protection information in BIM. With access to information on the number of people in the various parts of the building, the BIM model can determine e.g. that there must be three 1.2 m. wide exits. If the number of occupants is adjusted later, the model could be programmed to alert that the current escape door width is insufficient.

Other examples of applications are to integrate software for simulating fire development and smoke transport, e.g. FDS – Fire Dynamics Simulator with BIM (Dimyadi et al., 2008). The aim of this is primarily to build geometries, and secondarily to be able to simulate fires right in the model. However, several projects aimed at model-based fire simulation have been ceased, before reaching a functioning process or commercial product. For instance, Project Scorch focused on including FDS in the BIM software Revit (Autodesk Labs: Project Scorch).

Also, software is being developed to analyze the occupant movement, in order to design for evacuation within BIM models (Wang m.fl., 2014). Also initiated during the past year is program development of cloud-based analysis tools for evacuation simulations for some of the larger BIM software products.

Another idea that has emerged is to try to automate fire protection engineering, both in terms of "clash detection" with the building regulations, and in making simple analyses and calculations (Taciuc & Dederichs, 2014). However, the development of this is relatively limited at the moment.

Wang et al. (2015) describe how BIM can be used by the fire protection organization in the management phase to focus on maintenance of fire protection installations such as fire extinguishers, indoor fire hydrants, fire and evacuation alarms and sprinkler systems. Wang et al. propose a special module for BIM-based maintenance which could help the organization to quickly get access to the right information for various components, such as name, manufacturer, location, inspection interval, control dates, remarks, responsibility, operating manuals, etc. and use the information for management-technical maintenance of fire protection.

2.8 Industry's wish list and expectations

Within the framework of the project, the industry's wish list and expectations for the integration of fire protection in BIM have been collected by way of reference group meetings and in-depth interviews. Representatives of designers, contractors and property owners have shared their experiences and ideas for future applications. To sum up, the wish list concern access to updated, accessible information. Integrating fire protection in BIM is indeed about making information accessible for all, and avoiding static, two-dimensional drawings, which can be difficult to interpret and quickly become outdated. During the design, work is facilitated by the ability to visualize, and VR technology should be useable for positioning objects such as signs for emergency lighting directly in the model, for accessing information for specific objects, and for carrying out a virtual pre-inspection and control. It is also desirable if, at the room level, one can make lists of requirements, and compare these to the finished design.

The traditional clash detection during joint review, where any conflicts between various installations and building elements are identified, should be extended to also include a check of code compliance, where the proposed design is checked against fire protection requirements. In an early stage this could be about a room being fitted with emergency lighting, and in a later stage about checking that emergency lighting meets requirements for electrical supply, lighting strength, activation etc. Finally, during production, when the emergency lighting has been installed, it is possible to check the actual installation against the requirements.

During construction, BIM can be a valuable tool for doing a final control. For every object, e.g. a door in a fire compartment boundary, the model can contain information on how it should be installed, to meet fire class requirements. This information is presented in the form of job planning documentation, and with the help of photographs and signatures it is possible to efficiently check that the building meets requirements. The quality of the self-check, the final control and the inspection increase, which in turn has a positive influence on the entire deliverable and creates better conditions for a building's or a facility's entire life cycle.

As premises are adapted to their operations or are rebuilt, the model is changed. Here, information relating to fire protection must be available and dynamic. Walls are moved, room sizes are changed, openings are made. When this happens, work is facilitated by, in a dynamic model, having access to information such as maximum number of occupants, fire protection classes, evacuation routes etc. This makes it possible to understand, at an early stage, the extent and cost of the change, and to avoid changes that are not in line with the building's function and capability.

Further, during management phase, there are extra benefits of having fire protection information regarding installations. In conjunction with inspections and controls, all information can be available digitally, instead of on separate drawings and specifications of ventilation, sprinklers, fire alarms, etc. Another major expected benefit is the possibility of more efficient maintenance. When an error is reported, it should, via a model, be possible to retrieve specific information on the component in question, so the correct replacement parts can be secured without a time-consuming site visit.

3 The role of FPE in the building process

This section presents how fire protection engineering has traditionally been done, in relation to various stages of the building process. As there is no uniform standard for this process, a number exist in Sweden. But they have essentially the same agenda:

- Specification of requirements
- Overall plan of how requirements will be met
- Detailed plan of how requirements will be secured

In the following, this will be presented in one of the processes; the principles can also be translated to other forms of engineering processes.

In addition to the design processes, permit processes and procurement processes must also be handled. These will not be discussed here. The most important effect these can have on the engineering process is which contracting form is used in the procurement, because this can influence who does the detailed design. The presentation below does not take a position on this, because the technical needs are in principle the same; the difference is mainly legal in character. The focus is on the planning itself, but also in other phases there is a need for intervention by fire protection experts with regard to final control, technical solutions and communication. The phase in which fire protection engineering is started varies between projects, and the descriptions in this section aim to increase knowledge of suitable activities relating to the various phases of the building process, activities that are critical for the progress of the project and which must be included in the work processes for fire protection engineering in BIM.

A clear distinction should be made between fire safety documentation and as-built documentation. During the design stage, the fire protection documentation is always governing. Moreover, every phase is, as a whole, governing for the subsequent phase. A check that the as-built documentation meets the governing requirements must always take place before a phase can be finished. In the as-built documentation phase, all drawings are resulting.

3.1 Initial design document phase

The aim of the initial design document is to present and decide on the requirements. It shows the client’s requirements and vision for the building’s function, properties and performance. It also includes, for instance, the local plan’s requirements. Thus, the initial design document is a platform for design, and it specifies all the conditions that can affect the coming design work.

Fire protection design has most often not been initiated in this phase, except for larger infrastructure projects. Naturally, the architect can contact the fire protection consultant to gain assurance that the ideas for the building’s form and design are realistic, but this normally takes place in the next phase – the conceptual design document phase (see section 3.2) – which begins the design itself. Any fire protection engineering in the initial document phase is done in accordance with what is specified in section 3.2.

3.2 Conceptual design document phase

Conceptual design document phase is the phase where the general design begins. The aim of this phase is to test the preconditions stated in the initial design document. Overarching questions such as form and appearance, floor plans, bearing systems and technical supply systems are studied. Different solutions are compared, to find the best option. Based on these studies, and with an eye to financial and time constraints, a decision is taken to continue towards project planning documents and construction documents.

In the conceptual design document phase, fire protection engineering is most often initiated by developing a proposal that concretizes a suitable proposal for the design of fire protection for the building or facility, its operations and the client's wishes. This is compiled in a fire protection specification. The aim of the design work in this phase is to take an approximate inventory and to identify risks by:

- Studying the building's or the facility's design and operations.
- Identifying preconditions that affect the design of fire protection.
- Presenting ideas for the design of fire protection.
- Clarifying overarching societal requirements and any stakeholder requirements regarding fire protection in fire safety documentation, a fire protection specification.

3.3 Project planning document phase

The purpose of the project planning document phase is to form and coordinate at the overall level. The building's or facility's design is created by developing, coordinating and adapting the various systems that constitute the building or facility. At the overall level it should meet the client's vision. This phase is very important, because most decisions that affect the end product's function, performance and properties are made here. Normally in this phase one tries to finalize the floor plans, choice of technical system and critical sections.

This makes the project planning document phase a very important phase in the fire protection design. The overarching inventory and identification of risks that was initiated in the conceptual design document phase is developed further, with increased level of detail. There is a fire protection review, where the building's and the operation's preconditions are presented; applicable societal requirements or client's stakeholder requirements are concretized; and a proposal for the design of the fire protection is worked out, together with other disciplines. During project planning document design, the overarching design is concluded.

3.4 Construction document phase

The construction document phase aims to confirm and clarify the system solutions presented in the previous phases, and it constitutes the detailed design. It is the most time-consuming design phase. The level of detail increases so that volume, quality, form, dimension, color, appearance, surface and sequence are clarified and structured. In this phase it is critical to ensure that the chosen solutions and proposed products comply with fire protection requirements. Unfortunately, with today's work methods this often does not happen, which creates uncertainties and an increased risk of mistakes during the building phase.

Construction documents are often legal documents in contracts between client and contractor. Therefore, errors in these documents can have serious consequences for the project's finances and timetable.

3.5 Construction phase

In the construction phase, the design must be completed, but it is common that minor changes are required, or that requests for material substitutions lead to minor revisions in the construction documents, which then require supplementary work. During construction there is also a need for construction checks within the framework of the client's own checks, possibly supplemented with checks by a certified expert (Swedish SAK). There might also be a need to provide support during the actual construction at the site.

The building phase can be divided into three phases: start, construction and final. At the technical consultation, in order to get approval to start, the building's technical solutions must be able to be presented, and the control plan must be finalized, of which fire protection is an important part. In the building phase, the applicable construction documents are the starting point, and construction takes place based on the resources, procedures and instruments that are specified in the production plan. In the final phase, the building's parts, systems and entirety are put into operation, checked and adjusted. As-built documents and a plan for checks and maintenance of the building's fire protection are then drawn up. When the control plan has been met, the person in charge of checks applies for final clearance and when this is granted, the building can go into operation.

During the actual construction phase, the client often needs supplementary information on the design of the fire protection. Depending on the project delivery method and the fire protection consultant's role, questions may arise concerning possible options to the solutions presented in previous stages, depending on technical challenges or incomplete design. It is also important to carry out standardizing checks during the construction process, in order to be able to verify that the fire protection has been installed as per the fire protection design. There are several significant parts of the fire protection that are not feasible to check in the final phase. Instead these must be checked on an on-going basis during this phase. It is also essential that coordinated function testing is carried out in the final phase, in order to ensure that various fire protection installations perform as intended.

3.6 Communication and documentation

In the various phases, relevant fire protection information and proposed solutions are documented and compiled in a fire protection specification, and upon completion, in a fire protection documentation. The documents present details that are necessary to design the fire protection satisfactorily, based on requirements from the Swedish National Board of Housing, Building and Planning or from stakeholder requirements. In concrete terms it concerns fire protection classes for separating and bearing building parts (walls, doors, windows, columns, etc.), division of the building into various fire compartment boundaries, clarification of requirements for wall surfaces, specifications for sprinklers, design of fire and evacuation alarms, capacity of smoke ventilation, etc.

The documentation often lacks the precision required to achieve the desired quality (whether it is society's minimum requirements or the client's stakeholder requirements), because requirements and solutions are described generally, written in specialist language which is difficult for other actors to understand, and there is no clear link between requirement and solution. This creates challenges for everyone involved and can lead to unnecessary project risks. By transferring information from two-dimensional drawings and text descriptions to a three-dimensional model world, where all fire protection information is available through models and databases, better conditions are created for well-functioning communication and the aim of meeting industry expectations for a modern, integrated and more precise fire-protection engineering.

4 Fire protection engineering in BIM environment – work processes

Based on an initial literature study, interviews with various interested parties in the building industry and the tradition that exists around fire protection engineering, various work processes for BIM were developed. The focus when developing work processes was partly on the decentralized information flow, corresponding to BIM level 2, and partly on a more integrated, real-time-driven information flow, corresponding to BIM level 3. Below is a description of the work processes that have been developed, based on the various BIM levels that can prevail in various projects.

4.1 The decentralized information flow (BIM level 2)

Fire protection engineering in the decentralized information flow, BIM level 2, is based on each discipline in the engineering process working in its own models, locally in each organization, and where the various discipline models are combined into a coordination model with given intervals. Based on defining control parameters and parametric information/value, the preconditions are created to clarify various requirements and safety level, based on various control variables and specifying which discipline is affected by the requirements.

In an initial phase, a desired fire protection level for the project is defined and mapped, based on society's requirements, stakeholder requirements and engineering phase. Various fire-related parameters, such as fire rating, escape route, surface finishes class, rooms that are to be sprinkled, are clarified in the project based on the building in question. Depending on the type of parameter, these can be specified as "length", "free text" or as "Boolean" parameter.

If Revit is used, the parametric is grouped under "*Fire Protection*" is put into the project's "*shared parameter file*". The relative parameters should be defined by the fire protection designer, to secure the quality of the parameters.

The disciplines that work in Revit import the parametric that affect their model's different objects, e.g. walls, doors, windows, columns and technical installations. For the designers who use other software than Revit, local parameters are created in the relevant programming language for the same fire-protection related function.

When parameters are defined and included in the models of the other disciplines, the fire protection designer copies each discipline's model, or applies values directly in the model and synchronizes this with the relevant discipline. The copied models are given parametric values (e.g. via object lists in Excel format) based on the relevant protection level and type of dimensioning method. These are then imported back to the model of each discipline. For instance, the parameter "*fire rating*" can get the value "*EI 60*" for wall objects that must have a particular fire resistance.

To visually and spatially locate various fire protection related information and objects, e.g. fire extinguishers, emergency lighting and lines for fire compartment boundaries, graphics displays are created in a separate fire model. The fire model is linked to the models of other disciplines and constitutes part of the coordinated model. Figure 4.1 shows a schematic representation of the work flow for BIM level 2.

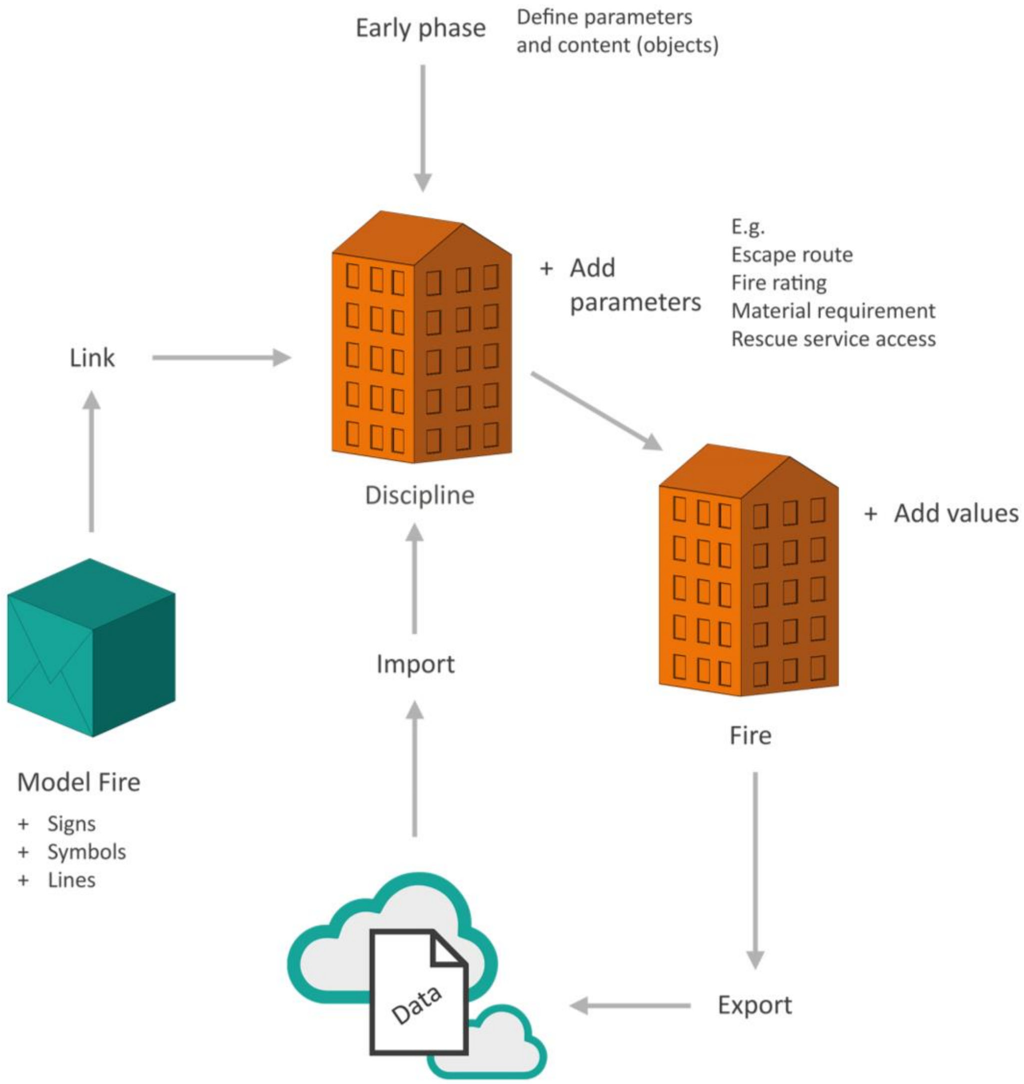

Figure 4.1 *Schematic description of fire protection engineering in BIM, in a decentralized information flow, BIM level 2.*

With an eye to the progress of the design work, the process will be iterative, where more and more fire-protection-related information is included, with increased level of detail. For instance, in the first process loop, technical fire protection requirements are added at room level, in loop two requirements are added at object level (manually or via automated functions), and in loop three, requirements for specific fire-protection-related objects such as door hardware and door closures on doors in fire compartment boundaries are added.

Section 4.3.2 presents a proposal for the type of fire protection information that should be introduced in various design phases, in order to create the right detail and information levels.

4.2 A collaborative information flow (BIM level 3)

In a collaborative information flow, corresponding to BIM level 3, information circulates between the various actors in a project, via common models and databases where the information volume and level of detail increases when a project moves through the various design phases. The starting point is that BIM data is in a common database (cloud-based) and that all disciplines work with the same model, but different editing capabilities.

By working to a cloud-based database and in a common model, fire-related information is specified as parameters in a model and as information in a project-wide database. The information can be edited in real time, without having to import/export object lists between different disciplines and actors.

In the common model, fire-related 'content' is also defined as extinguishing equipment, emergency lighting and lines for fire compartment boundaries by way of graphics display. A work flow via a common database and model offers a better information flow with information updated in real time. Also, this makes it easier for the fire protection designer and others in a project to control which parameters are required in each phase, which type the parameter should be and which value each parameter should have, based on applicable fire protection level.

The process consists of the following steps:

- In an initial phase, the desired protection level for the project is defined and mapped, based on societal requirements and stakeholder requirements.
- A common model is created and linked to a cloud-based database. Different editing capabilities are defined, for the different disciplines and roles in the project.
- The fire protection designer creates relevant parameters for various objects in the model, and clarifies which type of parameter it should resemble, for the decentralized work flow.
- The fire protection designer specifies values of the defined parameters (e.g. fire resistance of *EI 60* in the parameter "*fire rating*"), based on relevant protection level.
- The fire protection engineer defines which content is to be included, and where this should be placed spatially in the common model in the form of graphics display.

The information level is increased depending on the engineering phase of the project. Section 4.3.2 presents a proposal for which fire protection information should be included in the various project phases, in order to create the right level of detail and information. Figure 4.2 presents a schematic diagram of the work flow in BIM level 3.

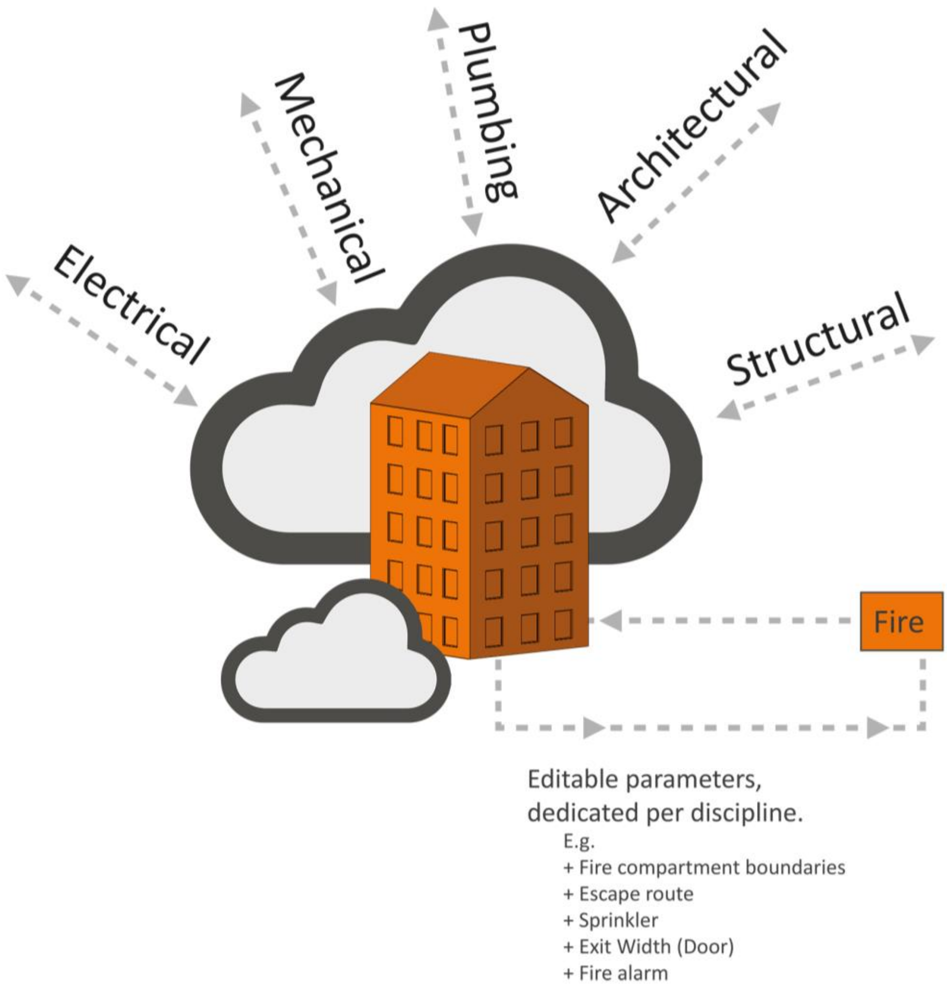

Figure 4.2 *Schematic description of fire protection engineering in BIM, in a collaborative information flow as per BIM level 3. For sprinklers and fire alarms, it defines areas to be fitted with the installations and the required quality of these.*

4.3 Level of information and detail

Below is a proposal on information level, depending on how a project is evolving. Depending on phase in the design process, different parameters with different levels of detail are specified. Different types of parameters and a schematic proposal for the level of detail for various phases are introduced in the following subsections.

4.3.1 Control parameters and requirement parameters

Based on the structure of Swedish building regulations on fire safety, the protection level in a building or facility is guided by superordinate and control variables, which define the society's protection level for the building's fire protection. Examples of such control variables are building class (based on building's complexity, number of stories, number of occupants etc.), occupancy class (based on building's or facility's planned use, i.e. residential, commercial, hospital), fire load (how much energy can be released in a fire in a specific fire compartment) and different types of active systems that must be present in the building.

The protection level and accompanying requirements placed on the building or facility by society or the client's stakeholder requirements are defined using the overarching control variables. These requirements are introduced in models or a database in the form of control parameters, and they get different parametric information/value, based on safety level.

Depending on the phase, it is suggested that a first level (level 1) of information is created for room objects (grouped to fire compartments). This information specifies different fire compartments, evacuation functions e.g. escape routes, locking, design measurements such as the longest walking distance within a fire compartment or escape route.

For level 2 the suggestion is that requirements and fire-protection-related parameters are specified for specific objects that have a critical effect on a building's or facility's fire protection. This could include fire ratings of doors and windows; surfaces finishes of walls, floors and ceilings; and various technical functions that must be present in fire compartments such as sprinklers, emergency lighting and evacuation alarm. In level 2, fire-protection equipment in the form of graphics display is added to a fire model that can be linked into the models of other disciplines.

Presented in level 3 are specific requirements and functions of the fire protection functions that are included. This can be the type of fire damper; fire protection cable; door hardware and self-closing devices on doors in fire compartment boundaries; and type and function of emergency lighting. Table 4.1 presents proposals for different control parameters; parameters at room level and object level with accompanying parametric information/value; and type of graphics display.

Table 4.1 Examples of different control parameters, parameters at room level and object level and proposal for content/graphics display in a fire model.

Control variables	Parameters at room level	Parameters at object level	Graphics display in a fire model
Building class Fire load Occupancy class No. of occupants Area of fire compartment Rescue service intervention time	Escape function Stairwell Tr2 Stairwell Tr1 Escape route • Number • Walking distance • Min. width Fire rating • Separating • Load-bearing Surface finishes • Wall • Ceiling • Floor • Door Ceiling coverage Smoke ventilation Standpipe Evacuation alarm Extinguishing system	***Door in*** *fire compartment boundary* Door hardware Door closure Fire rating ***Window for evacuation*** Size Hardware ***Damper*** Type Suspension system Insulation Detection Control function	Emergency lighting Handheld fire extinguisher Fire hydrants Fire protection control panel Smoke ventilation

4.3.2 Parameters during various engineering phases

The various levels can theoretically also be related to the various phases of the design process, where level 1 corresponds to information required at the initial and conceptual design document level; level 2 corresponds to project planning document design and level 3 corresponds to construction document level. Table 4.2 presents examples and proposals of information in the various levels, which parameters can be used and how values can be defined, from a fire-protection perspective.

Table 4.2 Proposal for level of information for different phases of design.

Phase	Parameter	Value
Initial design document Conceptual design document	***Control parameters***	
	Building class	Br1
	Occupancy class	Vk3A
	Fire load	< 800 MJ/m^2
	Rescue service response time < 10 min	Yes
	Room object:	
	Fire class - separating	EI 30
	Evacuation route	Yes
	Sprinkler	Yes
Project planning document	***Parameters at room level***	
	Fire class	
	• Wall	EI 60
	• Surface	B,s1d0
	• Ceiling coverage	Broof
	• Bearing	R60
	Evacuation route	Yes
	• Width	> 1.20 m
	• Distance	< 30 m
	Smoke ventilation	Yes
	• Standard	SS 883006: 2013
	Fire alarm	Yes
	• Standard	SS-EN 54-1:2011
	Sprinkler system	Yes
	• Standard	SBF 120:8
	Parameters at object level	
	Doors	
	• Fire class	EI$_2$30
	• Smoke density	Sm
	• Hardware	SS- EN 179
	Door closures	-C1
Construction document	***Damper***	
	Type	Smoke
	Suspension system	EI15
	Insulation	EI60
	Detection	Yes

4.3.3 Management of parametrics

Examples of how fire-related information is defined via parametrics are presented in Table 4.3. The various fire-protection related properties based on ”*Property Set*” and parametrics. The table presents the various properties or parameters that are standardized in ISO 12006-3 – Building construction – Organization of information about construction works, part 3: Framework for object-oriented information (International Organization for Standardization, 2007), buildingSMART (2018) and which constitute terms in IFC version 4.

Table 4.3 Examples of terminology for various fire-protection-related parameters. Property Set is based mainly on IFC version 4.

Swedish name	**Property (Property_set)**	**Parameter type/ Property**	**Relevant objects**
Fire class	Pset_FireResistanceRating	Text	Walls, Doors, Windows, Columns, Beams
Building class	Pset_FireRiskFactor	Text	Project
General fire protection requirements	Pset_SpaceFireSafetyRequirements	Value	Specific objects
Escape route	Pset_FireExit	Boolean	Rooms, Doors, Windows
Room with sprinkler	Pset_ SprinklerProtection	Boolean	Rooms
Air pressurization	Pset_AirPressurization	Boolean	Rooms
Surface finishes (walls, floor and ceiling)	Pset_SurfaceSpreadOfFlame	Text	Walls, floor
Smoke stop	Pset_SmokeStop	Boolean	Doors
Damper	Pset_DamperTypeFireDamper	Text	Specific objects
Fire and smoke damper	Pset_DamperTypeFireSmokeDamper	Text	Specific objects
Fire sensor	Pset_SensorTypeFireSensor	Value	Specific objects

There is a significant need for more standardized fire-protection-related names for various properties than what have been standardized thus far. For instance, standardized names relating to fire load, access routes for the rescue services, door hardware, etc. New properties should be based on terminology standard for fire terms ISO 13943:2017 (International Organization for Standardization, 2017) and relate to object-oriented information in the form of “Property Set” and type of parameter. To get a functioning international standardization, it is desirable that terms and fire-protection-related information is also added to future versions of IFC formats.

4.4 Fire protection engineering in BIM – increased quality

By implementing the proposed work processes for fire protection engineering in BIM, there is great potential to increase project quality. With a model-based work method and a common format, it is easier to check that requirements and specifications are compliant. Deviations are discovered earlier, by way of an iterative work flow and structured information flow. The potential quality gains in a project include:

1) Coordination is simplified and clashes with requirements and solutions of other disciplines can be identified early, which reduces costs and increases quality.
2) Cost estimates can be done with more precision and earlier in the process, which increases the chance of good, cost-efficient fire protection.
3) Compliance with government requirements and project-specific requirements can be reviewed and checked more easily and be matched to the proposed solutions.

But to ensure an efficient check of solutions, and that society's or the client's stakeholder requirements are met, terminology and the review process must be standardized.

Quality control is in focus in fire protection, and a new Nordic technical specification (INSTA/TS 952), related to control and review of fire protection requirements is expected to be published in the summer of 2018 (Inter Nordic Standardization (INSTA), 2018). The specification states when and how controls and quality assurance should be done, based on various process steps for the various stages of the building process – from design to construction and management. During the actual design phase of the fire protection, the proposal is that four controls are done, at various times, to ensure that the preconditions, the dimensioning method and the completed analyses are right (linked to input, output and calculation process), and that conclusions and solutions are in accordance with the project requirements. Proposed controls for fire protection engineering can be integrated in the proposed work processes in sections 4.1 and 4.2.

In the building phase a well-completed design phase in BIM can be a valuable tool for a structured self-check, to secure the quality of the finished building. Today, with traditional construction documents, this is an area that needs a lot of improvement.

5 Case studies

To gain an understanding of how well the processes work in practice, case studies have been done in projects with different purposes, BIM maturity levels and stakeholder requirements. The time available and the phase of the various projects have determined which parts of the work processes and the level of detail and information volume that were managed and communicated. However, the starting point has been to test various BIM levels in order to find any challenges and limitations for proposed work processes, and to identify how a future implementation of the work processes should be done over time.

5.1 Apartment building in Uppsala

A large apartment building is being built in central Uppsala. The project is in project planning document phase, and engineering has been underway for just over 1.5 years. The project is managed by NCC. The fire protection engineering has been done using simplified design with initial communication via fire protection specification and accompanying fire safety sketches with conceptual information.

For the model-based design, focus has been on visual rendering of information in line with BIM level 1. The project was coordinated via a common web-based project server. For Fire's design work, Revit software was used.

The architect's model was used to create a fire model containing fire compartment boundaries, evacuation routes and location of emergency lighting. The fire model was created as 3D, but with graphic rendering of lines and markings for all stories in 2D. The model could be linked to other disciplines, so these could create their own views and review functions. For internal review and for disciplines that didn't work model-based, data was also supplied in PDF and DWG formats.

Conclusion
The end product with graphics was on a par with what has previously been delivered from fire safety discipline but could also be used for export in PDF and DWG formats, and as a basis for a 3D model. It is assessed that the deliverable of graphic information in the fire model and with accompanying fire-related preconditions and requirements in a fire protection specification comply with BIM level 1, as fire-related content is added as graphics display.

5.2 New arena in Uppsala

A new arena incorporating an office block is to be built in Uppsala. The project is in project planning document phase, and design has been underway for about 1 year. The fire protection engineering has been done via analytical design and a fire protection specification with accompanying fire safety sketches has been drawn up and communicated within the project group. The project aims to work at BIM level 2.

The project was coordinated on a web-based project server. By way of initial dialog with the architect, necessary parameters for fire protection design were defined in the architect's model. Step by step, as the project progressed, more parametrics and accompanying values were included. The first parameters that were included were fire class for doors and walls, clearance for doors in evacuation routes, and evacuation routes for room objects. As design continued, parameters and values for fire alarms, emergency lighting, sprinklers and evacuation alarms were also included. The work process proceeded as per proposed work as per section 4.1. As a complement to the parametrics management (via Excel lists), a fire model was drawn up in Revit format with graphics, including fire compartment boundaries and emergency lighting, which could be linked to other disciplines' models.

Conclusion
The proposed work process as per section 4.1 has capacity to reach BIM level 2, but there is a reliance on export/import of values in the form of Excel lists. Unfortunately, the available export/import function in Revit was not satisfactory, which is required for a functioning information flow. With this in mind, a special export/import API to Revit was developed, to manage and secure the information flow of fire-related information. During the project, light was also shed on the organizational challenges that are present when starting to design in BIM; more planning, better preparation and more internal coordination ahead of deliverables are required.

5.3 New college in Västerås

A new college is to be built in Västerås, including extensions and new construction. The project is in the final phase of the construction document design. The fire protection engineering has been done via analytical design and a fire protection specification with accompanying sketches has been drawn up and communicated within the project group. The project aims to work at BIM level 2.

The project was coordinated on a web-based project server, and the tool used by Fire was Revit. Initial design focused on review of other disciplines' drawings, keeping in mind that the fire safety discipline came into the process late, and on creating graphics in a separate fire model via 2D plans. However, the aim was to create fire-related parametrics in the models of other disciplines but within the group there was uncertainty about Fire's knowledge level and capacity. During the latter part of the phase the architect model's structure was changed, and in conjunction with this, Fire was invited to include a few fire-related parameters that were linked to fire class of walls and doors.

The deliverables consisted of a fire model in Revit format, and information in PDF format, with graphic rendering of fire compartment boundaries, fire class of doors and marking of areas that are part of an evacuation route.

Conclusion
Because "Fire" came into the process at a late stage, there was little interest from other disciplines to incorporate all the information that Fire wanted. The work process described in section 4.1 worked in practice, despite the project phase. However, there is a need for clear communication and explanation of how Fire's information should be included in the models of various disciplines, and that other disciplines have the desire to do this. The resistance illustrates the challenges that exist, with regard to both responsibility and legal aspects, and there can be a perception that it creates extra work for a particular discipline, even when the total amount of work devoted to the project decreases. It is essential to plan and clarify which type and to what extent information is to be added to the model, and that there is a clear allocation of responsibility between different disciplines in a project.

5.4 Apartment building in Uppsala

In order to investigate the possibility of designing via a more centralized and collaborative method corresponding to BIM level 3, an evaluation was done in a project for an apartment building in Uppsala. The fire safety discipline was involved from the start and was able to establish good contact with the project's BIM strategist and the BIM coordinators from different disciplines.

In the project, Fire can use the project's common models with data management via a cloud-based server. All disciplines have access to the architect's model, so it is possible to add information right into the appropriate geometry, without having to export/import data between the models of different disciplines.

In order to add the parameters that Fire uses in the project, first a list of the relevant parameters was drawn up. The architect's BIM coordinator added the parameters to the model and synchronized the model with the cloud. The discipline Fire can define and include the parameters in the model itself, but for easier coordination and control, this job is assigned to the project's BIM coordinator.

The deliverable is a synchronized model that contains all data and geometry.

Conclusions
Model-based work via the cloud (BIM level 3) is the most ideal way to implement fire protection design in BIM. One of the biggest benefits is that no actor in the project has to wait for the latest information. Rather, delivery is continual, creating a better flow of information between different disciplines.

Because everyone is working from one and the same model, it is extra important to keep track of the software version. If one actor is using an older version, the model's compatibility is affected, and the model won't be available for everyone. The same applies if someone is working in a new version.

6 Success factors and future development needs

As a result of digitalization and development of BIM-based work flows, many actors can collaborate more effectively, and there is a lot of potential to generate considerable gains for everyone involved in the building process. Cerovsek (2011) points to a few factors that are decisive for being able to implement BIM. According to Cerovsek (2011) the three most important areas are standardization to create a basis for further development, interoperability between software, and that the life cycle perspective for BIM models and data is observed. Related to these areas are several important components that must be secured, so as not to limit the development and implementation of fire protection engineering in BIM-based work processes.

Other countries have identified critical success factors linked to matters of responsibility, legal aspects, prevailing business models, organizational and skills-related preconditions and technical challenges that can limit development and implementation, according to Eadie, Mclernon & Patton (2015) and Olatunji (2011). In Sweden, similar studies have been carried out in order to show success factors for successful implementation according to Bosch (2016). As additions to the international review, critical success factors also include regulation structure and control functions. Below is a summary of a few of the main success factors that must be observed in future development, in order to be able to change the current work methods and increase the probability of successful implementation of proposed work processes for fire protection engineering in a BIM environment within the entire building industry.

6.1 Standardization and interoperability

The need for standardization is great, in several ways. For instance, it is important that data, specifications and requirements can be matched with the content that is to be built into various buildings and facilities. To ensure an effective exchange between phases, it is important that parameters and properties are presented in a standardized format. Also, harmonization of terminology and nomenclature must function with digital tools and with various exchange formats, so the information can follow a building or a facility through its entire life cycle.

The standardization linked to BIM occurs mainly in BuildingSMART and ISO, and corresponding mirror groups in CEN. There is cooperation between these organizations. BuildingSMART owns the IFC format and develops it, while they also have formal cooperation with ISO.

Standardization is related to several other success factors, and will be instrumental in the necessary exchange between actors. This is important in order to secure interoperability between various systems. ISO standardization works with interoperability in three main areas: *data dictionary*, *process map* and *exchange requirements* (ER) and *data model*. These are defined in EN ISO 12003-3, which describes terminology and nomenclature, EN ISO 29481 which is about work processes and EN ISO 16739 which concerns data sharing.

In order to progress with the standardization of fire-protection-related information in model format, this should occur in an international arena and be handled at an industry-wide level. Here the IFC format is important, as it is a standardized, neutral and open file format that allows coordination, and in the long run joint review, of various disciplines' models, independent of the software they were created in. So, it is critical that in future versions of IFC a "*Model View Definition*" is created, linked to fire protection. This is so that fire-related information in the form of control parameters and parametric information/value and analysis results, linked to fire development investigations and evacuation analyses, can be communicated between parties, independent of the software used.

6.2 Responsibility and legal perspectives

The question of responsibility is essential. It concerns the roles of various actors, and what happens in the event of disagreement, faults and mistakes during design and construction. The building permit process also has its own specific requirements. Working in BIM has an effect on the solutions and deliverables presented, which also means that contract structures and the question of which documents are considered applicable when signing contracts should be reviewed and possibly revised. New risks relating to security also arise, e.g. how to deal with data theft or attacks that damage data. This challenge already exists but is expected to increase as the building process becomes more digitalized. Authorities and correct level of access to data must be controlled in each project but should follow standardized methods as much as possible. Further, the matter of responsibility between client and property manager must be clarified, to ensure that they have compatible software over time and between different phases of the building's life cycle. Therefore, future-proofing of data is necessary. With the right information in a standardized format, it is possible to safeguard gains for the building at later stages, which facilitates better, more efficient maintenance via newly developed services in, e.g., systematic fire protection work.

6.3 Changed business models

By way of model-based design and advanced data management via common databases, it is possible to automate various design and construction phases. This can (and should) generate large time savings for the entire project. But, with today's business model, which is mainly based on selling expertise by the hour, there is no business incentive to be more effective. Thus, to really succeed in BIM implementation, new business models must be developed for all the building industry actors. These models must value expertise in other ways than the number of billed hours in a project and offer a win-win setup for all involved parties.

6.4 Roles and organization

Work processes in BIM also require other skills in partly new areas. There is a need for new roles in an organization that has knowledge in model and data management – roles that fire protection consultants often lack today. This will be a challenge for existing structures and established work methods. But keeping up with digital developments in the building industry, and fully benefitting from a model-based work method, require organizational change and new roles.

There must also be a sufficient degree of collective understanding of terms and concepts, and a desire for collaboration between actors, in order to drive development and implementation in the building industry – in particular in the fire consultancy sector.

6.5 Need for technical development

The technical development of digital tools can greatly advance traditional fire protection engineering, and create better information flow, clearer communication and present the right information at the right time. That is, to the relevant actor, at the appropriate phase in the building process and ultimately throughout the building's or the facility's life cycle. However, tools and software that are used must be compatible with each other, so that disciplines and actors can communicate and collaborate effectively. Regarding technology, it is about creating a system that is neutral in relation to the software that is used.

There are also huge possibilities with new technology such as Virtual Reality (VR), Augmented Reality (AR) and sensoring that can facilitate the implementation of fire protection in a more digital format. Both VR and AR can be used to ease communication and improve the understanding of problems between different parties. For instance, rescue services can be offered better understanding of the fire protection in a building during a call-out. The benefits of VR have been studied in a project financed by SBUF (Roupé, Johansson, & Tallgren, 2017).

Control and monitoring are often an important part of fire protection, and together with the discipline Fire, have a great potential to develop by way of future digital tools.

6.6 Future regulation and control structures

Regulation and control structures affect the capacity to introduce new work processes for BIM. Current Swedish building regulations, which are complex, can be difficult to describe by way of executable code, and add to a computer model. This obstructs automation of control and regulation compliance and hinders quality assurance. But there is a lot of potential in the enabling of more effective regulation controls. Some regulations can be easier to change than to check – especially if they have a high level of detail. However, this is a challenge for the fire protection sector, where there is a division into simplified and analytical dimensioning.

Practical examples of proactive work with building regulations can be found in Norway where they have worked with the digitalization of building regulations over the past twenty years, and during the past year the fire protection regulations have been revised for the development of automated regulation controls. This points to future possibilities for the development of automated regulation controls.

7 Conclusions

Starting with the initial gathering of information, through a literature study and in-depth interviews with various actors in the building industry, two different work processes related to fire-protection engineering in a BIM environment were developed. The work processes were drawn up for different maturity levels of BIM and the focus was on projects at BIM levels 2 and 3.

For each work process, critical points were identified and proposals for handling were presented, relating to prevailing technical, organizational and responsibility-related preconditions. The various work processes focused on securing functioning design and information flows of fire protection information. This was so that both fire related information, in the form of parameters and accompanying parametric information/value, and visual rendering of various fire-protection-related functions can be communicated within a project. Depending on the design phase, proposals for various levels of information were defined. Based on control variables and various requirement parameters with specific values (e.g. EI 60), the applicable fire protection requirements for a building or facility based on current protection level were clarified.

Further, the various work processes were evaluated in ongoing projects, in order to identify strengths and weaknesses, and to learn about how a future implementation in the building industry should take place. With reference to the development of various work processes, functions for control and monitoring as well as automated regulation control were studied and outlined in relation to the work processes.

For projects at BIM level 2, there is a great need for coordination between disciplines, and that fire protection designers are allowed to specify fire protection related parameters in the models of the various disciplines. To render visual information such as fire compartment boundaries, evacuation routes and the location of emergency lighting, a separate fire model is created, with graphics display that can be linked into the other disciplines' models or make up part of a coordination model.

For projects at BIM level 3, design takes place via a cloud-based database and in a common model. Fire-protection-related information and requirements are defined as parameters in the model and as information in a project-wide database. In the common model, fire-related graphics display such as extinguishers, emergency lighting and fire compartment boundaries are defined. A work flow via a common database and model offers better information flow with the possibility of real-time updated information and greater potential for future development of functions for control and review.

To drive developments forward, and to succeed with implementation, critical success factors and future development requirements have also been identified, which in many respects are essential for the entire building industry. The most critical factors are:

- The need for more knowledge in the fire consultancy sector of BIM as a concept and of model-based engineering.
- A huge need to standardize concepts, processes and data management throughout the industry, and especially in fire protection.
- Future versions of IFC must have a "*Model View Definition*" linked to fire protection, to achieve a program-neutral data exchange format. This is so that both fire-related information in the form of steering parameters and analysis results can be communicated, regardless of software used.
- A need for new business models that incorporate quality, effectivization and offer a win-win perspective for all actors involved in a project.
- Clearer allocation of responsibility and collaboration between actors, and that legal aspects become more digitalized – for all actors in a project.
- Future building regulations are revised based on structure, content and format, in order to increase logic and to create a possibility to make executable code of our fire protection regulations.

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