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Systems Engineering applied in the construction industry to achieve a BREEAM certification

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Abstract. Buildings have environmental impacts over their entire life cycle, which often exceed 50 years. Today buildings are responsible for 40-50% of all energy usage and anthropogenic greenhouse gas emissions globally. Green constructions are gaining increased attention, and a variety of building certifications provide a rating system designed to help develop buildings that are more sustainable, i.e., energy efficient, with zero emissions. BREEAM is a well-known certificate with a clear outcome, and by satisfying different targets a building may gain points to achieve a certain benchmark rating. The construction industry in the last decade has shown an increased interest in Systems Engineering (SE). This thesis investigates the barriers to BREEAM and considers whether SE practices can help systematize the assessment process and make it less resource intensive. The research shows that there is a desire in the industry for a more systematic approach to achieving a BREEAM certification. The results indicate that an early life phase investment with a high focus on the requirements, in addition to a systematic use of the V-model and hierarchy diagram, is useful.

Introduction

The building industry is responsible for a third of global resources, 40% of all raw materials and 40-50% of all energy usage and anthropogenic greenhouse gas emissions globally (Doan et al., 2017). As a tool in the process of making the construction industry more environmentally responsible, several environmental certification systems have been developed and implemented. One of these tools is the Building Research Establishment Environmental Assessment Method, abbreviated BREEAM. BREEAM is a green building certification system and one of the most used assessment methods in the world. The certification was launched in 1990 and was the first comprehensive assessment method applied to buildings (Cole, 2005).

The civil engineering and construction industry have in practice and literature shown an increased interest in Systems Engineering in the last decade (De Graaf et al., 2017). Apparently, the gap between practice, theory and why things fail have narrowed, but much is still to be done to close this gap even further (Blockley, 2013). Therefore, there is still great potential in applying systems approaches in this domain.

INCOSE (2015) defines Systems Engineering (SE) as a transdisciplinary and integrative approach to enable the realization of a successful system. The approach has a high focus on defining customer needs and requirements early in the development cycle, on documentation, as well as validation and verification (INCOSE, 2015).

This thesis looks into the advantages of applying SE methods in the process of achieving a BREEAM certification. One possibility is that the industry is satisfied with ‘business as usual’ and lacks the

motivation to change. This study explores whether the application of SE methods can make this process less resource intensive, in terms of time, people and money spent. According to a Norwegian study from 2017 the BREEAM acceptance process is more challenging meeting the actual requirements (Ellingsen and Houck, 2017).

The main research question is as follows: *How can systems engineering processes help achieve a BREEAM certification?* This question has been divided into three research sub question:

RQ1: Why is BREEAM important to the construction industry?

RQ2: What are the barriers to a BREEAM certification, i.e., why do not more buildings qualify for a BREEAM certification?

RQ3: What systems engineering activities are recommended for the construction industry?

The thesis is structured as follows: first there is a chapter on theoretical foundations for the thesis, then the methods used under the research, followed by a report on the results achieved, discussion, and closing with conclusions and future work.

Theoretical Foundations

Building assessment methods. Building assessment methods are used to document that a building fulfills certain qualities or standards. There are usually different ratings, and a certificate of the grade achieved is issued. In recent years there has been a trend within real estate development to have a stronger focus on sustainable development and environmental consequences (Leikvam and Olsson, 2014). Certifications provide an objective benchmark to compare buildings with each other, and for outsiders to understand the degree of the sustainable measures. Since the building certification is completed by an independent third party and all measures have to be documented evidence exists that the measures actually are completed and that the document reflects the actual building (BREEAM.com, 2021b).

Building sustainability assessment methods are intended as measures to encourage reduced energy and natural resources consumption, and control of pollution emissions in the future (Indergård, 2019). A widely accepted definition of a green building is described by Li et al. (2016, p.1) as buildings that "*provide people with healthy, applicable, efficient space and natural harmonious architecture with the maximum savings on resources (energy, land, water, materials), protection for the environment and reduced pollution throughout its whole lifecycle.*". It may be reasonable to conclude that building certifications have a relevant position in future building development (Indergård, 2019), and that they promote green and sustainable choices in the construction industry.

According to Norsk Standard (Norwegian Standard), the term 'sustainable buildings' refers to a building's impact on the external environment, social and societal considerations and economic framework, and is also what is considered in most building certifications (Norsk Standard, 2010) (BREEAM.com, 2021b). Since the UN Agenda 2030 was ratified in 2015, the sustainable development goals (SDG) and respective targets have been established to help policy makers, industry, and individuals work toward a more sustainable future.

There are 17 main SDG goals and 169 targets developed as a joint global work plan to achieve a more sustainable and better planet for everyone. Among other things, the goals aim to eradicate poverty, fight inequality and stop or reverse climate change by 2030. All the SDG targets are tightly interconnected and contribution to one goal will in many cases contribute to another, such that repairing efficiencies in the construction domain will contribute to other targets as well (United Nations, 2015).

Today there exists more than 600 different building certification methods globally. Among these, the most used are BREEAM, LEED (Leadership in Energy and Environmental Design), Green Star and CASBEE (Doan et al., 2017). These certification methods come from different places in the world, therefore they are adapted to and used in these areas. For instance, BREEAM comes from the UK, LEED from the US, Green Star has one method adapted to New Zealand and one to Australia, and CASBEE comes from Japan. These countries and others are where each method is the most popular (Doan et al., 2017) (McArthur and Powell, 2020).

BREEAM. The Building Research Establishment Environmental Assessment Method arrived on the market in 1990 as the first and subsequently most used sustainable building certification method. Since then the BREEAM manual has undergone revisions (Cole, 2005). BREEAM has five different rating benchmarks: Pass, Good, Very Good, Excellent and Outstanding, as given in Figure 1.

BREEAM Rating	% score
OUTSTANDING	≥ 85
EXCELLENT	≥ 70
VERY GOOD	≥55
GOOD	≥ 45
PASS	≥ 30
UNCLASSIFIED	< 30

Figure 1. BREEAM rating benchmarks (BREEAM.com, 2021b).

These allow the client or stakeholder to compare the performance of the building with other BREEAM certified buildings and to form an impression of the sustainability level of the building (BREEAM.com, 2021b). In addition to its rating system, BREEAM has developed several standards to enable use of BREEAM throughout the life cycle of the building, these are BREEAM Communities, BREEAM-NOR Bespoke, BREEAM In-Use and New Construction (Indergård, 2019). This research will focus on BREEAM New Construction, which provides evidence that the building was at the documented level when the certification was completed (BREEAM.com, 2021b). However, there is no follow-up throughout the building lifecycle to record if the building improves or deteriorates. The steps for achieving a BREEAM rating are given below in Figure 2.

There is a Norwegianized version of BREEAM called BREEAM-NOR, which was launched in 2012. It is prepared by Norwegian Green Building Council (NGBC) together with representatives from the construction industry. The manual consists of nine environmental areas: those are management, health and wellbeing, energy, transport, water, materials, waste, land use and ecology, and pollution. In addition, an innovation category provides opportunities for innovation and performance beyond the requirements of the credit criteria to be recognized. BREEAM-NOR is the preferred method to certify sustainable buildings in Norway (NGBC, 2021a). More than 230 projects are certified with BREEAM in Norway as of March 2021 (NGBC, 2021b). However, in the rest of this thesis there will be no distinction between BREEAM and BREEAM-NOR, but whenever BREEAM is mentioned, it will refer to BREEAM-NOR.

Figure 2: How to get a BREEAM rating (BREEAM.com, 2021a)

Systems Engineering. Systems engineering is an interdisciplinary approach that focuses on the realization of a successful system. The structured development process is key, and the definition of customer needs, requirements and expectations is done early in the lifecycle to support the final solution throughout its life. When proceeding with design synthesis and system validation the whole problem and factors must be considered, such as operations, performance, test, manufacturing, cost and schedule, training and support, and disposal, (ISO/IEC/IEEE, 2010) (INCOSE, 2015) (Helseth, 2020). INCOSE describes Systems Engineering as relevant and valuable in all types of engineering. By using SE, collaboration will be more productive, and interdependence within complex systems will be uncovered and better understood. (INCOSE, 2014)

For these reasons, Sillitto et al. (2018), assert that INCOSE´s definition needs an update. They define three drivers, which include the observation that 21st century systems rely on a collaborative leadership paradigm. These systems are almost invariably networked, and part of complex extended enterprises with multiple and often conflicting stakeholder objectives, that are related to societal and naturally occurring challenges. Sillitto et al. (2019, p. 3) suggest defining Systems Engineering as a "*transdisciplinary and integrative approach to enable the successful realization, use, and retirement of engineered systems, using systems principles and concepts, and scientific, technological, and management methods"*.

Systems Engineering in construction. Building design is driven by cost and time to deliver according to specifications and governed by building regulations (Augenbroe, 2019). However, the regulations are becoming increasingly performance based, and the building projects are more ambitious than ever in terms of physical size, complexity of structures, and materials used. This leads to a constant growth in the number of requirements and stakeholders, and influence from the stakeholders (Emes et al., 2012). Only half of construction projects are completed on time and only half within budget (Tao and Tam, 2012), which puts a focus on the need for change in the industry. The construction industry can learn from applying a systems approach to design. Despite an increased interest in Systems Engineering in the last decade, the industry has been slow to adapt (De Graaf et al., 2017) (Emes et al., 2012).

Systems Engineering models. Hierarchy diagrams are useful as a static model to visualize the multiple levels of a system and the relationships among them. They begin with a single node, usually at the top, that branches out into elements, subsystems, components, et cetera. This means the lower

levels are sorted under the higher level units though a hierarchy (Takahagi, 2017) (Novick and Hurley, 2001).

The V-model is a classic systems engineering process model, so named for the shape of the model as it traces the steps for both validation and verification, see Figure 2 (Rook, 1986) (Fowler, 2014). The model is a modified waterfall representation and contributes to a relationship between activities in each of the development and testing stages. This is indicated by the left and right-hand sides of the V respectively (Balaji and Murugaiyan, 2012). Although the model has its inception in the software development it is also widely used by systems engineers.

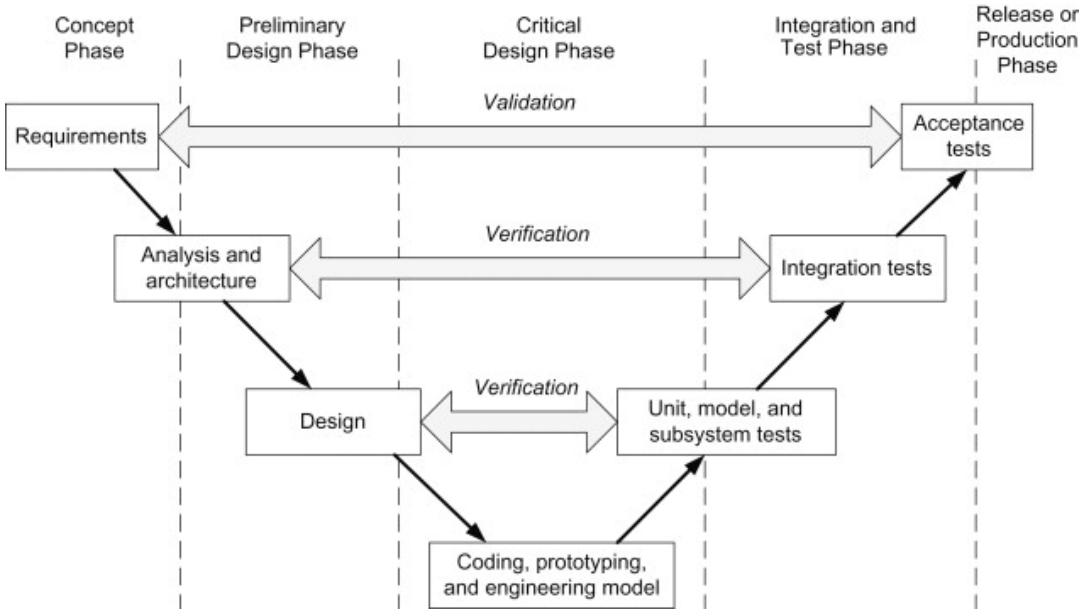

Figure 3: V-model (Fowler, 2014)

The V-model concept takes on a different meaning in construction. It is not about the levels of the systems, such as the integration of modules into equipment, to subsystems and then to the system. It is about the integration of the various parts of the construction process, defined by the different disciplines. The focus in the requirement development is on how, and not what or functional elements (Aslaksen and Merz, 2005). An adaption of the traditional V-model during building design and construction process could help optimize the trade-offs during the building lifecycle (Yahiaoui et al., 2006) (Emes et al., 2012).

Requirements. An important SE activity is the requirements analysis, which involves the definition of the requirements. The definition of requirements is also the first step in the V-model. The requirements analysis is about turning the needs and demands of stakeholders and clients into measurable requirements. The requirements are to define the purpose of the system and the performance level (de Graaf et al., 2016). Ryan (2013) divides the requirements analysis into three parts: business or mission analysis, stakeholder needs and requirements definition and system requirements definition. In BREEAM, these requirements are already defined by the BREEAM goals. However, those who build the building must in addition follow the requirements given by the building owner (Arayici, 2004).

Research Methods

As this is an exploratory research thesis to ascertain the potential benefits of applying SE approaches to green building certification, the methods relied on the background of the researcher, insights gained from literature review and a survey, with conclusions validated by interviewing experts in the domain.

Literature review. The research began with a literature review to gain understanding of the problem domain, and eventually derive the research questions (Snyder, 2019). It was conducted using databases, mainly Google Scholar and Oria, in addition to relevant papers provided by the university. Recent bibliometric analysis concluded that Google Scholar is able to capture more articles from a greater diversity of sources than other databases (Chertow et al., 2021). The following search keywords were used to find relevant literature:

- Building assessment methods, Sustainability assessment methods for buildings
- Building certification, Certification methods
- BREEAM barriers
- Systems Engineering construction industry
- Systems engineering BREEAM
- BREEAM reduction recycling reuse
- V-model, Hierarchy model

In addition to these search results, the BREEAM, Grønn Byggallianse and the UN SDG homepages were referenced frequently.

Survey. Surveys are one way of gathering information limited by the constraints of unidirectional communication. They can have either multiple choice answers or open questions (Muller, 2013). This research used mainly open questions supported by a few multiple-choice options for background information and a control question. A survey generation and data collection product, SurveyMonkey®, was used to construct, disseminate, and analyze the responses.

The target audience for the survey was people who work with BREEAM. The researchers drew upon personal networks and shared the URL for the survey on LinkedIn, where contacts were encouraged to participate. LinkedIn is believed to be helpful for academic researchers to collect rich data from industry (Unkelos-Shpigel et al., 2015). The survey ended up being shared by several people from the industry, including the marketing manager in Grønn Byggallianse, who owns BREEAM in Norway. The survey consisted of nine questions, where questions 2-7 were directly connected to the information desired in connection with the research. The questions are provided in Appendix A.

Interview. The questions from the survey were further discussed in an interview with a stakeholder who works as an environmental manager and has extensive experience with BREEAM in Norway. Interviews are interactive, which affords the researcher the opportunity to ask for clarification, or enter a new direction (Muller, 2013). Interviews can be divided into three types: Structured, semi-structured and unstructured. The interview in this research was semi-structured, which means a set of questions is prepared, in this case derivatives of the ones from the survey, and where not all had to be used, and the order could vary, and unprepared questions could be asked to follow interesting lines of discussion (Bärnholt and Lyngby, 2019). The researchers chose open-ended questions to give the interviewee a focus for the dialogue and the opportunity to add thoughts and experiences to the responses, thereby enriching the value of the exchange. The questions were shared with the interviewee in advance, to save time and to allow for minimum preparation such that more time could be spent discussing the underlying situation. In addition, much of the time was spent discussing the proposed approach and solutions to the problem as a way to validate, in a small way, the value of the proposition.

The interview was intended to provide an even deeper understanding of how BREEAM assessments are working today, and to elicit ideas for improvement and thoughts about the assessment method. As the interview was conducted after the survey it was also used as a way to validate the answers and discuss them with an experienced stakeholder. The findings from the interview were analyzed together with the findings from the literature search, survey and the proposed solution.

Ethics. The concept of research ethics refers to a diverse set of values, standards and international agreements that together help regulate and constitute scientific activities. It is very important to consider the ethics when conducting research. The most important concerns in this study will be to avoid plagiarism by following good reference practices and maintain the safety and privacy of the participants in the survey and the interview (Davies, 2019) (Helseth, 2020)

Validity concerns. In scientific research validity is a term used to evaluate the quality of the research. It will be important not to affect the result in any way, in order to avoid researcher bias. Especially during the interview, where there will be a risk that the participant could be influenced by the interviewer (Helseth, 2020). The unintended influence will have to be minimized, the interviewer will have to keep this in mind and not ask leading questions (Bärnholt and Lyngby, 2019). In addition, a video recording was made with permission for later analysis. Both the interview and the survey will have to deal with "soft" factors, such as human behavior. This is a typically uncontrolled context and analyzing these results will require an interpretation by the researchers (Muller, 2013). Another factor that challenges the overall validity of this research is the small number of persons eligible to answer the survey, and the reliance on a single expert to assess the value of the proposition.

Results

Literature review results. In total this research looked into about 65 different articles, which were found using the various search words. Upon analysis, the articles were divided into five categories:

1) Systems Engineering
2) SE and construction/other industries
3) SE models
4) Research methodology
5) BREEAM, certification methods and sustainability in buildings.

According to a Norwegian study from 2019 the barriers to achieving a certification are focused on the cost and time associated with the phases of certification (Indergård, 2019). The drivers that support certification are linked to reputation and social responsibility, as well as a future expectation that certified buildings can achieve higher rental prices. The latter prospect is not yet realistic as tenants do not seem willing to pay more for a climate-friendly property (Collins et al., 2018), but certified buildings do generate a higher turnover resale value. In the same study it was found that many tenants now are more concerned with the qualities associated with a certified building, such as a high focus on health and indoor climate, efficient appliances, and proximity to public transport (Indergård, 2019).

One example of a barrier is the passive-house Miljøhuset (The Environmental House), that is the own-built headquarter of the company GK. According to GK the building could have reached a "Very Good" BREEAM rating. In an email correspondence, GK states that as they did not consider a BREEAM certification until the construction was underway, by then it was too late for much of the work to be documented. This includes missing documentation on the cleaning and waste plan through the first part of the construction phase. Since it could not be documented that this was in place from the start, these points could not be obtained. Thus, the building could not be certified to achieve the certification ambitions, even if the building met the other points necessary (GK Inneklima 2021, personal communication, 20. April). This is consistent with literature reports on the observation that operational buildings are less likely to undergo the certification process (Ding et al., 2018).

BREEAM prevents greenwashing, as companies can easily state that they have built or rent in a green building, sort their waste, et cetera. However, BREEAM provides evidence of sustainability as it is documentation-based. Preparation of all the documentation is time consuming , but this is what is

needed to actually prove the measures that have been taken and that the building actually contributes to a greener society (NGBC, 2020).

BREEAM has worked through all the sustainable development goals and defined the interconnections between them and the possible BREEAM achievements. Appendix B summarizes BREEAM´s work and shows which targets they find relevant to BREEAM (BREEAM.com, 2021c). It must be mentioned that some of the goals have a limited or indirect contribution to meeting the UN goals and targets, some have moderate contribution, while others have a significant contribution and are explicitly worded. For example, 11.c states "Support least developed countries, including through financial and technical assistance, in building sustainable and resilient buildings utilizing local materials" (United Nations, 2015). The targets are also relevant to different parts of BREEAM which can be found online (BREEAM.com, 2021d). BREEAM New Construction has a significant contribution to goal 3, 6, 7, 9, 11, 12, 13 and 15, as shown in Table 1. Systems engineering also has been applied to creating a toolkit for analyzing sustainable development (Pearce et al., 2012).

Table 1: Relevant SDG targets (BREEAM.com, 2021c)

Sustainable Development Goals	Relevant targets
Goal 3: Ensure healthy lives and promote well-being for all at all ages	3.4, 3.6, 3.9
Goal 6: Ensure availability and sustainable management of water and sanitation for all	6.1, 6.2, 6.3, 6.4, 6.5, 6.6, 6.a, 6.b
Goal 7: Ensure access to affordable, reliable, sustainable and modern energy for all	7.1, 7.2, 7.3, 7.a, 7.b
Goal 9: Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation	9.1, 9.4, 9.5, 9.a
Goal 11: Make cities and human settlements inclusive, safe, resilient and sustainable	11.1, 11.3, 11.5, 11.6, 11.7, 11.a, 11.b, 11.c
Goal 12: Ensure sustainable consumption and production patterns	12.1, 12.2, 12.4, 12.5, 12.6, 12.7, 12.a
Goal 13: Take urgent action to combat climate change and its impacts	13.1, 13.2. 13.3
Goal 15: Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss	15.1, 15.2, 15.3, 15.5, 15.9

The construction industry and BREEAM can in many ways be compared to the space industry, where the systems engineering approach was matured (Brill, 1998). Even if elements or knowledge from a previous project can be reused, many things, such as customer demands, will be different. For a construction projects the technologies may be well known, but the design vision and context will be unique for each project. This means that both industries will have challenges which often are difficult to anticipate and that might have significant cost and time increases without a well working management (Shenhar and Bonen, 1997) (Ryan and Wheatcraft, 2017).

Even modern buildings seem to follow a relatively linear, sequential design process, but if work is done properly in early life cycle phases the chances are greater of avoiding recalls and rework in later stages. Investing in early lifecycle stages, also known as frontloading, is important as studies show that by the time the first 20 % of actual costs for a project has been accrued, 80 % of the total life cycle costs has already been determined (DAU, 1993). However, even though a left shift to invest in

early stages might seem like the ideal thing to do, there are reasons why it might be resisted by project managers and senior executives (Emes et al., 2007) (Farnham et al., 2009).

Naming of roles can also act as a barrier. Emes et al. (2012) point out the terminology issue surrounding architect and systems architect. Systems architect is a popular term used within the SE industry, and refers to the people involved in the top-level system design, which could create tension between them and the traditional construction architect. Another barrier to SE in the construction industry is perhaps related to its history, humans often like do things the way it has always been done, and currently there is low emphasis on SE in project management training and theory. Farnham et al. (2009) points out that it is quite common that projects are split in into separate segments where different consulting firms are in charge of the different life cycle phases. This cause SE application problems as each contractor see its phase as "the project" and the view on the project as a whole is mostly lost.

V-model applied to BREEAM. In this research the intention has been to connect BREEAM assessment to SE activities and methods as a way to systemize the steps and organize required artifacts and documentation. The proposition is that the V-model can be interconnected to the steps on how to get a BREEAM certification as illustrated in Figure 5. Modern buildings seem to follow a relatively linear, sequential design process (Emes et al., 2012), but this poorly accounts for impacts caused by delays and variations within an iterative process, such as design (Austin et al., 2000)

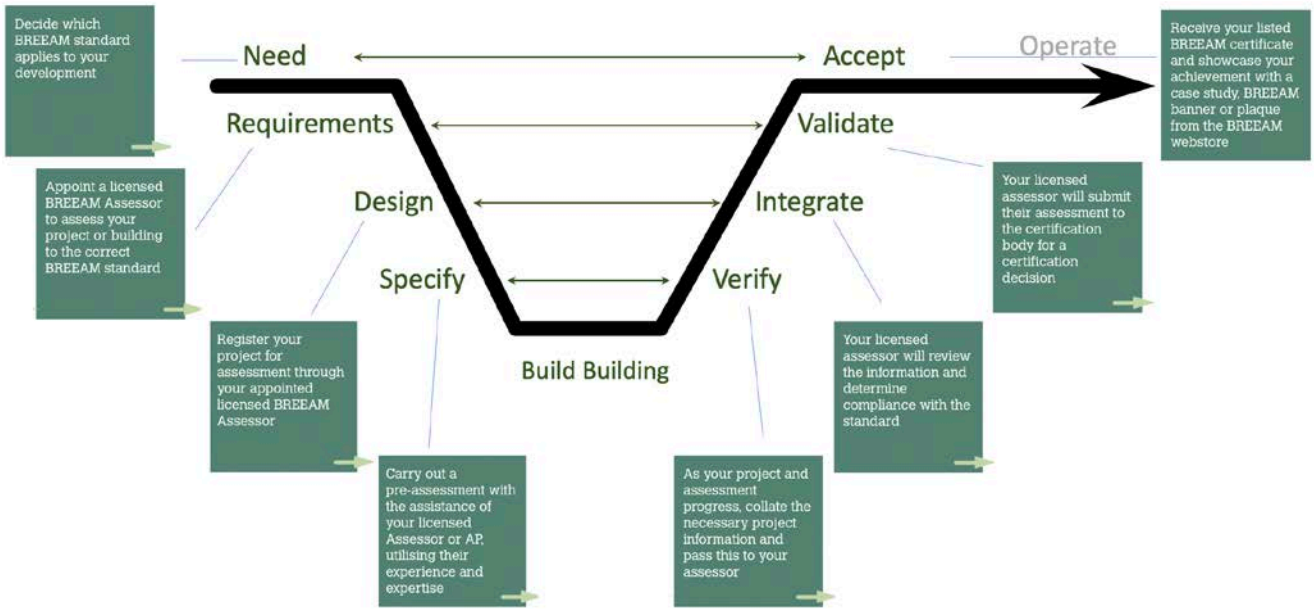

Figure 4: V-model and BREEAM (BREEAM.com, 2021a) (Davies, 2004)

Hierarchy diagram. The system of a building was put into a hierarchy diagram. This was done to illustrate the possible uses of systems engineering approaches in the construction industry and BREEAM as gleamed from the literature review. Not all parts of a building were included, and the overall level of detail is greatly simplified as a proof of the concept. The diagram has been placed in Appendix C for legibility. The design of a building can be divided into performance requirements that include cost, capacity, appearance, durability, strength, stability, thermal performance, comfort, weather tightness, fire protection, lightning, ventilation, security, safety, privacy and energy efficiency. These are all factors that needs to be included in a complete hierarchy diagram. In a full-fledged hierarchy diagram, all the BREEAM requirements will be linked to the various parts of the system, which in this case is the building. This way it is simpler to get an overview over what requirements belong to each part of the building.

An actual implementation of this concept will require someone outside of the BREEAM industry to design the software as an application. Model-based system technology will work by setting up the model and identifying the traceability. Once this is done only the right template should be added to get the right output. Different templates should be available to accommodate the variety of certification options. This is a complex process, but the perk is that it only needs to be done once. Systems engineering will help with the traceability required for BREEAM evidence. Then the documentation is something that can be extracted from the repository and printed out for precertification. A systematic hierarchy diagram combined with other systems engineering tools could be a way to systemize BREEAM and make it a less resource intensive process. For example, at least one article analyzed the construction industry from the systems engineering perspective and looked at modeling a building using SysML (Matar et al., 2017).

Survey results. The survey and the interview led the research into one of its last stages. It confirmed some of the initial thoughts and findings from the literature search, as well as uncovering some experiences of why buildings are applied for a BREEAM certification. The researchers were hoping the participants would have had more thoughts of the assessment process to share, because the survey results were more confirmation of what than new information. All the respondents seemed to have many sharing thoughts on BREEAM, and in Appendix D a selection of answers is provided. As the survey has open text boxes, the answers are different in terms of language and are open to interpretation.

Given the voluntary and anonymous nature of the survey dissemination, the researchers were pleased to receive 11 survey responses from a potential population of unknown size. The first question addressed whether the participants worked with BREEAM or not. Here, five were aware of the certification, but fortunately six were affiliated with the industry. This latter group included the following anonymous participants:

- Head of BREEAM in Norway;
- Market manager in Grønn Byggallianse (GBA),
- A GBA employee who works with QA (approval) on projects to be certified;
- One who was a BREEAM-NOR AP (accredited professional), BREEAM-NOR Auditor, BREEAM In-Use Auditor, RIF approved environmental advisor;
- A consultant who may advise customers to use BREEAM;
- Interviewed stakeholder, works as an environmental manager.

The second question asked why BREEAM is important to the construction industry. Most respondents focused their answers on the documentation aspects of the BREEAM certification and its use as a benchmark in the industry.

Question 3 asked about the barriers to BREEAM. Cost was a repeated answer, and one of the respondents argued that as of today many wish to build cheap. Even though BREEAM work hard towards being profitable, BREEAM certification costs money and is in any case an expense compared to the TEK level, which is the guide to the minimum requirements for construction in Norway.

Questions 4 and 5 it asked for reasons why a BREEAM certification is chosen. Most of the respondents answered that reputation was the main reason, while some also meant it is the SDGs or rental opportunities. Figure 5 shows the results from the multiple-choice responses for question 5. Ironically, none of the respondents mentioned energy savings.

Question 6 asked what the respondents think is the most important way a BREEAM certification contributes to the Sustainable Development Goals. The responses to this question mostly included that BREEAM embraces many areas that are important for sustainability. It also forces systematic work with project quality and documentation of actual quality, so one must implement the measures.

Question 7 addressed changes the participants would like to see within the construction industry and within the execution of BREEAM assessments. In short this included: regulatory and financial instruments that contributes to an increased use of BREEAM, increased systematization to lower the expenses and an increased focus on *why* a certificate is wanted, instead of not just having a certificate. However, it was mentioned that anything concerning the documentation should carefully considered, as it is what makes BREEAM valuable.

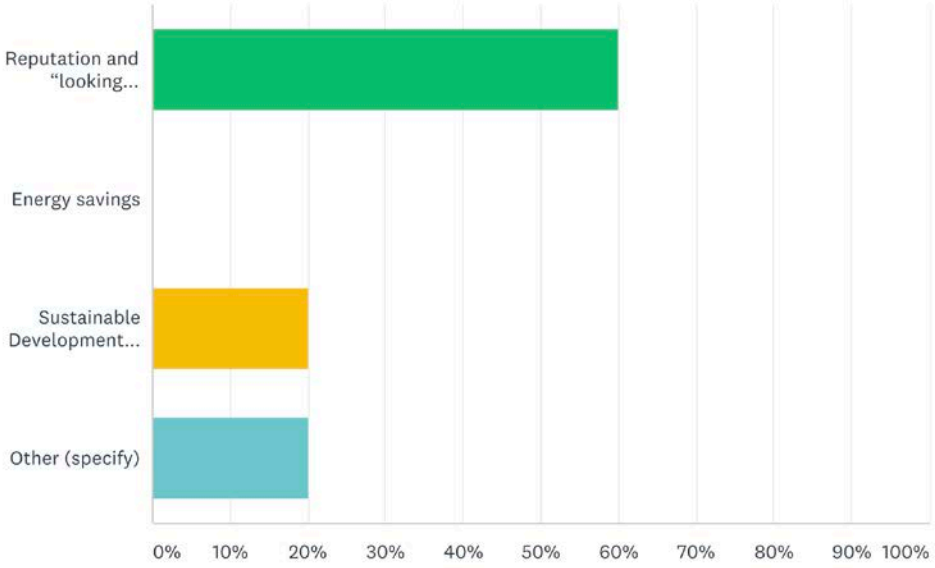

Figure 5: Motivation for BREEAM

Interview results. The interview was conducted in April and after all the survey responses had been processed. These results are reported in two parts; 1) the part where the questions from the survey were discussed, and 2) the part where the SE propositions were discussed. What follows is paraphrased summary from the researcher's own notes and reviewing the video recording.

In part 1, the interviewee clearly expressed that BREEAM is important as it pushes the industry towards sustainability, is unbiased and science based, and offers the same framework for building projects in many countries. The barriers to a BREEAM certification are awareness among landlords and investors, and the cost of the application process. On the other hand, it is chosen because of sustainability concerns, long-term investment benefits, and corporate reporting and image. It contributes to the SDGs in many ways: the projects are often energy efficient and use renewable energy, they do more for biodiversity, more for circularity, and they facilitate cooperation towards sustainable development. Desired changes in the industry consisted of a more digitalized processes related to sustainability and a process that leads to lowered costs for sustainability-related measures.

For the second part, the models from the thesis (Figure 4 and Appendix C) were presented, and the proposition to apply SE approaches explained. At this point only prototypes of the models were completed, but the idea of them was explained. As the models are not made into a software yet it is hard to dig into their potential usefulness. However, the interviewee seemed interested in any system that could systemize BREEAM while still keeping its values. As answered in part 1, the stakeholder is interested in more digitalized processes related to sustainability, and the systematization considered in this study appeared to be a reasonable way of achieving that.

Discussion

This research has looked at how systems engineering processes can help streamline the processes for a BREEAM certification. Through research, it has emerged that there is a limited presence of systems

engineering in the construction industry. The industry is becoming more ambitious when building, and with an increased number of stakeholders and requirements it could benefit from adopting an approach to design from systems engineering. The survey and the interview uncovered that many BREEAM stakeholders are eager to have the process systemized and eventually digitized. The discussion will continue with an evaluation of the results as they address the research questions, beginning with the sub-questions.

Why is BREEAM important to the construction industry?

BREEAM is important to the construction industry as it provides a good management tool and extensive guidelines for construction projects to become more sustainable and implemented in a more systematic way. It allows for innovation and rewards foresightful owners and renters who want to extend their responsible behavior beyond the applicable laws and regulations. Previous research, the survey and the interview suggest that the most prominent reason why BREEAM is chosen is reputation and social responsibility. BREEAM is also closely interconnected to the SDG targets, even though the targets are not the main direct reason why the certification is chosen.

The survey uncovered that many also see a BREEAM certification as a usable quality to reach a larger rental market. However, the literature review found that there is not a profitable rental market for BREEAM certified buildings today, although there is a prospect that certified buildings can achieve higher rental rates in the future. More and more companies have internal environmental strategies that say that they should only rent environmentally certified buildings. This is likely to be positive both for those who have a BREEAM certificate and as motivation for an increase in certified buildings in the future.

What are the barriers to a BREEAM certification, i.e., why do not more buildings qualify for a BREEAM certification?

The survey confirmed the findings from the literature search on the barriers to BREEAM. The most common answer is that it is costly to achieve. As one of the respondents to the survey said, "*one cannot cut on the documentation, this is what makes BREEAM so valuable*." Therefore, there is a need to systemize the process to make it less resource intensive, while keeping the values of its documentation. One thing that reinforces the finding that reputation is the most important reason is that all the measures and recommendations in BREEAM can be followed without achieving a certification. Then one merely adheres to the same steps without doing the documentation, and it is less resource intensive, but no certificate is issued. Achieving a certification is therefore most relevant to market exposed actors.

What systems engineering activities are recommended for the construction industry?

As the construction industry is becoming more complex, careful management is important to keep the quality, cost and time on track. Modern buildings seem to follow a relatively linear, sequential design process, which means adapting the V-model will be important as a linear model poorly accounts for impacts caused by delays and variations within an iterative process. The hierarchy diagram is a potentially effective tool that can be used to create linkages between the parts of a building or a building process to the requirements that apply to them. This would require a repository that could provide an overview and could be managed by other systems engineering tools.

Main research question: How can systems engineering processes help achieve a BREEAM certification?

The main research question is tightly connected to the last sub-question. As BREEAM looks at buildings belonging to the construction industry, much of what can be used there can also be applied to the BREEAM assessment method. As elaborated in the results chapter and the previous paragraph, the V-model and the hierarchy diagram are systems engineering tools that can be used to advantage

to achieve a BREEAM certification. The hierarchy diagram can be used to connect the parts of a building or a building process to the BREEAM targets. Since many of the BREEAM targets deal with more than just the physical building subsystems, such as risk management and waste management, a hierarchical diagram will have to address this as well. This has to be done either by integrating it into the diagram as separate branches, or by connecting each non-physical relationship to the various subsystems, such as linking the waste management directly to a certain subsystem or component. This also implies the need for digitization as manual record keeping is tedious and prone to errors.

The V-model emphasizes an early requirements analysis, as it is also the first step in the model. In SE a structured development process is key and customer needs, requirements and expectations are defined early in the life cycle. Also, a BREEAM certification requires an early adoption into the projects to be able to take as many BREEAM requirements possible into account. The early adoption leads to a higher sustainability rating in BREEAM certified buildings. A higher sustainability rating contributes to more of the SDG targets. As reported, BREEAM contributes to almost all of the SDGs.

Focus on the first SE activities shifts the focus to an early life cycle phase investment (frontloading) and may save construction costs related to redesign or rework in later phases of the building life cycle. Frontloading supports making the right decisions and taking the right choices over the entire life cycle. A digital tool that implements a hierarchy diagram that is interconnected to requirements can be used to systemize the whole process of achieving a BREEAM certification. This will make the process not only a checklist, but a systematic way to do BREEAM assessments.

This thesis also drew parallels between the construction and space industries. Every industry has a history of working a certain way which can create barriers when change and innovations are introduced. A barrier to SE methods could be as simple as a terminology issue with the roles of systems architect and architect. This may sound like a small problem, but then one must not forget that the architects in the construction industry are used to working in a certain way and having a certain responsibility.

Validation of the survey. With open answers to the survey, it is more difficult to compare the answers. Several of the answers are indirectly similar, and it is easy to interpret that the participants have roughly the same thoughts about BREEAM on certain points, even though the answers they give are expressed differently. This leads to the need to apply personal interpretations on the part of the researcher. Since the purpose of the survey was to get a picture of what people think about the certification and collect their inputs, there would was no alternative to doing it any other way than with such a short survey in the limited time allocated for this project. The positive aspect of the survey was that the respondents were not unduly influenced by the researcher while answering the questions.

Validation of interview. The interview was used as a validation of the responses from the survey and as a possibility to discuss the researcher's interpretations of the answers with an expert. While the two-way communication was both enjoyable and informative, at the same time, it was important not to put words in the mouth of the interviewee. However, even though a need for systematization and digitalization was identified, the person interviewed did not have experience with systems engineering, which undoubtedly affected the ability to give helpful feedback on the approach and the proposed solution.

Conclusion and future work

This research has worked to lead BREEAM and the construction industry forward by diving into how the industry can be further systematized with the help of systems engineering. SE is well developed in several other industries, such as the space industry. This is another complex industry that is constantly evolving, and can by this and in several other ways be linked to the characteristics of the

construction industry. At the same time, there are major differences and barriers that separate them, and these and general barriers to BREEAM have been clarified. There are several articles that have looked at SE in the construction industry, at the same time it is limited in number and no papers have been found that focus mainly on SE and BREEAM. This meant that this research could not rely solely on a literature review for perspective. The interview and surveys were helpful in giving insight into the BREEAM process and to explore the further development and the proposition central to this research.

Today, building design follows a relatively linear, sequential design process. The V-model and hierarchy diagram will be able to help the industry with innovation and systematization. SE has a high focus on the project´s early stages, which also applies well to BREEAM as the requirements need to be accounted for early to be able to reach the highest rating possible. The hierarchy diagram is a useful tool as it can be used to connect the parts of a building or a building process to the BREEAM requirements. Although the V-model is helpful as a linear model of a development life cycle, it accounts poorly for impacts caused by delays and variations within an iterative process. The model also emphasizes an early and prioritized requirements analysis.

The researchers have found it exciting to become acquainted with a topic that is still a relatively unexplored application for SE. What is quite certain after this research is that there is a need and desire for a renewal and systematization of BREEAM, preferably in the form of digitization. BREEAM has both advantages and barriers when it comes to implementation. This research has not been able to clarify if SE is the best way to solve the challenges experienced, but SE certainly offers opportunities. It is probably healthy for the industry to look for ways to renew itself and if a completely SE approach is not the solution, it can possibly lead the industry in the right direction.

Future work. Due to limited time and resources this research has focused on theoretical possibilities and benefits of applying SE approaches to BREEAM. In future research, development and testing of prototype software could put the findings into practice and support validation with stakeholders within the BREEAM environment. The hierarchy diagram should be pre-populated with the BREEAM requirements and be made usable. To be able to fully implement SE and the processes discussed in this thesis it will probably require testing, adaption and time. It is not a matter of course that an entire industry will participate in such an upheaval right away.

Reflections. The construction industry has a traditional way of working and there are very complicated projects where there is much more than just a physical product to be completed. BREEAM is a small part of the construction industry, but even to achieve a certification, all construction phases must be included. Hopefully, more research will be done on SE and BREEAM in the future, as part of additional research conducted on SE and the construction industry. We will then have to see if BREEAM or the construction industry takes inspiration from SE eventually.

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Biography

Hanne Helseth. Hanne holds a bachelor's degree in Energy and Environment in buildings from Oslo Met and a master's degree in Industrial Economics with Systems Engineering from the University of South-Eastern Norway. This report is the result of research done for her master's degree in 2021.

Cecilia Haskins. Cecilia is recently retired and continues in emeritus status with the University of Southeastern Norway (USN). Her career included over 30 years as a practicing systems engineer and over 20 years educating the next generation of engineers on the importance of systems approaches. She joined INCOSE in 1993 where she held a variety of leadership and other volunteer positions, was recognized as an INCOSE Founder, and continues to be active as a mentor and author. Her educational background includes degrees in chemistry, business, and eventually a PhD in systems engineering from NTNU.

Appendix A: Survey Questions

Question 1: Is BREEAM a part of your job?

Question 2: Why do you think BREEAM is important to the construction industry?

Question 3: What are the barriers to a BREEAM certification, i.e., what do you think is the reason why not everyone (every building) applies for a BREEAM certification?

Question 4: What do you experience as the reason to why people/companies choose to get a BREEAM certification?

Question 5: Which of the following do you see as the most important reason to why people choose to get a building certification, such as BREEAM? (1. reputation and looking sustainable from the outside, 2. energy savings, 3. Sustainable Development Goals, 4. Other)

Question 6: What do you think is the most important way a BREEAM certification contributes to the Sustainable Development Goals?

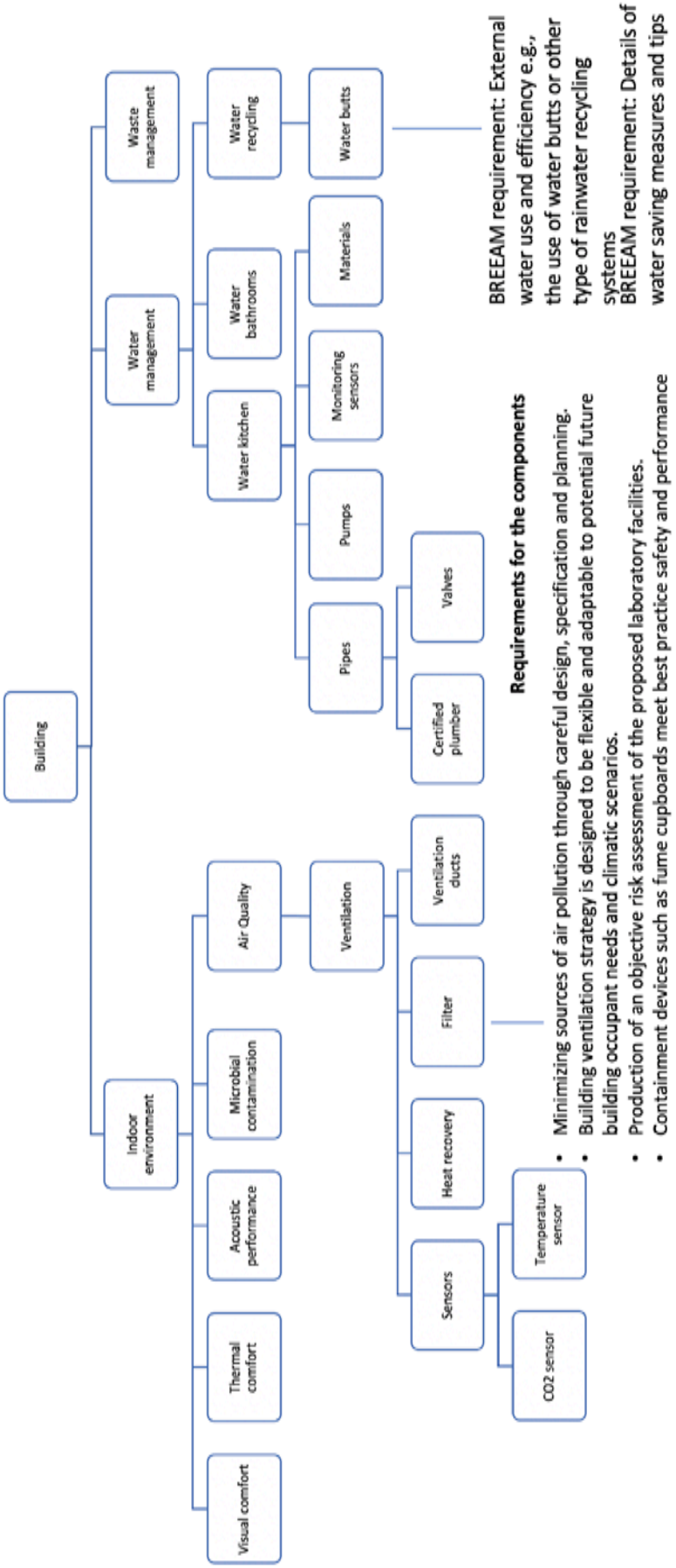
Question 7: What changes would you like to see within the construction industry and within the execution of BREEAM assessments?

Question 8: Anything else you would like to add?

Appendix B: BREEAM´s contribution to the SDGs

Sustainable Development Goals	**Relevant targets**
Goal 1: End poverty in all its forms everywhere	1.4, 1.5
Goal 2: End hunger, achieve food security and improved nutrition and promote sustainable agriculture	2.4
Goal 3: Ensure healthy lives and promote well-being for all at all ages	3.4, 3.6, 3.9
Goal 4: Ensure inclusive and quality education for all and promote lifelong learning	4.a
Goal 5: Achieve gender equality and empower all women and girls	None
Goal 6: Ensure availability and sustainable management of water and sanitation for all	6.1, 6.2, 6.3, 6.4, 6.5, 6.6, 6.a, 6.b
Goal 7: Ensure access to affordable, reliable, sustainable and modern energy for all	7.1, 7.2, 7.3, 7.a, 7.b
Goal 8: Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all	8.3, 8.4, 8.7, 8.8, 8.10
Goal 9: Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation	9.1, 9.4, 9.5, 9.a
Goal 10: Reduce inequality within and among countries	None
Goal 11: Make cities and human settlements inclusive, safe, resilient and sustainable	11.1, 11.3, 11.5, 11.6, 11.7, 11.a, 11.b, 11.c
Goal 12: Ensure sustainable consumption and production patterns	12.1, 12.2, 12.4, 12.5, 12.6, 12.7, 12.a
Goal 13: Take urgent action to combat climate change and its impacts	13.1, 13.2. 13.3
Goal 14: Conserve and sustainably use the oceans, seas and marine resources for sustainable development	14.1, 14.2, 14.3
Goal 15: Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss	15.1, 15.2, 15.3, 15.5, 15.9
Goal 16: Promote peaceful and inclusive societies for sustainable development, provide access to justice for all and build effective, accountable and inclusive institutions at all levels	16.2, 16.5
Goal 17: Strengthen the means of implementation and revitalize the global partnership for sustainable development	None

Appendix C: Hierarchy diagram



Appendix D: Survey responses

Question 1: Is BREEAM a part of your job? (What is your BREEAM related work?)

Respondent 1: Head of BREEAM

Respondent 2: Market manager in Grønn Byggallianse (GBA), who owns BREEAM

Respondent 3: Ansatt i Grønn Byggallianse som forvalter BREEM i Norge. Jobber med QA (godkjennelse) på prosjekter som skal sertifiseres.

Respondent 4: BREEAM-NOR AP, BREEAM-NOR Revisor, BREEAM In-g Revisor, RIF godkjent Miljørådgiver

Respondent 5: BREEAM is one of several tools in the toolbox that we may advise our customers to use

Respondent 6: Interviewed stakeholder, works as an environmental manager

Respondent 7: Respondents who do not work with BREEAM (a selection).

Question 2: Why do you think BREEAM is important to the construction industry?

Respondent 1: Helhetlig. Unngår sub-optimalisering på enkelttemaer. Robust fordi den krever dokumentasjon. Enkelt å kommunisere miljøresultater. Viser tydelig prestasjonsnivå, unngår grønnvasking.

Respondent 2: Helps the project to work systematically with environmental issues and lower the impact on climate from construction work

Respondent 3: BREEAM-manualen gir et godt styringsverktøy ifh ivareta bærekraft i et byggeprosjekt. Det favner alle prosjekter fra de som har ambisjon om å være "godt nok" til de som ønsker å dytte bransjen fremover og være innovative.

Respondent 4: BREEAM er et styringsverktøy for prosjektene til å bli mer bærekraftige. Det bidrar til å konkretisere FN's bærekraftsmål ned til hva Byggebransjen kan gjøre for å gjøre sin del av jobben. BREEAM inneholde de aller fleste miljøaspektene i bransjen, og bidrar til at bransjen strekker seg langt utover hva som er gjeldende lover og forskrifter.

Respondent 5: Allows focus on a wide set of environmental aspects for building

Respondent 6: 1. It pushes the industry towards sustainability. 2. It is unbiased and science based. 3. It offers the same framework for building projects in 80+ different countries

Respondent 7:

- Helps the project to work systematically with environmental issues and lower the impact on climate from construction work
- Jeg ser BREEAM som ett kostnadseffektivt middel for å anerkjenne verdien av bærekraftig utvikling. Det hjelper investorer, utviklere, design- og konstruksjons team å bruke ressurser mer effektivt.
- To use as the Benchmark for Carbon foot printing

Question 3: What are the barriers to a BREEAM certification, i.e., what do you think is the reason why not everyone (every building) applies for a BREEAM certification?

Respondent 1: Kostnader. Noen ønsker å bygge billigst mulig. et svært godt marked muliggjør det. For komplekst system.

Respondent 2: Knowledge, cost, market penetration

Respondent 3: Kunnskap. Vaner - slik har vi alltid gjort det. Bruker som ikke etterspør bærekraft. Bærekraft er ikke en del av byggherrens strategi. Når det er sagt, så er vår erfaring at mange av disse barrierene er på vei til å forsvinne. Byggebransjen har mange framoverlente aktører som viser vei og inspirerer andre.

Respondent 4: BREEAM sertifisering koster penger, selv om vi prøver å jobbe mot at det skal være lønnsomt så er det uansett en utgift sammenlignet mot TEK nivå. Bygg som sertifiseres får tilbakebetalt investeringen først ved salg, og ikke alle bygger for å selge, men å eie over tid (f.eks. stat og kommune). Her benyttes BREEAM ofte som styringsverktøy uten at prosjektene nødvendigvis sertifiseres. Lønnsomhet er det viktigste, slik er det i alle bransjer. Hadde det ikke vært dyrt ville samtlige BREEAM sertifisert.

Respondent 5: Cost, usefulness (you can do all the things in BREEAM w/o getting the certification). Certification most relevant to market exposed actors.

Respondent 6: 1. Awareness among landlords and investors. 2. Cost

Respondent 7:
- Needs to be developed for each country according to the local system
- Cost

Question 4: What do you experience as the reason to why people/companies choose to get a BREEAM certification?

Respondent 1: Omdømme, bankens krav, eiers krav og noen leietakere krever det. en måte å nå interne bærekraftsmål på

Respondent 2: Market position, finance demands, market demands, part of their strategy

Respondent 3: Byggherre med bærekraftsmål i sin strategi. En fremtidig leietaker/bruker som etterspør miljøambisjoner og -kvaliteter.

Respondent 4: De som skal leie ut byggene (kontorer) ønsker dette for å treffe et større uteleimarket. Flere og flere selskaper har interne miljøstrategier som sier at de kun skal leie miljøsertifiserte bygg. De som selger byggene gjør det for å treffe en større kundegruppe. De store oppkjøpsfondene har i sine miljøstrategier at de kun skal investere i miljøsertifiserte bygg. Igjen, alt handler om økonomi/lønnsomhet. Stat og kommune sertifiserer langt fra alle bygg, men noen, med de bruker BREEAM som styringsverktøy og krever at prosjektene skal bygges etter BREEAM, men at de ikke skal sertifiseres.

Respondent 5: Marketing, need to "do something"

Respondent 6: 1. Sustainability concerns. 2. Long-term investment benefits. 3. Corporate reporting and image

Respondent 7:
- A well-known certificate with a clear outcome
- Image

Question 5: Which of the following do you see as the most important reason to why people choose to get a building certification, such as BREEAM? (1. reputation and looking sustainable from the outside, 2. energy savings, 3. Sustainable Development Goals, 4. Other)

Respondent 1: Reputation and “looking sustainable” from the outside

Respondent 2: Reputation and “looking sustainable” from the outside

Respondent 3: Sustainable Development Goals

Respondent 4: Other; Økonomi og Lønnsomhet!!! Men selvfølgelig er "looking sustainable" også viktig for de fleste, de har egne miljøstrategier etc.

Respondent 5: Reputation and “looking sustainable” from the outside

Respondent 6: Reputation and “looking sustainable” from the outside

Respondent 7: two votes on Reputation and “looking sustainable” from the outside, one vote on “Sustainable Development Goals” and one on “other”.

Question 6: What do you think is the most important way a BREEAM certification contributes to the Sustainable Development Goals?

Respondent 1: Dokumenterte kvaliteter. Kan ikke "snakke seg til" et sertifikat. Unngår grønnvasking. Helhetlig.

Respondent 2: Tvinger frem systematisk jobbing med prosjektkvalitet og dokumentasjon av faktisk kvalitet

Respondent 3: BREEAM favner mange områder som har betydning for bærekraft og setter fokus på områder som man tidligere ikke nødvendig ble ansett som en del av miljømålene. Eksempler på slike er lokalisering, vannforbruk og påvirkning på natur/økologi.

Respondent 4: BREEAM setter helt konkrete krav til mange/alle miljøaspekter, slik at vi ikke kun bygger "energieffektive bygg" slik vi gjorde tidligere.

Respondent 5: Focus on more than one aspect of building performance

Respondent 6: Several aspects: BREEAM projects are often energy efficient and use renewable energy, they do more for biodiversity, they do more for circularity, and it facilitates cooperation towards sustainable development

Respondent 7: To be required in building national codes

Question 7: What changes would you like to see within the construction industry and within the execution of BREEAM assessments?

Respondent 1: Økt fokus på HVORFOR de ønsker sertifikat. Ikke bare for å få sertifisering.

Respondent 2: Lavere klimapåvirkning, bedre prosjektprosesser, bedre inneklima, etc.

Respondent 3: Regulatoriske og finansielle virkemidler som bidrar til at aktører som per i dag ikke vurderer BREEAM, blir "dyttet" i den retning. Eksempler på slike er det som DnB gjør, med å sette krav til BREEAM ved bank-lån/finansiering av byggeprosjekter.

Respondent 4: Selve sertifiseringsprosessen bør systematisere i større grad. Slik at kostnadene blir lavere. Men robust dokumentasjon er det som gjør BREEAM verdifullt, så det er en balansegang.

Respondent 5: -

Respondent 6: More digitalized processes related to sustainability, lower cost on sustainability-related measures

Respondent 7:

- Include Embodied Emission
- Sustainability

Question 8: Anything else you would like to add?

No relevant answers.