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Promoting Energy Efficiency in the Built Environment through Adapted BIM Training and Education

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Abstract: The development of new climate change policies has increased the motivation to reduce energy use in buildings, as reflected by a stringent regulatory landscape. The construction industry is expected to adopt new methods and strategies to address such requirements, focusing primarily on reducing energy demand, improving process efficiency and reducing carbon emissions. However, the realisation of these emerging requirements has been constrained by the highly fragmented nature of the industry, which is often portrayed as involving a culture of adversarial relationships and risk avoidance, which is exacerbated by a linear workflow. Recurring problems include low process efficiency, delays and construction waste. Building information modelling (BIM) provides a unique opportunity to enhance building energy efficiency (EE) and to open new pathways towards a more digitalised industry and society. BIM has the potential to reduce (a) waste and carbon emissions, (b) the endemic performance gap, (c) in-use energy and (d) the total lifecycle impact. BIM also targets to improve the whole supply chain related to the design, construction as well as the management and use of the facility. However, the construction workforce is required to upgrade their skills and competencies to satisfy new requirements for delivering BIM for EE. Currently, there is a real gap between the industry expectations for employees and current training and educational programmes. There is also a set of new requirements and expectations that the construction industry needs to identify and address in order to deliver more informed BIM for EE practices. This paper provides an in-depth analysis and gap identification pertaining to the skills and competencies involved in BIM training for EE. Consultations and interviews have been used as a method to collect requirements, and a portfolio of use cases have been created and analysed to better understand existing BIM practices and to determine current limitations and gaps in BIM training. The results show that BIM can contribute to the digitalisation of the construction industry in Europe with adapted BIM training and educational programmes to deliver more informed and adapted energy strategies.

Keywords: building information modelling (BIM); energy efficiency (EE); skills; training; digital construction

1. Introduction

With the aim to reduce energy use in buildings, the European Commission has defined a clear (2020) target to decrease energy consumption by 20% and to increase the proportion of energy supplied by renewable sources by 20% [1]. The reductions in energy consumption and carbon emissions have become essential objectives that have been considered in strict policies and regulations at the European and national levels. For example, the recast of the Energy Performance of Buildings Directive (2010/31/EU) imposes strict energy efficiency (EE) requirements for new and retrofitted buildings.

Some previous studies are looking for solutions that will pave the way for a fundamental change to systematic delivery, observable and productive energy-efficient buildings through building information modelling (BIM) training in order to efficiently achieve European energy and carbon reduction objectives [2]. Engineering actors need to develop into a well-trained, world-leading generation of BIM decision-makers, professionals and blue collars for EE [3]. Moreover, a world-leading BIM training platform for EE is needed, nurtured by an established community of interest [4]. Research and related assessments were discussed in Europe across the building value chain (including lifecycle and supply chain), highlighting EE linkages, qualification priorities, distribution networks, skills and accreditation processes, while highlighting training deficiencies and the potential for progress [3]. This includes (a) better identifying future skills needs; (b) clear entry routes and clear career progression paths; (c) clear, standard means of recognising skills; (d) exploring ways to make apprenticeships more flexible; (e) reviewing current skills and capacity delivery mechanisms by industry; and (f) reviewing career planning, training and development approaches with a commitment to rationalisation.

BIM technologies and related implementations have grown steadily over the years, intending to encourage more successful multidisciplinary partnerships aiming to complete lifecycle and supply chain integration [5]. BIM includes the process of producing and maintaining data and information about the built environment throughout its life cycle, from concept design to decommissioning [6] (see Figure 1). Over the past decade, the BIM technology has brought significant transformative power to the architecture, engineering and construction/facility management domain (AEC/FC) in terms of its fundamental lifecycle and integration of the supply chain and digital collaboration [7]. Such technology enacts and exposes methods and techniques that can transform the construction industry, for which global yearly spending is forecasted to exceed $11 trillion by 2020 [8].

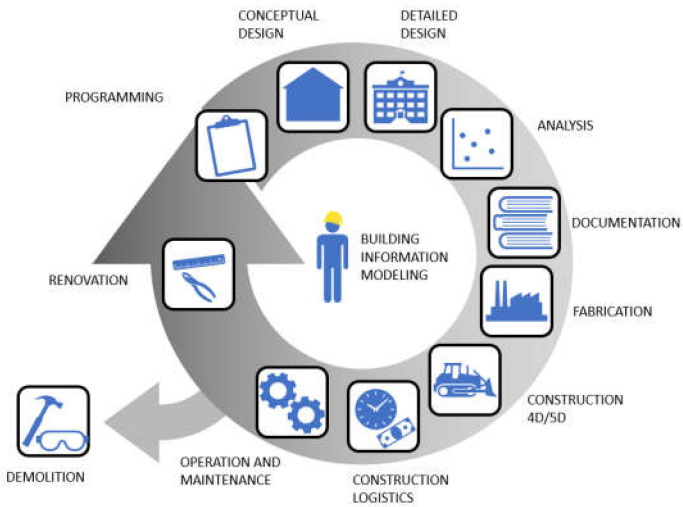

Figure 1. Building information modelling (BIM) applications across buildings' lifecycles.

Several studies aimed to harmonise energy-related BIM expertise and skills available in Europe and to achieve a global consensus through a BIM for the EE External Expert Advisory Board (EEAB) [9]. The emphasis is on developing a mutual recognition system of qualifications and certifications between different member states, accompanied by an effective strategy to ensure that methods of qualification and training are retained and unified [3].

The construction industry has continuously changed in the field of BIM in recent decades, through developments and global technical and management advances [10]. The identification of this change and the corresponding adjustment of existing training programmes to develop new skills and competencies for construction professionals remains a critical area to address in the industry.

This paper explores the gaps and requirements for the implementation of BIM for EE with associated BIM training by carrying out a thorough analysis and identification of the relevant skills and competences. Consultations and interviews were used as a method for collecting the requirements and a portfolio of best practice use cases was collected to understand existing BIM practices and to identify the existing limitations and shortcomings in BIM training in Europe.

In general, this paper provides the following contributions:

- Adaption and utilisation of an online web portal to collect and analyse best practice case studies with a view to delivering BIM for EE training and education in the EU construction projects;
- Conducting a consultation process involving key BIM experts and training organizations within the EU construction sector around BIM for EE;
- Elaborating a comprehensive set of requirements to inform future BIM training for upskilling the next generation of construction professionals to implement EE for the construction sector.

The work presented in this study is part of the EU H2020 BIMEET project, which aims to deliver training and education for BIM implementation for EE.

The remainder of the paper is as follows: The authors present a history of BIM for EE in Section 2. Section 3 outlines the overall methodology of the study and Section 4 explains the outcomes of the analysis in terms of the BIM for EE training requirements. Then, Section 5 provides a consolidated list of requirements. The conclusions are presented in Section 6.

2. Related Work

With the recent digitalisation trend of the construction industry, the EU community has released regulations to promote improved energy performance in buildings, taking into account cost-efficiency, local conditions and requirements (local climates and cultures significantly influence energy consumption in buildings) [11]. The global market for construction is set to grow by more than 70% by 2025 [12]. Most countries have already set the goal of achieving ambitious targets. For example, the UK construction agenda aims to achieve (a) a 33% reduction in both the initial construction cost and the entire life cost of assets; (b) a 50% reduction in greenhouse gas emissions in the built environment; (c) a 50% reduction in the overall time from start to finish for new buildings and restored assets; and (d) a decline by 50% in the trade gap of construction goods and materials [13,14].

There is also an increased interest, in the engineering sector, to find novel technical solutions to decrease energy demand, improve process efficiency and minimise carbon emissions [15]. The process of designing, re-purposing, constructing and operating a building or facility involves not only the traditional disciplines but also many new professions in areas such as environment and energy [15]. In addition, there is an increasing alignment of interests between those who design and construct a facility and those who subsequently occupy and manage it, and this requires dedicated skills and competencies to address multi-objective sustainability (including energy) requirements [16]. The built environment digitalization supports the clean environmental agenda by firmly placing this sector on the road to sustainability and sustainable growth; The European Commission industrial policy recognises the strategic importance of the construction industry, as witnessed by the Energy Efficient Buildings Public Private Partnership launched under the FP7 recovery plan and now funded in H2020 [17].

There is a wide range of training and education suppliers in the construction industry in Europe, with an equally diverse set of training courses. Such training courses aim to improve the communication process by using new virtual educational methods to create skilled and deep-seated groups, as well as the quantity and quality of educated and trained professionals in the built environment to support the ambitious BIM agenda across Europe [18].

Offers of education and training focus on a small subset of the industry; main courses concentrate on construction and design, not briefing or planning, which impacts the BIM effect on improving asset operations [19]. Furthermore, the research also shows that training courses target more technical participants, rather than blue-collar workers or management teams, and strategic positions within organisations. BIM training and education also seems not to address the large infrastructure projects entirely but predominantly focuses only on buildings [20].

In recent years, some strategies and methods have been proposed in the construction industry in an effort to improve its services [20]. Some strategies have been comprehensively reviewed and explored by Cooper et al. [21], and a summary is provided in this section. According to Hibberd and Djebarni [22], the idea of procurement raises awareness of the issues involved in questioning generally accepted policies and setting strategies; therefore, new approaches to the design and construction process need to be considered. Latham [23] argues that reducing project process variations will improve performance and make significant cost savings. The main advantage of such an improved project design and construction process should be to optimise the predictability of construction projects. This advantage can only be realised when the project is a multi-disciplinary project involving collaboration between disciplines [21,24]. Information technology (IT) can help to coordinate and manage a new project if its function and the relationship between the parties are properly stated and understood [23]. The current perception is that consistency in a construction project is a challenging task, as the supply chain constraints for each project and partnerships are complex. Despite the lack of a "normal" project plan, the construction process includes several well-recognized models, such as the Royal Institute of British Architects' (RIBA) work plan [25].

The development of building energy models (BEM) has provided the ability to embed additional information required to run energy simulations. EnergyPlus [26] is an energy analysis and thermal load simulation tool that allows building performance simulations such as lighting/day-lighting, heating, ventilation and air conditioning (HVAC), service water heating, and on-site energy generation. The objective of the BEM application case is to apply accurate energy monitoring, real-time decision support systems actuators and the identification of consumption patterns that can impact the overall energy profile in a building pilot. In order to undertake this BIM optimization, we have tested in previous work the use of Simergy [27], a building energy modeling (BEM) tool that facilitated the creation of a digitalized BIM model of a sports facility FIDIA pilot and have also interfaced with the EnergyPlus [28] software based on which we deployed our simulations.

With such software interoperability, the information can be seamlessly shared between two or more software applications. In a BIM-based energy simulation, it is possible to satisfy the requirements of energy simulation and pass data flawlessly from a BIM to an energy output simulation system (e.g., EnergyPlus [26] or DOE-2 [29]). In 1999, Bazjanac et al. [30] showed the benefit of using BIM and achieving true interoperability for simulating energy in buildings through numerous case studies. We demonstrated the high potential of achieving cost interoperability, time savings and the elimination of duplicate data and errors in the implementation of the energy simulation model [31].

Training and education around BIM can be taken at the individual and the collective level in relation to the experience of the team and project-based requirements. Such educational programmes should also consider environmental psychology, which emphasises the effect of past behaviour, information, perceptions, emotions, social networks and institutional trust on individual attitudes with a view to progress towards more informed environmental strategies [32].

3. Methodology

In this paper, we present quantitative and qualitative analyses for the identification of the gaps and skills required to improve BIM practices for EE. The methodology adopted in this study utilises computing data analysis techniques, including interviews and consultations for determining the requirements and specifications for delivering adapted BIM training and education in the construction industry.

3.1. General Methodology

This study aims to address the following research questions:

1. How does one capture the transformation of the construction industry in relation to BIM and its integration for achieving energy efficiency?

2. What are the requirements, limitations and gaps in BIM training and what strategies are required to promote BIM for energy efficiency in Europe?

To address these questions, we are proposing a methodology for capturing the industrial trends, requirements and gaps, and show what strategies and training are required to ensure the effective implementation of BIM for energy efficiency. We adopt a use case-based approach within a community of BIM stakeholders and experts with a view to contribute to the digitalization of the construction industry and associated high-level BIM strategy evaluation.

The methodology utilised to conduct the analysis identifies three main parts:

- A user engagement tool in the form of an online web platform to support data capture and analysis while maximising the engagement of users by creating a community of practice around the BIM for EE theme;
- An online web-based, Europe-wide BIM use cases collection template and questionnaire from which 38 best practice case studies have been collected;
- An expert panel consultation process in Europe consisting of one workshop (around 40 participants in total), a series of 15 semi-structured interviews with key industry representatives and other study partners meetings.

We have adopted an incremental methodology underpinned by the energy-bim.com platform to enable the management and exchange of data resources and experiences relevant to BIM training.

In the first phase of the consultation process, we aimed to define the best practices, regulatory awareness and BIM gaps for the EE domain and to determine a collection of training requirements. Such consultations have been facilitated through a series of workshops to discuss stakeholders' awareness, perception and behaviour with a view to identifying the primary obstacles to BIM applicability for EE. The identified barriers were discussed and debated from a variety of socio-technical perspectives. This first phase has aimed to identify the gaps, requirements and competencies in the field of BIM for energy efficiency (Section 4) by leveraging on the quantitative analysis process facilitated through the use of web technologies via the energy-bim.com platform and a portfolio of use cases.

In the second phase of the consultations, we have focused on a qualitative analysis by validating the outcome of the analysis process undertaken in the first phase of the consultations (Section 5). This has involved the identification of the relevant gaps and requirements based on intensive discussions and debates within the consortia members and our EU and international experts in relation to projects' objectives.

The consultation and workshops were run with a total of 40 experts, including construction companies and professionals, advisory councils, professional organisations, consultants, politicians, and educational and training bodies.

As part of the methodology process presented in Figure 2, the authors have undertaken a set of actions, which focused on (i) conducting research consultations while optimising ongoing interactions with the expert panel and BIM community of practice; (ii) using collaborators, expert panel representatives and a group of practitioners to register on a study platform with authoritative BIM information sources; (iii) create a framework for categorising all retained best practice use cases using two dimensions, i.e., the lifecycle (from briefing to recycling) and supply chain (i.e., from architects and structural engineers to blue-collar workers); and (vi) create a structure for the selected use cases implemented directly on the study web portal. Such measures lead to increased group visibility by publishing use cases research and encouraging individuals to register if they wish to access study materials around BIM for energy efficiency.

The energy-bim platform has helped to identify the BIM training requirements for EE and also aims to resolve the issue of knowledge dissemination in, and the involvement of stakeholders with, BIM practices and construction. The scope of the web platform is to recognise the gaps and requirements as an initial phase, as well as to support the project implementation process by providing the necessary training to building professionals while developing their BIM skills for their energy-efficient and low-carbon expertise, also enabling them to access and use the current best practices and regulations in the field of BIM for EE.

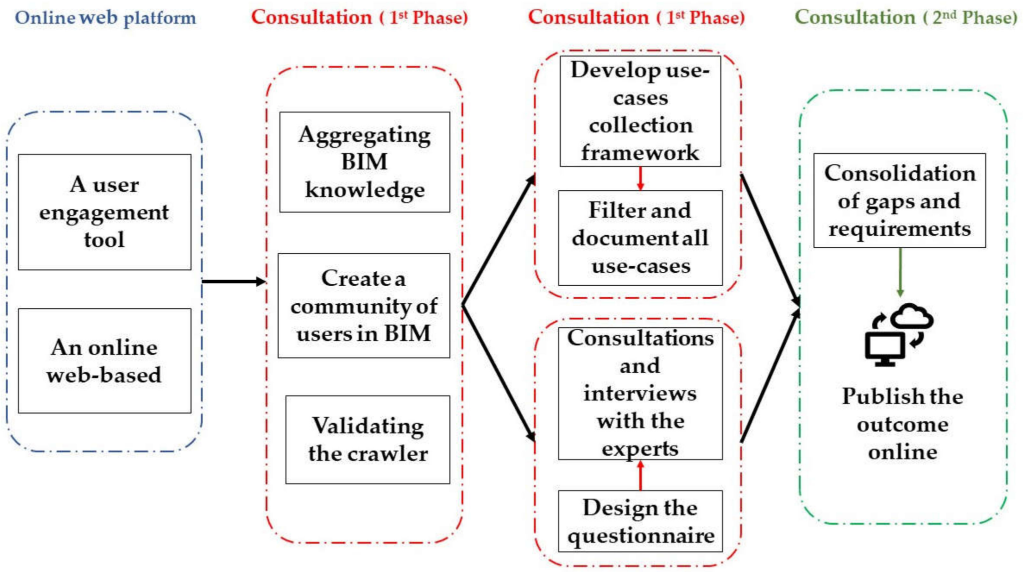

Figure 2. General requirements methodology.

3.2. *A Supportive Community Platform Capturing BIM Training Requirements*

The authors have adapted and redeveloped a web-based platform system that offers access to BIM resources and provides an open user community environment for capturing the requirements and gaps for BIM training. The online platform is context-based, solution-free, scalable and polymorphic, with modules that enable BIM information searching and knowledge discovery using different technologies such as social networks and semantic searches [5].

Overall, the energy-bim.com platform has been used to:

- Enable partners and construction stakeholders to input best practice use cases in the field of BIM for EE from their countries;

-To create a community of construction professionals around BIM for EE that can share resources and data to achieve a higher order of collaboration in the construction industry;

- A platform to disseminate and host BIM for EE training and educational programmes for the European countries after the completion of the BIMEET project.

3.3. *Researching Sampling Techniques*

The methodology has focused on community knowledge extraction involving project consortia partners, expert panel members and skilled BIM experts. Such experts have engaged in validating the use case collection template and supported the questionnaire elaboration. Based on the use case collection template, the consortia partners have been asked to provide five relevant use cases from their country of origin to cover a broader European BIM perspective. Use cases have been collected from Greece, Finland, France and the UK followed by an analysis and requirements elicitation. From the community of experts, interviews and consultations have been conducted as a means to validate the findings in the assessment of the use cases and to lead to a more comprehensive BIM training set of requirements. One workshop for consulting the BIM community on the existing BIM practices, areas of improvement in BIM training and education for energy efficiency has been organised in Brussels. As part of the workshop, brainstorming sessions with experts were organised with a view to understanding the current gaps in BIM for EE, while also aggregating new best practice use cases.

3.3.1. Searching Authoritative URIs

Partners and experts of the BIMEET project have been asked to contribute and register a list of authoritative URI (Uniform Resource Identifier) sources to support in the process of the use case collection. These sources have been stored within the energy-bim.com platform and indexed for crawling with a view to generating BIM knowledge for the community. Such sources have been integrated into the searching service, enabling users to extract best practices, regulations and to support the requirements definition and training. As part of the energy-bim.com platform, a specialised crawler service has been implemented to help with information searching based on the provided URIs within a BIM knowledge repository for a community of users. A human-based process has been utilised to validate these relevant sources and searching URIs based on specialised keywords. These have been verified by experts in the field of BIM and supported by the consortium partners. Such keywords include BIM, energy efficiency, best practice, case study, training and education.

3.3.2. Searching Education Indexed Engines

To support with the process of the requirements elicitation, we have conducted searches in indexed educational engines such as Scopus and Google scholar based on which key BIM concepts have been determined, and additional use cases practices have been identified and included in the use cases repository.

The authors conducted a comprehensive critical review of the academic literature, international standards, regulations and major economic and political developments around BIM, training and education, energy systems and their management. The study corpus was then divided into chronological and thematic groupings. Following the observation of new challenges and opportunities that arise imminently from a mismatch in these projections, key concepts were identified from the related fields. The rest of this section details the scope of the subject domain review and initial observations.

Based on the literature review, it was identified that BIM for EE, as an emerging field, covers many other areas and requires a well-considered scope. Hence, we disregarded papers that focused on national or building level energy management, or which only considered the design phase of energy systems.

To capture the recent technological change in the construction industry, the authors have only considered recent publications and concentrated the analyses on BIM training for EE. As shown in Figure 3, since around 2005, a pattern of increased popularity around BIM in the construction sector has been observed. The sources filtered to those deemed most relevant and influential, to a final bibliography of circa 547 references.

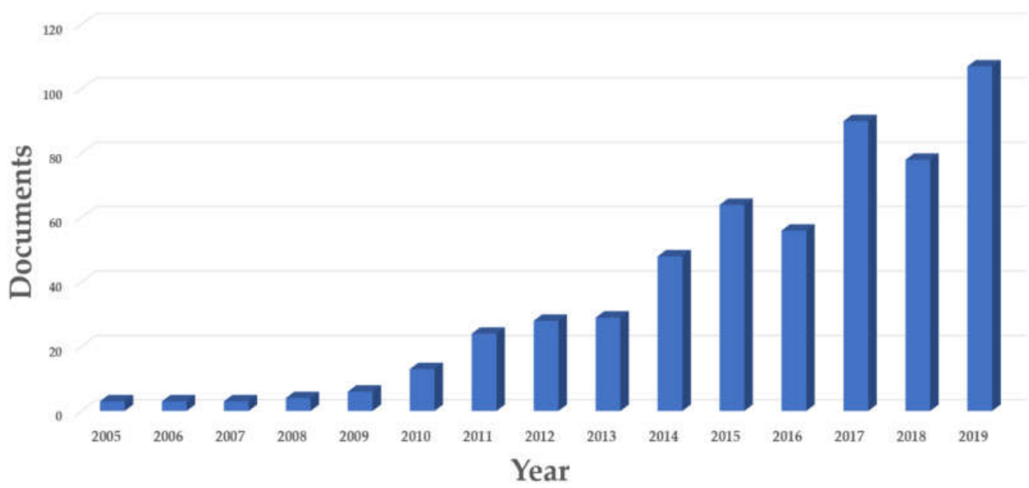

Figure 3. BIM's success over time as the number of relevant Scopus publications per annum for the energy efficiency analysis.

4. Results

The results process focused on performing a thorough analysis of the best practice use cases as well as identifying the gaps and skills around BIM for energy efficiency. The outcomes of the requirements capture process are focused on six months of data collection supported by consultations and interviews.

4.1. Collection of Case Studies

Based on the repository of use cases, the authors aim to determine how BIM can support the development of energy-efficient designs, and the construction and maintenance of buildings in various ways. BIM can improve and ease the implementation of energy-efficient buildings by facilitating improved data sharing and communication flows, and examples of the practical benefits include the speeding-up energy simulations and discovering useful solutions, encouraging the participation of end-users, setting and commissioning criteria, and providing opportunities for proactive maintenance management. The AEC/FM industry can leverage BIM for greater EE in the development of new designs as well as in retrofitting and renovation projects, amidst the positive impacts that BIM has brought within the industry. Table 1 provides two best practice use cases where the life cycle applicability is aligned with eight work stages of the 2013 RIBA work plan. Many variables were evaluated and listed below based on the usage cases. The structure of the best practice use cases collection template has been elaborated during the consultations and workshops sessions. Each parameter and variable included in the collection template has been discussed and validated by the project partners, construction stakeholders and BIM for EE experts from the European countries in relation to project objectives.

A set of automated analyses has been applied using the web platform on 38 use cases collected from a European community of BIM experts in the construction industry. The results show the distribution of impacts according to criteria such as discipline, the type of building and the lifecycle stage.

Table 1. Examples of BIM for energy efficiency (EE) best practices (energy-bim.com).

Variables/Use Cases	Use Case 1	Use Case 2
Title	Intelligent management and control of the HVAC system: SPORTE2 project	Shopping centre using around half the energy of a typical development
Use Case Type	Research and Development	Real-world application
Target Discipline	Facility Management	Architectural design/Structural engineering/HVAC engineering/Electrical engineering/Builders/Construction companies/Building managers
Target Building Type	Public building	Commercial building
Lifecycle Applicability	In use stage	"Preparation and brief, concept design, developed design, technical design, construction, in use"

Table 1. *Cont.*

Variables/Use Cases	Use Case 1	Use Case 2
Brief Description	The European Sport and Recreation Building Stock accounts for around 1.5 million buildings or 8 per cent of the building stock as a whole. Such facilities are distinctive because of their physical nature, their energy consumption profiles, people's usage patterns within, ownership criteria, and comfort needs [33]. SPORTE2 aims at managing and optimising the triple dimensions of energy flows (generation, grid exchange and consumption) in Sport and Recreation Buildings by developing a new flexible and modular BMS focused on smart metering, centralised control, efficient decision making and multi-facility management [34]	The project is a large shopping and commercial development centre located in Pori, southwestern Finland. Designed for LEED Gold, the architecture has received a global BIM award for its creative use of modelling during design and construction [35]
Impacts	Energy savings up to 30% Emission reduction up to 30%	In this project where 50% of energy savings were achieved compared with the Finnish Code and 50 %t savings in water consumption compared to conventional retail growth in Finland, BIM was used. Measured power output from geothermal heat pumps and free energy benefits for heating and cooling have also exceeded expectations

4.1.1. Analysis of Use Cases Type

Based on the data collected over four months in a portfolio of 38 best practice use cases around BIM for EE, we have applied statistics as part of the requirements elicitation process. We have used key variables such as use case type, discipline, building type, project type and project lifecycles to discover under-developed BIM aspects within the use cases database.

Figure 4 investigates the distribution of different BIM for EE projects utilising the use case type as an evaluation criterion. The experiment presents in percentages how many best practices use cases within the existing portfolio have been identified, namely (1) research and development, (2) real-world applications and (3) BIM guidelines. According to the study, it was found that research and development covers 17 use cases, the real-world framework has 13 use cases and the BIM guideline has only one use case. Similarly, Figure 5 shows the distribution of the best practice use case studies based on different discipline categories such as facility management, architecture design, structural engineering, mechanical engineering and other.

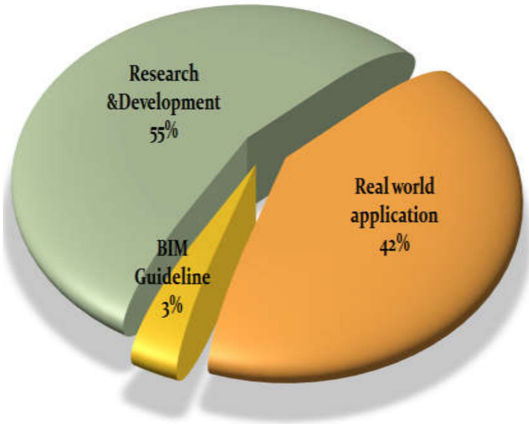

Figure 4. Use case type analysis.

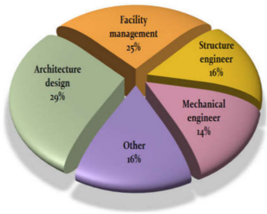

Figure 5. Target discipline analysis.

4.1.2. Analysis of Target Discipline

The use cases portfolio is organised according to the target discipline. Figure 5 provides the use case distribution based on the target discipline, showing that BIM is used more commonly in architectural design and facilities management projects, while BIM is used to a lesser extent in structural engineering and mechanical engineering projects. The analysis has determined that various target disciplines utilised BIM for EE such as architectural design, facility management, structural engineering and mechanical engineering, and others, in the study. Architectural designers were targeted at 29% and facility management at 25%, while structural and mechanical engineers were targeted at 16% and 14%, respectively.

4.1.3. Evaluation of Buildings Type

In this section, the authors analyse the use cases based on the type of building projects that adopted BIM for EE. According to Figure 6, a majority of BIM projects are for public buildings, whereas residential, commercial and industrial buildings are less popular in adopting BIM. The most popular building type projects are public buildings, while there is a lower percentage of residential, commercial and industrial buildings.

As shown in Figure 6, BIM is applied in 7.65% of these case studies to public buildings, 17.5% to domestic buildings and the rest to commercial and industrial buildings.

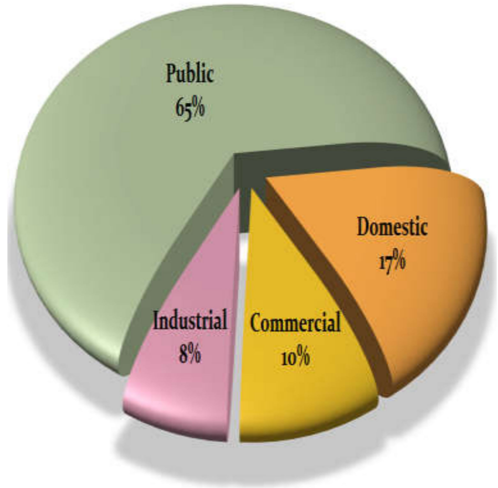

Figure 6. Building type analysis.

4.1.4. Analysis of the Lifecycle Stage

As we have used RIBA stage lifecycles for the study, this section is intended to evaluate the relation of the lifecycle stages for every best practice use case. Figure 7 shows that 56% of the projects are reported using BIM for EE in the design phases during the project's lifecycle, while the in-use process represents 13% of the project lifecycle.

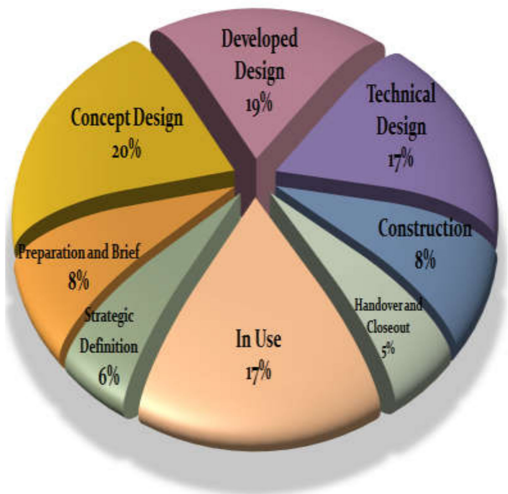

Figure 7. Lifecycle stage analysis.

4.1.5. Analysis of the Project Type

The authors investigate the set of use cases that have adopted BIM and classify based on the project type variable. From the study reported in Figure 8, it was observed that a majority of use cases use BIM for existing and new buildings, whereas extension and renovation projects tend not to adopt BIM. There are 84% of project types, and new build projects and the remaining project types are renovation and extension projects, respectively.

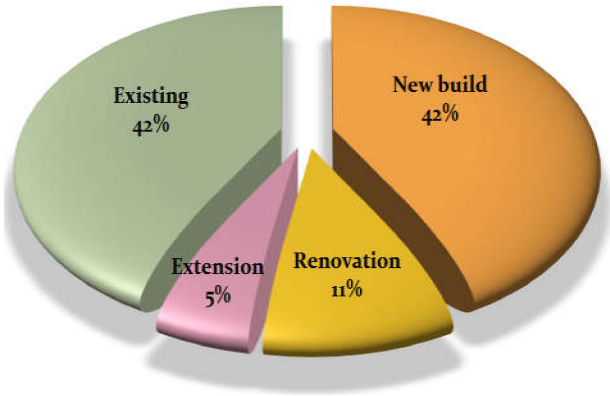

Figure 8. Analysis of project type.

4.1.6. Analysis of Impact and Target Discipline

The first variable used for the study is the target discipline, which the authors compared with the impacts to find the corresponding association between the target discipline and the impacts of use cases. Table 2 presents the majority of use cases that implement BIM for EE associated with the facility management discipline. However, some use cases implement a BIM for EE methodology for multiple disciplines, with significant impacts being seen on energy and water savings. To the present, BIM has been further implemented with more convincing results for some building types. In particular, certain cases of retail and office buildings provide good examples of how BIM has supported the need for requirements management, simulations and the search for solutions to realise ambitious energy targets. For instance, the availability of 358 uses of BIM data contribute to a 25% energy reduction in facility management (use case 1). Likewise, BIM has been effectively applied to a shopping centre (use case 2), using around half the energy of a typical development, and results associated with commercial buildings report energy savings of about 50% and water consumption savings of 50%.

Table 2. The relevance of the discipline and its effect.

Use Cases/Target Discipline	Architecture Design	Facility Management	Structure Engineer	Mechanical Engineer	Other	Impacts
Reduce the gap between energy consumption expected and real in buildings [36]		✓				A 25% drop in energy compared to baseline estimates.
Minimising operational costs and carbon emissions through matching supply with demand for heat and electricity production [37]		✓				Leading to a 32% increase in profit and a 36% reduction in CO2 emissions.
Intelligent management and control of HVAC system [38]		✓				Up to 30% of energy saving up to 30% emission reduction
Friendly and affordable sustainable urban districts retrofitting (FASUDIR) - Heinrich-Lubke housing area, Frankfurt, Germany [39]		✓				GWP reduction of 60%. Operational energy consumption reduction of 35%

Table 2. *Cont.*

Use Cases/Target Discipline	Architecture Design	Facility Management	Structure Engineer	Mechanical Engineer	Other	Impacts
(FASUDIR)- Budapest Residential District [39]		✓				Operational energy reduced by 35% and energy running costs reduced by 35%
A revolutionary integrated framework for tracking and evaluating energy performance in buildings (the project tackles the difference between expected and actual energy performance in buildings) [40]		✓				Achieve building energy performance
Parametric design of a shelter roof in an urban context [41]	✓	✓	✓	✓	✓	Early BIM for parametric optimisation through simulations
Building as a service [42]	✓	✓	✓	✓		Optimise energy performance in the application domain of non-residential buildings
Delivering highly energy-efficient hospital centre [43]		✓				41% reduction in fabric loss heat, a 29% reduction in carbon emissions, a 15% reduction in overall energy usage
Shopping centre using around half the energy of typical development [44]	✓	✓	✓	✓	✓	50% energy savings, 50% savings in water consumption
Design of energy-efficient library with high architectural goals [44]	✓	✓	✓	✓	✓	Energy optimisation results impacted the building and HVAC design
Use of an optimisation tool to compare hundreds of concepts energy efficiency before the actual design [45]		✓				Use of an optimisation tool has the potential to save money and time while directing to more optimal energy efficiency solutions.

By using the RIBA Plan of Work for lifecycle applicability, we can also observe the associations between lifecycles and the impact of BIM on EE. This reflects increasing the requirements for sustainability and BIM, and it allows the creation of simple, project-specific plans. The RIBA Plan of Work organises the design process into different stages, including briefing, designing, constructing, maintaining, operating and using the building. According to these stages, various ways of use and levels of impact can identify BIM for EE. A taxonomy of the different evaluation criteria used in the use cases analysis is presented in Figure 9.

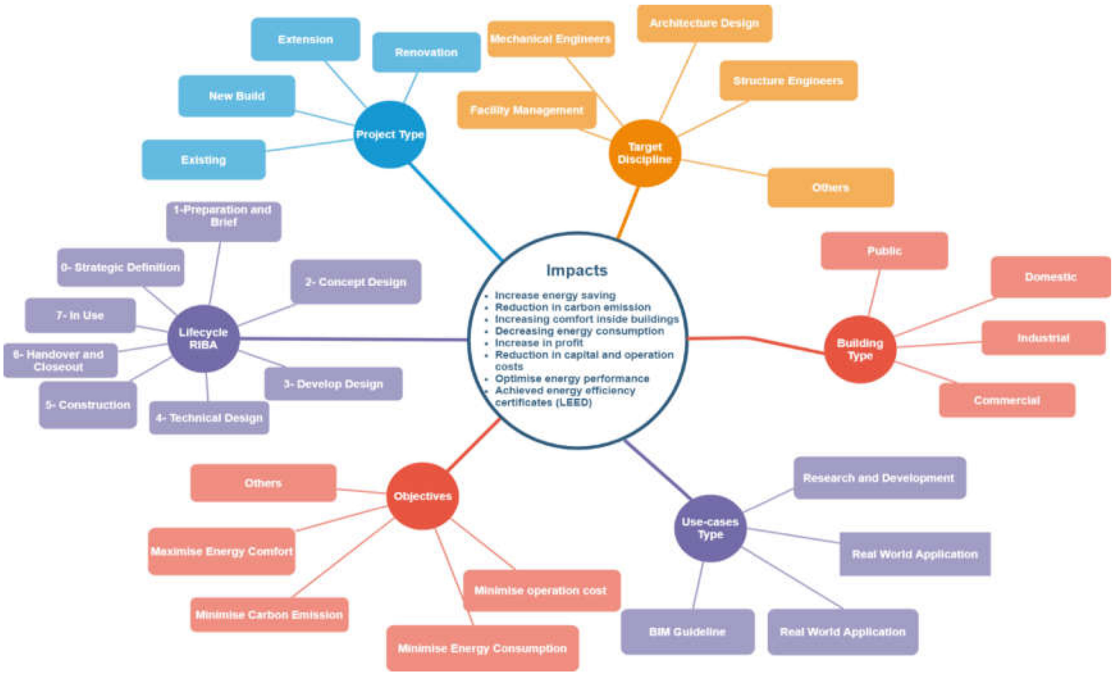

Figure 9. Ontology of use case concepts of BIM for EE.

4.2. Interview Collection

The paper provides an in-depth analysis and gap identification about the skills and competencies involved in BIM training for EE before integration with the following training models and strategies. Consultations and interviews were used to determine the requirements, and a portfolio of use cases has been created to understand the existing BIM practices and determine the existing limitations and gaps in BIM training.

As it was not simple to obtain access to use cases in BIM and EE in all of the consortiums' countries, it was apparent that this trending topic was not sufficiently mature in many European countries. Therefore, we conducted interviews with 15 BIM industry experts from Europe to obtain a more global understanding of the maturity associated with the application of BIM to EE, and to determine the gaps and requirements in this field. An interview was designed using a questionnaire with three sections, which are the experiences of BIM and energy, BIM for EE skills and using BIM for EE in projects.

For the selection of interviewers, we used two criteria in order to choose a panel of experts of BIM for EE. In terms of the first criteria, we have selected the panel of experts' interviewees who provide broad coverage of the representation of the entire lifecycle of the construction project and the supply chain. They represent the blue-collars, designers, contractors and manufacturers. For the second criteria, the credibility of experts, we targeted interviewees for credibility and invention in the field of BIM, and they either play roles in the BIM agenda or the BIM training agenda within the European countries level.

4.2.1. Experience of BIM and Energy

Figure 10 shows the BIM expertise of the experts, and this includes research in BIM assessment, architecture service, design and construction, and EE training and durability of construction. In addition, we interviewed experts with different levels of expertise in the applied technology for design and engineering project delivery, sustainable designs and physical buildings.

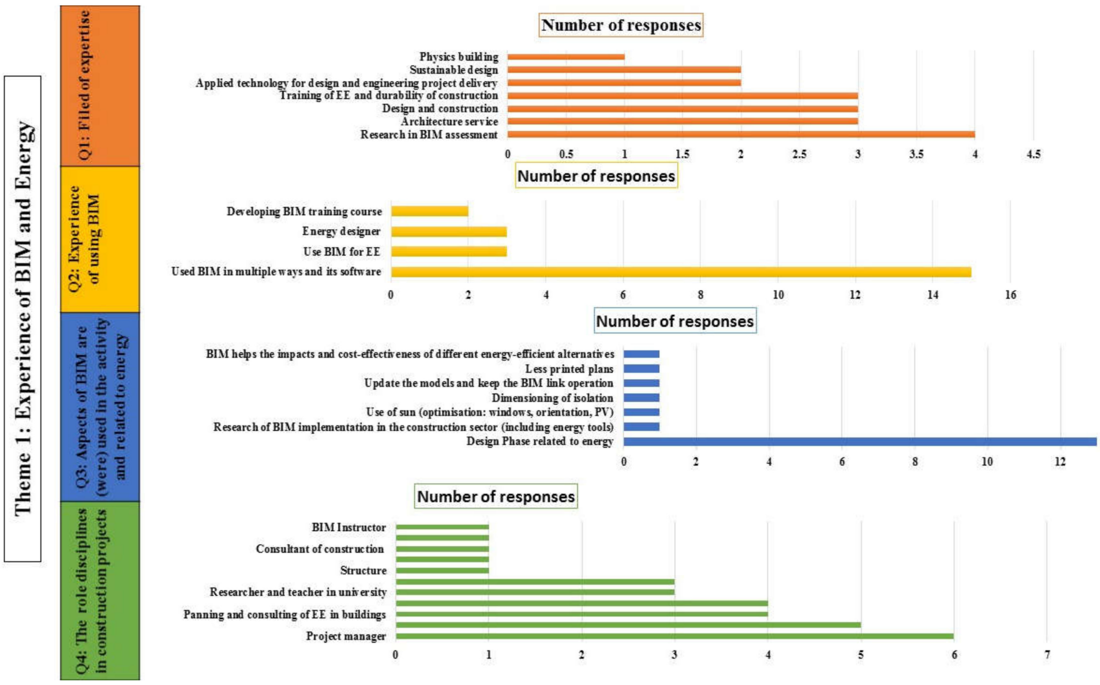

Figure 10. The number of responses for experiences of BIM and energy.

The main aim of the interviews was to approach the experts with experience in a wide range of BIM activity, so the aggregated feedback was expected to be comprehensive and inspired by industrial expertise. Figure 10 presents the experts' historical experience. Two-thirds of the experts have experience using BIM in multiple ways, and they also have extensive experience with BIM software.

4.2.2. BIM for EE Skills

Experts were asked to specify the skills required to improve BIM management, with an emphasis on EE. The skillsets that were identified by the experts as being necessary for handling BIM data for EE associated with the role of designers, contractors and blue-collar workers. Several skills are highlighted by the experts for designers, and they are presented in Figure 11: (1) ability to use CAD programmes and other EE software, (2) knowledge of the principle of EE and sustainability, (3) maintaining data of different varieties and solutions, (4) formulating the model using EE simulation programmes, and (5) good communication between designers, clients and suppliers. A high percentage of feedback identifies as an essential skill for managing BIM for EE the ability to use CAD programmes and other EE software as well as a knowledge of the principles of EE and sustainability.

The identified contractor skills (see Figure 11) in BIM for EE are (1) skills to separate the information required, (2) knowledge of how to use BIM, (3) BIM training to enable the implementation of BIM construction projects with energy space, and (4) collaborate with designers to manage the information from the model. The four skills have almost the same degree of importance as recorded from the interviews. Therefore, these skills should be considered for a further training course in order to improve BIM competencies in the field of EE.

Some of the primary tasks in industrial construction activity are carried out by blue-collar workers and are presented in Figure 11. The identified skills are (1) knowledge of how to read the plans and separate the information needed, (2) communication with clients and contractors to ensure that best practices are met, and (3) simulate use case scenarios for the design.

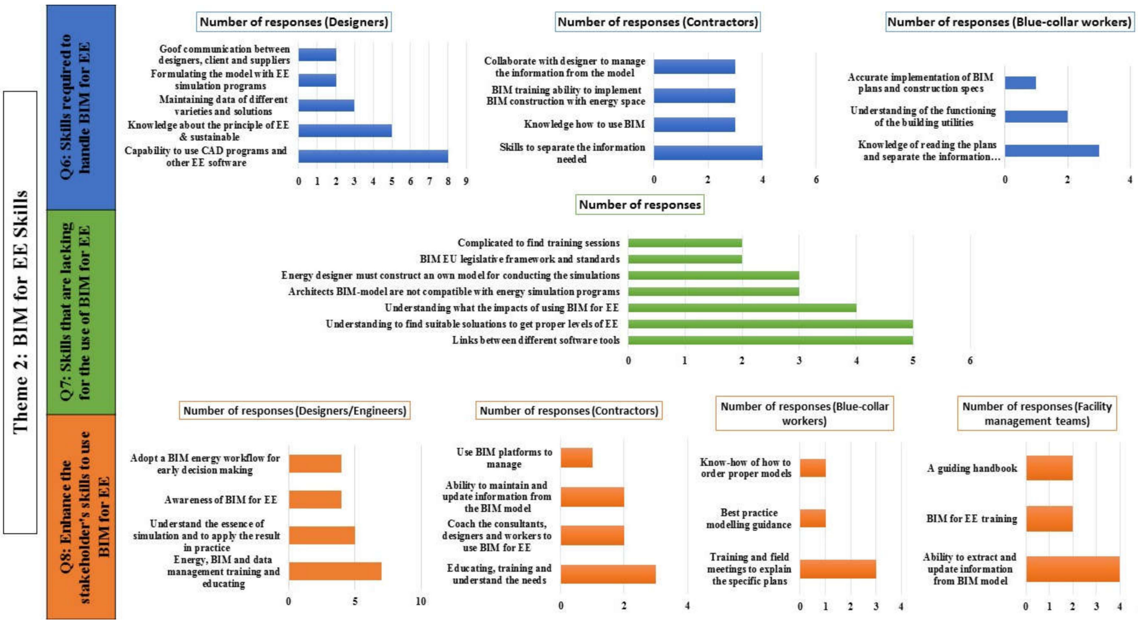

Figure 11. The number of responses for BIM for EE skills.

In addition, we observed a set of common gaps for which recommendations are made to improve BIM for EE. Such common skills are related to knowledge about principles of BIM and EE, skills to separate the information needed and to realise good communication between the disciplines in projects.

Based on the experience of the interviewed experts, Figure 11 shows the skills that are currently lacking for the use of BIM to achieve EE in the construction field. Moreover, a high degree of importance has been given by the experts to the shortage of skills related to the link between different software tools, understanding and finding good solutions to attain an exceptional level of EE, and understanding the impacts of using BIM for EE.

Furthermore, almost 40% of the experts highlighted that other gaps necessary for using BIM in EE are related to architects' BIM models which are not compatible with energy simulation programmes, energy designers who should construct their models to conduct the simulations, BIM EU legislative frameworks/standards and the difficulty association with locating training sessions. These limitations and the lack of skills need to be addressed by developing appropriate training programmes in the use of BIM to achieve EE. To enhance the stakeholders' skills for using BIM for EE in projects, the experts highlighted several methods to improve these skills according to (1) blue-collar workers: workers, technicians, etc., (2) designers/engineers, (3) contractors and (4) facility management teams.

For blue-collar workers, the experts mentioned that the hosting of training and field meetings to explain the specific plans is an efficient way of improving the BIM skillsets. The experts also reported as essential skills the "know-how" of how to order proper models, finding best practice modelling guidance and the ability to change old attitudes in order to add value obtained from using BIM. One of the experts highlighted that blue-collar workers should not be held responsible for this sort of work and that this is beyond their job description and knowledge.

Similarly, specific methods to enhance the designers'/engineers' skillsets include BIM data management training and education, understanding the essence of simulations and how to apply the result in practice, increasing the awareness of BIM for EE, and adopting a BIM energy workflow for early decision making (see Figure 11). Moreover, based on the experts' consultations in Figure 11, there are several ways to enhance the contractors' skills, as a third of the experts have listed education and training as requirements to understanding BIM and improve its use. Other experts have highlighted novel methods to improve skills, including encouraging consultants/designers/workers to use BIM for EE, maintaining and updating information from the BIM model, visualising the model and using BIM platforms to manage product data.

Furthermore, the facility management teams require different ways to develop their skills for the use of BIM for EE. Based on the experts' recommendations, a solution that is considered important is the ability to extract and update information from the BIM model. One of the experts said that it is a necessary condition to increase BIM practices in construction projects and to enhance facility management teams. According to the experts' consultation, these methods have been proposed to enhance the stakeholders' skillsets, and corresponding training is required to use BIM for EE.

To support BIM training for EE on an organisational level, experts have provided several insights on what aspects should be addressed. As shown in Figure 11, the experts have reported that organisations should support BIM training for EE. More than 60% of experts expressed that their organisations undertake training programmes on the utilisation of BIM in energy design. Further, more than 20% of the experts consider that the teaching of software programmes for the use of BIM for EE is important alongside continuous learning on the issue of standardisation and to improve the skills of BIM coordinators.

4.2.3. Using BIM for EE in Projects

The experts explained the advantages of using BIM for EE with respect to the project lifecycle. According to the experts, there are many benefits to using BIM for EE during the lifecycle of the project. Figure 12 demonstrates that several benefits are to be realized during the design phase: BIM can improve the design process and increase energy performance. In addition, advantages include managing banks of materials, analysing them and giving better information as a result as well as fewer mistakes. The linking of monitoring operations and maintenance measurements to BIM was mentioned by four of the experts as significant benefits. Others highlighted other benefits, for instance, the ability to make collaborative work on the same model version, ability to link the building system with future users' behaviour and ability to use energy simulations to inform more realistic design work. All of these benefits confirm our previous findings that stable BIM training courses are required.

Figure 12. The number of responses for using BIM for EE in projects.

Based on the questionnaire, there are many benefits to using BIM for EE. However, there are several barriers to using BIM for EE in real industrial applications. Figure 12 illustrates that a significant obstacle is a lack of understanding of the use and potential of BIM, followed by the diversity of software tools and a lack of expertise in using these problematic programmes.

Some barriers are listed twice, such as tight schedules, the high cost of programmes, internet connectivity issues, achieving a proper BIM model and a lack of fundamental skills. Other experts mentioned other barriers, such as the absence of information management standards and the lack of real case studies where BIM and EE were successfully implemented.

Figure 12 highlights that the majority of experts identify the need to carry out performance evaluations and to institute appropriate training mechanisms for BIM. BIM tools should be utilised in the early stage of the project. Incentives on the adoption of BIM for EE are determined to be essential recommendations. These recommendations will feed into the implementation phase of the study and will be considered when developing training programmes for using BIM for EE.

As shown in Figure 12, some of the organisations have no training programmes for their staff and as mentioned in the interviews, use experienced staff to train the other members of the team. Other organisations appear not to have time to provide energy simulation training, while others do not support the training, considering the training to be unimportant; in contrast, other institutions are reported to be working on integrating BIM training.

5. Consolidation of Gaps and Requirements

In this paper, the authors have critically reviewed and investigated the current BIM practices landscape and determined the requirements for developing a BIM training scheme to address current industry collaboration problems on projects. This solution aims to facilitate and guide the collaboration processes of construction teams, taking into account the requirements of construction practitioners. The outcomes of the first consultation analysis phase and the resultant list of requirements from the first stage of consultations have been validated by the experts and BIM specialists in the project consortia. This second validation consultation phase has focused on qualitative analysis with a view to filter and consolidate the list of requirements and competencies for delivering BIM for EE in the European construction sector.

Further, some requirements for developing a training scheme have been identified and are classified into two main categories: (a) socio-organisational and legal requirements and (b) technical requirements. In addition to contributing to the growing body of BIM adoption and collaboration knowledge, this report underlines the importance of BIM training as the foundation for future research and development in this area.

This section identifies a set of general and specific requirements for developing BIM skills, competencies and training, with a particular emphasis on EE, as informed by the use case analyses. This subsection provides the list of gaps which were identified by the use case analyses and validated by the interviews conducted. Table 3 presents the gaps identified in the study of the use cases.

Table 3. Identified requirements based on use cases analyses.

No.	Parameters	Requirements and Training
1	Use case type	Users need training in understanding and applying BIM guidelines (see Figure 4).
2	Building type	Training is required to enhance skills and competencies for using BIM for industrial and commercial buildings (see Figure 6).
3	Project type	Training is required for expanding BIM applicability for renovation and extension projects (see Figure 8).
4	Target discipline	Training is required for education on BIM methodology towards mechanical and structural engineers (see Figure 5).
5	Lifecycle stages	Training is needed to address other RIBA stage lifecycles, such as strategic definition, preparation, and brief construction, handover and closeout (see Figure 7).

Table 3. *Cont.*

No.	Parameters	Requirements and Training
6	Impacts on discipline	Increase BIM applicability and impact for architecture and design, structural engineers and mechanical engineers (see The first variable used for the study is the target discipline, which the authors compared with the impacts to find the corresponding association between the target discipline and the impacts of use cases. Table 2 presents the majority of use cases that implement BIM for EE associated with the facility management discipline. However, some use cases implement a BIM for EE methodology for multiple disciplines, with significant impacts being seen on energy and water savings. To the present, BIM has been further implemented with more convincing results for some building types. In particular, certain cases of retail and office buildings provide good examples of how BIM has supported the need for requirements management, simulations and the search for solutions to realise ambitious energy targets. For instance, the availability of 358 uses of BIM data contribute to a 25% energy reduction in facility management (use case 1). Likewise, BIM has been effectively applied to a shopping centre (use case 2), using around half the energy of a typical development, and results associated with commercial buildings report energy savings of about 50% and water consumption savings of 50%.Table 2).

Table 4 presents a summary of the findings and associated requirements as recorded in the interviews. The experts have specific inputs for BIM training for industrial roles such as designers, blue-collar workers and contractors. A particular emphasis was on the BIM software tools and the need to deliver specialised training programmes which can help actors to understand and utilise such tools. At the organisational level, the experts have presented several strategies that can be adopted to improve staff BIM skills and practices.

Table 4. Gaps identified in the interviews.

No.	Parameters	Requirements
1	Skills required to handle BIM for EE	**Designer:** Formulating the model with EE simulation programmes, maintaining data of different varieties and solutions. Good communication between designers, clients and suppliers. **Blue-collar worker:** Simulate use case scenarios for the design; communication with clients and contractors to ensure best practice. **Contractors:** Knowledge of how to use BIM and training ability to implement BIM for EE, collaborate with the designer to manage the information from the model (See Figure 11).
2	Skills that are lacking for the use of BIM for EE	The link between different software tools, finding suitable solutions to promote BIM in EE, understanding the impacts of using BIM for EE (See Figure 11).
3	Specific ways of enhancing the stakeholders' skills for the use of BIM for EE	**Blue-collar workers:** Training and field meetings to explain the specific plans. **Designers/Engineers:** Energy, BIM, data management training and education and understanding the essence of simulation and how to apply the results in practice (See Figure 11).

Table 4. *Cont.*

No.	Parameters	Requirements
4	BIM training for EE by organisation	**Designers:** Teaching software programmes; BIM for EE, continuous learning: issue with standardisation, skills of BIM coordinators and BIM managers should be defined. **Contractors:** Education and training should be adapted based on the specific requirements. **Facility management teams:** they need the ability to extract and update information from BIM models (See Figure 12).
5	Common barriers to the use of BIM for EE	Lack of understanding of the use of BIM, limitations in the use of different software tools, lack of expertise in using BIM programmes (See Figure 12).
6	Recommendations to enhance the use of BIM for EE	Assess the performance and appropriateness of the training mechanisms; tools should be utilised in the early stage of the project; incentivise the adoption of BIM for EE (See Figure 12).

In particular, the conducted analyses have reflected the need for awareness-raising across all stakeholders in the building lifecycle to form the basis of initial training and more comprehensive education programmes around BIM for EE. The analyses have reported that key strategies would be to tackle the performance gap and to improve the effectiveness and efficiency of the provision and manipulation of data relating to the energy efficiency of buildings and their sustainability in general. In terms of the performance gap, the main challenges identified are as follows:

- Poor understanding of policies and standards;
- General lack of awareness of BIM and energy efficiency;
- Unable to build effective models;
- Limitation of models (e.g. interoperability);
- Unable to use models (extract data from and enter data into).

This should be the case for both new build and refurbishments, and should cover the design, construction and management. Such outcomes have informed the development of learning objectives and associated competencies matrix that are now adopted by the European Commission to deliver BIM training and education around BIM for EE in the construction industry.

As construction projects involve multi-discipline/multi-actor collaborations during the project lifecycle, the results from the survey also explored the current Information Communication Technologies (ICT) and collaboration practices among the teams on typical BIM construction industry projects. Setting up and maintaining a collaborative team environment is an essential task in collaborative construction projects. Based on the analysis results, most respondents agreed that project managers are responsible for preparing the construction project's collaborative environment, and they were of the opinion that the responsibility for this varies from one project to another. The establishment of online communities requires a robust mechanism for controlling the interactions between end users and their access to resources. With the proposed energy-bim.com platform, the authors intend to contribute to the establishment of online BIM communities that enable access to knowledge and provide more informed construction practices. This assumes the existence of trust between users within such a system, thereby overcoming some of the restrictions to sharing and information exchange, which is a significant problem in the context of online communities. For instance, in the context of such a community, clients and providers from the construction industry can contribute resources in addition to using funds provided by others (at different times and for access to differing services). This symbiosis of technologies, knowledge representation and artificial intelligence related to sustainability in constructing and maintaining (potentially complex) real-world models can enable new business models such as online communities, online marketplaces and advertising-supported sites, and can offer facilities for the use of user profiles (including personal data), with a view to achieving a higher order of BIM knowledge integration.

6. Conclusions

In this paper, we addressed the requirement elicitation criteria phase for the identification of gaps and new strategies for delivering BIM for EE. The authors used a participatory and incremental approach and involved an expert panel with a view to reaching key stakeholder communities in order to help identify and then screen and analyse past and ongoing projects related to EE involving aspects of BIM.

This work aimed at assembling evidence-based quantitative/measurable scenarios and use cases that demonstrate the role of BIM in achieving energy efficiency in buildings across the whole value chain. The authors have recorded 38 best practice use cases from the field of BIM for energy efficiency and conducted an in-depth analysis to determine the gaps in BIM for energy efficiency training and possible areas of improvement. These use cases are published and maintained on the energy-bim.com platform and are accessible to potential users across Europe. The resulting evidence has been structured by stage and discipline, highlighting stakeholder targets, ranging from blue-collar workers to decision-makers.

As part of the paper, the primary objective was to identify the gap between the demand for skills and the learning for BIM application in EE. We used a consultation-driven approach and use cases aggregation techniques assisted by a semantic search engine to promote the submission of BIM questions with collections of relevant ontological principles to capture "real" BIM information and to look for best practices. The consultation process has helped to define BIM-related skills as well as the corresponding demand for energy efficiency in buildings in order to identify BIM training requirements across the value chain (from blue-collar workers to middle/senior level workers). Therefore, in this paper, we have addressed two major objectives: (a) identify the essential BIM skill gaps and associated training programmes based on the current situation evaluation and (b) deliver a set of requirements as derived from the consultations, interviews and use cases analysis.

In general, we have identified the need to establish an open BIM community of BIM actors with access to resources, and to facilitate training and education programmes for overcoming some of the constraints around sharing and exchanging BIM information, which is a significant problem in the field. Specifically, we have identified that BIM is applied only for certain public building types and disciplines, whereas commercial and industrial buildings seem to require more skills and competencies on how to adopt BIM for EE. Similarly, we have determined that BIM is predominantly implemented for in-use construction stages and more expertise is required for other lifecycle stages such as the definition and preparation. In terms of impact, we have observed that the implementation of BIM can significantly reduce energy and water but other construction domains necessitate additional expertise for integrating BIM. At the discipline level, we have identified that blue-collar workers and engineers need training in BIM for EE as well as at the organisational level, where designers, contractors and facility management teams should be integrated in future BIM training.

In this paper, we have analysed the specific context of the EU to understand the current state-of-the-art around BIM for EE. This research reflects the construction industry within developed economies, as BIM is used by the global dimension of organisations and BIM is applied in their projects. While the analysis process has been developed using Europe, the people involved in the consultations have worked with global organisations and emphasised that the outcomes in developed economies around the world will extend to another context.

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