MASTER THESIS PROJECT REPORT

INFORMATION EXCHANGE BETWEEN BIM, ENERGY PERFORMANCE ANALYSIS AND SUSTAINABILITY ASSESSMENT IN CONCEPTUAL DESIGN

SCHOOL OF ENGINEERING & SCIENCE

MSc in Management in the Building Industry, 4TH semester

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STUDENT PROJECT

Abstract

This master thesis is a theoretical report which takes its point of origin in the sustainability design and building energy performance. The report identifies that those can be fully implemented in the early design only through the multidisciplinary environment of BIM, which requires a much more integrated project process than the traditional one, currently experienced by the construction industry.

The main problem deals with the possibilities for information exchange between Revit as a BIM tool, Be10 as an energy analysis tool and DGNB (LCAByg) as a sustainability certification system, with the ultimate purpose of enabling more efficient and optimized process of high-performance building design in the early design stages.

The report follows the buildingSMART methodology for development of Information Delivery Manual and therefore goes through an assessment of all process, actors, information exchange needs and requirements, as well as challenges and future possibilities associated with further development in the area.

The final outcome of the report is presented in the form of a process map, defining the integrated sustainable design process in a way, which would facilitate a most efficient collaboration and information exchange in the Conceptual Phase.

Group 10

Main report: **92** pages

Appendix: **11** pages

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Preface

This master thesis is an original intellectual product, carried out in the period 01.09.2015 to 06.01.2016, by group 10 or as self-named due to multiple collaborations, team MEI. The three group members - **M**artin Stamenov, **E**katerina Petrova and **I**va Romanska, have worked together to prepare the project in accordance with the academic requirements for a final dissertation project of the MSc in Management in Building Industry programme, department of Civil Engineering at Aalborg University (AAU), Denmark.

The problem is generated from a theme suggested in the Master thesis inspirational catalogue, provided by AAU and stated as 'Sustainability assessment and BIM based building design'. Therefore, during the entire process, the main focus was kept on that topic. The main product of the thesis report is an in-depth investigation, followed by proposal for development of an Information Delivery Manual and the associated with it process discovery and mapping.

The project knowledge is gained and improved by review of numerous research and conference papers, studies, legislations, books, and BIM handbooks and DGNB certification manuals. Worth mentioning is that the group expresses a very big personal interest in the area, which also happens to be of major significance within Research and Development in the construction industry.

The report is focused on exploring the possibilities for information exchange. Energy analysis tools and sustainability certification systems in an integrated conceptual design process. The main objective is enabling high-performance building design and better efficiency in the collaboration between the parties involved. The choice of tools comprises Revit, which has specifically been developed for BIM and is widely used in the Danish building sector, Be10, as required by the government for energy frame compliance check, and DGNB, as the locally adopted green building certification system.

In general, the group set an initial problem formulation that was further transformed into a final problem statement, the main purpose of which is to analyse the conceptual design processes, which include the three chosen tools, find the issues related to the associated information exchange and thereafter suggest a solution, in the form of methodology for efficient and optimised information management framework.

Acknowledgements

The years of our education that have brought us to the completion of this master thesis, were extremely valuable for its accomplishment due to the given inspiration, knowledge and help from many people.

As a group, we would like to use the opportunity to express our deepest gratitude to our supervisors- associate professors Kjeld Svidt and Rasmus Lund Jensen, for the provided invaluable guidance and willingness to share their extensive knowledge and ideas with us. Moreover, we are thankful for their illuminating views that gave us a direction to follow and kept us on the right track. The student seminar arranged by them met us with fellow students working within the same area and helped us narrow down the initial vast theme to a specific purpose oriented project.

Additionally, we would like to thank to PhD student Peter Gade, who gave us a great insight into his work and provoke our logical thinking with the right questions.

Last, but not the least, we would like to thank our lovely families for the outstanding support, endless motivation and constant understanding during the entire education. Most importantly, we are thankful for each other's constant help, encouragement and dedicated work, which made our team a family for life.

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List of Abbreviations

AEC - Architecture, Engineering and Construction
AIA - American Institute of Architects
BDS - Building Description System
BIM - Building Information Modelling/Model
BPM - Building Product Model
BPMN - Business Process Modelling Notation
BR - Danish Building Regulation
bSDD - buildingSMART Data Dictionary
CEN - European Committee for Standardization
COP - Conference of the Parties
DB - Design-Build
DBB - Design-Bid-Build
DK-GBC - Green Building Council Denmark
DRY - Design Reference Year
EPBD - Energy Performance Building Directive
EU - European Union
GBM - Generic Building Model
GBPN - Global Buildings Performance Network
GDP - Gross Domestic Product
GHG – Greenhouse gas
HVAC - Heating, Ventilation & Air-Conditioning
IAI - International Alliance for Interoperability
ICT - Information and Communications Technology
IDM - Information Delivery Manual
IE - Information Exchange
IEA - International Energy Agency
IFC - Industry Foundation Class
IFD - International Framework for Dictionaries
INDC - Intended Nationally Determined Contributions
IPCC - Intergovernmental panel
IPD - Integrated Project Delivery
IT - Information Technology
LCA - Life Cycle Assessment
LOD - Level of Detail/Development
MVD - Model View Definition
nZEB - nearly-zero energy building
OPR - Owner's Project Requirement
R & D - Research and Development
SBA - Sustainable Building Alliance
SBi - Statens Byggeforskningsinstitut (Danish Building Research Institute)
SETIS - Strategic Energy Technologies Information System
US - United States
USGBC - US Green Building Council

Chapter 1: INTRODUCTION

The following chapter presents the context in which the study took place, the background of the problem to be solved, the initial research question, the main objectives and delimitations, as well as the research methodology applied.

1.1. Project context

The construction industry nowadays is one of the biggest consumers of energy, which causes a great environmental impact and contributes to the raising concerns related to climate change. That has led to an increased awareness and higher consideration of sustainability and energy performance, and pressure for those to be integrated earlier in the building design. More and more prominent companies within the industry have started implementing sustainability principles on all corporate levels, which is also in many cases being dictated by the national institutions and building regulations.

Together with that, sustainability has become a major and mandatory part of the modern architectural theory and design practices. That is owed not only to people's environmental consciousness and the growing related concerns, but also to the increasing energy costs, which have created a demand for buildings with much smaller impact and much better performance. The stakeholders' perception and requirements have also shifted. For example, while a building owner's biggest objective in the past would have been justified mostly by cost-efficiency, present results show that sustainable/resource-efficient buildings perform best according to those criteria anyway, with significant reduction in operating costs. (Autodesk, 2009). Additionally, by using sustainable materials and renewable energy resources, such buildings have lower impact on the environment, minimise waste and air pollution, save water and 'green-up' the overall image of the industry.

However, as stated by Aksamija (2012), a supreme building performance is not self-explanatory at all. It relies on the obeying of multiple sets of requirements and has its roots in a constantly improved, dedicated and complicated design process. Architectural design has been greatly influenced by the significant development of information and communications technology during the last two decades.

A comprehensive design process in architectural practice is being enhanced by energy and thermal simulations, improved visual representations and supported by collaboration via digital media between the different parties involved in a project (Aksamija, 2012). However, none of that would have been possible without a proper medium. Thanks to Building Information Modelling (BIM), better collaboration between the different professionals is achieved. It improves the building design process tremendously, by allowing the integration of multi-disciplinary information within the same three- dimensional object-oriented building model (Zanni, et al., 2013). That way, information about material types, properties and quantities, energy performance, site disturbance, lighting, etc. can be obtained and included in analysis on a comparative basis, as soon as such data is available.

By the use of sophisticated energy analysis tools, immediate feedback can be received, and uncertainties, as well as problems related to energy demand and consumption can be eliminated in the early design phase. As a result, a building energy model can be created, which, if used for multiple iterative analyses, can help reaching established energy performance targets. (Moakher & Pimplikar, 2012)

However, such practices early in the building design process are not yet commonly adopted and the extent of their potential is not yet fully reached.

The demands for particular building performance from owners, national regulatory bodies, as well as the introduced from them sustainability rating tools are constantly becoming bigger. BIM and its possibilities for synergy with sustainable and energy-efficient design have started to be recognised among architecture, engineering & construction (AEC) professionals, as they can use them in order to meet those demands. Naboni (2013) claims that current practices are somewhat evolving and the traditional sequential design process is transforming into a circular, interdisciplinary one, where sustainability and its implementation of rating tools are navigating the process. In essence, according to Kibert (2013), the environmental performance of an entire building can be quantified and compared to established baselines. Despite this being far from widely adopted, it allows designers to consider numerous alternative solutions related to building layout, systems and materials, and select those that fulfil the targeted performance criteria for the chosen type of building.

Unfortunately, due to sustainability certification not being mandatory, it is entirely up to the client to require such, even though there are multiple benefits not only for the environment, but for all stakeholders. Labelling a new building with sustainable award, will ensure better market opportunities, higher value for money for the building owner/ investor, as well as a lower risk of their investment. The future users will be provided with a better indoor environmental quality.

Including a certification system also has a positive effect on the focus and organisation of the design by promoting integrated planning and optimising the whole process. Aiming for sustainability certification award from the very beginning sets a common objective for the entire design team, which has to collaborate and integrate various types of expertise, related to aesthetical and functional requirements, energy performance and improved building life-cycle.

If applied effortlessly, such an integrated process would eliminate the numerous problems associated with the traditional design approaches, improve building quality, performance, team productivity, and save valuable resources such as money, time and effort to all stakeholders (Moakher & Pimplikar, 2012).

However, that transformation is quite young and ongoing, and the industry still seems to suffer the lack of a flawless and effective connection between BIM, energy design and sustainability rating methodologies. Hence, the full potential of such an integration still cannot be fully reached. The following will outline the aspects of that problem, which will serve as a foundation for further research in the following chapters.

1.2. Problem background and initial problem formulation

As discovered from the outlined project context, sustainable buildings require anything, but a conventional design approach. From that perspective, Aksamija (2012) summarises the key fundamentals of high-performance design as '*building performance predictions, use of simulations and modelling, research-based and* *data-driven process.'* For an effective process and fully optimised sustainable design to be achieved, it is essential that they are integrated and applied as early as possible- in the conceptual design stage, when decisions can be easily altered, alternative design proposals can be evaluated and any associated potential losses or gains, as well as potential effects on the building's life-cycle- identified. (Azhar, et al., 2008); (Jalaei & Jrade, 2014).

However, contrary to those requirements, performing energy analysis and simulations after the full completion of the design is still a common practice. Ironically, the vital for the design decisions feedback from the energy simulations, requires a fairly complete model of the building. That leads to the fact that by the time of simulation, major changes cannot be done and those that are led by simulation results are becoming way more difficult to implement, which affects the entire project economy. As a result, a closed circle of inefficiency and bad practice is created, where a retroactive modification of the design is being done, so that the set of performance criteria are met. One reason behind that problem lies within the fact that BIM models are not usually built up from the very beginning with energy modelling in mind. (Schlueter & Thesseling, 2009)

A whole other nuance of the problem is related to the collaboration between the relevant parties involved in the Conceptual Design stage of the project, namely architect and energy engineer. Usually, the latter is not involved early enough and consequently, feedback based on the energy analysis cannot be provided when it is most needed- during consideration of different design alternatives. That by itself also enhances the inefficiency, otherwise created by the lack of automation between modelling and analysis/simulation processes (Carriere, 2015). In general, the lack of collaboration, combined with possible imperfections or ambiguities in the BIM model not only complicate and slow down the energy analysis process, but also hinder the implementation of energy performance feedback and the facilitation of integrated design in general (Jalaei & Jrade, 2014).

The process is also further complicated, as energy analysis requires a range of data inputs, additional to the ones usually included in a typical BIM model. Apart from building geometry, information concerning for instance location, schedules of operation, mapping of HVAC zones, lighting, surface reflection, occupancy data is equally important (Malin, 2007). With regards to sustainability, the BIM model also has to contain relevant specifications as early as the Conceptual Design stage, so that an evaluation according to the chosen rating system and its performance criteria for the particular type of building can be done (Jalaei & Jrade, 2014).

Undoubtedly, the current practices involving BIM-supported sustainability design and certification within the AEC industry prove to be immature and unsystematic. The lack of a proper information delivery process serves as the biggest barrier to exploring the benefits and utilizing the full potential of the available tools during the design process (Wu & Issa, 2013). Despite the constant attempts for providing an efficient information exchange methodology, as well as the topic being a major R&D part of IT in construction, effortless information exchange and interpretation between BIM and energy analysis tools still seems to be promised, but not yet achieved. Technical problems, such as geometric misrepresentations, loss of information during data transfer, confusions associated with data re-input and object parametric information deficiency result in inefficiencies and loss of money, time and effort (Garcia, 2014).

With regards to the sustainability assessment, BIM allows a potential integration of sustainability analysis within the design process. However, a standard methodology for implementation of guidance concerning criteria requirements in the traditional design process does not exist. Such would be especially valuable during the early design stages, where it can crucially influence the decision-making and hence the building performance.

From an organisational perspective, the success of a project depends on the project team. However, due to the fact that project teams are not uniform in terms of participants, but usually unique for every project, each time a new differentiation of roles and responsibilities takes place, the determination and understanding of appropriate BIM strategies and standardizing of methods for information exchange (IE) is challenged. That makes the success from one project relatively hard to replicate in another, which is also an important issue to be solved (Wu & Issa, 2013).

1.2.1. Research question

Considering that the future of the construction industry demands a decision- making process, shaped by the principles of sustainability, interoperability between tools that generate, collect and use information to support that process is now becoming a vital necessity. Since as of the current moment the probability of existence of a tool that will single-handedly handle all necessary computations seems relatively low, creation of an effective interoperability framework is considered an objective of a highest priority. That is why the research question in the following study can be stated as follows:

What conditions can facilitate a successful information exchange methodology that links BIM and energy analysis tools with sustainability rating systems in the Conceptual Design phase of a construction project?

1.3. Objectives and scope

This section presents the goals and delimitations of this thesis, where the focus, as well as a description of the different decisions and approaches that have been taken will be highlighted.

The primary intent of this master thesis is to explore the possibilities for information exchange between BIM, energy analysis tools and sustainability certification systems in an integrated process, with the ultimate purpose of enabling better, high-performance building design. Successful exchange and communication within the project team is crucial and strongly depends on good project management. The main objective is to propose a process methodology for interoperability between the above mentioned from an information management perspective. That also includes assessment of the benefits of such an integration, opportunities and restrictions in current practices, including evaluation of the project-relevant existing tools and their performance, as well as challenges and future possibilities associated with further development in the area.

The aim of this framework is to define a way of conducting energy analysis and sustainability assessment within BIM collaborative environment at Conceptual Design stage, in order for a much more efficient building design process to be achieved. The main concept is to conduct an analytical study, clarify all sub-processes and identify the challenges that need to be overcome and the conditions that can facilitate a successful overall information delivery process. For that to be achieved, a clear definition of project development phases has to be presented. Since the current project focuses solely on concept design in an integrated design process, the following section will specify that matter.

The concept building design is developed during and until the end of the Conceptual Design stage described below, but is dependent on the phases before that and the information content that they carry. That is why the design process with all sub-processes included is studied from the moment of idea generation and project start until the end of the Conceptual Design phase. For comparison purposes, both traditional and integrated design process phases have been reviewed. The specification of relevant for the project design phases only is as follows:

TRADITIONAL DESIGN PROCESS PHASES		INTEGRATED DESIGN PROCESS PHASES
Program	↓	Design Brief Development
Feasibility		Pre-Design
Schematic Design		**Conceptual Design**
Design Development		Preliminary Design

Conceptual Design Phase

'Through the sketching process, architectural ideas and concepts are linked to principles of construction, energy and environmental building concepts, indoor environment as well as to functional demands. Different conceptual design solutions are developed and their relative merits are continuously evaluated, including their architectural qualities, against the goals in the building design brief. The outcome is an integrated building concept.' (Heiselberg, 2007)

The thesis is further delimitated to focusing on Denmark, even though some global and EU data, statistics and trends have been presented and discussed where relevant, in order for a comprehensive overview to be given. That by itself serves as a basis for further delimitation, concerning the tools for BIM modelling, energy analysis and rating. Such delimitation is necessary due to the existence of hundreds of different kinds of software applications for thermal simulation and energy demand calculation, and the numerous such concerning BIM modelling and sustainability rating.

Together with that, with regards to successful information exchange, the group's project-related research has identified that such exists and is available between various BIM and energy analysis tools. Those are showcased in numerous studies (Jalaei & Jrade, 2014), (Garcia, 2014), (Kumar, 2008), (Lam, et al., 2014), which either refer to already established best practices or attempt to develop new technical solutions as required. For instance, interoperability solutions are already available between BIM tools such as Autodesk Revit and ArchiCAD on one side and Green Building Studio, EnergyPlus, IES-VE, Ecotect on another, just to name a few.

However, in relation to energy performance in Denmark, the mandatory compliance calculations are to be executed by the use of Be10. For that reason, the literature review neither explores other energy performance calculation and simulation tools, nor the possibilities for information exchange with BIM tools each of them offers.

From the same perspective, but in relation to sustainability certification systems, DGNB, despite not being mandatory in Denmark, is the locally adopted one. For that reason, proven possibilities for information exchange between BIM, energy design and sustainability assessment tools, which concern other systems such as LEED have not been pursued.

Based on that, the final choice of tools for the thesis is in accordance with the Danish Building Regulations and the local construction industry practices. It can be summarised as follows:

(1) Building design software: **Revit**- specifically built for BIM
(2) Energy analysis: **Be10**- for overall performance frame: Maximum energy demand-Supplied energy and final energy assessment (supplied energy is considered)
(3) Green building certification: **DGNB-** at this stage voluntary: Life Cycle Assessment criteria are considered

The master thesis focuses on information exchange process discovery and mapping, which is why physical modelling, validation, energy performance analyses and calculations have not been performed, as they are not a direct subject of focus. It is the design process itself, with all relevant activities and events, as well as participants that is the main area explored and analysed, according to methodology developed by buildingSMART.

The tools defined above also determine the participants and their tasks involved in the design process and any other ones, not concerned with the use of those, have not been included. However, their input is considered and mentioned where appropriate. All of that is applied to the context of new office/administrative buildings, with the purpose of further delimitation and narrowing down the scope of the project.

1.4. Research methodology

The intention behind this thesis is to propose a methodology for integrated sustainable design, executed within BIM environment in the Conceptual Design Phase. The aim is to identify the influence and related issues of the key elements, namely BIM, energy performance analyses and sustainability rating, as well as the actors and information exchange principles and requirements related to them. The thesis also intends to provide the theoretical base for a more efficient and optimised design process, as well as the references for development of technical solutions for decision-making support in the early design stages.

Data collection is executed via qualitative approach and the research methods applied in this master thesis include, but are not limited to: literature review, comparative approach, inductive reasoning and interviews.

- **Literature review**

The term literature review is defined by Hart (1998) as '*the use of ideas in the literature to justify the particular approach to the topic, the selection of methods, and demonstration that this research contributes something new*'. In addition, Webster and Watson (2002) present a further elaboration of what an effective literature review is- one that '*creates a firm foundation for advancing knowledge. It facilitates theory development, closes areas where a plethora of research exists, and uncovers areas where research is needed.*'

The data for this research is primarily collected via a comprehensive literature review, in order to evaluate the current state of collaborative BIM-enabled energy design and sustainability assessment. That serves to understand and define the impacts, drivers and benefits of sustainability analysis integration in the BIM-collaborative processes, as well as identify the barriers and limitations of the current practices. Aspects such as project team member roles, processes, technology, regulations and information exchange are reviewed and analysed.

The sources for the literature review include numerous research papers, conference proceedings, books, scientific reports, journal articles, manuals, handbooks, legislative documentation and regulations, and websites of official organisations and regulatory bodies. The group has made sure that the information used is objective and trustworthy, from verified sources and right publication intent.

- **Comparative approach**

By the use of the comparative approach, different interrelated objective matters are compared, so that relevant conclusions, concerning advantages and disadvantages, as well as similarities and differences are drawn. For instance, this master thesis project comparatively analyses the traditional and the integrated design approaches, so that the issues in the current practices are identified and eliminated from the design process. Together with that, the influence of the different stakeholder roles in relation to each other and different ways for information exchange have also been comparatively analysed.

- **Inductive reasoning**

Carroll (1993) considers inductive reasoning a general aspect of human intelligence. It begins with specific observations and measures, which then continue with the detection of patterns and regularities, from which certain hypotheses are drawn and can then be tested, which would finally lead to a general conclusion. In the current thesis, inductive reasoning was used to reason particular design decision-making elements, which led to the identification of patterns in best practices for information exchange and collaboration during the early design process.

- **Interviews**

As one of the most common methods of qualitative data collection, it was also used in this report to explore the set of knowledge, experience and views of individuals, with the purpose to gain a deeper understanding in some of the determinative topics, related to problem identification and interoperability between BIM, sustainability assessment and energy performance analysis.

- **Point of intersection between project management and information delivery**

Besides the methods applied, the master thesis uses a general project management concept, which relates to a specific information exchange methodology in the BIM context. In the general case, project failure is often the result of poor communication, as it is a vital factor is project scheduling of activities for instance. The Project Communication Plan (PCP) as a project management concept maps the information flows to and from all stakeholders in a given project. In relation to the development of a PCP, the elements that have to be considered include: stakeholder communication requirements, format, content and level of detail of the information to be communicated, an identification of who will be the receiver and the producer of the communicated information, suggested methods, a glossary of common terminology. For a PCP to be developed, stakeholders' analysis needs to be performed and information needs, sources of information, etc. need to be identified. (Passenheim, 2009)

Taking that in consideration and based on the literature review, the group has drawn a parallel between the concepts of Project Communication Plan (PCP) and Information Delivery Manual (IDM), developed by buildingSMART as a methodology to identify and specify processes and information flow during the life-cycle of a building.

That serves as an interchange between the groups study programme background and area of interest.

Chapter 2: LITERATURE REVIEW

The following chapter contains a review of the work of previously published authors, the purpose of which is to support the group's analysis and arguments. Moreover, the literature review will help answering the set of questions needed to find a solution of the final problem and fulfil the objectives of the study.

2.1. SUSTAINABILITY ASSESSMENT AND DGNB CERTIFICATION

This sub chapter of the literature review focuses on sustainable development, sustainable buildings and their assessment worldwide and more specifically the relatively new certification system DGNB. Generally, rating tools can be a framework for effective decision-making at an early design stage, but currently the building performance simulations that are most necessary for the assessment are typically executed after the design phase. In order to evaluate the needs of performance criteria for the building, its materials and technical systems, sustainability assessment has to be seamlessly integrated into the initial design process (Schlueter & Thesseling, 2009).

2.1.1. Defining sustainable development

According to the World Commission on Environment and Development (the Brundtland Commission), sustainable development is one '*that meets the needs of the present without compromising the ability of future generations to meet their own needs.*' (World Commission on Environment and Development , 1987, p. 43).

Otherwise stated, it is not only about fulfilling the current requirements, raising awareness or shifting responsibilities towards nature and society in the present. The sustainability principles applied today, have to be aiming for the future and become a highest priority in all of life's aspects, from simple daily routines and behavior, to major changes in industrial activities, as well as local, national and global policies. That is also why sustainability by itself is not a one-, but a multi-dimensional matter, consisting of three equal pillars, the goal of which is to achieve a perfect balance between economic development, social development and environmental protection (United Nations, 2010).

2.1.2. Sustainability in the construction industry

Nowadays, almost all industries are focusing on sustainability, but when it comes to global sustainable development, some of the most major simultaneous impacts on all three pillars come from the construction industry.

First, it has a crucial direct effect on the environment, due to consumption of natural resources, water, land- use and Greenhouse gas (GHG) emissions (Pinkse & Dommisse , 2010). According to Levy (2012), on a global level, US and EU buildings together consume over half of the total energy consumption of Brazil, Russia, India and China together. The 2010 Energy Performance of Buildings Directive (2010/31/EU from 19 May 2010) specifies that buildings account for 40% of the total energy use and 36% of the CO_2 emissions in EU. Together with that, the industry in general is responsible for about 40% of the natural resource consumption and waste generation.

From an economic perspective, construction industry is one of the most important global contributors. As of 2012, it has been estimated that it accounts for one tenth of the world economy, with a total output of 3.000 billion Euro per year, as European capital comprises more than 30% of that amount (European Commission, 2012). In EU alone, it contributes to 10% of the GDP and is the provider of about 20 million jobs (European Commission, 2015).

Indirectly, the building sector affects public health, urban environment, transportation systems and human activity in general, as the surrounding built environment is an integrated part of the human existence (Pitt, et al., 2009). From that perspective, it can be said that the industry also plays a central role in the general quality of life and well-being of people and affects even their social behavior and interactions.

Despite the fear-provoking statistics and trends, many AEC professionals are working towards obliging and applying of the sustainability principles and a paradigm shift in the construction industry's approach has started to emerge. The sustainable performance of the buildings has grown into one of the main considerations for a variety of reasons, such as the rising awareness of climate change and the building industry's impact on the environment. That has resulted in a number of measures and regulations worldwide in addition to many national and regional targets. (Schlueter & Thesseling, 2009)

Kubba (2012) states that a rise in investment in sustainability and green building practices can also be observed on the worldwide construction market and although buildings are still responsible for a massive percentage of the energy consumption and they are substantial CO_2 emitters, a decrease in those levels can be witnessed among many countries in the EU.

Even though the challenges to a global sustainable development are immense, the results of a global effort are already contributing to a new, positive range of statistics. GHG emissions in EU are marking a reduction in almost all sectors, as renewable energy from biomass, as well as wind and solar energy utilization is growing steadily. Additionally, huge effort has also been put in recycling, waste management and combating illegal logging, just to name a few. (Eurostat, 2014)

2.1.3. Green building practices

According estimates from EuroACE (2012), there are about 210 million buildings in the European Union that represent an enormous environmental footprint. Most of these buildings use energy inefficiently, generate large amounts of waste, release large quantities of pollutants and GHG emissions. In contrast to those conventional buildings, green buildings are smart, they seek to use land and energy efficiently, conserve water and other resources, improve indoor and outdoor air quality, and increase the use of recycled and renewable materials. For that reason, Howe & Gerrard (2010) suggest that even though green buildings still constitute a tiny subset of the existing buildings, their number is increasing incredibly fast.

Logically, a definition of what 'green building' precisely constitutes would be appropriate, but it turns out to be a difficult assignment, since as mentioned by Howe & Gerrard (2010), the meaning is constantly evolving. The Environmental Protection Agency (EPA) offers a useful working definition to this term:

'Green building is the practice of creating structures and using processes that are environmentally responsible and resource-efficient throughout a building's life-cycle from siting to design, construction, operation, maintenance, renovation and deconstruction. This practice expands and complements the classical building design concerns of economy, utility, durability, and comfort. Green building is also known as a sustainable or high performance building.' (EPA, 2014)

The explanation clearly mentions the life-cycle of the building and in the particular context of green buildings, life-cycle assessment (LCA) comes to evaluate building materials and energy use over the course of their entire lives. It takes into account a full range of environmental impacts, including: a material's embodied energy; the solid waste generated in its extraction, use, and disposal; the air and water pollution associated with it and its global-warming potential. (Howe & Gerrard, 2010) LCA is an essential part of the chosen scope of work and it will be reviewed further as a criteria of the chosen sustainability rating tool.

According to Kubba (2012), whatever one wishes to understand from the term 'green building', the movement towards sustainable development is a fact and it has had a profound impact not only on the European, but the global construction market over the last two decades. Since there is no uniform definition of 'green', it is in great importance that instruments with concrete goals and guideline indicators are required within an adequate framework of a sustainability assessment (Ebert, et al., 2011).

2.1.4. Sustainability assessment worldwide

According to Ebert, et al. (2011), assessing and rating the sustainability of a building by the use of a certification system is an essential part of the sustainable development, since such systems most often take all three sustainability dimensions(ecological, economic and social) into account in its assessment structure. The authors explain that most certification systems combine existing green building practices and planning techniques (energy-efficiency, ecological balance, life cycle costs, etc.) and are built up on the basis of existing national standards and legislation. That can give designers the possibility for project evaluation at an early stage, from which guidelines can be then derived for completing the sustainable planning goals of a green building project.

Many countries and international organizations have already introduced new voluntary rating and certification systems to assess sustainability level in the construction and to provide best practice experience in their highest certification level (Figure 1) (Reed, et al., 2009). Most of them are trying to push the development towards greater sustainability, by setting requirements that are actually stricter than the standards, in order to increase the building's quality.

Figure 1: Sustainable Rating Tools, Source: JOSRE 2015

Currently, some of the most recognized once are BREEAM (UK), LEED (US) and DGNB (Germany) and even though they serve the same purpose – environmental assessment, they all differ greatly in philosophies and business models, and demonstrate sustainability in the construction industry in different ways (Ebert, et al., 2011). There are a lot of different factors and criteria, on which the certification can be based. Some have criteria that only cover aspects of the building approach, such as energy efficiency, others cover the whole building approach by identifying performance in all sustainable key areas (Bauer, et al., 2010).

2.1.5. Sustainability assessment in Denmark

According to Birgisdottir, et al. (2010), a stronger recognition of sustainable practices or at least a growing awareness of the need for sustainability in Denmark have come both from within the country (through the competitive influence of progressive companies in the building industry), the wide-ranging international pressure, coming from the European CEN/TC 350 standard series on Sustainability of Construction Works (CEN Afnor Normalisation, 2015), the ISO/TC 59/SC 17 International Standard for Sustainability in Buildings and Civil Engineering Works (ISO, 2015), and organizations such as the Sustainable Building Alliance (SBA, 2015). (F. Cottrell, 2015)

In the Danish context, the establishment of the Green Building Council Denmark (GBC – DK) in 2010 can be recognized as the beginning of a cooperative effort of the Danish building industry to create a nationally tailored sustainability assessment platform for new building projects and for existing buildings (Rasmussen, et al., 2013). In 2012, the selection of the German developed DGNB international certification over competing certification systems was announced after a careful review process from multiple actors in the Danish building sector (Birgisdottir, et al., 2010).

Presently, GBC – DK has two schemes that operate fully in Denmark – the DGNB for new office buildings, which is the one introduced in 2012, and the DGNB for Urban Areas, introduced in the recent 2014. Also, as presented by GBC – DK, some additional schemes are currently listed as in the pilot-phase, and there is an intent to address even more in the future. All of them assess overall performance, have slight differences in the content with similar implementation process and are based on similar values for quality. (DK-GBC, 2014) However, this report is further focused only on the new office buildings schemes, so others will not be taken into consideration.

2.1.6. DGNB certification system

The German Sustainable Building Council (DGNB for Deutsche Gesellschaft für Nachhaltiges Bauen) was originally founded in June 2007 and together with the German Federal Ministry of Transport, Construction and Urban Development have created the DGNB certification system and introduced it in January 2009. (Bauer, et al., 2010). The goal back then was to build living environments that are *'environmentally compatible, resource-friendly and economical and that safeguard the health, comfort and performance of their users.'* (Bauer, et al., 2010)

The DGNB is based on current European norms and standards, it has a comparable core system and high flexibility, and that is why it can be applied anywhere in the world through an appropriate local tailoring, which is exactly how it happened to the Danish system. (DGNB, 2014)

According to the DGNB manuals, the system is indispensable for anyone who plans sustainable buildings and wishes to document their quality. It is grounded on the base of all DGNB members and takes into account all relevant topics of the sustainable construction. It is adapted to fit a wide range of building projects and they can achieve a pre-certificate and/or certificate in three categories: platinum, gold and silver, depending of course on the degree to which they have met the relevant scheme criteria. There used to be a bronze certificate, but it is no longer applicable for awarding new buildings after the 1st of July, 2015 (DGNB, 2014). Impressively, DGNB is the only green building rating system that emphasizes economic sustainability and also allows a building's entire life-cycle to be monitored and optimized systematically according to unified standards and for its specific qualities to be displayed at maximum transparency (DK-GBC, 2012).

Six key aspects with around 40 different criteria affect the evaluation: environmental, economic, sociocultural and functional aspects, technology, processes and site. These evaluation areas are weighted differently, depending on the building type to be evaluated. Thus, each version of the system, hence each building type, has its own evaluation matrix (DGNB, 2014) . For the building scheme on focus- new office buildings, the environmental, economical, socio-cultural and functional aspects and technical quality each account for 22.5% of the total, process accounts for 10% and the site quality is given a separate grade (Figure 2). (SBA, 2015) The chosen evaluation area for a supplementary review in this report is the Environmental quality and as mentioned above one specific criteria group related to it – the life-cycle analysis (LCA).

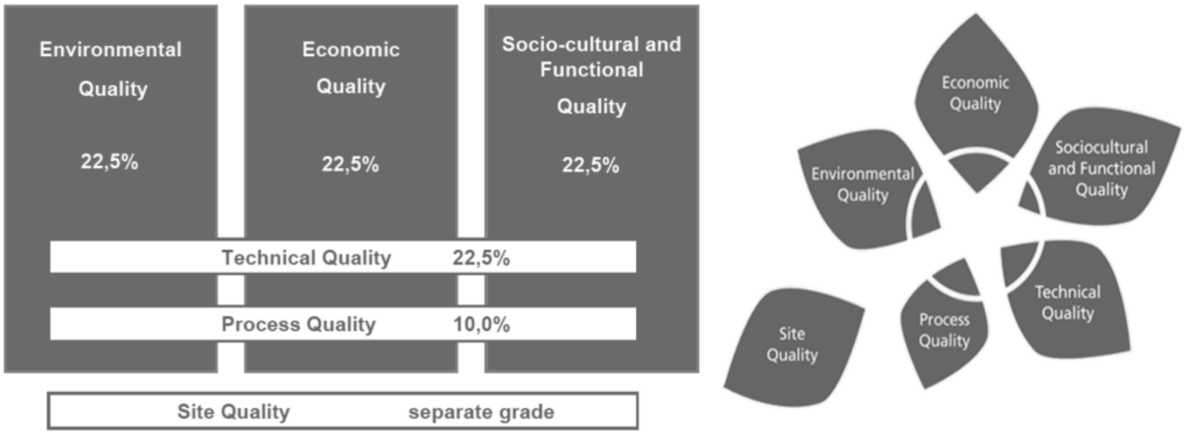

Figure 2: DGNB qualities, Source: www.dgnb-system.de

2.1.7. Life cycle analysis – chosen criteria group

DGNB as a certification system is one of the most concerned with LCA (13,5%, see Attachments- 'DGNB CORE14 criteria overview)) and the emphasis is on total life-cycle assessment on building material usage and operation of energy. It also incorporates all involved lifecycle stages: Construction; Operation including supply & disposal, maintenance, repairs and replacements; End-of-life including recycling and disposal. (DK-GBC, 2012)

Data for LCA on building material usage derives from:

- EPDs (Environmental Product Declarations)/MVD (Miljøvaredeklationer) ISO 14025/DS 15804
- ESUCO database (EU)
- Ökobau.dat database (Germany)

Data for LCA on energy consumption derives from:

- BE10 calculations
- Generic data for energy supply (DK-GBC, 2014)

According Rasmussen (2013) the important settings for the LCA in DGNB are:

- The chosen study period, in which the environmental effects of the building's life-cycle are taken into account, is defined as 50 years for new office buildings.
- The chosen energy supply for the building's use stage, which takes into account the technologies producing energy for the building's consumption of heat and electricity. For new office buildings, the input of electricity is indicated to be the European grid mix and for reference input of district heating to be a mix of 65% thermal energy from natural gas and 35% from hard coal.
- The choice of impact categories, which for new office buildings are ENV1.1 Life Cycle Impact Assessment and ENV2.1 Life Cycle Impact Assessment – Primary Energy.

The ENV1.1 covers the emissions from the buildings in all phases of their life-cycle, from manufacture through use, up to their end of life. It includes five environmental impact indicators (global warming, eutrophication, acidification, smog-formation and ozone depletion potentials). The main aim is therefore to reduce the buildings' emissions throughout their entire life cycle as much as possible. (DGNB, 2014)

The ENV2.1 evaluates the complete primary energy requirement of a building and includes two environmental impact indicators that concern the non-renewable and the renewable primary energy use. The main objective is over achievement of the legal regulations, in order to benefit the global protection of the climate and resources. (DGNB, 2014)

- **LCAByg**

LCAByg is a digital tool that is recently developed by the SBi to perform calculations for the building environmental performance. The necessary information input concerns the building general information, the building elements and their materials' specifications (e.g. EPD, ESUCO, Ökobau.dat) and the building's energy consumption (e.g. Be10 energy data). (SBi, 2015)

The tool automatically prepares life-cycle assessment and the results can be downloaded in a .pdf file report. Additionally, there are more detailed results and charts that can be switched between different views and downloaded in .png image files. (SBi, 2015)For a complete environmental profile, the Be10 calculations are required.

However, there is a possibility to make LCA without them, but it must be noted that the results will concern only the building materials and not the overall building performance, as recommended by SBi. (See Attachments- 'Brugervejledning til LCAbyg')

2.1.8. Pre-certification

As mentioned above, DGNB gives the possibility of both certification and pre-certification for projects. In other words, investors, building owners, and other interested parties can ask for gold, silver, or platinum pre-certification, as early as the conceptual stage. Since the report is concentrated in exactly this early planning phase, a further review is given.

According to Just & Maennig (2012), DGNB as a pre-certification process has two main advantages: firstly, it can optimize the sustainability in a project from its very beginning and secondly, it can be used to promote and market buildings, as early as the planning and execution phases. As a method it can be a guiding instrument in the planning phase that supports risk management and ensures transparency and clear processes. The use of it as early as possible in a project can be extremely beneficial, since it defines specific performance objective and allows time for the design to be influenced (Figure 3), and therefore the building's quality to be significantly increased. Overall, it has the potential for a tool that can support integrated planning and early establishment of communication. (DGNB manual, 2012), (Just & Maennig, 2012)

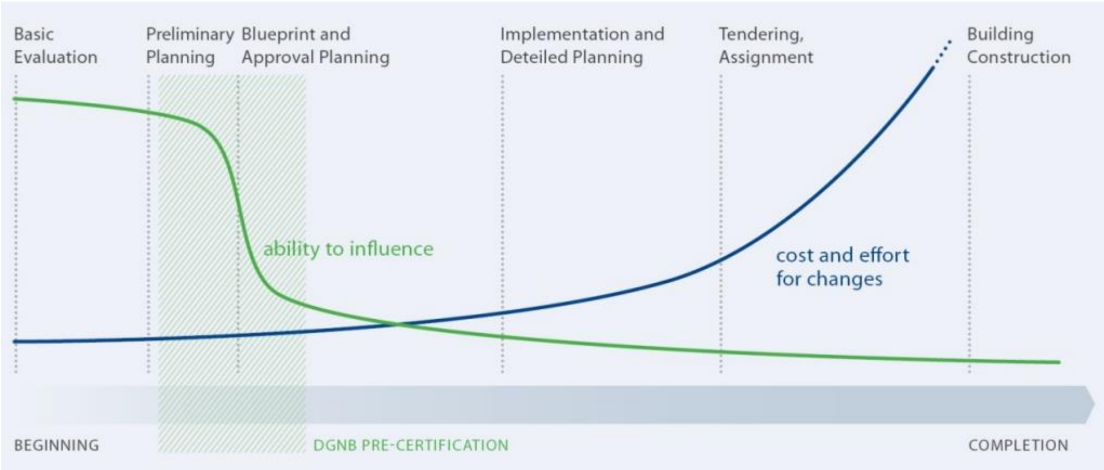

Figure 3: DGNB Pre-Certification, Source: DGNB, 2013

The process of DGNB application is interesting for the further detailed analysis on information flow between the involved parties in the early phase of a project and that is why it is briefly presented here in the literature review. According to publications available on the DGNB website and the DK-GBC, all core sustainability criteria for the pre-certification must be set as intentions or goals that will be pursued in the project together with a DGNB auditor, the building owner and the design team. This is the first step of the process and besides the team's preparation, the auditor also registers the project with the DGNB. The next step includes inspecting, assessing and submitting by the DGNB auditor the available documents at the time of the planned pre-certification. Following the submitting, is the compliance testing, where after a couple of careful reviews, the DGNB certification team sends a final assessment report to the building owner and the auditor, normally in a period of 6-8 weeks. If all parties agree on the results, DGNB sends a notice of certification, which is followed by the award for the project. (DGNB, 2014), (DK-GBC, 2012)

Hence, pre-certification can support decision-making, while also emphasizing the importance of the requirements, which transforms the whole process into a great way of communication between planning and construction objectives (Just & Maennig, 2012). Moreover, pre-certification raises the probability that a building's planned performance objectives will be accomplished once it is built. That way the completed building will be able to get a final certification much easier, since the pre-certification are fully valid certificates in their own right, but only until the building is completed.

Overall, it might be concluded that the DGNB certification system gives impressive possibilities to be incorporated in the early stages of a project and has the potential to be successfully applied in the information management methodology planned to be achieved in the end of this report.

Since besides sustainability assessment, this methodology is supposed to include two other main elements – energy analysis and BIM, they are reviewed in the next sub chapters.

2.2. ENERGY PERFORMANCE AND DESIGN

Quoting IPCC's Fourth Assessment Report (2007) and IEA's statistical report (2014), a considerable percentage (80% as of 2003, 70% as of 2014) of the GHG emissions and more specifically anthropogenic CO_2 are owed to the combustion of fossil fuels. IPCC (2007) recommends that If those emissions are to be reduced significantly in the future, as required by governmental institutions and regulatory bodies, either energy use has to shift focus from fossil fuels to alternative low and zero- carbon sources, or new technological approaches towards capturing and handling of CO_2 emissions have to be adopted.

In fact, as of December 2015, global warming still remains a major concern, as recent United Nations report suggests that the rising of the global temperatures is halfway to the critical 2 degree Celsius threshold, which if reached, will have a dangerous environmental impact. That is why working towards reduction of GHG emissions and global warming is a main priority, expressed in global national climate plans or so called Intended Nationally Determined Contributions (INDCs). The latter are to become the foundation of a new treaty on climate change, agreed on during COP 21between 30 Nov - 11 Dec 2015. (United Nations, 2015); (IEA, 2015)

In that relation, because of the strong environmental impact of the construction industry, this sub chapter will outline the need of building energy performance optimisation, the relevant regulations in EU and Denmark, as well as the factors influencing the energy consumption as the main concern. Thereafter, the effect of energy analysis on the design process, with the relevant tools and their data input needs will be presented. The purpose is to identify all significant factors and parameters related to energy design in and before the Conceptual Design Phase, so that the most important processes are outlined and an efficient information exchange process is achieved.

2.2.1. Need of energy performance optimisation in the construction industry

Taking in consideration the above stated and as suggested by Matsumoto (2011), usage of fossil fuels in the sense of both potential diminishing of reserves (may it be arguable) and the environmental impact (i.e. global warming) caused are not matters to be underestimated and preventative measures and strategies have to be applied on a global level. As a testament to such attempts comes the growing trend for decreased energy use and utilisation of renewable energy (e.g. solar, wind, geothermal, tidal, biomass resources etc.), which is an essential substitute.

With regards to building design, Schild (2010) suggests that the above specified issues and the potential energy crisis that they may lead to have amongst other things led to constant tightening of building codes related to energy performance. Additionally come the building owners' increasing requirements for comfort, optimised energy performance, reduced costs and minimised environmental impact. That makes every possibility for performance assessment, in the sense of prediction, analysis, simulations and modification of building design according to desired future performance all the more necessary, as early as possible in the project development process.

For such potential to be fully reached, Denmark's Eco Council (Det Økologiske Råd) suggests that a particular level of motivation, approaches and conditions have to be present, from the moment of conceiving of an idea, throughout the design development stages. However, all of the above mentioned, as well as the required technical data and calculation inputs are neither simple, nor easy to control.

As summarised by SETIS of the European Commission (2012), since the main objective of early energy analysis and simulations is to improve performance, it is essential that a baseline for all involved processes is set and most importantly- relevant measureable indicators are used. In other words, a certain level of objective standardisation is required, where means and patterns for measuring energy efficiency of buildings are clarified and implemented in a set of rules, which target both satisfying client requirements and building codes.

The European Commission (2012) also précises the several different reasons, which explain the need of proper building energy performance assessment. With regards to new office buildings as the main focus of this project, they emerge from the necessity of a practical and efficient way for meeting design intentions. For them to be achieved, the institution concludes that effective energy performance assessment has a point of origin in decision- making supporting design tools on one hand and measuring of the performance of already functioning buildings and comparing them to their design figures on the other. (European Comission, 2012)

Based on the identified needs, prescriptive measures have been specified, which, besides influencing the design process in the intended way, also have a legislative regulatory function.

2.2.2. EU legislation related to building energy performance

The above specified need for energy performance optimisation is evoked from the targets set by the Energy Performance of Buildings Directive (EPBD) (2002/91/EC and recast 2010/31/ EU), which requires all EU countries to apply requirements for minimum energy performance for both new and existing buildings (The European Parliament and Council, 2010).

The EPBD directive's main objective is to promote implementation of the energy efficiency principles in the design process, taking in consideration factors such as outdoor and indoor climate, specific local conditions and cost efficiency. With regards to new buildings and new building units, it specifies requirements as follows:

(a) A general framework for methodology for calculating the buildings' overall energy performance
(b) Application of minimum energy performance requirements
(c) Plans on a national level for increasing of the amount of nZEB
(d) Energy certification
(e) Regular inspections of the buildings' HVAC systems
(f) Independent control systems for energy performance certificates and inspection reports. (The European Parliament and Council, 2010, p. 17)

In addition, EPBD also includes provisions for obligatory construction of nZEB by 31 December 2020, though all buildings, occupied and owned by public authorities have to be nearly zero-energy after 31 December 2018. (The European Parliament and Council, 2010, p. 21). The latter is declared achievable in SETIS of the European Comission (2012) via a combination of both energy efficiency and renewable energy measures.

The term nearly-zero-energy is not further specified. Together with how strict requirements should be, as well as what actions have to be taken in order to comply with them, it falls in the category with specific variables, decided upon by each EU Member State individually. However, EPBD suggests strategies for implementation and compliance, which include: (The European Parliament and Council, 2010)

- EU Member States should enable and encourage AEC professionals i.e. architects, engineers and other related planners to consider and implement optimal combination of energy efficiency improvements during building design.
- Buildings occupied by public authorities and those, which are frequently visited by the public should be exemplary of environmental and energy considerations being taken into account. (The European Parliament and Council, 2010, p. 16)

Based on EPBD, the European Committee for Standardization (CEN) has introduced a number of different standards for energy performance calculations for new buildings. The main purpose of the standards is to create a comparative baseline for the EU Member States and furthermore serve as a basis for the creation of national standards, which can be applied, so that the local building codes are complied with.

For that reason, the following sub chapter will go further in depth into the currently acting Danish Building Regulations (BR10) dictating the rules for energy performance and calculations.

2.2.3. Energy efficiency objectives and assessment according to BR10

The GBPN (2013) lists Denmark as the first country to have implemented prescriptive requirements for building energy efficiency performance back in 1961. By 1982, compliance option has already been included in the code, which in 2005 is updated to a regulation for overall performance, which has been further tightened through the years.

The constant tightening of the requirements is directly related to the global trends related to the climate change, which by themselves have been implemented in the government's 2050 Energy Strategy, the main focus of which is the reduction of energy use of buildings. (Klima- og Energiministeriet , 2011)

Together with that, major government objectives are related to independence from fossil fuels, thermal comfort and indoor climate, as well as achieving carbon neutrality. The strategy considers that since the buildings' life-cycle is relatively long, long-term solutions and decisions are required. (Klima- og Energiministeriet , 2011) To ensure those, important milestones have been set, which come to secure the reaching of the targets of the 2050 Energy Strategy (Figure 4).

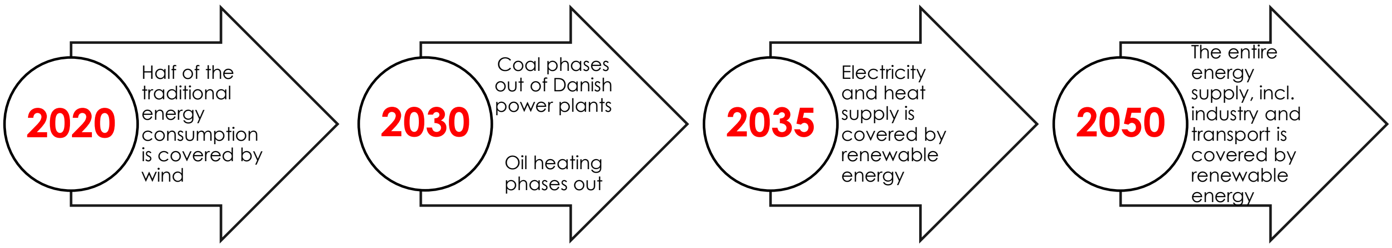

Figure 4: 2050 Energy Strategy, Source: Klima- og Energiministeriet, 2011

Based on EPBD and introduced in June 2010, BR10 are performance-based and require a mandatory energy frame calculation, so that a maximum building energy demand for both residential and non-residential buildings can be established (Energistyrelsen, 2010).

According to Dansk Byggeri (2015) and Trafik- og Byggestyrelsen (2015), as of the moment of writing of this report, the newest Danish Building regulations BR15 are released and to be implemented in a transitioning period (valid from 1st of January 2016 to 30th of June 2016 together with BR10) and are to be fully implemented from 1st of July 2016. As expected, the most major changes in the Building Regulations affect precisely Chapter 7 Energy consumption and consequently Chapter 8 Services.

Based on that, the following sections will present the latest accessible information, as well as a comparison between BR10 and BR15 where necessary, so that the changes in the requirements can be highlighted.

Article 7.1(1) of BR10 states that:

'Buildings must be constructed so as to avoid unnecessary energy consumption for heating, hot water, cooling, ventilation and lighting while at the same time achieving healthy conditions.'

When it comes to new buildings in particular, Article 7.2.1(1) of BR10 defines that:

'The energy performance framework covers the total requirements of the building for supplied energy for heating, ventilation, cooling, domestic hot water and, where appropriate, lighting.'

With regards to the above cited, BR 10 specifies concrete requirements for permissible energy consumption of buildings, which as of autumn 2015 are also actual. Additionally, requirements concerning the 2015 and 2020 targets- milestones on the way to CO_2 neutral communities, have also been stated (Trafik- og Byggestyrelsen, 2014). Those represent the current and future mandatory energy frames and are summarised in Table 1as follows:

	Residential buildings	Non-residential buildings
Current permissible energy consumption requirement (BR10) [kWh/m2 /year]	52.5 + 1650/A	71.3 + 1650/A
Low energy class 2015 (BR15) [kWh/m2 /year]	30 + 1000/A	41 + 1000/A
Building class 2020 (BR20) [kWh/m2 /year]	20	25

Table 1: Energy frame, Source: Trafik- og Byggestyrelsen, 2014

The energy frame is defined by the Danish Building Research Institute, SBi as:

'the maximum allowed primary energy demand for a building, which includes e.g. thermal bridges, solar gains, natural ventilation, heat recovery, cooling, lighting (non-residential buildings only), boiler and heat pump efficiency, electricity for operating the building, and sanctions for overheating.' (Aggerholm, et al., 2010)

Besides as a regulatory code, it also serves as a tool for benchmarking of high-performance buildings within the construction industry.

As stated by the Danish Building Research Institute (Statens Byggeforskningsinstitut (SBi)) (2008), the tightening of the energy requirements from 1st of January 2006 has led to procedural changes in the entire project development process. Besides the introduction of a new building energy labelling scheme, which requires the obtaining of an energy label before the building permit, building owners are also required to document the building's compliance with the energy frame at the time of applying for one (SBi, 2008).

As a secondary result, a need for a guideline to facilitate compliance has emerged, which has been fulfilled by the creation of SBi Directive 213 concerning the Energy demand of buildings. Initially, it consisted of Be06- a calculation programme and guidelines, aiming to determine the energy needs of buildings and facilitate compliance with the energy regulations. (SBi, 2008) (Aggerholm & Grau, 2008)

However, the changes in energy requirements have created a dynamic process, which has not only led to multiple modifications in BR, but logically also in the calculation programme version and the related guidelines, which have also been modified according to the latest requirements.

The latest updates in the calculation procedure and programme version from 10.12.2014 have been implemented to match the latest requirements in BR10. The following section will further investigate the details concerning energy performance calculations.

2.2.4. Energy performance assessment tool- Be10

Developed by SBi, Be10's main purpose is to document that the energy requirements according to BR have been met. Additionally, SBi states that if applied during the project development phases, it can be extremely helpful to architects and other consultants in making calculations and establishing the building's energy demand and use. As a result, the best possible design choices can be made, including related energy costs. (SBi, 2012)

According to Aggerholm, et al. (2010), since Be10 is created with the purpose to support the fulfilment of the requirements of the building code, from a legal perspective, all other programs for certification and compliance checks have to use the Be10 'core'. It is also the tool to be used not only when it comes to compliance with BR10, but also Low energy class 2015 (BR15) and Building Class 2020.

As summarised by Christensen, et al. (2013), the calculations executed in Be10 rely on assumptions, concerning variable use-related values, which serve as input parameters (e.g. heat transfer coefficient, light-transmittance, infiltration, user behaviour and function of the building).

In that relation, SBi 213 states that the factors to be taken in consideration comprise:

- Location and orientation of the building (including daylight and outdoor climate)
- Building envelope
- Heating system and hot water supply
- Heat-accumulating properties of the building
- HVAC systems, including natural ventilation and planned indoor climate
- Solar radiation and solar screening.
- Use of solar energy and cells, heat pumps, boilers, district heating, heat recovery, etc. may also be taken in consideration (Aggerholm & Grau, 2008).

Schematic representation of the tool and the input categories, with regards to non-residential buildings as the focus of the project, is shown in Figure 5.

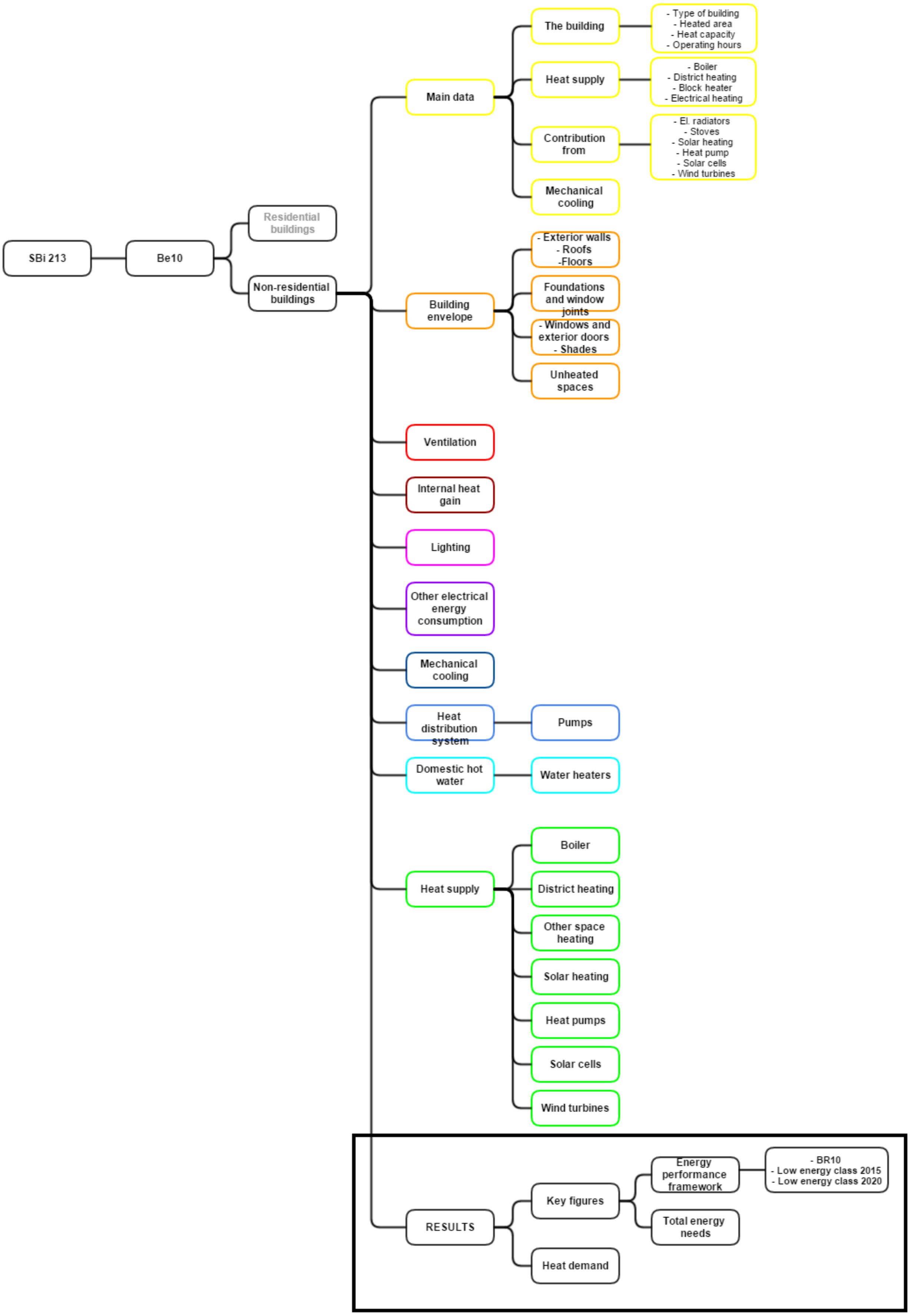

Figure 5: Schematic representation of Be10, Group 10 own contribution

- **Be10 misapplication and its effect on the design process**

As seen in the representative scheme (Figure 5), after the input and consideration of all relevant for the particular project data and factors, the calculation results present the required total energy performance framework and demand. The necessary compliance checks may then be done and in case of non-compliance, certain design parameters need to be modified.

However, various studies and professionals (Holst-Mikkelsen & Brodersen, 2012); (Christensen, et al., 2013) within the construction industry report that Be10 has certain flaws, which put in question the effectiveness of the tool and the credibility of the results it gives. For instance, according to Christensen, et al. (2013), one of the most major issues identified, is related to the large deviations between the calculated and the actual measured building energy performance results, which has put the accuracy of the tool in question.

That statement is also supported by Peter Gamst, consultant for Dan- Ejendomme on a project for a shopping centre in Copenhagen, where the company has experienced the same problem: '*We have experienced that the actual energy consumption of the building is considerably larger than the calculated in Be10, because the user behaviour is not included in the default values used in the programme.*' The latter is crucial, since as reported by European Comission (2012), the energy consumption of buildings is very much dependant on the occupancy usage behaviour.

Together with that, Christensen, et al. (2013) state that since Be10 is based on the basic methodology for calculation suggested by EPBD, the procedure is fairly simplified, as the interior of a building is treated as a single thermal zone. The building envelope is considered surface areas with different orientation and performance is calculated by input of data in spreadsheets, based solely on a quasi-steady- state model, using a mean monthly outdoor climate data.

Holst-Mikkelsen & Brodersen (2012) claim that it is the building code that requires the use of Be10, which explains why more powerful and comprehensive energy performance calculation and simulation tools are not being used. From that perspective it can be stated that the legal requirements also partly determine the process.

Contrary to the allegations for shortcomings of Be10, the authors also note that potential incorrect use of the tool, based on insufficient understanding mainly contributes to execution of inadequate calculations. That by itself may lead to inappropriate building design, errors and contradictions, which are very difficult to fix at a later stage in the project development. For instance, such may be related to ventilation and cooling systems working at the same time, e.g. against each other, the same working at maximum capacity when such is not needed or in parts of the building, which are not currently being used. All of those problems are obviously diminishing or completely counteracting the energy efficiency principles, which are first and foremost required to be applied.

As a result of the misapplication, general motivation and collaboration problems between the different parties involved in the building design process may arise. They could have potential solutions, if a good insight and knowledge on program application is present. (Holst-Mikkelsen & Brodersen, 2012)

In conclusion, it has to be noted that Be10 should be used to document compliance with BR10 and alone cannot give a precise and comprehensive result concerning energy performance the same way that other more advanced tools or a combination of them could. (Holst-Mikkelsen & Brodersen, 2012), (Christensen, et al., 2013), (Aggerholm, et al., 2010)

2.2.5. Energy analysis and its influence on the design process

According to EPBD, the requirement for nZEB will by itself lead to a necessary change in the design process, based a lot more on the building's energy flows and expressed in use of dynamic energy performance simulation and assessment tools. That will lead to a lot more precise determination of the building's energy consumption, the main requirement for which is to be significantly reduced. In that relation, the following three main approaches have been specified: (European Comission, 2012)

- A more in-depth consideration of the relation between the indoor and the outdoor environment
- Use of renewable energy to a much larger extent
- Use of ICT in design optimisation, leading to a smarter energy use

The European Commission's suggestion for utilisation of ICT tools for design optimisation serves also as a support system to the theory of Eastman, et al. (2011), which states that the contemporary design process is defined by the possibility for adjustments at any given moment of the different project development stages. Since the focus is on the process and not on the final product, this allows investigation of how the changing of different parameters affects the design and how big the impact is. The results show that the degree of impact is strictly dependent on the stage of execution, i.e. the adjustments made in the early stages of the process have a bigger impact at a lower cost, while the impact of those made in the later stages is lower, but the cost is greater. (Eastman, et al., 2011)

In that relation, energy analysis tools have a significant contribution to the decision - making support at the various design stages, which in fact is their main objective. Urbina (2015) determines that the support of decision-making is achieved by the results that energy analyses provide. For instance, estimation of a building's energy consumption at various stages in the design process delivers important information, which allows resource optimisation. As stated in his research, considering that the different input parameters influence the results in a different way, multiple analyses can be performed, where the roles of constant and variable parameters may be changed, so that the variation in performance is explored. The effect of the following main groups of variables is examined: building information, local weather data, analysis method and hence the results, according to the chosen method.

With regards to the early design stages, Urbina (2015) suggests that even though the uncertainties are bigger, the impact of potential design adjustments, led by simulation results is actually much higher compared to the cost for their execution. Even at a very early stage, where only the main strategies are laid out, energy analyses and simulations can be performed with a very simplified building mass, so that a general evaluation of potential energy performance is made. The effects of the local weather data and alternative building mass orientations can be explored, which can actually be perceived as the very first design concepts. With the increasing of the LOD, further analyses can be performed that already include changes in defined constant and variable parameters and the results can help in decision- making for strategies, which will later be validated by results. (Urbina, 2015)

2.2.6. Energy performance analysis inputs/outputs in Conceptual Design

According to OGC & buildingSMART (2013), in the start of a project, energy analysis is conducted in a matter of attempt for foreseeing the energy consumption and the overall energy usage profile of the building. The impact a very first annual energy performance estimate can be determined by the design team during the Conceptual Design Phase. Sufficient needed information may not yet be available at this point, hence a variety of assumptions have to be made by the designer in a matter to perform series of simulations.

Input data which has to be included in the preliminary energy analysis for obtaining of optimal for decision-making support initial results, with regards to new office buildings is as follows: (OGC & buildingSMART, 2013)(see Attachments- 'Information Delivery Manual for Building Energy Analysis)

- Building geometry, including initial layout and space configuration
- Building orientation and shadings (critical parameters in the context of office buildings)
- HVAC systems (cooling, considerations for natural and mechanical ventilation and heating operation systems are as well in the critical parameter category)
- Building structure, including thermal properties of the construction elements (walls, floors, roof, windows; doors are important as well, but with consideration that many of their thermal performances will vary from the initial to the main energy frame.)
- Building usage, including function
- Internal loads and schedules of operation
- Space conditioning requirements
- Utility rates and Weather data

Output results of the initial energy analysis may include: (OGC & buildingSMART, 2013)

- Overall estimate of the energy consumption
- Assessment of energy performance for compliance with regulations and targets

- Estimate of the building's energy use
- Life-cycle estimate of the energy use and cost for the building

Now that the relevant for the process analysis elements related to sustainability assessment and energy performance analysis in the Conceptual Design phase have been outlined, the following sub chapter will continue with review of the third essential for the project part- BIM.

2.3. BIM

2.3.1. Need and understanding of BIM

Normally, in a construction project, there are many different professionals involved and they are all linked to each other. Those independent parties have to work in a close collaboration and coordination, in a matter to achieve a successful project development. Some of their paramount concerns are cost, efficiency and control of time. (Douglass, 2010)

According to Arayici, et al. (2012), the inadequate communication of information within design and contracting organizations, results in many problems, which may compromise the project development and delivery. The amount of information involved in any construction project should not be underestimated. A project has many different stages and at any stage, distinctive types of information are required by various actors, in various formats. That by itself carries multiple possibilities for misunderstandings and therefore creates an urgent need for early efforts by all the parties involved in the same project, to resolve potential problems and ensure that the construction documents and correct design are delivered. (Arayici, et al., 2012)

A solution for the mentioned organizational issues is Building Information Modeling (BIM), which is defined by Azhar et al. (2012) as '*the process of creating and managing information regarding a building, usually in a three-dimensional computer model which embeds data relating to its construction from the very beginning of the project*'.

Parsanezhad & Tarandi (2013) suggest that BIM is probably the best way for collaboration in the early design, due to the many possibilities of the digital technologies that unlock more efficient ways of designing, creating and maintaining assets. If adopted to its full extent, it can be used as a part of the whole building process – from conceptual design, throughout the actual construction to operation and maintenance of the executed project, so it can benefit every aspect of the AEC industry.

Patrick MacLeamy, CEO of HOK (the largest U.S.-based architecture & engineering firm), reflects that ´*BIM is the first truly global digital construction technology and will soon be deployed in every country in the world. It is a 'game changer' and we need to recognise that it is here to stay - but in common with all innovation this presents both risk and opportunity*´.

2.3.2. BIM through the years and in the future

- **Beginning of BIM**

BIM originates in the late 1970s and the first conception was established by Professor Charles Eastman at the Georgia Tech School of Architecture. Since then, there has been a massive progress in a matter of its perspectives, including the design and construction process, estimation, life-cycle, technology and building performance (Latiffi, et al., 2013). The AEC industry practically started using BIM for some of the projects in the mid-2000s.

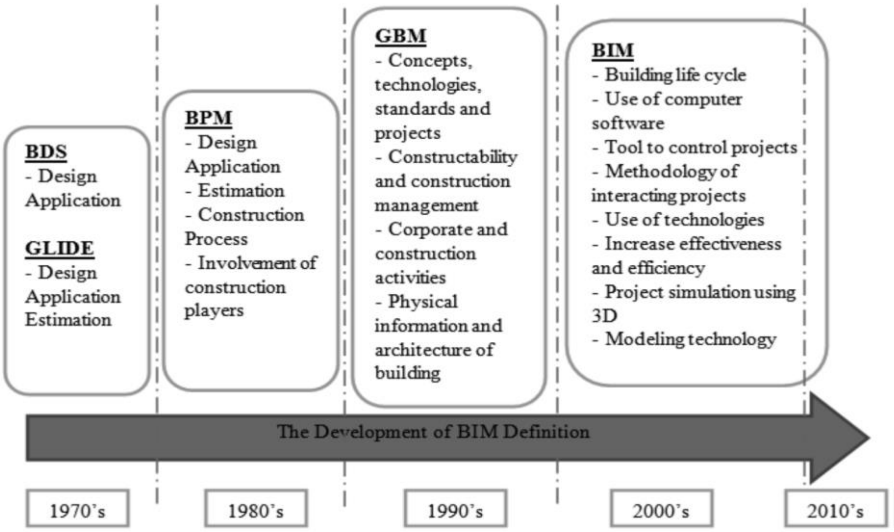

Figure 6: The Development of BIM Definition 1975- 2013, Source: Latiffi et al., 2013

- **Building Description System (BDS)**

As illustrated in Figure 6, in 1975 BIM started as BDS – Building Description System and was less comprehensive than what it is nowadays. It was introduced as a database, capable of describing buildings and allowing design and construction (Latiffi, et al., 2013). Later, the first significant upgrade was made in 1988 by the BPM (Building Product Model) program in Finland, which could cover design and construction process, estimations and probably the most significant – involvement of different professional parties. According to Shi (1995), the main difference between the BDS and BPM was a project library, where information from construction planning to the actual completion of a project was stored. The AEC industry requires information that is used for design and construction management, but BPM was only concentrated on product information. BPM had some issues, so in 1995 by the use of the same concept, Generic Building Model (GBM) was introduced. (Latiffi, et al., 2013)

- **Generic Building Model (GBM)**

Approaching more and more the present time, the construction industry was becoming more complex and even though GBM had the ability to improve project information that enhances incorporation of construction activities, it was not enough. Adoption of a software with better performance and higher expectations was required, in a matter to fulfil the newest industry demands, which led to BIM known nowadays. (Latiffi, et al., 2013)

- **BIM as we know it today**

BIM has been developing through the years, but the most significant improvement was made in 2005 and according to Eastman & Siabiris (1995), the use of it was expanded from pre-construction to post construction phase. The biggest achievement of BIM was noticed between 2008 and 2013, when it helped transform the way buildings were conceived, designed, constructed and operated after that. (Azhar, et al., 2012), (Latiffi, et al., 2013)

Improving the efficiency of facility operations, construction and planning and generally managing construction projects, are some of the highlights related to BIM's contribution to today's AEC construction operations. Probably the best one, especially with today's construction comprehensiveness, is the possibility of modifying and editing the information of a project at any point.

The near future looks promising for the use of BIM. In the UK for instance, the government's construction strategy requires all government projects to utilize BIM in the form of a fully collaborative 3D computer model (Level 2) by 2016, with all project and asset information, documentation and data being electronic. Similarly, other EU member states, such as the Netherlands, Denmark and Finland also require the use of BIM for publically funded building projects. The rest of the 28th EU member states will recommend, specify or mandate BIM for publicly funded construction building projects in EU again till 2016. (Giacomo, 2015), (Glover, 2013)

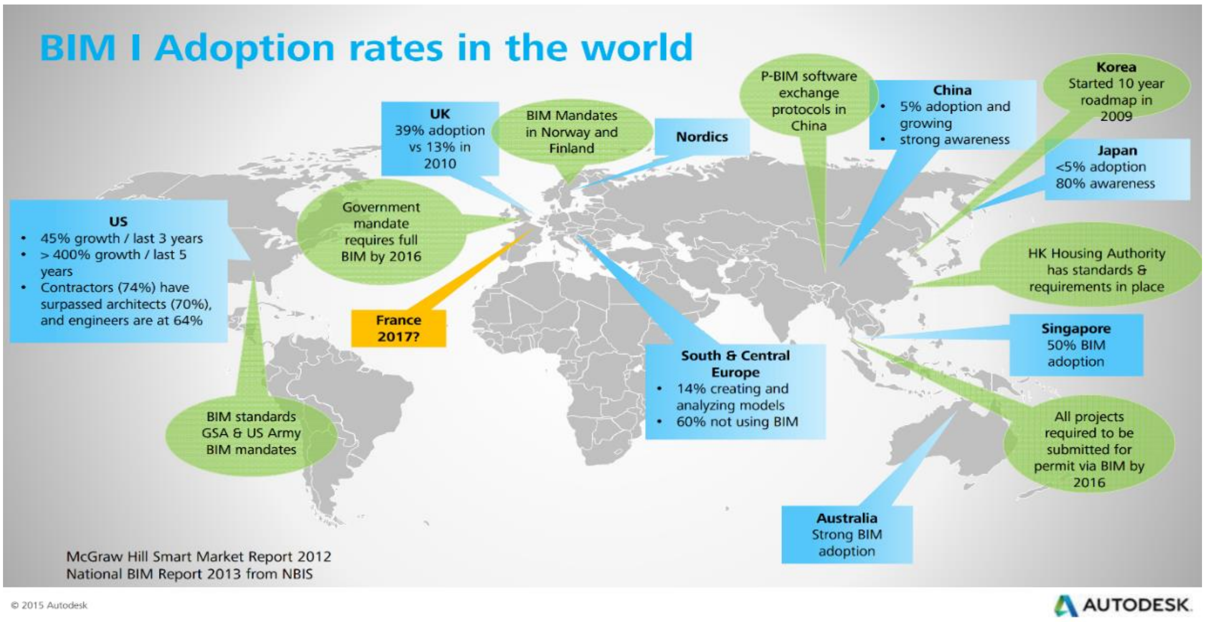

Figure 7: BIM adoption rates in the world, Source: Di Giacomo, Autodesk, 2015

2.3.3. Benefits of the utilization of BIM

As the history shows, the need of BIM in the building industry has been colossal. The newest trends, faster growing demands and the more and more cutting edge technologies have required a better process to guide, present, preserve and shape the market. Figure 8 showcases how the adoption of BIM has been going in the past few years from the perspective of the different AEC members.

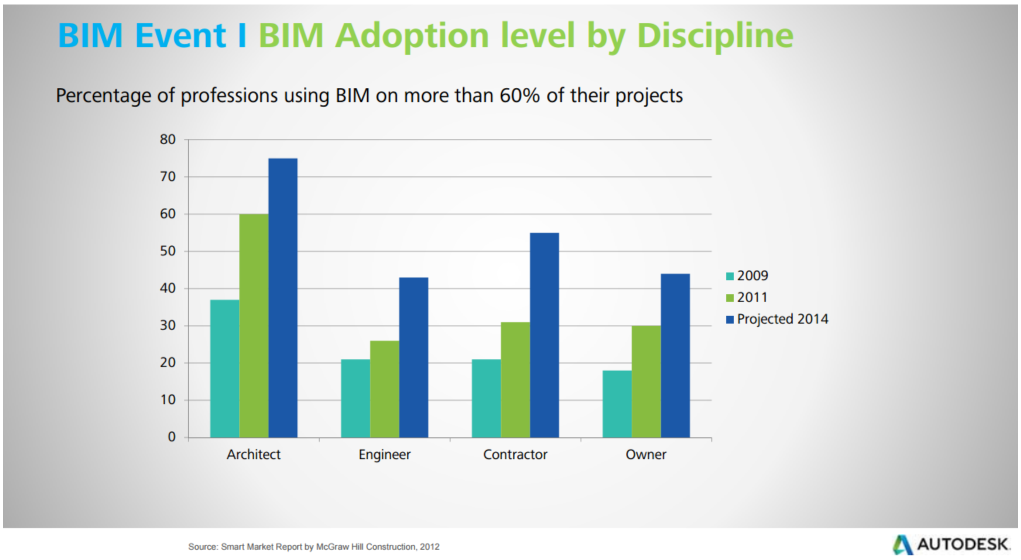

Figure 8: BIM adoption level by discipline, Source: Di Giacomo, Autodesk, 2015

Faster and more effective processes are a proven result of BIM utilization that can also lower the risk of errors and bring many benefits for the whole project team. For instance, architects, engineers and even contractors can achieve better coordination and efficiency. Besides the 3D modelling as a dimension, scheduling (4D) and cost management (5D) are additional strengths, which make BIM every developing company's weapon of choice. Besides the AEC professionals, the building owner is also a beneficiary when using BIM tools. Reducing time for the entire project duration, lowering the construction cost and reducing the amount of rework are among some of the most essential benefits that BIM offers. *(Giacomo, 2015)*

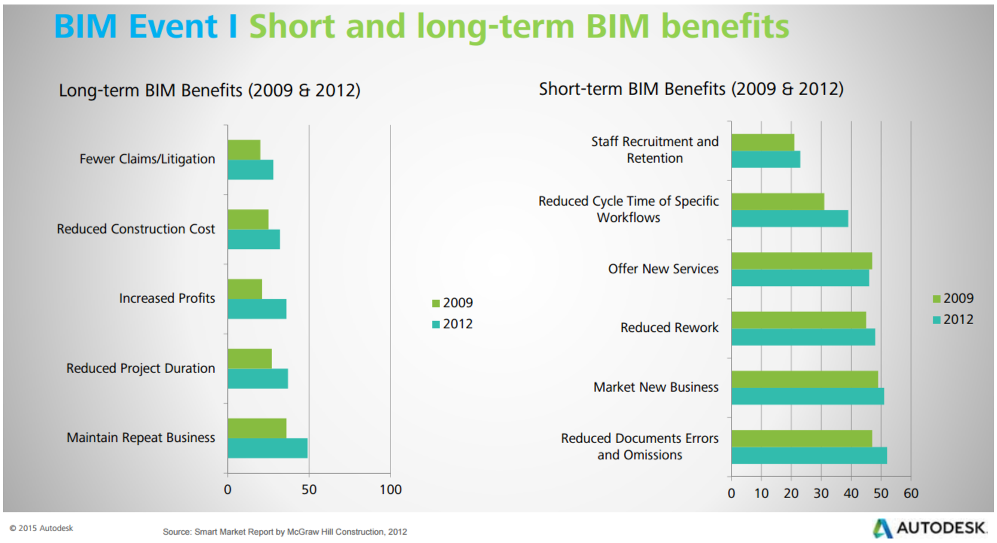

Figure 9: Short and long-term BIM benefits, Source: Di Giacomo, Autodesk, 2015

2.3.4. BIM data content

As stated by Azhar, et al. (2008), project life-cycle information, physical and functional characteristics and series of 'smart objects' are related information that the BIM model carries in one building project.

- **BIM data**

Azhar et al. (2008) also define that the typical data included in a building model is the geometry, spatial relationships, properties and quantities of building elements, information from geographic character, and as mentioned above- estimation of cost, project scheduling and materials inventories. Additionally, every element updated to the main BIM server may also contain information about supplier, operation and maintenance, flow rates and clearance requirements, etc. This information can be used to demonstrate the entire building life-cycle and can be accessed by anyone involved in the design, construction and maintenance after the project is done. As an outcome of all the data inputs in a single file, quantities and shared properties of materials can be extracted. Drawings, procurement details, submittal procedures and other construction documents can be easily interrelated. (Azhar, et al., 2008)

- **BIM maturity**

Figure 10 presents the diagram arranged by Mervyn Richards and Mark Bew in 2008, which is probably the most effective way to comprehend BIM and its levels (Sinclair, 2012).

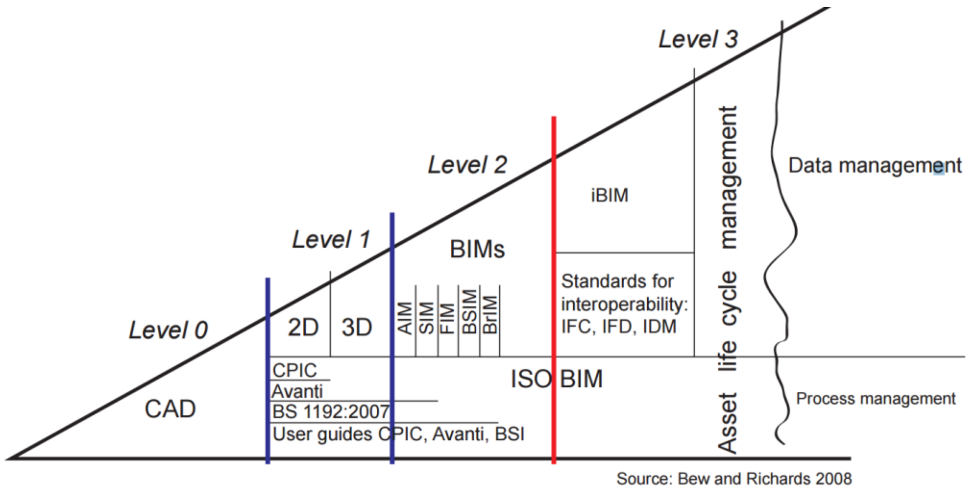

Figure 10: BIM levels, Source: Sinclair, RIBA, 2012

In order to categorize types of technical and collaborative working and understanding for construction processes, techniques and tools, levels from 0 to 3 are defined. The chain is therefore made respectively to the client's understanding and process made to- date in the construction IT application. It is widely referred to from most of the construction firms which are currently operating in Level 2. (Muthu, 2015)

According to RIBA (2012), Level 0 is certainly not used by the majority of the companies any more, but has been the drawing beginning of BIM. Nevertheless, some companies are still forced to implement both 2D drawings and 3D modelling in their work processes.

Hence, Level 1 is introduced by RIBA as containing mainly 3D software, which could be used by the architect in the early project stages for visualisation of the main ideas for the client. The drawings contain three-dimensional data of the building, with a fair level of information regarding materials, performance, energy and etc. and exactly in this context the project scope can be illustrated. Since the first BIM level is only used by the designers and maximum from some of the management team, in theory it will be easy to be linked with some of the other parties involved in the thermal and energy performance assessment. (RIBA, 2012)

On the other hand, BIM Level 2 requires 3D information from all the key members and designers, and can ensure that all the work so far is done properly, so it can be passed to the other integrated team members, such as subcontractors and co-design team. All parties involved in a project are using their own 3D CAD model, but work is not necessarily done on a shared central model. Still, it is a collaborative way of working and actually nowadays is the most common one. Combination of different information is exchanged between everyone involved through a shared common file format, so it can be used in order that the merged BIM model is fully readable. The data in those separate models is not losing its identity, even though it is merged in a central file, which gives the opportunity for even more information to be included. (RIBA, 2012)

The last stage or Level 3 is described by RIBA (2012) as the 'Holy Grail'. Achieving a fully collaborative online shared project in a single centralized model is in its essence and purpose, but it is not currently applied in the industry. Level 3 has some unsolved technological, legal and time consuming issues, but the main aim is to be a single collaborative online project model, including sustainability and project life-cycle information.

2.3.5. Green BIM

Using BIM in every phase of the project's life-cycle, starting from the early design along with some sustainable construction techniques is known as 'Green BIM'. The use of Green BIM in general benefits not only the AEC professionals, but also the building owner and/or user by providing more detailed information about the building's impact on the environment through its entire life-cycle. (Krygiel & Nies, 2008)

According to SKANSKA (2015), the use of "*Green BIM helps project stakeholders make informed decisions early in the design process and enables a greater impact on the efficiency and performance of a construction project*".

Engaging BIM in the very first stages of the design can benefit the entire process. The use of energy analysis can for example help evaluating the energy efficiency and recommending alternatives to boost the performance of the building (Krygiel & Nies, 2008). Also, a combination between BIM and software like Be10 can put together 3D modelling and simulations, and as a result optimize the energy use and improve indoor climate.

In the Conceptual Design, Green BIM can support experimenting with alternative solutions and evaluating the results from them. For example, such related to carbon footprint can be examined, and can therefore help make the choice, which would lead to the optimal low impact solution, both during the pre- and construction phases, and later in the building's operation. It can also support the decision-making with regards to selecting sustainable design solutions, which can reduce the energy use significantly. (SKANSKA, 2015)

2.3.6. Revit as a BIM tool

As mentioned above, BIM can be implemented and used in almost any construction process and by all the AEC participants. However, BIM should be perceived as an intelligent model-based process and not a tool (AUTODESK, 2015).

According to Eastman, et al. (2011), Revit is so far the best-known BIM architectural design tool since its first introduction by Autodesk in 2002. Joined together, BIM process and the three-dimensional Revit are changing the design drafting and modelling process for good. Since the report is based on the Conceptual Design, Revit can already be used by designers to sketch basic layouts of the building footprint. Important for the future clients is the initial visualisation, which can be changed and adapted in the beginning for maximum satisfaction and less mistakes to be fixed in future. The exceptional 3D view of the project is giving the designers opportunity to try different design ideas at early stage. (Eastman, et al., 2011)

Revit combines drafting, design, facility and construction management processes in one distinct central environment. Another reason for choosing Revit is the possibility for using a central shared project file, where all the information is stored and all the involved users can work together and make changes at the same time. That way, misunderstandings between architect, engineers and other concerned parties, such as technical contractors will be avoided. Besides that, Revit can export and import files in different formats such as: JPEG, DXF, DWG, PDF, DGN. (AUTODESK, 2015), (Eastman, et al., 2011)

Revit is a family of integrated products, which is a part of all the AEC sectors' current practices with the different tools- Revit Architecture, Structure and MEP for all the HVAC systems. Important here to be mentioned, is the capability of the different types of Revit software to link with other programs and to exchange data between them. With regards to energy analysis for instance, the data from Revit can be exported to different formats (gbXML, IFC) that can then be imported into other programs for more complex energy analysis without the inefficient manual data input that usually is necessary (Bokmiller, et al., 2014). Unfortunately, such flawless interoperability process between the various tools is still very imperfect and 'under construction'.

- **Strengths and weaknesses**

The biggest asset Revit has, is the excellent strength of the drawing production. Of course, not everything is included in its database, but all the designers demanding to go beyond can easily import the finished products into Revit for production modelling. Revit's interface is very user friendly and well-organised, which explains why it is so broadly used according to the latest research by Autodesk regarding the use of BIM (Robert Middlebrooks, 2012). Scheduling, cost, information for updates and management from drawing and model views and many other activities can be supported by the software. Also the project library with material database has vast amount of objects, which is constantly developing and expanding. (Eastman, et al., 2011)

Understandably, Revit as all software types has some issues. For instance, if larger than 300 megabytes, the command response significantly lowers down. It also has some limitation on parametric rules. This is an ongoing issue, a solution to which would be essential to the design process, as many of the BIM related Revit projects contain large amounts of data. Other technical issues are also present- the lack of object-level timestamps and the lack of full support for object management (Eastman, et al., 2011). However, these issues do not have a direct link with the aim of the report, so their impact will not be further reviewed.

2.3.7. Change in design method and approach

All the information above about history and why the user shall switch to 3D modelling software and more intelligent programs does not actually give a sufficient idea about transition from the traditional design development to a contemporary design process, which includes the use of BIM in it. The following section describes the different aspects affected by this change, and shows in brief the comprehensiveness of the entire workflow. As a part of the design process, BIM requires to be maintained by responsible participants in different project delivery agreements. In order for the full potential of BIM to be reached, the main procurement types and the BIM opportunities they give have to be reviewed. The reason for that is due to specific determinative factors related to its implementation, associated with each of them. This will serve as a base for the further analysis of the concerned areas and the respective processes they are included in.

According to Gustavsen (2012), the most common processes in the AEC industry can be divided into two groups – Traditional and Collaborative. He determines that the most common traditional ones for the industry are Design-Bid-Build (DBB) and Design-Build (DB), but there are newer approaches such as Integrated Project Delivery (IPD).

Figure 11 represents the difference between the two approaches. In a traditional process, flow starts from the owner and goes subsequently through the architect, engineers, etc. to the final product that should be delivered. On the other side the collaborative process is planned in a way, totally different from the linear approach. In the second approach, the flow has no pre-defined structure and all main actors are engaged to integrate from the very beginning at the same time. (Thomassen, 2011)

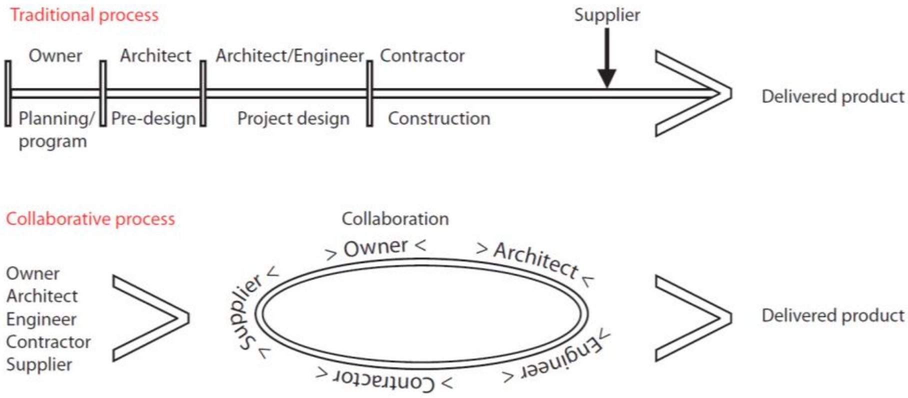

Figure 11: Traditional vs. collaborative process, Source: Dansk Byggeri, 2005

The collaborative approach with the help of BIM allows changes to be made at any point during the design, which adds value to the entire project process. Previously mentioned with regards to modifications led by energy performance results, this is also valid for the general case of integrated design. Figure 12 represents the MacLeamy curve, which showcases the relationship between design effort and time. It illustrates how impactful design decisions made in the early stages are to the overall functionality and cost of a construction project. (Eastman, et al., 2011)

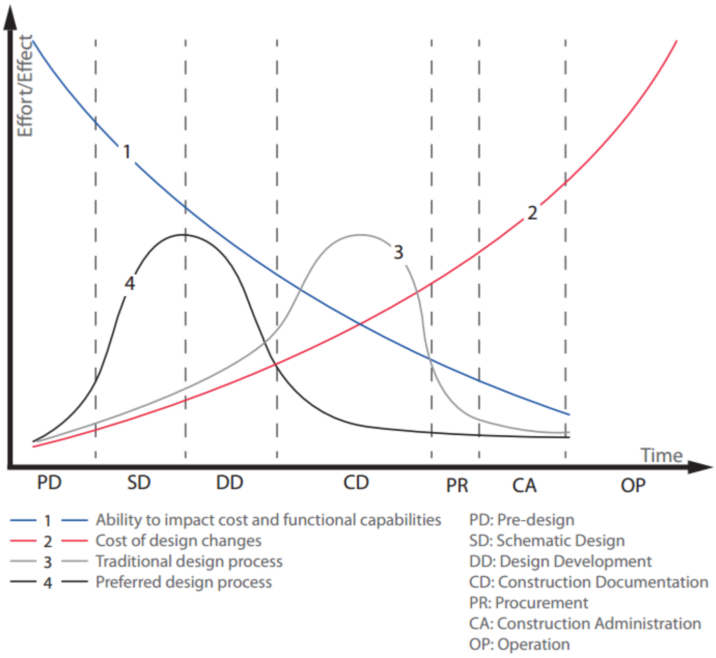

Figure 12:MacLleamy curve , Source: CURT, 2007

- **Design-Bid-Build**

As stated by Eastman, et al. (2011,) this traditional design approach is considered most common for public construction projects. The figure below pictures the main seven stages DBB consists of: Program, Schematic Design, Design Development, Tender, Detailed Design, Construction and Operation, with the main involved AEC professionals.

	PROGRAM	SCHEMATIC DESIGN	DESIGN DEVELOPMENT	TENDER	DETAILED DESIGN	CONSTRUCTION	OPERATION
BUILDING OWNER							
ARCHITECT							
ENGINEER							
CONTRACTOR							
FM							

Figure 13: DBB Approach, Phases and actors involved, Group 10 own contribution

In general, the diagram (Figure 13) describes the different parties in one construction project with their functions and responsibilities. After the architect choses its final design, the engineer, the contractor and the facility manager are taking part in the further processes. This leaves the architect responsible for the entire Schematic Design and for HVAC, structural, etc. related decisions, based only on own assumptions. The biggest flaw in DBB approach is related to the tender procedure happening before the beginning of the Detailed Design. In this case, the possibility for different specialist actors to influence the design process, when it is economically reasonable according to Figure 12, virtually does not exist. Hence, their specific knowledge in the field of expertise cannot be implemented in the original project. (Gustavsen, 2012)

Despite the clear disadvantages, this approach remains common, as a main reason for which according to Gustavsen (2012), seems to be that the building owner has the possibilities to choose the lowest bid. When it comes to implementation of BIM tools the lack of early collaboration in DBB is apparent, and early energy calculations and initial cost are just some of the parts missing.

- **Design-Build approach**

This approach is mainly established to improve on the DBB construction process flow in the Tender phase. Figure 14 shows how the tender process has been excluded. By eliminating it, the specialist expertise is available earlier in the project development, which benefits the entire process.

	PROGRAM	SCHEMATIC DESIGN	DESIGN DEVELOPMENT		DETAILED DESIGN	CONSTRUCTION	OPERATION
BUILDING OWNER							
ARCHITECT							
ENGINEER							
CONTRACTOR							
FM							

Figure 14: DB approach, Phases and actors involved, Group 10 own contribution

Gustavsen (2012) claims that this approach is economically not beneficial for the building owner, since all the decisions are handled by the main contractor, who is in control of all the sub-contractors. Regarding BIM implementation in DB, many of the obstacles and the legal boundaries are not relevant, since there is no tender procedure to limit involvement of specialist parties at an earlier stage. However, according to Gustavsen (2012), a limitation is still present when it comes to designs modifications and changes in the building owner's requirements. Since all of the planning work is handed to the main contractor, changes made in the later stages can be time- and cost-consuming, if at all possible.

- **Integrated Project Delivery (IPD)**

Contrary to the traditional approaches, the IPD method closely follows the BIM objectives, where collaboration between the building owner and the design teams happens from the very beginning. According to Heiselberg (2007), generally, the IPD method incorporates actors, organisation structures, information exchange and design practises into a collaborative system, where all involved parties can provide their insight and expertise for a mutual benefit. BIM engages all stakeholders in a project to communicate from the very beginning, the main objective of which is to reduce overall time and cost, while increasing efficiency.

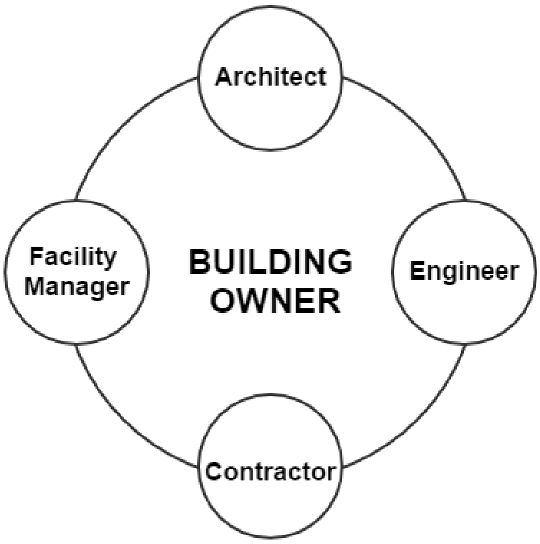

Figure 15: IPD approach, Actors involved, Group 10 own contribution

To conclude the literature review, the following chapter will further define in context and review the matter of interoperability, as it is the binding element between the already reviewed sustainability certification, energy analysis and BIM, in the search for clarification and categorisation of processes during design, involving exactly those.

2.4. INTEROPERABILITY

2.4.1. Background

Until here, the literature review has looked through three specific topics – sustainability assessment, energy design and simulations and BIM. The main purpose of the report though, is to find out how the processes involving them interact with each other in the Conceptual Design of a building project environment. The involvement of all key project team members from each of this areas is vital even before this phase begins. According to US GBC (2009), 70% of the decisions associated with the environmental impacts are made during the first 10% of the design process. Moreover, in order to achieve the best results in meeting the progressive goals for energy and carbon reduction, mentioned earlier in the report, today's construction professionals have to work together towards one seamless collaborative process (ASHRAE, 2011), (RIBA, 2013).

Problems related to the sustainable and energy efficient building design can be addressed by the use of BIM, which respectively may result in significant opportunities for the whole AEC industry. While the potential advantages of such an integration have been already recognized by for instance Mahdjoubi, et al. (2015), the required conditions for a successful information exchange remain in their early stage of development. That brings confusion rather than organization between the participants involved in the attempt of interoperability processes. They are not well defined and quite often fail to bring the benefits of a smooth information flow to various stages of the design process and especially in the early ones that is full with uncertainties. According to Hyun, et al. (2015), major long-term issues can be recognized also in term of interoperability standards and definition of level of detail/development, necessary to upkeep diverse design activities, typical for this early stage of a building project.

This sub chapter aims to review the main known processes of information exchange, their requirements, models and formats, in order to build up a base for further analysis, discussions in the next chapters of this report and to propose potential solutions at the end.

2.4.2. Defining interoperability

The use of BIM is significantly growing, but together with that the interoperability issues between different tools and software are increasing. It is in great importance for the future optimization of BIM that the rich database a BIM model consist of, is available and can be shared among the within project team. Hence, the technological interoperability is a factor with great influence on the decision to use BIM. Actually, duplicating work and re-entering existing data from one software to another, only due to lack of good interaction processes, is a significant waste of time and money. (Pniewski, 2011)

An investigation executed by McGraw-Hill Construction (2007), discovered that a lack of interoperability brings chaos to the workflow and reflects on the budget with approximately 3.1% of project costs. The biggest amount of the interoperability related cost drivers, is the manual data re-entry from one application to another, followed by time spent on duplicating, time lost to document version checking, money for data translators, and increased time processing requests for information, which are all illustrated on Figure 16.

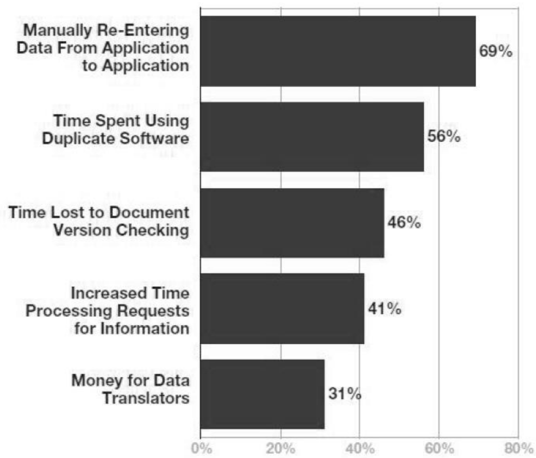

Figure 16: Effects of lack of interoperability, Source: McGraw-Hill Construction, 2007

The term interoperability can be defined as the ability to exchange data information between two systems, to simplify workflows and facilitate automation (Eastman, et al., 2011). As indicated before, BIM models should be generated and developed with the use of various tools and applications, especially in the early stages of a project, where design must take into account many different aspects. From a purely technology-based view, interoperability is managing and communicating project data among the collaborating professionals from cross-disciplinary project teams. Ultimately, if all participants can freely exchange information across different applications and platforms, then all of them can contribute to a better integrated project delivery. (McGraw Hill Construction, 2007)

2.4.3. Data model and LOD

- **IFC**

Depending on the included information, BIM might present many interoperability issues. The beginning of their first resolving in the AEC industry was in 1999 with the founding of the Industry Foundation Classes (IFCs) (Mahdjoubi, et al., 2015). IFC has been developed and maintained by buildingSMART (formerly the International Alliance for Interoperability, IAI) (bips, 2015). IFC utilizes a common data schema that actually creates not only possible, but effective information exchange between different software applications (Arayici, 2015).

Generally, IFC is an open data model for object orientated models such as BIM. It has been developed with the ability to describe, exchange and share information in neutral platform (See , et al., 2012). Since the IFC model specification is open and available, it is independent and not controlled by a single software vendor or group of vendors. It is registered by ISO and is an official International Standard ISO 16739. (Arayici, 2015)

The schema is organized to hold and exchange data from many disciplines and that brings advantages to the whole project from conception, through design, construction and operation, to refurbishment and demolition. Furthermore, the IFC model stores information data for tangible components, such as walls, windows, columns, furniture, and etc., as well as the more abstract non-physical concepts of shape, geometry, materials, schedule, activities, and etc. (Kumar, 2008). According to buildingSMART, IFC schema *'may be encoded as XML (markup language commonly used for document-related data) or SPF (STEP Physical File commonly used for engineering-related data)'*. The IFC file may also serve for different data extraction and transfer into excel spreadsheets by plugins such as IFC-File Analyzer (also developed by buildingSMART) in cases when a software program does not interact well with other file formats. Overall, the result data can characterize an entire project, a section or changes of information within a project. (Arayici, 2015)

Due to the above facts and also IFC's main focus on interoperability solutions, not only numerous private companies, contractors and designers, but also many countries have already chosen it as a main file format in their building projects (buildingSMART, 2011). Denmark is one of those, the government of which has made the use of IFC mandatory for publicly aided projects (bips, 2015).

It can be concluded that IFCs may be the resources behind every interoperability success in building projects. On the other hand, as identified by Aram et al. (2010), the industry-wide use of IFC still remains a challenge. In order to improve the reliability of IFC, it is required to specify concrete and well-documented guidelines for particular information exchange scenarios. This is the reason why buildingSMART has proposed the Information Delivery Manual (IDM) and Model View Definition (MVD), which are further reviewed in this sub-chapter. (Wix & Karlshøj, 2010)

- **gbXML**

The Green Building XML (gbXML) is another important data model worth mentioning. It is an open schema, developed to simplify the transfer of building properties stored in 3D BIM models to engineering analysis tools (Kumar, 2008). It has been developed as a format by Autodesk's Green Building Studio team and is the main export option from their modelling products. (gbxml.org, 2015)

According to Garcia (2014), gbXML schema is not supported that broadly as the IFC one. It is currently supported only by Autodesk, Graphisoft and Bentley. Still, gbXML has become an industry standard schema, due to the fact that those supporting it as a format, are some of the leading 3D BIM vendors. In general, gbXML permits interoperability between cross functional project teams to understand the results of energy analysis, not depending on the software. In order to integrate with other software applications than the mentioned though, it is necessary to use file converters such as DOE-2 input files (INP file). (Graitec, 2014), (Garcia, 2014).

However, as stated in the project scope, the analyses will follow methodology created by buildingSMART and for that reason application of gbXML will not be further reviewed and possibilities for IFC interoperability will be explored. Brief comparison between both data models is presented in Appendix 1.

When actors interact closely in a business process, they not necessarily receive the same amount of information from the initial model. As mentioned, IFCs can be structured differently and therefore they can carry different information that concerns different users (Berlo, et al., 2012). In order to be effective, the teamwork also requires to supply information with the right content for the exact team member rather than just sending everything all the time. For example, a ventilation engineer can receive an IFC file from the architect that is exported with different settings than the one sent to the heating and plumbing engineer.

- **LOD**

The described above has a close link with the 'Level of Detail/Development' (LOD) as well. Generally, BIM tools limit interoperability for use in sustainable design and energy analysis without the appropriate format and definitions of LODs (Mahdjoubi, et al., 2015). It can be said that what is in great interest for the users is what they can do with the information (Berlo, et al., 2012). There are cases where the model contains more information than it is required for a particular project phase and that can affect as a loss of time and efforts in reducing the level down. The information flow has to be designed in a way that fits the phase properly and satisfy the specific user needs.

According to specification from BIMForum (2013), the LOD is a reference that allows professionals from the AEC industry to clearly state the content and the level of completeness of Building Information Models in different project design phases. It was first introduced by the American Institute of Architects AIA, Document E202 in 2008, where the LOD describes the logical transition from the lowest BIM model level of the conceptual design, to the highest level of accuracy. (Thomassen, 2011)

Moreover, five are the levels of development defined by the AIA and they generally specify the extent to which the BIM model is established. The levels are defined as LOD 100, 200, 300, 400, 500 and the codes resemble the project stage: conceptual stage, approximate geometry, precise geometry, fabrication and as-built stage. It is a requirement for these levels that all participants in a building project must coordinate and be aware of who is responsible and to what extend for the development of each BIM component. The content of each level can be described as follows (Arayici, 2015, pp. 95-98):

- **LOD 100** Conceptual: the model includes basic overall building massing such as: area, height, location, volume and orientation.
- **LOD 200** Approximate geometry: generalized systems of assemblies with approximate size, shape and quantities as an addition to LOD 100.
- **LOD 300** Precise geometry: specific systems, object or assembly accurate in terms of size, quality, shape, orientation, and interfaces.
- **LOD 400** Fabrication: the model is graphically represented by a specific assemblies and systems accurate in terms of size, orientation, shape, and quantities with complete fabrication and detailing.
- **LOD 500** As-build: accurate and verified constructed assemblies in terms of shape, size, location, orientation and quantities.

Important to be reviewed is the difference between the level of detail and level of development. On one hand, the level of detail shows how precise the details included in the model element are. On the other hand, the level of development is all about the degree of information which the element's geometry has been thought through and the information on, which the project team members can rely on. Generally, level of detail can be seen as input to the elements, while the level of development can be reviewed as an output (BIMForum, 2013).

2.4.4. Information exchange process overview

Currently, the coordinated terminology source used from buildingSMART is the International Framework for Dictionaries (IFD), also called buildingSMART Data Dictionary (bSDD) and the information model schema used for information exchange is the Industry Foundation Classes (IFC) (See , et al., 2012)

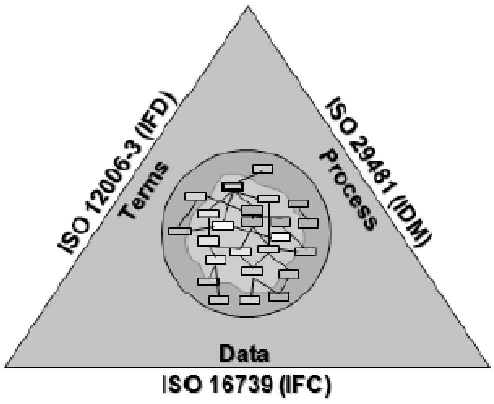

Figure 18: Interoperability solutions, Source: buildingSMART, 2013

With regards to information exchange in the construction industry, it is vital that all sub processes constituting the main process, as well as the specific needs, related to them are well defined. According to buildingSMART, the process of information exchange can be divided into four main phases (Figure 18), each of which has specific purpose, requirements, as well as associated deliverables, tools and actors involved. (See , et al., 2012)

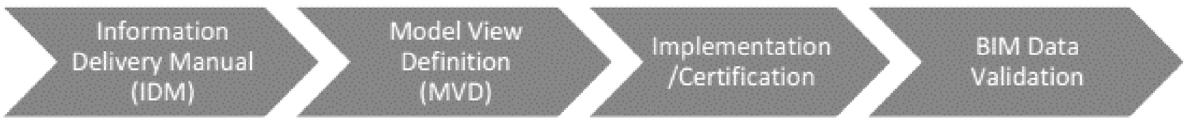

Figure 17: Transformation of needs into solutions, Source, See et al., 2012

- **Phase 1: Information Delivery Manual (IDM)- Requirements Definition**

It is well known that AEC industry brings many different companies and authorities together every time a project is about to begin. According to Karlshøj (2011), in order to work in an efficient way, it is required that all professionals in the organization know which, when and how, different kinds of information have to be communicated. He also states that this matter is even more significant when ICT tools are applied, since most of them have low tolerance of interpretation of different digital data.

In order to address these issues, buildingSMART, has developed and introduced the Information Delivery Manual (IDM) that suggests a common understanding of when and what information is required during collaboration (Arayici, 2015). IDM is '*a process standard that has been proposed to define information exchanges between any two project participants in an AEC/FM project, with a specific purpose, within a specified stage of the project's life cycle*' (See , et al., 2012).

Hence, the IDM is a methodology that can be used to document business processes (both new and existing ones) and gives a detailed description of the user information exchange, which therefore makes the benefits from BIM much more achievable (buildingSMART, 2011).

From another perspective, buildingSMART defines that the purpose of IDM is to supply a cohesive reference for the processes and data, which BIM requires. For that to be achieved, first of all an identification of all distinct construction industry processes has to be made. Furthermore, the information, which their execution requires has to be determined, and finally the results of the actions undertaken. That being done, will provide knowledge concerning: the relevance of the process and where it fits; the main actors involved and how they contribute and benefit from the process; what kind of information is used and exchanged; what kind of software solutions are necessary to support that. (Wix & Karlshøj, 2010)

In other words, it can be stated that IDM specifies that information and answers the following set of questions: (Karlshøj, 2011)

- WHO is requesting information?
- WHY in relation to a process or decision?
- WHEN as in what stage in a project?
- WHAT information is to be exchanged?
- WHO is delivering/receiving the information?

The main objective is to confirm that the relevant data is interconnected to such a degree that the recipient software in the end can interpret it. Important feature of the IDM is that in order to be functional, it has to be supported by software. Its output is actually what can serve as a basis for a software development process. (Arayici, 2015)

Phase 2: Model View Definition (MVD) - Solution Design is defined by buildingSMART (2015) as '*a subset of the IFC schema that is needed to satisfy one or many Exchange Requirements of the AEC industry.*'

MVD also specifies the software requirements, which are necessary for the implementation of IFC interface, so that the particular Exchange Requirements are fulfilled (Graphisoft, 2015). Otherwise stated by See, et al. (2012), MVD's title role is to provide '*IFC based technical solutions*', which are needed by the end users and are defined according to particular requirements.

Based on the representative diagram (Figure 19) and buildingSMART's statement that '*MVD is for software providers to support industry defined IDMs in software products.*' (See , et al., 2012), it is hereby noted that the following sections of this sub chapter, as well as the forthcoming analysis chapter will solely focus on Requirements Definition(IDM) that will serve as a basis for potential further development and execution of Phase 2: Model View Definition (MVD) - Solution Design, Phase 3: Software implementation/ Certification and Phase 4: BIM Validation. The group's overview of all phases is available in Appendix 2.

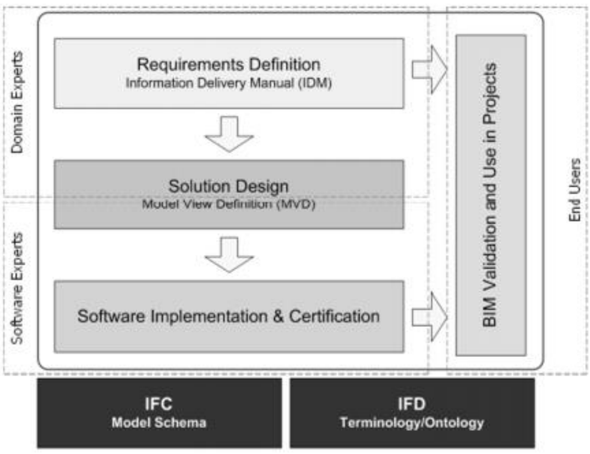

Figure 19: Four phase integrated process, Source: See et al., 2012

2.4.5. Developing an IDM

At the present time, there are major collaborative attempts in order to create usable IDMs. The main idea behind all activities is to find the best possible practices for the processes. IDMs are progressively being accepted in the construction industry and many have already been tested in real construction projects (Berard & Karlshoej, 2012). In (2011), BuildingSMART recorded 98 IDMs that were in a process of development and 4 of them were already approved (a general process of IDM development and a full list are available in Attachments, 'Overview of Information Delivery Manuals independent of their status').

However, it has been concluded that making IDMs in some particular areas of the industry is challenging due to lack of organization and structure in their processes (buildingSMART, 2011). Those cases require a certain level of agreement when it comes to documentation and exchange of the relevant information, and activities in the process. As mentioned before, most of the development work on an IDM is followed by a development of a software. Therefore, it is fundamental to ensure that the originator behind an IDM has a clear idea on what the future IDM implementation in software is desired to achieve.

As shown in the figure below, IDMs have fundamental deliverables, summarised as follows: (See , et al., 2012)

Figure 20: IDM Deliverables, Source: See et al., 2012 and own contribution

- **IDM scope**- after the definition of a particular area of need, a targeted working group has to define the project/life-cycle process, for which solutions have to be found. Potential available software tools, which could support the process should also be identified at this point. That includes considerations concerning possibility for IFC interoperability, if such is needed. Additionally, it has to be reviewed whether IDM can embrace an existing process, which could be enabled or modified, or an entirely new one, evoked by interoperability-, technology- or information management needs. That process can be also referred to as use case discovery.

- **Use case narrative-** the use case narrative aims to explain the particular industry process, which is the subject of the IDM. It can comprise the following:

  - Exchange of information between two parties only- e.g. architect sharing their model with an engineer;
  - A repeating activity between parties with Level of Detail increasing with time, e.g. space validation;
  - One actor, contributing to an information network, developed during a construction project or a building life-cycle, e.g. estimations.

During the outlining of the use case narrative, it is essential to specify the following elements:

- Problem statement- identifying a particular need within the industry;
- General description of the workflow;
- Participants;
- Information content;
- Necessary flow for achieving of the intended results- how and when the exchange between the different actors involved (who) succeeds in reaching the intended outcome, including the necessary software tools and the necessary requirements towards the information;

- **Process maps**- the main objective of the process map is to visually represent and give an in-depth understanding of the sequence and logic between the diverse activities, information exchanges, parties involved and outcomes in the industry process, previously described in the use case.

  A process map has: a specific targeted outcome; specific inputs and outputs (from and to other exchange requirements/data sources; requirements towards specific resources; a sequential order of activities; an effect on one or more organisational units; customer value; (See , et al., 2012)

  With regards to IDM, a process map: (See , et al., 2012)

  - specifies constraints for the information, which the process encompasses;
  - gives a detailed specification of the activities and the logical order they are arranged in;
  - defines the exchange requirements, supporting the activities;
  - makes possible the determination of reference processes;

When it comes to process map development, standard Business Process Modelling Notation (BPMN) templates are used. Their main characteristics are related to the visual appearance, where specific terms and shapes are used to graphically represent the featured elements.

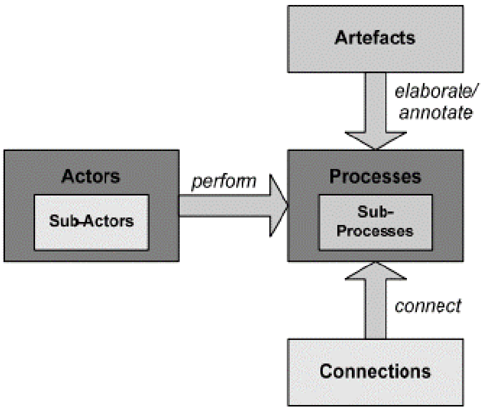

Figure 21: Main elements of BPMN, Source: IDM Technical Team, 2007

As stated by IDM Technical Team (2007), the four primary notation elements are actors, processes, connections and artefacts. They are interrelated in a logical manner, where actors perform processes, connections connect processes and artefacts elaborate or annotate processes.

With regards to that, the following principal notations and associate rules apply: (IDM Technical Team , 2007)

Actors- a single process map is referred to as a 'pool'. The separate projects are identified as organisations and the actors involved- as parts of them. Identification of the process map is done via its pool name, as each pool consists of individual partitions/'(swim) lanes', where the activities of each actor are shown. Actors may also include a sub category (e.g. a department in an organisation).

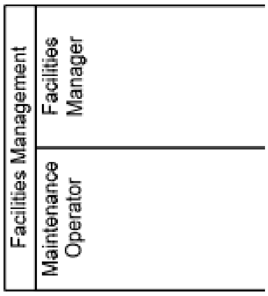

Figure 22: Pool containing multiple lanes, Source: IDM Technical Team, 2007

Processes- differ according to whether they can be further broken down to sub processes (compound) or not (atomic, also called Task). In this category Process Markers are included, which define the processes' attributes.

Figure 23: Task, Source: IDM Technical Team, 2007

Connections- define the links, e.g. information flows between the different processes. May define the processes' sequence or an eventual message passing between them, so the two principle types are sequence and message flow.

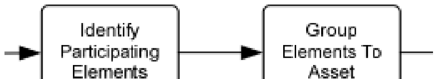

Figure 24: Sequence flow, Source: IDM Technical Team, 2007

Artefacts- may elaborate on data expression within or between processes, or in the sense of annotation- make available further information.

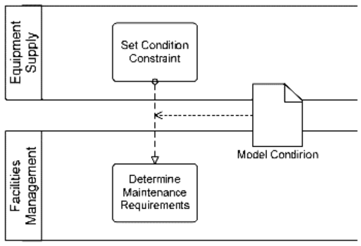

Figure 25: Data object in a message flow, Source: IDM Technical Team, 2007

Events- self-explanatory terms, they are associated with triggers and have an effect on the process flow, which leads to particular results. Based on the moment of affecting the process, they may be classified as start-, intermediate- or end events.

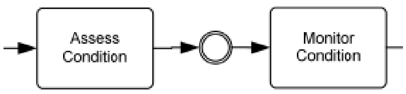

Figure 26: Intermediate event, Source: IDM Technical Team, 2007

Gateways- they control the sequence flow's divergence and convergence, or in other words- branching, forking, merging or joining of paths. Usually express the result of taking of a particular decision and hence is by understanding equivalent to a decision within the flow. Specific markers can be further applied to the symbol, defining specifics concerning decision/merging, e.g. exclusive data or event-based decision/merging, inclusive, complex or parallel decision/merging (for full guide, see Attachments- 'Quick Guide Business Process Modelling Notation (BPMN)).

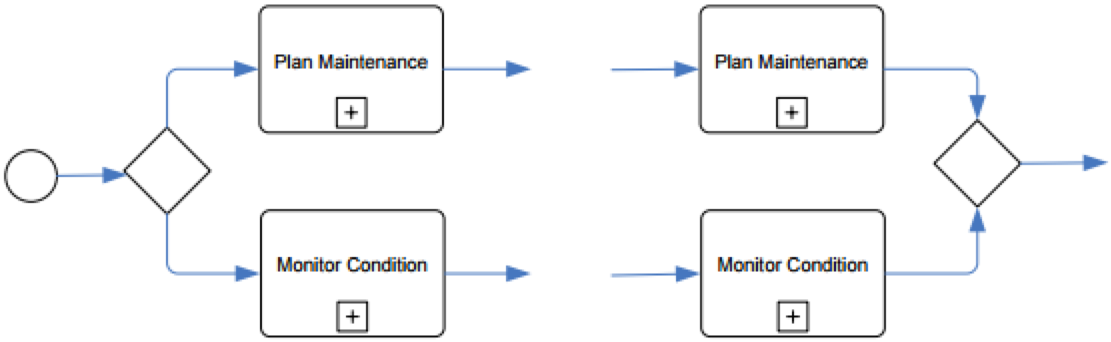

Figure 27: Diverging and converging gateways, Source: IDM Technical Team, 2007

- **Exchange requirements**- According to buildingSMART (2011), exchange requirements specify the information needs of the exchange between the parties involved in the process and symbolise the connection between data and process. See, et al. (2012) in particular suggest that an exchange requirement '*applies the relevant information defined within an information model to fulfil the requirements of an information exchange between two business processes at a particular stage of the project.*'

  Simple or complex, it is provided by the user (as seen in Figure 28) and resembles a non-technical-terminology description of the information, which is supporting the exchange. It is further used by the MVD tech team, as it enables the provision of the technical solution. Exchange requirements may also provide information for multiple operations, i.e. in cases where for instance an architectural model is used for various purposes, such as energy analysis. (See , et al., 2012)

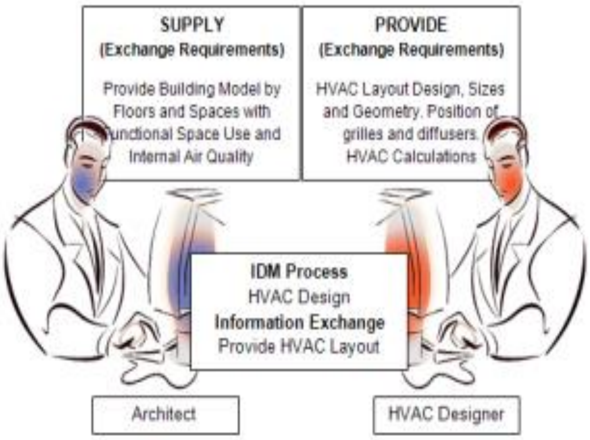

Figure 28: Example exchange requirements, Source: See et al., 2012

- **Exchange Requirements Models (ERM)** - the technical solution for the exchange requirement, they provide a comprehensive schema, which can be supported by a software application for information exchange in specific conditions. (See , et al., 2012)

  In other words, the documented in a table or a spreadsheet data from the exchange requirements is then organised in series of entity relationship diagrams, which are developed for each high level

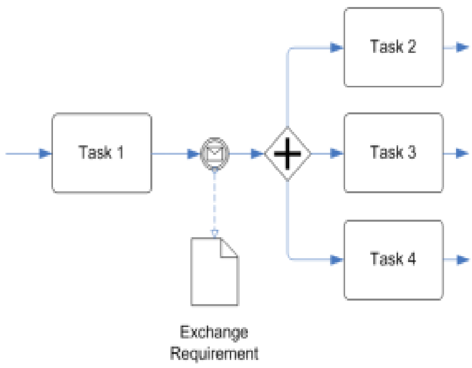

Figure 29: Exchange requirement notation, Source: See et al., 2012

exchange object- Building site, Wall, Door, etc. The diagram blocks are then organised in Exchange Concepts, defining the information to be exchanged. (See , et al., 2012)

- **Generic BIM guide**- provides information about best practices for the end users. Based on the use case narrative, information exchanges and process map, it defines the objects that have to be included in the exchange, as well as their properties and the applicable reference standards. (See , et al., 2012)

- **IDM target groups**

  One of the main goals of an IDM is to make sure that definitions, specifications and descriptions are delivered in a convenient and understandable form for the target groups. There are three target groups in an IDM: (Wix & Karlshøj, 2010)

  - **The executive user:** the person, who decides to use IFC in the first place and who is not only familiar with the concerned business process, but also recognizes the future effect of possible improvements in it. However, the executive user is not required to have technical knowledge, neither about the use of information in the process, nor any software development.
  - **The end user:** the person, who actually uses IFC and who is required to have an exact knowledge of what information to expect and how to apply it in the business process. Just as the executive user, the end user does not have to know about software development or IFC model.
  - **The solution provider:** the person, who practically writes a software application with an IFC interface, on the base of what both the executive and the end users are looking for. Needless to say, the solution provider is required to have a deep technical knowledge of the IFC model.

2.4.6. Transition to MVD

As soon as all of the above described deliverables have been developed and a full agreement within the developing team, MVD development can start. However, as stated by (See , et al., 2012), it is a much more complex process, which requires an extensive expertise not only in the construction industry, but at the same time in IFC schema, software applications and data modelling. For that reason, MVD development will not be a subject of further work in this semester report.

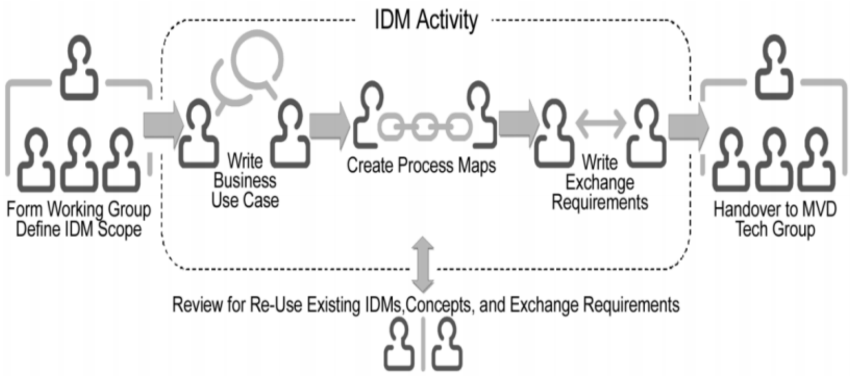

Figure 30: Identifying processes for IFC based exchange, See et al., 2012

Chapter 3: FINAL PROBLEM FORMULATION

The following chapter demonstrates a summary of the literature review, on the base of which the initial problem formulation is further developed into a final problem statement. The final research question sets the focus of the group's specific analysis and the answer of which is considered as the main objective of this report.

3.1. Summary of the literature review and transition to final problem

As previously identified in the literature review, Be10 should be referred to as a compliance check tool and not as a tool intended for energy design and advanced calculations. The latter is considered a misapplication, as the initial creative intent behind Be10 has always been related to verification of compliance with the energy frame stated in the Building Regulations. Due to being mandatory and in relation to the contemporary design process, it is clear that Be10 needs and provides information, which is important for the performance of additional assessments. In that sense, the required input and output data needs to be available and successfully interpreted by all tools reviewed and involved in the process.

In other words, being limited as a tool also contributes to the lack of interoperability solutions for Be10 and Revit, which is otherwise the main source of information, required for the performance of the necessary calculations. The extraction of the necessary data from the BIM model and its import in Be10 is a cumbersome and lengthy process, which is pursued by professionals in the industry, but at this point in time is still quite imperfect and depends on third party applications such as Excel.

Automated information exchange between Revit and Be10 is non-existent and the existing solution i.e. extraction of data from the architectural BIM model to Excel spreadsheets and then importing them to Be10 is far from efficient. That by itself creates collaboration problems between the actors involved in the building design, which is crucial, because in Conceptual Design, collaboration is the key to a successful integrated sustainable design.

From another perspective, it is also the stage, which gives the biggest possibilities for design influence and eventual changes, in order to ensure that the building meets the necessary legal and sustainability requirements without putting the budget and schedule in danger. DGNB as a sustainability assessment system can be used as guiding instrument in the planning process and can serve to demonstrate an outstanding commitment to meeting sustainability objectives.

With regards to information exchange between either Revit or Be10 with the third element of interest- DGNB rating system, the present study has not identified any existing interoperability solutions. Revit's potential to give information for a building's performance to be analysed, offers an opportunity for the architect to outline the project in a way, so that it can achieve certain DGNB credits. It is certain that DGNB assessment needs to identify the growing use of BIM and the benefits from an integrated design process that provides information about sustainability from the beginning of a project. Efficient information exchange can significantly improve the decision making when it comes to high-performance building design, due to the fact that a guidance from the DGNB auditor may also be a part of the integrated process.

If DGNB can be recognized as a roadmap to sustainability, then it is important to look for a comprehensive way for managing changes and for smooth communication between actors involved. The input of data through Revit gives potential possibilities for integration with DGNB performance criteria. Therefore, it can provide a clearer picture of whether there is a success or failure in meeting the DGNB objectives.

3.2. Final problem statement and research question

The needed technical solutions for information exchange require an entirely different skillset. The main reason why such are still not fully developed though, is related to the young transition from traditional to integrated design methodology. The new collaborative design process, with all of its sub-processes and issues has not yet been well-defined in this context. In order for such to be developed, the processes have to be very well understood.

Moreover, mapping of this processes and a structured workflow, visualising the integration of sustainability assessment and energy analysis within a BIM environment at the same time, in an efficient way, does not exist and up to this moment has not even been officially attempted.

Overall, there is an industry demand for successful interaction between the participants involved. That is why the main objective of this master thesis is to clearly define the actors and processes that they are involved in, and put them in context not separately, but simultaneously, so that the entire process, with its three dimensions is understood and further able to serve as a base for development of technical solutions.

Based on all that, the final research question in this project can be stated as follows:

What processes, actors and requirements define the information exchange between Revit, Be10 and DGNB LCA in the Conceptual Design phase and how can they be optimised, so that a more efficient overall process is achieved?

Chapter 4: IDM DEVELOPMENT

The following chapter represents the group's own analyses and the results that originated from them. It includes a wide investigation of the main areas and processes of interest that the group has already reviewed in the literature review, with a concentrated focus on answering the final problem statement and research question. The overall output of this chapter and the whole project report is the suggested solution illustrated in a comprehensive detailed flow diagram.

4.1. Action plan and proposal for development of an IDM

Based on the reviewed literature and industry practices, it can be concluded that efficiency in the construction industry is a target of a highest value. Since all processes in this area are associated with collaboration between many different parties and authorities, their outcome is directly dependent on the quality of that collaboration.

Realising that, the industry is slowly shifting from traditional to integrated design practices, but even in that setting mutual understanding between the parties, common language, information exchange and interpretation principles still seem to be missing, not fully identified or adopted. Additionally, despite the fact that digital tools have become a significant part of the sustainable building design process, a general lack of interoperability between them contributes to the inability to reach full efficiency and flawless information exchange.

By introducing IDM, which outlines a collaborative methodology, aiming to identify, specify and illustrate the industry process flows and their associated information content, buildingSMART's attempt to resolve those problems comes relatively close. However, the available existing IDMs focus only on some general parts of the process (such as energy analysis) and can be very wide-ranging, with too complex structures for information exchange. IDMs defining process flows involving BIM, energy analysis and sustainability assessment at the same time have not been developed or up to this moment even proposed.

Those findings are also applicable in the context of the current project. Considering the great extent, to which the building design process in Denmark is influenced by the use of Revit and Be10, and in the cases of green building certification- DGNB, it is essential that further research in the area is performed. That way, all processes, actors and information exchanges between them until the end of the Conceptual Design phase can be well defined and clarified in a new IDM. Once done, that will help optimise not only that phase itself, where most of the fundamental decisions, concerning the building's life-cycle are taken, but also the following project development stages.

Acting as the group's proposal to undertake an IDM, the above stated sets the scene for an extensive amount of work to be done. It is important to note, that an IDM can be fully functional only if it is supported by software. Considering that, an efficient information exchange in this case also means possibility for automated extraction and interpretation of data between the tools in question, the future IDM has to assure that the communicated data from the Revit model is interpretable by the receiving sides, Be10 and LCAByg.

However, as previously noted, due to the background of the study group and the limited time for project work, a full IDM cannot be developed in this master thesis project alone. That is why, with regards to the development of the proposed IDM, the main target of this study is to perform a comprehensive process discovery and mapping, the result of which will be a well-defined and coordinated workflow, clearly specified interactions between the parties, and simplified, but detailed information exchange structure with the essential to the exchanges requirements. The output of this can then become the basis of exchange requirements models and concepts, as well as a more detailed technical study and a software development process.

For that to be achieved, the analysis and IDM development until and including process mapping and stating of exchange requirements will follow the order suggested by buildingSMART and described in the literature review.

4.2. Summary of business need and target

The earlier the design process is influenced by the simultaneous input of the various professionals, for example exploring the interdependence between energy performance and design parameters, the more efficient the entire project development through the different stages of the design, and the better the outcome.

For instance, bringing daylight into the building's spaces influences the design in a positive way from both architectural and energy perspectives. The right approach would integrate the architect's and the energy expert's know-how related to that matter, which would lead to a way more optimised building performance. From another perspective, the outcome would comprise a project, which neither compromises with the energy performance and indoor environmental quality, nor with the aesthetics of the architectural design of the building. A necessary condition for that though, is that it has to be implemented in the building performance goals from the very beginning. In that relation, it can be stated that many of the common design and performance issues would not exist, if the building was properly designed in collaboration from the very beginning.

It is also indisputable that BIM presents the best environment for such collaboration, due to its ability to support a multidisciplinary design process. However, it is the quality and the efficiency of the collaborative process itself that seem to suffer from ambiguity and certain lack of definition and standardisation. Even though the same BIM model can be used from each AEC professional for their concrete purposes and that simplifies the entire workflow, it seems that the different actors wanting different things from the same model still leads to collaborative issues.

With the data world getting richer, the use of analytical digital tools as decision-making support during the building design process is progressively increasing. Yet, the actors involved still need to find a well-functioning way to dynamically work in the same flow and exchange information in the same language. Despite presenting numerous possibilities, the integration of decision support information exchange early into the design process is still far from explored. It is still work in progress and an ongoing learning process for all involved, where right and wrong cannot really be distinguished, because everything is dependent on the needs of the end users.

4.3. IDM scope/ Use case

4.3.1. Prerequisite for integration of BIM, Be10 and DGNB LCA

The general necessity of integration between BIM, energy analysis and sustainability rating during the early design has already been explicitly outlined in the previous chapters of this report. As previously specified in the introduction chapter, that time frame refers to the Conceptual Design stage of the integrated design process phases. This is where after the Design Brief Development and Pre-Design stages, the initial design proposals are being worked out, many fundamental decisions are being taken, but the Preliminary design phase, where the LOD increases has not been entered yet. Together with that, it has already been clarified that the current project is only concerned with new, non-residential buildings, particularly offices and administratively occupied establishments.

However, those two conditions, separately or together, do not necessarily require the simultaneous use of BIM, Be10 calculations and DGNB LCA analysis for every project. Since the purpose of this master thesis is to identify the necessary conditions, which would make exactly such an integration efficient, it is necessary to outline the cases, where it will be required.

Since BR10 energy frame compliance check calculations are mandatory, it is only Be10's use that is legally required for every project. DGNB LCA criteria are taken in consideration and as previously outlined have a significant weight. However, green building certification is not mandatory and depends only on the building owner's sustainability-related ambitions and requirements, justified by all benefits that acquiring of an award carries. With regards to utilization of BIM in the context of the current report, it is necessary that Level 2 is adopted from the design professionals, as collaborative working and information exchange are best supported by it. The efficiency of the overall process also depends on how the different design and engineering parties are involved in it from a BIM perspective. How this applies exactly in the process, will be further explained in the following sections.

Based on the above mentioned, it can be summarised that in order for such an information exchange process to be pursued in the Conceptual Design, it is first and foremost the building owner's determination to achieve pre-certification and optimised energy performance, and approach BR compliance as early as possible that is required. Therefore, as a prerequisite for such an integration can be stated that the project development process has to aim for complying with the regulations for targeted energy frame and achieve pre-certification from the very beginning.

4.3.2. Possibilities for IFC interoperability

In the process of identification of the IDM scope, it is essential to identify possibilities for IFC interoperability in the sense of data transfer between the different applications. In general and also in this particular case though, the final outcome is very much influenced by and dependent on the various technical issues that are present or may arise. For that to be avoided, first and foremost a clear methodology, specification and user data definition have to be present. It is the professionals from the AEC industry that define the processes and since IFC's purpose is to support those, then the gap between needs and performance abilities needs to be smaller, so that the process is smoother.

In Denmark, as stated by Bygningsstyrelsen, an IFC-based exchange is mandatory for publicly aided projects, with an estimated contract value of minimum 5 million DKK excl. VAT. All basic text and 2D project deliverables (drawings, meeting minutes, schedules, etc.), as well as 3D deliverables (such as discipline models), should be uploaded to the project web throughout the entire ongoing design process. With regards to the master thesis relevant project phase- Conceptual Design, which in the ICT Services Specification corresponds to Outline Proposal, information level should be in the range 0-2 and IFC custom property set should be created. The various discipline models should be able to be compiled in a confederate model, used for visualisations according to the project's current stage. With regards to exchange formats, all text and 2D documentation should be presented in .pdf and may be supplemented with 2D DWF, whereas all 3D deliverables have to be in both native format and IFC 2x3. (See Attachments- 'ICT Services Specification). (Bygningsstyrelsen, 2014)

From a technological perspective, the possibilities for IFC interoperability have to be considered from the perspective of Revit, Be10 and DGNB. It has to be noted that the information exchange between Revit and Be10 is and will continue to be a subject of further integration, due to the general necessity of integration between BIM and energy performance analysis tools. LCAByg on the other hand, as the main technical aid for performance of LCA, is created as a tool to support a process on a much bigger scale, where LCA is significant, but still a fragment of all DGNB criteria. For that reason, there is a limit to the intent and motivation for integration of that tool with other tools.

However, with regards to information exchange, there is still quite a big motivation for achievement of flawless process. A development project, which is the result of a collaboration between bips, DTU, Aarhus University and other esteemed organisations called cuneco, aims for development, testing and implementation of common standards for better information exchange in all phases. Based on DGNB and its criteria, its purpose is to make the process more efficient and prevent duplication of work, by establishing a link between the BIM model and the DGNB material databases (e.g. ESUCO).

The idea is that the relevant for the certification object parameters from the BIM model are transferred to the databases, which means that building materials, which fulfil the DGNB requirements can be directly imported and used in the BIM model. The result of that would be mean thta the necessary LCA calculations can be performed directly in the BIM environment, by the use of the BIM model. However, this link is not fully functioning yet, so at this point it just remains a work in progress. (Høibye & Petersen, 2015)

With regards to information exchange between Revit and Be10, even though a flawless, automated and fully efficient process does not exist, there are particular functioning methodologies applied.

In the general case, Revit provides possibilities for both IFC import and export, based on buildingSMART data exchange standards (IFC4, IFC2x3, IFC2x2). When the Revit model is exported to IFC format, other actors involved in the design process may use the information from it directly. After a Revit model is saved as an .rvt file format, the same can be exported to IFC via an IFC certified application, which does not use the native .rvt format. Afterwards, a non-native application may be used for further work. The other way around, and IFC file may be imported to Revit, after which, the created from it .rvt file may be used for further work in the Revit project environment.

As of now, exchange of information between Revit and Be10 is achievable via IFC File Analyser, as it generates Excel spreadsheets from IFC files and sorts data, according to the different entities in the model. In the spreadsheet, a worksheet is created for each IFC entity type and every row contains the related IFC attributes.

Other custom ways for integration between Be10 and Revit are also explored from various organisations (MOE A/S, Dalux), however, work to solve that particular interoperability problem is still ongoing. Since the purpose of this project is to identify the main processes, the exchange of information via IFC will refer to the method described above and adopted by Autodesk.

4.3.3. Discovery, analysis an adaptation of existing IDMs

With regards to the development of an IDM, it is important to identify whether there are any existing IDMs, which could be re-used or by modification and adaptation, to contribute to the development of a new one. The research done in relation to the development of this master thesis has identified a full list (see Attachments- 'Overview of Information Delivery Manuals independent of their status)), which presents an overview of all approved, proposed, drafted, stopped, as well as currently developed and reviewed IDMs.

The necessary due diligence performed has identified that an IDM, which can directly contribute or is in any way similar to the proposed and developed in this master thesis one, does not exist. In fact, there is no evidence of even an idea proposal about an IDM, involving BIM, sustainability assessment and energy analysis in an integrated process.

Separately, there are IDMs with various development statuses, which in one way or another relate to the three different elements, but for various reasons are not really applicable to the current case. The group found one IDM, which is relevant to the current case- GSA-003 Architectural Design to Building Energy Analysis (see Attachments - 'Information Delivery Manual for Building Energy Analysis), with project manager Richard See, some main concepts of which have been modified to fit the current case.

4.4. Use case narrative

4.4.1. General description of the workflow and problem- 'as is' process

Currently, the process that represents the integration of BIM, energy analysis and sustainability assessment brings many challenges to the surface, especially when it comes to describing it and that is the very base of the problem reviewed in here. The fact that there is no set common project process, brings confusion to all involved participants. Therefore, a general 'as-is' process diagram has to be developed, so it can serve as a foundation for further analysis on how problems can be resolved and processes can become more efficient in the future.

It is true that the use of BIM is rapidly growing and Revit as a tool is the usual choice, especially for the specialists from the Danish AEC industry. However, the process that includes collaboration with other participants in the first phases of the building project is rather chaotic than organized, especially in the more traditional contract agreements. The involving of structural and HVAC engineers normally happens too late. Still, according to industry professionals (See interview with Rasmus L. Jensen, Appendix 3) the process has been through some changes.

Today, some architects will cooperate with the HVAC engineer even before involving the structural engineer. Including an energy specialist in the conceptual stages happens much more often than it used to a decade ago. However, this is far away from usual and depends on the company's scale and scope of work, as well as whether the mentioned specialists work closely in one organization or they have to communicate from a distance. Overall, the concept of sustainability design has become almost mandatory in building projects in Denmark, but the assessment and rating with systems like DGNB is certainly far from a common practice.

Since the development of a concept with the use of BIM that includes both sustainability and energy practices, is considerably different from the traditional design processes, there is a certain need for tailored solutions. The phases before the Detailed Design Development are a lot more uncertain, hectic and depend on the type of the project, the type of the contract agreement, the building owner's knowledge, the role allocation, the division of responsibilities among the professionals, etc.

Therefore, it is found necessary to demonstrate in a simple flow diagram what the group found to be the traditional design process and some of the most common tasks that are included in it. A decision to not focus further into each type of contract agreement is taken, due to the fact that main reviewed phases are similar till the end of the concept. The so called 'as-is' diagram represents a summary of the flow in those phases and it is visible in Figure 31. It shows the biggest characteristic of the traditional procurements or namely that the work is delivered in phases in a linear sequence flow of activities. In order to represent the current traditional practice objectively, the group has included some interactions that are still not common, however present in separate cases.

The Building Owner (BO) gives the start of the process by defining a business case. The first planning/program phase traditionally includes the identification of the first project requirements, the building function, use and type, the building location and available site information, and the initial budget and schedules. This stage normally is developed by the Building Owner alone or sometimes with the help of competent advisors.

This identification of owner's project requirements (OPRs) is in great significance, due to the fact that it serves as a base for the further development of the project, so it is crucial that the Building Owner is capable of taking important decisions and formulating them properly. The fact that the Architect (A) is not appointed yet might result in not well recognised needs and requirements. Moreover, the building's sustainability and energy performance are not considered as targets, which may have a big impact on the project economics in case of future changes.

The Schematic Design is the phase where normally architects are involved in traditional processes. Still, the group has added an already common task of the Architect as a lead designer of the project, with the responsibility to review whether it is feasible or not. Once the OPRs are finalized with the appraisal of the architect, the first building concepts and location layouts can be visualized.

The phase might include numerous proposals in order to detect the most promising design, but generally those proposals are executed solely by the Architect. Nevertheless, the group has recognized the involvement of structural and energy consultants in this phase as a current event, but still not common enough to add value to the design at the process moment. Therefore, the architects are mainly responsible for executing the schematic design alone, by taking decisions for spatial relationships that concern MEP and HVAC on simple assumptions.

The general process at the moment is hard to be described and that is actually a part of the problem. The fact that there is no set common project process brings confusion to all involved participants. Therefore, a general 'as-is' process diagram (Figure 31) has been developed, so it can serve as a base for further analysis on how problems can be resolved and the process can be transformed to a more efficient one.

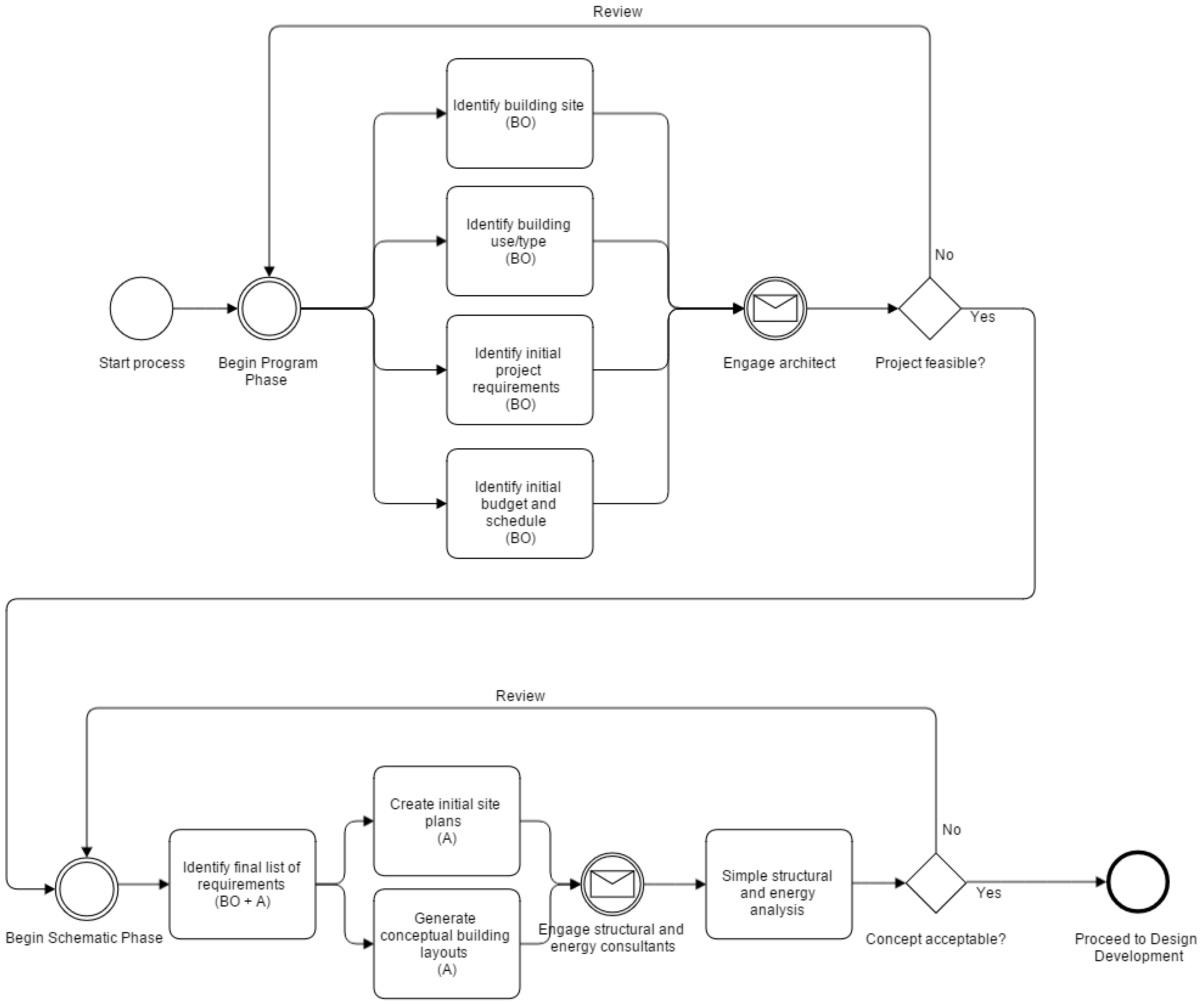

Figure 31: Traditional design process- 'as is' diagram, Group 10 own contribution

4.4.2. Definition of actors and their roles

- **Architect**- There is no doubt that the Architect has a central role to play in the early stages of the project and it is him/her that has to bring all of the parts of the process together. Traditionally, as the project moves beyond the Schematic Design Phase, there is a need for co-ordination and technical input, and this is where the Architect starts to struggle, especially in the bigger projects. In an improved design process, the Architect's collaboration with engineers and consultants should start from the beginning of the project. That increases the amount of design alternatives and the ability to influence the decisions of the Architect on reasonable cost and effort.

  Once engaged, the Architect is responsible for synchronising the goal-defining process together with the Building Owner. Core objectives for the whole project team and of significant importance for the Architect are to develop the project goals including quality objectives, project outcomes, sustainability targets and budget.

As soon as there is a clear project definition and the OPRs are set, the Architect can start with the first task of information gathering on the future project location. All data and analysis that concern the site potentials such as wind, water, sunlight, green areas and soil type, landscape, orientation and neighbouring structures, have to be acquired by the designer of the building before they can start sketching. Part of the Architect's role is to consider all regional, municipality and local restrictions and together with the owner's demands for space and function, to set benchmarks for the design process and create building design concepts. Synthesizing those initial parameters, give the right direction to the Architect, so assuming the most complete architectural expression is possible.

The Architect normally develops concept drawings, documents or other media that show different initial design ideas. In those they include spatial relationships, scale and form, so the Building Owner can review and discuss them. It is important that the Architect has a clear sense of the project budget and any restrictions and issues that might come with it. Moreover, the Architect has to keep their creativity in the process and of course be concerned mainly with the aesthetics of the future building, but they have to be able to stay on track with the energy and structure as well. Architect's role nowadays has to include impressive ability to work in a strategic and interdisciplinary manner, in order to create strong and realistic design concepts that take into consideration the principles of construction, energy and environment.

When such collaboration is present, it is obvious that using BIM is a necessity. Architects are the fastest adopters of BIM with their design modelling and drawing production, but quite often the use is limited due to software incompatibility. In an integrated process, where a BIM coordinator role is not present, the architects have to be aware of the methods for sharing relevant model information with the rest of the project team and are the ones responsible for providing sufficient detail of the information, so engineers and consultants can adequately use it. The model that they create has to be sufficient even in the Conceptual Stage of a project, so a final design concept can be agreed with the Owner, initial sustainability and energy design decisions can be taken, and the project process can go smoothly towards more detailed design development.

- **HVAC Engineer**- the HVAC Engineer is responsible for the effectiveness of following major processes: heating, ventilation and air-conditioning. Ideally, the HVAC Engineer should be involved in the design team from the beginning of the project, coordinating with other team members and the Building Owner. This way, the HVAC Engineer can have the possibility to look at the appropriate building service systems, regulations, budget, etc. and integrate good decisions to the design before shapes, structures and orientation are already finalized.

Commonly identified tasks of an early-active in the design process HVAC Engineer, begin in the same way as of any other team member - with recognising and codifying the OPRs. Later, the documentation might include basic load calculations, mechanical system space requirements, energy-efficiency, potential impacts, evaluation of solution alternatives via life-cycle analysis, selection of HVAC equipment and others.

The HVAC Engineer develops fundamental information for the project design and if addressed at the early stage, it can help improve the energy-performance of the building and reach the desired sustainability rate. He/She pays attention to local weather issues and how they might impact the future building, takes into account every element of the building envelope and its thermal quality performance. Besides the heat gains and ventilation, lighting possibilities are also analysed. Additionally, engineers are responsible for energy compliance with the mandatory building regulations and in charge for the sustainability objectives of the project.

The HVAC Engineer should work in coordination with the LOD provided by the Architect and design the HVAC systems in a way that avoids big assumptions, that will likely change as the overall project design development. Ideally, sufficient LOD can be reached by using BIM for managing the project data among the whole design team. If there is a lack of proper information at that time, it can be turned as an obstacle and so the flow of necessary information for the general energy frame may be postponed.

Detailed information can vary from something big like complete layout of functional spaces, to small missing details like overall orientation concepts. This actions can directly affect the system engineers negatively and the work can be postponed until all the vital data is gathered. The complexity of the HVAC systems is increasing every year and that is why the HVAC Engineer's role expands too, having many more design and legal responsibility issues to deal with. Therefore, the right amount of information, exchanged in the appropriate time frame is in vital importance for the Engineer, so the accepted concept design can be passed to the next design stage.

- **DGNB Auditor**- All project participants must be involved systematically in an integrated design, in order to have a successful DGNB certification process and that should include the DGNB Auditor as well. The process has to be simultaneously coordinated, due to the fact that he/she is a highly qualified professional with a high level of expertise in the area of sustainability and its assessment. It is only through them that the DGNB certification materializes, because they are both the organizational and content link between the DGNB and the project to be certified.

  Tasks and particular skills of an Auditor are still not that commonly understood in the AEC industry, simply because DGNB is relatively new as a sustainability rating system and most importantly it is voluntary decision to take. These bring some sort of confusion around their role in the process and therefore, quite often the design team and the Building Owner are unaware of the added value an Auditor can actually bring. With their knowledge in the planning and design, they can be included in the project from the very beginning and bring benefits far beyond the certification.

The DGNB Auditor can guide the pre-certification process during the planning stage, which gives the possibility to identify efficient and economically reasonable sustainable solutions, help decision-making and go together with the integrated approach to the project's design. Almost all green building decisions affect the investment and the budget of the project, and therefore it should be clarified at an early stage, which certification target (platinum, gold or silver) is to be achieved. The Auditor has to help the Building Owner in setting the desired sustainability rating and to ensure the integration of the criteria in the planning and implementation process.

The role of the DGNB Auditor in the process of pre-certification includes advising and leading the Building Owner on the path to certification, and these can be provided to different extent. It is either that the Auditor only handles documentation, verification and organizational tasks, or they can be integrated much more in the optimization of the design in terms of sustainability.

The first extent includes the Auditor's main tasks of registering the project with DGNB, assessing the available documentation and submitting it to DGNB. The second one includes additional tasks such as estimating the building performance by pre-assessing to what extent the requirements of the different key areas are fulfilled and therefore determining the possible award. Moreover, they can collect and evaluate data, and support design teams in setting sustainable objectives that will actually bring certification results. If auditors are involved as early as the project begins, they can make sure that the Owner and the design team are familiar with the DGNB assessment process, by participating in regular meetings and coordinating verifications among the involved parties.

The Auditor's basic knowledge embraces the individual rating points, the level of requirements and the methods of detection known. Additionally, they must have expertise in life-cycle assessment of buildings (LCA) and the calculation of life-cycle costs (LCC), but also on issues such as ecological building and facility management. For a sustainable building concept and a good certification result, the Auditor must have also expertise in the fields of building physics and energy design, so they can work in a proper balance with the rest of the project team. Finally, in order to reach transparency and clear process, as well as to reduce the project risk, the Auditor needs expertise in the field of management. Here, the classic project management plays a crucial role in the form of cost, schedule and quality management.

Optimal is an Auditor who combines all these competencies. When the commissioned expert can do this and work in maximum synergy with the rest of the project team members, the possibilities for great collaboration process and easy information exchange are high, and therefore the chance of a successful project.

- **Building Owner**- it is the role that refers to an organization or individual that stands in the very beginning of a project and the one that sets the start of a building development. The Building Owner is responsible to identify their own business need, which may or may not result in the need for a project.

  The ability of such identification depends very much on how experienced the Owner is in the construction industry, whether they are going to be only an owner of the building, or also a user. The Building Owner might be reviewed also as the client, funder, stakeholder, employer, etc., but overall they need to be aware of their requirements and state them in a preliminary business case and an initial strategic brief for the project. In case they don't have the full range of knowledge and skills, they may wish to appoint an advisor (separate from the design team) to help and guide them at this very early stage of project justification.

  Once the business need is clarified by the Building Owner, he/she might decide to involve a design team to carry out the feasibility studies and make an appraisal of whether the project may progress or not. They should discuss together the initial requirements towards the design, the sustainability and the energy performance targets of the building. Moreover, an initial budget and schedule, as well as any restrictions related to them, have to be set.

  If the project is passed through the feasibility stage, then often the Owner is responsible for providing sufficient information for the potential location, as well as funds for additional site surveys if necessary. Later in the design process, the Owner's main responsibility is to agree or not with the suggested from the design team concepts, so the project can move forward.

4.5. Process discovery and mapping

4.5.1. Overview of necessary flow- 'to be' process

The indisputable ability of BIM in information delivery is well acknowledged in the building industry, especially when it comes to early design decision-making and sustainability oriented projects. BIM and more specifically Revit as a tool plays a central role in the integrated design optimization, reviewed in here. This new approach to the process is reinvented in order to include the vast advantages of the sustainable and energy design. Design teams that include not only the architects, but different specialists, such as the HVAC engineers for example, may be formed early in the project and develop the design in a collaborative process from Design Brief Development Phase to the final Detailed Design Phase.

The aim of this overview is to describe the necessary flow of the so called 'to-be' process diagram (Figure 32), which the group has developed as an answer of the project research question. In it, a significant importance is given to the fact that the building energy use and the environmental impact can be reduced without the use of advanced technologies and software, but mostly through the efficient collaboration of the involved parties and their integrated design. This way the early phases of the process can be extremely valuable when it comes to meeting the stated OPR's for high-performance building design and sustainability award targets.

Due to the already described roles of the main actors in both the traditional and the integrated design process, hereby, a better representation of their tasks and most importantly the interactions between them is given. This general summary goes through every concerned phase and reviews the iteration of activities involved in them. However, a detailed explanation of every event, task, data object and decision gateway is given in the specification tables in the next sections.

From the start of the process, given by the Building Owner, a specific document based data exchange is required. The project justification is used for the appraisal of whether the business need of the Building Owner is feasible for a future building project or not. The engagement of the entire design team in the beginning of the Design Brief Development (in the described case – HVAC Engineer, Architect and DGNB Auditor) is immediately followed by stating and registering the OPRs. The end of this phase is marked with the execution of a final strategic brief, based on the result of the collaboration between the Building Owner and the design team.

The beginning of the Pre-Design Phase is marked by the Architect, who continues the initial investigation of the location in order to start visualizing his/hers first design sketches. At the same time the DGNB Auditor, who has already registered the sustainability targets of the Building Owner, can provide guidance in order to benchmarks the pre-certification and raises the probability that a building's planned performance objectives will be accomplished. Simultaneously, the HVAC Engineer can evaluate the initial design and energy target criteria with the help of the available reference data. The latter can serve as a general approach for the initial energy analysis and the creation of the thermal zoning that respectively can be done on the base of the already developed initial architectural model by the Architect. The results of this initial design can be reviewed as initial concept sketches and architectural visualizations of basic shapes and aesthetic forms, so the Building Owner can give his/hers first agreement of the design. That by itself lead to a pre-assessment of the project according to the DGNB criteria and if the design requirements are met, then the DGNB Auditor can initiate the registration with DGNB.

After the first pre-design is approved, the project may continue to the Conceptual Design Phase, where the professional knowledge of the involved parties is even more combined to provide a successfully integrated project design. This is the start of a more accurate conceptual expression, due to the fact that the Architect and the HVAC Engineer add more details to the design in a matter of the geometry, scale, HVAC related spatial requirements, etc. That develops the model furthermore and with the help of the required reference data from the space type libraries, the Architect can be able to identify the main building elements and the initial material choices related to them.

The latter brings to another design check from the Building Owner, which if approved can serve as a base for further energy analysis. The model can be adjusted and validated, and with the appropriate inputs can assist in the estimation of the energy demand and consumption, as well as the initial BR compliance check with Be10. The consequences of the design decisions are determined by simple calculations and later compared.

If the proper technical choices are made at this stage of the project, the budget target can be almost certainly met due to the fact that the building environmental performance in terms of energy, resource consumption, indoor air quality, etc. can be significantly improved. Such technical choices may refer to preliminary assumptions for building envelope, materials, lighting, orientation and site plan, conceptual plans and elevations, HVAC services, etc.

If the energy performance results are accepted, then the Architect can prepare a submission for a review and approval. On the base of the last with all the relevant results and design decisions, the DGNB Auditor can perform the first assessment of LCA criteria group and to determine some interim points. By the same time the final decision of the Building Owner in the end of the Conceptual phase has to review whether all defined OPRs, criteria and target values are considered in the development and evaluation of the design solutions. If the Building Owner accepts a proposed integrated design concept, then the project can continue to the next Preliminary Design Phase.

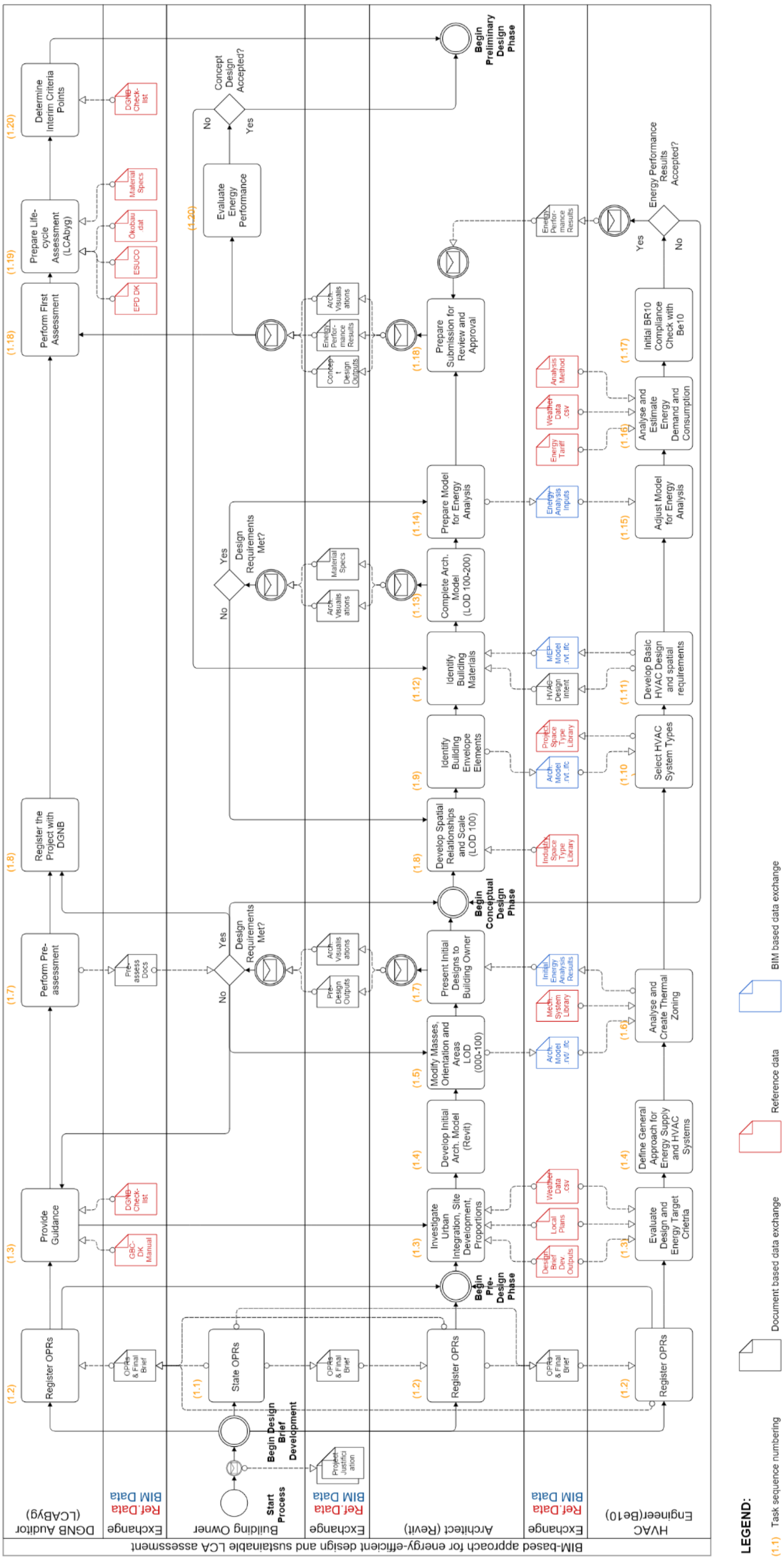

Figure 32: Integrated design process map, Group 10 own contribution

4.5.2. Specification of processes

Start Process

Type	Start Event
Actor	Building Owner
Documentation	This is the general initiation of the project start, planning and design. It happens after it has been identified that a certain business need can be fulfilled by a construction project. At this point, the client may decide to consult or not independent advisors, before engaging a design team. The objective is to justify that the undertaking of the construction process is reasonable. **Outputs:** clear definition of the business need, preliminary business case and initial strategic brief.

Begin Design Brief Development

Type	Intermediate Event
Actor	Building Owner
Documentation	The main objective is to clearly outline the project deliverables and define the Owner Project Requirements (OPRs), the main design goals and criteria. With regards to sustainability, setting of targets, concerning energy and environmental performance is essential. This is the moment of the process when the Building Owner appoints the design team and facilitates the necessary appraisal and feasibility studies. **Outputs:** final strategic brief, OPRs, review of Building Regulations and requirements from the local authorities, site surveys and collection of general site information.

State OPRs (1.1)

Type	Task
Actor	Building Owner
Documentation	The Building Owner gives a detailed statement of expectations and requirements, concerning the building function, use, operation, overall project budget and schedule. In addition, specific desired design details, sustainability and energy performance targets, desirable certifications and execution plans are also stated. Any project limitations (physical, environmental, cost-related) should also be noted.

Register OPRs (1.2)

Type	Task
Actor	DGNB Auditor
Documentation	Receives and registers the Building Owner's requirements, as special attention is given to the building site, building function and occupancy, sustainable design intent, energy performance targets and desired award, as well as possible budget restrictions. Based on the building-specific use, life-cycle expectancies can be determined.

Register OPRs (1.2)

Type	Task
Actor	Architect
Documentation	The Architect should consult with the Building Owner in order to specify the goals and determine the final project requirements. The Architect's perspective should also cover all requirements equally, with special attention given to intent concerning building site, design aesthetics, space functionality and use, sustainability targets, project budget and schedule, as well as any limitations that may apply. After being registered, those initial parameters are synthesised in a way, so that the most optimal architectural expression is achieved.

Register OPRs (1.2)

Type	Task
Actor	HVAC Engineer
Documentation	From the perspective of the HVAC Engineer, main attention falls on requirements related to environmental and sustainability objectives, energy performance and efficiency, indoor environmental quality, and HVAC systems expectations, including performance and operational cost considerations.

Begin Pre- Design Phase

Type	Intermediate Event
Actor	Architect
Documentation	The main purpose of this phase should comprise exploration of advanced building site properties and potential for urban integration, development options and possible building proportions and orientation, dictated by the existing conditions. In that relation, it is important that at this stage, guidance from the DGNB Auditor is already available for the design team. All of that will serve as the foundation for creation of the initial design proposals and energy strategy.

	Outputs: Initial architectural design concept proposals, Initial energy analysis and performed DGNB pre-assessment.

Investigate Urban Integration, Site Development and Proportions (1.3)

Type	Task
Actor	Architect
Documentation	With the help of the reference data (Design Brief Development Outputs, Local Plans, Weather Data), the Architect should assess all previously performed building site surveys, collected information, local plans and relevant planning permission requirements, and further investigate possibilities for development of building proportions and approach overall design.

Provide Guidance (1.3)

Type	Task
Actor	DGNB Auditor
Documentation	The DGNB Auditor should at this point already be available for initial guidance to all design team members, so that the decision making related to the design process is coordinated from the very beginning, and the sustainability and energy targets are kept in mind and implemented. By the use of the DGNB reference data (DGNB Manuals and Checklist), the DGNB Auditor can influence the future building's overall performance. The guidance process can be organised in the form of workshops, where necessary expertise is provided, the certification process and tasks are explained.

Evaluate Design and Energy Target Criteria (1.3)

Type	Task
Actor	HVAC Engineer
Documentation	The HVAC Engineer should evaluate the provided from the Design Brief Development phase outputs and by the use of the relevant reference data (Local Plans and Weather Data) evaluate the design and energy target criteria from the perspective of their potential influence on HVAC system choice. As a minimum that should include site analysis, which takes in consideration solar radiation, wind patterns, existing structures that may affect the design, as well as the surroundings and any potential issues they may present.

Develop Initial Architectural Model (Revit) (1.4)

Type	Task
Actor	Architect
Documentation	At this point the Architect should begin with loading a parametric mass family or create in-place families and adaptive geometry (.rfa, .rft), which after that are loaded in the Revit project environment, to create the conceptual masses, constituting the initial architectural model of the building (.rvt). The Revit family library is accessed by default in the following way: *Insert tab* ➤ *Load from Library panel* ➤ *(Load Family)*. The BIM environment allows flexibility even at this earliest of stages, where the LOD goes as far as surfaces, which will then be further developed.

Define General Approach for Energy Supply and HVAC systems (1.4)

Type	Task
Actor	HVAC Engineer
Documentation	Based on the OPRs and the performed criteria evaluation, options for energy supply and general HVAC systems features and styles, as well as approximate price ranges are determined. The HVAC Engineer should assist the Architect with consultancy regarding indoor environmental comfort issues, caused by architectural features and initial spatial considerations, related to accommodation of HVAC systems.

Modify Masses, Orientation and Areas (1.5)

Type	Task
Actor	Architect
Documentation	In the Revit project environment, the initially created model can then be manipulated, so that various massing concept shapes, orientations and areas are explored. That would give the first ideas about how changing of different variable parameters leads to changes in the overall design. Those modifications will also create the basis for considerations related to the effect of the design on the performance of the building. The created mass concepts can then be further detailed. At this point, the modelled elements can be within the range of LOD000-100.

Analyse and Create Thermal Zoning (1.6)

Type	Task
Actor	HVAC Engineer

Documentation	The created by the Architect initial alternative building models/masses, can then be used from the HVAC Engineer for initial energy analysis. The conceptual masses should be divided into different thermal zones, the purpose of which is to analyse the initial behaviour of the building and help determine the number and type of necessary HVAC systems. Thermal zoning at this stage can either be simplified or advanced, as this is again based on the detailing of the mass. The simplified thermal zoning precepts the building as one core and four thermal zones, dictated by the directions (S, W, E, N). The advanced zoning uses additionally created analytical spaces and surfaces, defining different zones, e.g. added floors, exterior or interiors surfaces. This can either be done automatically in the Revit project environment or by the use other energy analysis tools/plug-ins. It has to be noted that the decision to use simplified or advanced zoning would affect the accuracy of the analysis at this point of the process and consequently also the work of other involved parties, such as the Architect. In both cases, the analysis should include multiple iterations, so that different results are compared.

Present Initial Designs to Building Owner (1.7)

Type	Task
Actor	Architect
Documentation	The Architect in the role of the lead designer is responsible for presenting the Building Owner with the Pre-Design Phase outputs and alternative architectural proposals for the initial concept of the building. The objective at this point is to provide the Building Owner with the current progress documentation and designs, so that a first evaluation of OPR implementation is done.

Perform Pre-assessment (1.7)

Type	Task
Actor	DGNB Auditor
Documentation	At this stage in design development, the DGNB Auditor should perform an initial assessment of the project, from the perspective of the DGNB criteria. If necessary, additional guidance may be provided, so that the transition from Pre-Design to Conceptual Design is easily made. The pre-assessment is documented and available at the decision point gateway for decision making support for the Building Owner on one hand, and the design team on the other, if changes in the design are required.

Begin Conceptual Design Phase

Type	Intermediate Event
Actor	Architect
Documentation	The purpose of this phase is to integrate the architectural concepts created in the Pre-Design Phase with more precise environmental, structural, energy concepts and functional demands. Building envelope elements, systems and structure, as well as initial choice of materials will be determined, which will create the basis for more detailed design development. Spatial relations and geometry is defined, which allows the configuration of a basic HVAC design that further facilitates more advanced energy analysis and simulations. The results from the latter would then be used for an initial LCA and can serve as a base for determination of some interim DGNB criteria points. **Outputs:** Variety of integrated building concepts, including considerations for further development with chosen building elements and materials, Basic HVAC system design, Further energy performance and compliance analyses and calculations, Initial DGNB LCA assessment

Register Project with DGNB (1.8)

Type	Task
Actor	DGNB Auditor
Documentation	In order to register the project, the DGNB Auditor should submit a completed Project Certification Form (PCQ). Based on performed reviews by DGNB, additional criteria adaptation proposals may need to be developed.

Develop Spatial Relationships and Scale (1.8)

Type	Task
Actor	Architect
Documentation	The Architect should further develop the initial architectural model from the Pre-Design Phase by defining more accurate spatial relationships and concrete scale. The upgraded building model should consider the Industry Space Types Library, as it will serve as a basis for further decisions, related to choice of HVAC systems and their performance. The result should comprise space identification, space type, space location, space elevation, space boundaries and space 3D geometry). LOD provided by the Architect should determine an extent, which would allow the HVAC Engineer to further develop the energy design in the conceptual phase.

Identify Building Envelope Elements (1.9))

Type	Task
Actor	Architect
Documentation	Once the spatial relationships are developed, the Architect is responsible for identification of the primary building envelope elements- walls, roofs, floors, openings, etc. and their general characteristics. The design of the building envelope should implement knowledge of building materials and heat transfer properties, and consider the effect that the different choices may cause. Having those in mind would also help for the development of basic HVAC design and further energy analysis.

Select HVAC System Types (1.10)

Type	Task
Actor	HVAC Engineer
Documentation	Based on the initial energy analysis results, the defined spaces and the identification of the building envelope elements, the HVAC engineer should at this stage select and propose project appropriate HVAC system types.

Develop Basic HVAC Design and Spatial Requirements (1.11)

Type	Task
Actor	HVAC Engineer
Documentation	Consequently to the selection of the main HVAC system types, the basic HVAC design should be developed. After building envelope elements have been selected, more accurate zoning, heating and cooling load calculations can be executed. The basic load calculations should consider thermal energy losses and gains from the elements, building orientation, shading, daylight, user contributions and factors, natural and mechanical ventilation needs and their related requirements. This gives a green light to the initial development of HVAC design. The spatial requirements concerning the chosen equipment should also be determined, so that it is made sure that adequate space for units and ducts is provided.

Identify Building Materials (1.12)

Type	Task
Actor	Architect
Documentation	The identification of building materials begins at this stage, but is finalised during the detailed design. The Building Owner has a significant input in the choice of materials, but the main decisions are still taken by the design team. The most important aspects to

	be considered are sustainability, cost, technical performance and aesthetics. The created or pre-defined building element types should be assigned with specific performance characteristics, such as material layer identification and type, composite U-value, solar factor g-value, surface reflectance value, shading value, visible transmittance value.

Complete Architectural Model (1.13)

Type	Task
Actor	Architect
Documentation	After the HVAC Engineer has developed the initial HVAC design and has specified the related spatial requirements, they can serve as an input for the completion of the architectural design. At this point, the design should comprise basic floor plans, areas, façade appearance, building envelope elements and initial material specifications. The architectural model at this stage should be in the range LOD100-200.

Prepare Model for Energy Analysis (1.14)

Type	Task
Actor	Architect
Documentation	At this point, the model is prepared for energy analysis, as final adjustments and validation are made by the Architect. It is important to be made sure that the quality of execution and precision are at an appropriate level. After that the model is exported to IFC for the necessary analyses and simulation.

Adjust Model for Energy Analysis (1.15)

Type	Task
Actor	HVAC Engineer
Documentation	BIM validation, model checking in the case of advanced simulation tools

Analyse and Estimate Energy Demand and Consumption (1.16)

Type	Task
Actor	HVAC Engineer
Documentation	By the use of the necessary reference data (Energy Tariff, Weather Data and chosen Analysis Method) at this project development stage, the HVAC Engineer should be ready to perform energy demand and consumption analyses and calculations.

	It is recommended that more advanced energy analysis tools are used to run the simulations, the sole purpose of which is such estimations, so that more accurate results can be achieved. - Energy demand- represents the maximum thermal load (peak load, heating and/ or cooling loads) of the building, which can be used for the purposes of precise HVAC system sizing. It is important that the simulation results consider the highest value of the peak loads that the building experiences throughout the year. - Annual energy consumption- the amount of energy used yearly for the HVAC systems, lighting and equipment in the building. The annual energy consumption is of a major importance as an input data performance of LCA.

Initial BR10 Compliance Check with Be10 (1.17)

Type	Task
Actor	HVAC Engineer
Documentation	Developed by the Danish Building Research Institute, Be10's main purpose is to document that the energy requirements according to the Building Regulations have been met. Be10 is created with the purpose to support the fulfilment of the requirements of the building code, from a legal perspective, all other programs for certification and compliance checks have to use the Be10 'core'. It is also the tool to be used not only when it comes to compliance with BR10, but also Low energy class 2015 (BR15) and 2020.

Prepare Submission for Review and Approval (1.18)

Type	Task
Actor	Architect
Documentation	This is the final presentation of overall conceptual design outputs, energy performance results and final for the stage architectural visualisations, prepared from the Architect in the role of a lead designer for the Building Owner. The purpose at this point is to provide the Building Owner with all relevant information, supporting the decision making and approval of the conceptual building design.

Perform First Assessment (1.18)

Type	Task
Actor	DGNB Auditor

Documentation	First assessment of building performance in terms of sustainability should be performed. For the purposes of the current case this only refers to a particular criteria group from the environmental quality, but in the general case an assessment of all criteria should be made. The First Assessment of building performance is made on the basis of the Conceptual Design Output documentation and Energy Performance Results.

Prepare Life-cycle Assessment (LCAByg) (1.19)

Type	Task
Actor	DGNB Auditor
Documentation	It is important to be noted that at this stage, a full LCA cannot be completed, due to the fact that the relevant data will be further modified in the next project development phase. However, an initial LCA, based on the current energy performance results and material specification, as well as the necessary material reference data (EPDs, ESUCO Database and Ökobau.dat), can be performed in LCAByg.

Determine Interim Criteria Points (1.20)

Type	Task
Actor	DGNB Auditor
Documentation	Once the initial LCA is performed, a general determination of potential interim criteria points can be estimated with the help of the DGNB checklist.

Evaluate Energy Performance (1.20)

Type	Task
Actor	Building Owner
Documentation	At this project development stage, the Building Owner has to evaluate not only if the design OPRs have been fulfilled, but also if the outcomes of the performed energy analyses meet the sustainability and energy frame targets. This will help take the final decision about whether or not the concept design is accepted.

Begin Preliminary Design Phase

Type	Intermediate Event
Actor	Architect
Documentation	This is the end of the Conceptual Design Phase and in case of approval, the beginning of the Preliminary Design Phase. Since the current project is only concerned with the definition of processes until the end of the Conceptual Design Phase, this is considered a general process end.

4.5.3. Specification of Data Objects

Project Justification

Type	Data object
Documentation	A document based data exchange between the Building Owner and the officially engaged design team, which should include: - Business need definition- identification of whether or not the project is necessary, and if yes- is there a need of a construction of a new building or not. - Preliminary business case- represents the initial effort to validate that the investment should be undertaken. Contains options for funding of the investment, necessary legal documentation, such as procurement contract drafts, and organisational structure behind the Building Owner as an entity. - Initial strategic brief- serving as a basis for carrying out of the upcoming feasibility studies, it resembles the transformation of the initial business need into documentation, providing project information and risk assessment, which would justify the engagement of a design team.

OPRs and Final Strategic Brief

Type	Data object
Documentation	A document based data exchange between the Building Owner and the involved design/consultant team members. Should include: - Final strategic brief- based on the initial strategic brief and a result of the collaboration between the Building Owner and the design/consultant team. Includes the team's assessment of the building site and documents existing conditions, surveys, access options, legal constraints and necessary approvals to be acquired. - OPRs- updated periodically to the current version, they include the owner and user requirements, which can be used for benchmarking, as well as success and quality tracking throughout the stages of the project. They can also serve as a foundation for the procurement documentation and help avoid related conflicts. Main categories include: Project- specific design objectives, Functional requirements, Building type and use, Sustainability and energy performance concepts, Building site, including access options, Building envelope, Indoor environmental quality, Interior design, Overall cost and schedule considerations, Operation and maintenance, Project limitations.

Design Brief Development Outputs

Type	Data object
Documentation	Final strategic brief, OPRs, Review of Building Regulations and requirements from the local authorities, Site surveys and Collection of general site information.

Local Plans

Type	Data object
Documentation	Reference data, which should help assess the permissions and restrictions that may apply to the architectural and consequently the energy design of the building. The local plans (Lokalplan) are detailed plans with binding rules, regulating construction in particular local areas/neighbourhoods. The following is determined: how the local area may be used, location and extent of the building, roads, open spaces, etc., materials and appearance of the building. Based on that, it is important that this reference data is consulted from the very beginning of the design process.

Weather Data

Type	Data object
Documentation	Reference data (dataset), used as input for energy simulations, which in Denmark is Danish Design Reference Year (DRY), provided by Danish Meteorological Institute (DMI). Used during determination of indoor thermal climate conditions, heating and cooling loads of the building and HVAC equipment sizing. The dataset contains the following relevant parameters: one year of hourly data for temperature, relative humidity, wind speed and direction, atmospheric pressure, global radiation, cloud cover, diffuse irradiance, illuminance and one year of daily data for soil temperature. A specific data subset used for energy performance calculations for obtaining a Building Permit is also included. The DRY data set and the Building Permit subset are contained in zip-file, which contains a csv-file for each station and parameter: DRY_<parameter>_hourly_<statid>.csv Hourly values for <parameter> and <station number> format: Station number Timestamp in UTC4 format *yyyymmddhh* Value Quality index (1100 indicates an observed value, 1000 indicates an interpolated value)

	DRY_soil_temperature_daily_<statid>.csv Daily values for soil temperature and <station number> format: Station number Timestamp in UTC2 format *yyyymmdd* Value Quality index (1100 indicates an observed value, 1000 indicates an interpolated value)

GBC- DK Manuals

Type	Data object
Documentation	Reference data, containing the necessary detailed information about the six different DGNB evaluation areas and their specific criteria groups. Used in assessing the sustainability and rating potential of the project at this stage.

DGNB Checklist

Type	Data object
Documentation	Reference data, containing specific for each criteria requirements and a maximum amount of points that can be obtained. Weighting factor and share of total score are also included for each of them. At this stage, used for guidance and determination of the maximum potential amount of points that might be obtained on the way to the achievement of the desired award.

Architectural Model

Type	Data object
Documentation	**Pre- Design Phase:** BIM based data exchange of different architectural inputs (conceptual masses) for initial thermal zoning and energy analysis. The data input is a responsibility of the Architect and even at this earliest of analysis stages, the simulation results from the HVAC Engineer are dependent on the quality and relative detailing of the architectural model. **Conceptual Design Phase:** BIM based data exchange, which should specify building site information (identification, location, elevation, 3D geometry, adjacent buildings geometry), building information (identification, type, location, elevation, orientation) and building elements (identification, type, placement, 3D geometry). Again, the exchange requirement to the data is

	fulfilled by the Architect and the precision of all upcoming analyses depends on its quality. Based on the contractual agreement and whether the architectural and engineering services are provided by the same company or different ones, the requirements to the exchange of BIM data may vary. In the case of consultancy being provided by one company only, the exchange of the architectural model may be done with the native file format only (.rvt) or the work may be executed by the use of the Architect's central file. In the cases, where the different consultancy services are provided by different companies, legal restrictions to the exchange may apply. That is why such exchanges are governed by the use of a common data model (.ifc). **Exchange requirements:** The necessary minimum requirement is to transfer the architect's spatial programme (according to COBIM (2012) as-required model) as a document format for energy analysis initial data purposes. With regards to data content, the main requirement towards the ifc file is that it should include the following two views defined by buildingSMART in the IFC Standard: - Coordination view (the view, used for collaboration between the Architect and the HVAC Engineer) - Space boundary add-on view (defining space surfaces and their connection to different structures, openings etc.)

Mechanical System Library

Type	Data object
Documentation	Reference data, containing diverse HVAC system types, which the HVAC Engineer can apply when analysing thermal zones.

Initial Energy Analysis Results

Type	Data object
Documentation	BIM based data exchange of initial energy simulation output, containing thermal zoning and initial HVAC considerations, related to heating/cooling loads. **Exchange requirements:** There are no requirements, which concern the export of energy analysis results to BIM. Export limitations may apply based on the simulation program (COBIM(2012))

Pre-Design Outputs

Type	Data object
Documentation	Site analysis and development documentation, including initial site plans and building orientation, Various options for initial architectural design, including general description, Initial HVAC system proposals, including principles and considerations, Applicable sustainable design strategies, Assessment of compatibility with the OPRs, Assessment of potential Building Permit issues that may arise, Overall budget and schedule with main milestones, Risk assessment of the different options.

Architectural visualizations

Type	Data object
Documentation	Computer-generated renderings and 3D images of the current building design should be provided by the Architect, in order for the client to visually assess the implementation of the aesthetic OPRs in the design. Since the Building Owner will be presented with architectural visualisations numerous times during the process, they should reflect the latest design development and changes made.

Pre-assessment Documentation

Type	Data object
Documentation	Document based data exchange that contains a general description and conclusions, based on the assessment of the sustainability principles, implemented in the design up to this moment.

Industry Space Type Library

Type	Data object
Documentation	Reference data, providing information about space parameters, used in calculation of heating and cooling loads of the building. In Revit, default occupancy, lighting and power schedules are available and their settings can be modified, so that a more precise analysis is performed. It may be available from open access industry space type libraries or as an energy analysis tool-specific template.

Project Space Type Library

Type	Data object
Documentation	Reference data, which is project-specific and is a result from modifications or additions, which the HVAC Engineer has made to the Industry Space Type Library.

HVAC Design Intent

Type	Data object
Documentation	Document based data exchange, which includes descriptions of the intended HVAC-related design decisions. The main objective of the HVAC Design Intent is to present an insight to all concerned parties (including Operation and Maintenance ones) about justification for selection and design of the HVAC systems. Should also reflect the latest changes in the design.

MEP Model

Type	Data object
Documentation	BIM based data exchange, which is based on the provided architectural inputs and specifies information about HVAC units and ducts, their type, location, elevations and dimensions with respect to the current project development stage. **Exchange requirements:** The exchange requirement is to transfer the MEP target information (according to COBIM (2012) MEP as-required model) as a document format for energy analysis initial data purposes.

Energy Analysis Inputs

Type	Data object
Documentation	Energy demand will be determined based on: - Building geometry, including initial layout and space configuration - Building orientation and shadings (critical parameters in the context of office buildings) - HVAC systems (cooling, considerations for natural and mechanical ventilation and heating operation systems are as well in the critical parameter category) - Building structure, including thermal properties of the construction elements (walls, floors, roof, windows; doors are important as well, but with consideration that many of their thermal performances will vary from the initial to the main energy frame.)

	- Building usage, including function - Internal loads and schedules of operation - Space conditioning requirements - Utility rates - Weather data

Energy Tariff

Type	Data object
Documentation	Reference data, providing information about the costs that apply to the energy supply. In the early design stages, such information can be provided by already executed similar projects and later specified by the energy provider.

Analysis Method

Type	Data object
Documentation	The selected method for performance of the analysis at this stage. Refers to chosen simulation engine and/or software interface. In this particular case, for calculation of energy demand and annual energy consumption, the use of advanced energy performance simulation tools has been considered necessary, whereas for BR compliance checks the mandatory Be10 has been applied.

Energy Performance Results

Type	Data object
Documentation	Document based data exchange, which includes the complete set of results of the performed conceptual energy analysis and represents the building's energy demand, annual energy consumption and BR10 check for compliance with the energy frame requirements, as well as space requirements. **Exchange requirements:** There are no requirements, which concern the export of energy analysis results to BIM. Export limitations may apply based on the simulation program (COBIM(2012))

Material Specifications

Type	Data object
Documentation	Document based data exchange, which also serves as reference data for DGNB LCA performance. At this stage, a simple informative document, specifying a list of chosen building materials and their properties (durability, cost, environmental

	impact, aesthetics, thermal performance and warranty). May also include manufacturer/ supplier data.

Conceptual Design Outputs

Type	Data object
Documentation	Site context and strategy, including site plan and layout plan with considerations for access and parking, Landscape strategy, Conceptual floor plans, elevations and sections, 3D visualisations and models, Sustainability and building energy performance, Basic fire safety strategy, HVAC, plumbing, electrical and telecommunication systems and services, considerations for main loadbearing structures and definition of building envelope elements, Material specifications, Quality standards, LCA, Risk assessment of the various options, Updated budget and schedule with main milestones,

Environmental Product Declarations (DK)

Type	Data object
Documentation	Verified standardised reference data, used for quantification of the environmental impact during the products' life-cycle assessment. EPD Denmark is a member of the European initiative ECO Platform and allows users to fairly compare environmental performance, reflect continuous environmental improvement and present relevant environmental information.

ESUCO Database

Type	Data object
Documentation	ESUCO or European Sustainable Construction database contains country specific data about around 500 construction materials and ecological data related. An essential element from the DGNB LCA methodology for building materials, it allows the performance of consistent calculations.

Ökobau.dat

Type	Data object
Documentation	Ökobau.dat is a German database, used for building services and construction products published by the German government (BMUB).Still it is an important element of DGNB even in the Danish context. It contains more than 700 LCA datasets of materials and products.

4.5.4. Specification of Decision Point Gateways

Design Requirements Met?

Type	Decision point
Documentation	**Pre-Design Phase:** At this point, the Building Owner should decide if the project reflects and meets the stated OPRs. If yes, then the project is ready to move on to the next development phase. If no, then changes in the Pre-Design concepts have to be made. Those on one hand may be evoked by wrongful or incomplete implementation of sustainability related requirements in the project, in which case additional guidance from the DGNB Auditor should be provided. On the other hand, changes in the design may also be required due to OPRs not being fully met. **Conceptual Design Phase:** After the completion of the architectural model, the Building Owner should again be presented with the latest architectural visualisations and material specifications, in order to again decide whether the OPRs have been fully met. If yes, then the project may continue to a stage where more detailed performance analyses and BR compliance checks are performed. If no, then the design has to be reviewed again.

Energy Performance Results accepted?

Type	Data object
Documentation	At this stage, the HVAC Engineer should determine whether the energy performance results are acceptable from both legislative and energy performance target points of view. If yes, then the energy performance results are sent for preparation and submission for Building Owner review. If no, then modifications in the design should be explored.

Concept Design accepted?

Type	Data object
Documentation	The very final decision, concerning the acceptance of the building concept that the Building Owner has to take. If it is accepted, the project continues to the next development phase- Preliminary Design. If not accepted, then new design modifications should be explored.

Chapter 5: CONCLUSION

The following chapter represents the conclusion of the entire project report and summarizes the findings of the group during the semester work. It reveals once again the answer of the final problem question, discusses possible future developments and reflects on how the group feels about the achieved results.

5.1. Conclusion

Nowadays, climate change proves to be an issue of greatest concern. By being a major consumer of energy and generator of considerable amount of greenhouse gas emissions, the construction industry has a significant contribution to the negative environmental impact. With the increased awareness of those issues, both building owners and the design/consultancy teams are required to take sustainability and energy performance of the building a lot more in consideration.

In order to make sure that the building design reflects those concerns, crucial decisions should be made as early as possible in the project development by all key participants. Important feature in the process is the collaboration between them, the quality of which has a direct effect on the overall design development.

For ambitious sustainability targets to be achieved, the contemporary design process requires a systematic and well- organised interplay between energy performance analysis and green building certification within a BIM environment. However, that states additional requirements to the organisation of the design process itself, which needs to rise up to the conditions that BIM provides- allowing the implementation of multidisciplinary information within the same model. In other words, the traditional linear design approach has to be transformed into an integrated one, where all essential for the Conceptual Design information can be exchanged and available to support the early decision-making.

The latter requires the presence of an efficient and optimised information exchange methodology, which up to this moment seems to not have been fully achieved. In order for it to become possible, the group has decided to undertake an investigation in the conditions related to information management, necessary to facilitate it. That includes the identification of all processes, actors and requirements that define the information exchange between the chosen tools- Revit, Be10 and DGNB LCA.

A technical solution to such an interoperability issue is highly desired, but the group has decided to take a step back and look at the foundation, on which such a solution would be built- an in-depth understanding of the collaboration and information provision/ delivery requirements. Following the methodology developed by buildingSMART, an Information Delivery Manual has been proposed and developed until the stage of process discovery and mapping.

The particular need for such an integrated process within the industry has been clearly defined and a general description of the traditional workflow has been illustrated in an 'as is' process diagram. The issues leading to the lack of efficient information exchange in sustainable conceptual design have been outlined together with the main four actors involved- Building Owner, Architect, HVAC Engineer and DGNB Auditor. As a result, their information exchange needs have been summarised and organised to serve as the basis for an improved communication flow within the design process, which has been suggested in the form of a 'to be' model diagram.

As a result, the group has concluded that it is not the advanced tools alone, which lead to better energy performance and sustainable design, but a fundamental understanding of how those should be utilised by all actors in a collaborative design process and what information needs should be fulfilled.

5.2. Discussion and recommendations

This master thesis has been prepared so that it ultimately answers the final research question stated, namely what processes, actors and requirements define the information exchange between Revit, Be10 and DGNB LCA in the Conceptual Design phase of a building project. Therefore it concludes with the findings, organised in the form of a process map, defining an integrated process in a way that it would facilitate a most efficient collaboration and information exchange.

However, as a group, we believe that it would be of a great interest to continue the IDM proposal development further and investigate other related issues, which in this case could not have been explored due to time limitations. The group's recommendations for further work comprise the following:

- Further development of exchange requirements, mapping in exchange requirements models and concepts, and transitioning into the development of a MVD. That will then comprise the full basis, required for development of technological solutions to the problem stated.
- Testing of the developed concept, so that possible flaws, related to its theoretical nature are identified and eliminated, possibly by substitution of certain processes, tasks, etc. with such that are practically more efficient.
- Investigation of how the current legislation in Denmark would actually affect the proposed concept and if there are particular laws that would prevent the methodology from being practically possible.
- Due to the comprehensiveness of the IDM, it would be beneficial to investigate the possibility to break it down to separate IDM packages, with their own exchange requirements, so that better clarity is achieved.

5.3. Reflections

We used to say for this project that 'It is not our area of expertise, but our area of interest'. That is why we have applied our area of expertise (the management one) to the area of interest for our future career. This group motto has helped us stay focused and boosted our motivation on collaboration between what we know and we are good at, and the new knowledge which has to be gained in a matter to develop this paper.

As every new beginning, we started with massive research. Team work is the foundation of the project success, in a matter to develop, cover and accumulate the huge amount of information discovered for the short amount of time we had.

Despite the limited time, we covered sufficiently all main objectives, initially stated together with the suggested topic in the Inspirational Catalogue:

- Identify strength and limitations in current practices and identify opportunities with upcoming technologies in the area
- Review of enabling Information and Communication technologies (ICT), including software, data models, international standards, and human computer interaction tools
- Examine today's possibilities with existing tools
- Identify needs for new ways of working and from that derive a list of requirements on technical solutions
- Demonstrate possible solutions for the near future and describe issues for future development

As a group, we believe that we managed to execute a comprehensive, in-depth and future-oriented master thesis, which fulfils not only the university- and the supervisor's, but first and foremost, our own quality standards. We succeeded in extravagantly combining the areas of project management with Building Information Modelling and sustainable design, and we hope that we have contributed to an on-going research in a new, technologically-oriented area of development in the construction industry.

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