Standardized Qualification Framework for achieving Energy Efficiency Training for BIM

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Abstract

The European construction sector is facing unprecedented challenges to achieve ambitious energy efficiency objectives and generalize near-zero energy buildings during an economic crisis that is dominated by reduced investments, and a search for cost effectiveness and high productivity. Moreover, the industry is experiencing a digital revolution and the Building Information Modelling (BIM) approach has been gaining interest across Europe. The member states of the EU have implemented many different approaches through regulations and maturity targets, which have to constantly face the traditional low-tech and informal practices of construction businesses. This fragmented sector is dominated by Small and Medium-sized Enterprises (SMEs). In addition, the qualifications of the current construction workforce are not good enough to satisfy the work-related demand. The main courses have concentrated on construction and design, while training courses target more technical participants.

This research aims to leverage the take-up of information communication technology and BIM by introducing a significant upgrade for the qualifications of the EU construction workforce. This research aims to pave the way towards a fundamental step change in delivering systematic, measurable, and effective energy-efficient buildings through BIM qualifications to handle construction projects with a view to effectively address European energy and carbon reduction targets. It also aims to promote a well-skilled leading generation of decision makers, practitioners, and blue-collar workers in BIM for energy efficiency. The principal output of this research is a standardized qualification framework that includes: (1) a skills matrix related to BIM and energy efficiency, harmonized thanks to the European Qualifications Framework standard, to assess and support energy efficient handling of BIM projects, and (2) a skills map that will help to widely distribute the BIM skills required during the project lifecycle to achieve energy efficiency based on the Royal Institute of British Architects *Plan of Work*.

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Abbreviations

AEC	Architecture, Engineering and Construction
BEM	Building Energy Model
BIM	Building Information Modelling
BMS	Building management System
EPBD	Energy Performance Buildings Directive
EED	Energy Efficiency Directive
EEAB	External Expert Advisory Board
EQF	European Qualification Framework
CPD	Continuing Professional Development
CCD	Continuing Craft Development
ICT	Information and Communication Technologies
QA	Quality Assurance
RIBA	Royal Institute of British Architects
PoW	Plan of Work
RegEx	Regular Expressions

List of Publications

Published Journal Papers:

Alhamami, A., Petri, I., Rezgui, Y. and Kubicki, S., 2020. Promoting energy efficiency in the built environment through adapted BIM training and education. *Energies*, *13*(9), p.2308.

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Alhamami, A., Petri, I. and Rezgui, Y., 2018, September. Use-case analysis for assessing the role of Building Information Modelling in energy efficiency. In *eWork and eBusiness in Architecture, Engineering and Construction: Proceedings of the 12th European Conference on Product and Process Modelling (ECPPM 2018), September 12-14, 2018, Copenhagen, Denmark* (p. 31). CRC Press.

Petri, I., Alhamami, A., Rezgui, Y. and Kubicki, S., 2018, September. A virtual collaborative platform to support building information modelling implementation for energy efficiency. In *Working Conference on Virtual Enterprises* (pp. 539-550). Springer, Cham.

Hodorog, A., Alhamami, A.H.S., Petri, I., Rezgui, Y., Kubicki, S. and Guerriro, A., 2019, June. Social media mining for BIM skills and roles for energy efficiency. In *2019 IEEE International Conference on Engineering, Technology and Innovation (ICE/ITMC)* (pp. 1-10). IEEE.

Suwal, S., Jäväjä, P., Kubicki, S., Häkkinen, T., Mäkeläinen, T., Marzougui, D., Mccormick, S., Alhamami, A. and Petri, I., 2018. Building energy-efficiency delivered with the help of improved building information modelling skills.

Introduction

This chapter will provide an overview of this thesis. It begins by detailing the research background, focusing on key drivers of Building Information Modelling (BIM) in promoting an energy efficiency (EE) agenda, which includes BIM, energy efficiency, and the skills, training and education of professionals and blue-collar workers in the construction industry. This will be followed by a discussion of the rationale and motivation for this research. This chapter continues by setting out the research aim, hypothesis, research questions and objectives. This is followed by the main contributions that this research offers to the body of knowledge. Finally, this chapter will conclude by giving an outline of the structure of this thesis.

1.1 Background

Global warming has drastically increased the pressure to reduce energy use in buildings. In the EU (for example), energy use by the building sector represents more than 40% of Europe's energy and CO2 emissions [1]. The EU Commission defined a clear target to reduce energy consumption and CO2 emissions by 20%, and increase the share of renewable energies by 20% by 2020 [1]. These objectives have been translated into stringent regulations and policies at the European and national levels. For instance, the Energy Performance of Buildings Directive (2010/31/EU) imposes stringent energy-efficiency requirements for new and retrofitted buildings.

The global construction market is forecast to grow by over 70% by 2025 compared to 2013[2] [3]. Several countries have already set-up targets to achieve sizeable objectives, such as the UK's construction agenda: (a) 33% reduction in both the initial cost of construction and the whole life cost of assets; (b) 50% reduction in the overall time from inception to completion for new build and refurbished assets; (c) 50% reduction in greenhouse gas (GHG) emissions in the built environment; and (d) 50% reduction in the trade gap between total exports and total imports for construction products and materials [3], [4].

The construction industry presents a major opportunity to reduce energy demand, improve process efficiency and reduce carbon emissions. It is also traditionally highly fragmented and often portrayed as having a culture of adversarial relationships and risk avoidance, which are exacerbated by a linear workflow that often leads to low efficiency, delays and construction waste. 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 energy and the environment [5]. 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. This demands dedicated skills to address multi-objective sustainability (including energy) requirements.

In this context, BIM can facilitate more effective energy modelling and multidisciplinary collaborations with a total lifecycle and supply chain integration perspective. BIM can be defined as the process of generating and managing data and information about the built environment throughout its entire life cycle, from concept design to decommissioning [6] (see Figure 1-1). BIM has brought the most transformative power into the Architecture, Engineering and Construction/Facility Management (AEC/FM) domain during the last decade in terms of its fundamental life cycle, and supply chain integration and digital collaboration [7]. BIM also offers the prospect to revolutionize the construction industry, which is forecasted to reach over $11 trillion global yearly spending by 2020 [3].

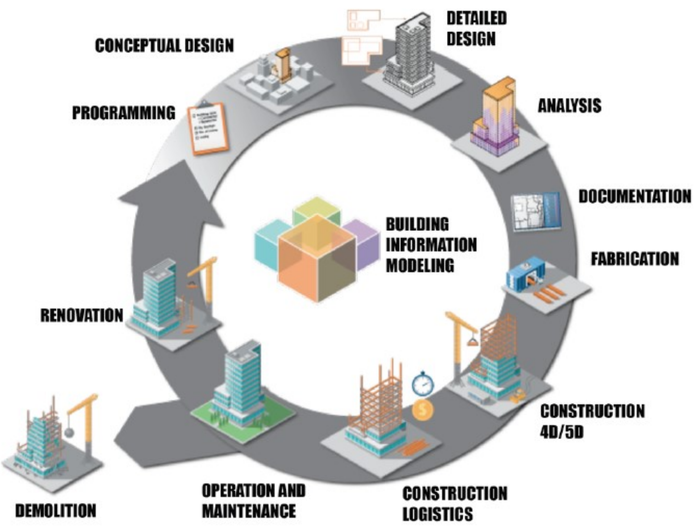


Figure 1-1: BIM uses across the building lifecycle.

BIM can help the sustainability agenda because the digitalisation of product and process information provides a unique opportunity to optimise energy efficiency related decisions across the entire lifecycle and supply chain. To bring about a transformation in our built environment, as spelled out by the EU Commission in its vision for Horizon 2020, and set the sector firmly on a path towards competitiveness and sustainable growth, the EU Commission's modern industrial policy recognises the strategic importance of the construction industry, as witnessed by the Public Private Partnership Energy Efficient Buildings launched under the

Recovery Plan in FP7, supported in Horizon 2020, and pursued in the context of Horizon Europe and the overarching Green Deal [8]. The construction industry in Europe has a wide range of training and education providers, with an equally diverse set of training courses. Consequently, it is essential to improve the breadth, depth, quantity and quality of educated and trained professionals in the built environment to support an effective BIM agenda across Europe. A large number of training and education offerings are currently concentrated on quite a narrow band of the industry. The main courses focus on design and construction, and not on briefing or planning, and they do not consider the ability of BIM to improve the operations of assets [9]. In addition, training courses largely target technical users rather than blue-collar workers or management teams and strategic roles in organisations. Finally, BIM skills, education and training is focused on buildings, and it rarely examines infrastructure [10].

1.2 Key Drivers

The wider context in which this research is carried out has been discussed in Section 1.1. This section will aim to outline the specific, key drivers, partially resulting from this context, for the work carried out in this thesis.

1.2.1 Building Information Modelling

BIM sits at the heart of the digital transformation across the built environment. For the construction industry, BIM provides a critical opportunity to significantly improve performance and stimulate more innovative ways of delivery and operation [11].

BIM is a collaborative way of working that facilitates early supply chain involvement, which is underpinned by digital technologies that unlock more efficient methods of designing, creating, and maintaining our assets [12]–[14]. BIM provides a digital representation of the physical and functional characteristics of an asset to support reliable decision making and management of information during its lifecycle [15]. At its core, BIM uses 3D models and a common data environment to access and share information efficiently across the supply chain, and so boost the efficiency of activities around asset delivery and operation. By helping the entire supply chain to work from a single source of information, BIM reduces the risk of error and maximises the team’s ability to innovate [16].

On a global level, there are many definitions of the term BIM and what this means. There are even three separate definitions of the acronym BIM, which are: building information model, building information modelling, and building information management.

Building Information Modelling (BIM) relates to the process of constructing the building information model, which is dependent upon the deliverables required. How a model is constructed to produce 2D drawing deliverables can be very different from modelling for visualisation purposes. When the specified BIM dimension is 4D (to analyse time), 5D (for cost management purposes) or 6D (for facilities management purposes), then the modelling methods and the required levels of information within the model will change dramatically [17].

1.2.2 Energy Efficiency

Improving energy efficiency is considered to be one of the basic keystones of the main national and international strategies to reduce GHG emissions with acceptable economic costs [18]. The need for simple and clear measures and for all citizens to contribute to energy savings have been addressed in many studies [19]. However, changes and adaptations are required at the social, economic and technological level to preserve our wellbeing and the welfare of future generations, although they will result in a change in our way of life. To reduce the energy consumption of buildings, almost all governments have opted to adopt measures aimed at improving energy efficiency in buildings for public use [20].

Governments and non-governmental organisations (NGOs) have focused on other issues in their plans and programmes to boost renewable energies, energy-efficiency strategies and strategies to fight climate change [21]. In Europe, the legislation of the different countries in this area comes, on the one hand, from the creation of certificates of energy efficiency that were developed in the early-1990s as a primary strategy to reduce energy use and carbon emissions [22]; while on the other hand, it comes from the energy policy that was adopted in 2007, which was called Horizon 20-20-20, in which the EU demands the fulfilment of certain objectives by the end of 2020, including saving 20% of energy in its primary level in comparison with 2005, lowering GHG emissions by 20% compared to 1990, and increasing renewable energy in the total energy mix to a minimum of 20% by 2020. This policy is popularly known as the “20-20-20 goal”, which implies improvements in energy efficiency [23].

The Directive on energy efficiency in Buildings [24] states that all newly constructed buildings should be listed as "zero-energy buildings" (ZEB) by the end of 2020, and by the end of 2018 in the case of public buildings. This new concept refers to buildings with minimum levels of energy, whose origin is from renewable sources. Nevertheless, this is a very complex concept, especially because of the lack of a clear and standardized definition and a common energy calculation methodology for all countries to evaluate using the same criteria [25]. In this context, the industry is faced with the challenge and opportunity to improve process efficiency, which involves the entire construction supply chain, to comprehensively reduce energy demand and carbon emissions in line with the Energy Performance of Buildings Directive (2010/31/EU). In this context, energy efficiency demands have led to adoption of technology solutions, strategies (including training and education), and policy-making approaches that should be embraced by the entire supply chain across the whole lifecycle of a project. The related energy audits, energy management systems, and energy manager/assessor training and certification are awareness programmes that are usually effective in promoting energy efficiency and increasing the demand for a skilled workforce.

1.2.3 Skills, Training and Education

Education is a process that implicates activities such as teaching, inducing, motivating, learning, and examining, which is usually offered in schools and colleges [26]. For a better understanding of the term, Garavan [27] lists its intrinsic characteristics as follows: it must include a learning method, this method must not be an individual event, it is fundamentally humanistic, and learning must include understanding.

Training is one of the processes involved in getting an education [28]. Oladosu [26] defines training as the acquisition of skills in a particular field of specialisation, which requires an exercising routine, continuous repetition, and a definite end and objective. It is also important to mention that training is an activity that is commonly used in organisations, and can even be identified under the term "employee training" [29], which means obtaining on-the-job skills for a specific role.

The construction industry is labour intensive [30]. The skill of a worker is one of the essential factors that determine the quality, productivity and profitability of a project [31]. However, the shortage of skilled construction workers is a well-recognised and persistent problem [32].

For example, many studies have found that the shortage of skilled workers is one of the main factors that can cause delays in construction projects. Le-Hoai et al. [33] identified 21 critical issues that cause delays and cost overruns in large Vietnamese construction projects. The lack of skilled construction workers was one among these critical issues. Similarly, Tabish and Jha [34] found that the availability of trained resources at the site was one of the essential traits for the success of any construction project. Therefore, the possible implications of a lack of skilled workers are significant for the successful completion of construction projects. This has led to several research studies of the efficient use of the workforce, involving adequate and relevant training [35], [36]. If the efforts in training succeed, then rewards in terms of competitive advantage, quality, reliability and profitability of the projects can be achieved [37].

BIM education and training is necessary not only within the whole construction industry but it must also be directed to different levels, including secondary level, undergraduate, practitioners' site and office staff, and even at the strategic level [38]. To bring about the transformation of our built environment, as spelled out in the vision for Horizon 2020, and set the sector firmly on a path towards competitiveness and sustainable growth, the European Commission's modern industrial policy recognises the strategic importance of the construction industry, as witnessed by the Public Private Partnership Energy Efficient Buildings that was launched under the Recovery Plan in FP7 and which is now supported in H2020 [39]. In Europe, the construction sector has a diverse collection of training and education providers, as well as a diversified number of training courses. Consequently, it is critical to increase the breadth, depth, quantity, and quality of educated and skilled professionals in the built environment across Europe to support an effective BIM agenda.

Overall, these definitions are considered to be the key drivers for approaching and supporting an effective BIM agenda to improve and promote energy efficiency in construction projects, which require BIM education and training for construction stakeholders.

1.3 Global Motivation

Nowadays, international directives are oriented toward maximising building energy efficiency, where BIM provides a significant opportunity to assess and achieve these targets. This section has expanded and provided more detail and information about the key drivers of global motivation. This section will explore some of the related works from the field of BIM skills for energy efficiency, emphasising its roles in the construction industries.

1.3.1 BIM in the Construction Industry

BIM is defined as the process of generating, storing, managing, exchanging, and sharing building information in an interoperable and reusable way [40]. This requires the development and use of a computer generated model to simulate the planning, design, construction and operational phases of a project [41]. The BIM Industry Working Group shows that the UK government believes that its use can bring many efficiencies and benefits across the project lifecycle [7].

To successfully implement BIM processes, all of the members of the construction team need secure access to confidential data, both external and internal to the BIM model. While the BIM model can be part of an extranet [42], this may lead to legal issues. Therefore, legal issues need to be addressed through the construction contract to reduce this significant risk [42]–[44].

The significance of the cost of implementing BIM in terms of resources and training has been seen to act as a substantial barrier within the construction industry [45]–[50]. Despite the significant cost of implementation, BIM will ultimately be driven by clients [48]. Hore et al. [51] suggest that if adoption becomes a requirement, then training must be subsidised by the government to facilitate implementation.

As the adoption of BIM has grown in the last decade, many of the technical, legal, contractual or process-related issues that it faces have been addressed through extensive research conducted in several communities (e.g., information and communication technologies (ICT), engineering, architecture, and social sciences).

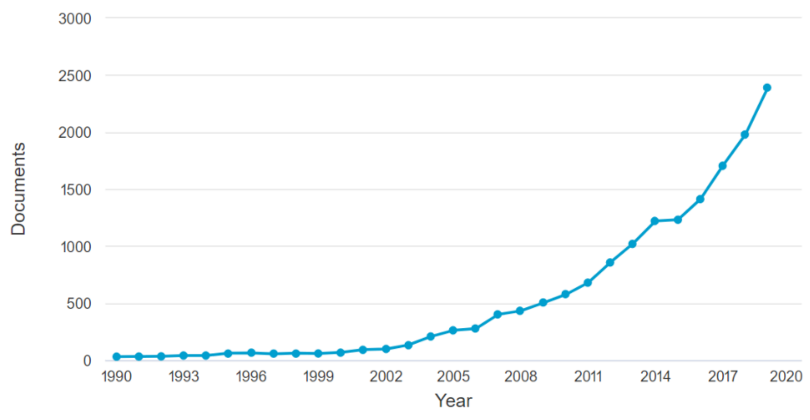


Figure 1-2: Scopus search for the "BIM" keyword.

Figure 1-2 shows the intensity of publications citing “BIM”, either in the title, abstract or keyword sections. This shows that researchers have addressed many of the issues related to knowledge management in construction since the 1990s, particularly for product and process modelling. In the last decade, the field and research intensity have become more important, thus accompanying the digital transitions in the most developed countries.

1.3.2 BIM for Energy Efficiency

BIM provides a digital representation of the building process, which facilitates the exchange and interoperability of information in digital format. This modelling can greatly contribute to energy reduction. BIM has a number of socio-technological advantages, not only at the technological level but also the process level. It can complement the way in which architectural design artefacts are created. It can also profoundly change the collaborative process associated with the act of building. Given that the construction industry is facing increased pressure from regulations calling for significant gains in energy efficiency, increased economic pressure and competition, and a dramatic evolution of working culture and practices, BIM can represent a game-changing factor that would support the transition to more energy and cost-efficient practices [52]–[55].

ICT can contribute to BIM for energy efficiency by enabling faster and more reliable design decision-making and construction follow-up [52]. BIM has enhanced design support (e.g., through 3D visualisation, physical simulation, and upstream assessment of design options) and construction planning and monitoring (e.g., construction phasing and continuous monitoring) [53]. This advanced support from digital tools is likely to allow for significant improvements of the quality and performance of buildings [54]. It will also lead to time- and cost-savings to preserve the competitiveness of European businesses. During these different phases (as presented in Figure 1-1), BIM has to be enriched by large data, notably related to building components, or simulated and/or sensed usages to support the energy analyses and simulations. Several attempts in the field of BIM and energy efficiency have tried to develop a methodology for utilising BIM for reducing energy consumption and emissions in buildings.

BIM in construction projects can support collaboration between employers, designers, suppliers and facilities managers through a range of design and construction tasks [56]. BIM has also been validated in studies as an instrument for addressing: (a) project failure caused by lack of effective project team integration across supply chains [57], [58]; (b) the emergence of challenging new forms of procurement, including design–build–operate contracts [59]; and (c) decreasing the whole life cost of a building through the adoption of BIM in facilities management [60]. BIM also facilitates information that is collected and stored in a BIM-compliant database, which often could be beneficial for a wide variety of practices (e.g., energy management, maintenance and repair, and space management) [61].

The implementation of BIM for energy efficiency may help to provide energy savings through the combination of accurate energy monitoring, real-time decision support systems, and actuators and identification of consumption patterns. Moreover, the optimal management of the evolution of energy use in buildings will be informed by (a) the reliance on a semantic approach (i.e., BIM, real-time data analysis, behaviour modelling, etc.); (b) enhanced supervision of energy flows and use in buildings; and (c) new partnerships between energy managers, energy distributors, energy equipment suppliers, and technology (including smart software tools). This will result in quantifiable energy consumption reduction. It will also provide an analytic operating capacity, KPI (key performance indicator) control, annual consumption forecast progress, reports and personalized alerts [62].

A smart distribution of (reduced) building energy consumption may lead to economic savings that will be commensurate with the targeted energy reduction. Although according to some thermal regulations the energy consumption of a building is expected to not exceed a given limit, the real energy performance is usually lower. One means to reduce the gap between prediction and reality is to improve the entire process, from the early design phase to the operation phase [54], [55].

1.3.3 Construction Worker Qualifications

In European societies, as well as in most parts of the world, education is recognised as a key pillar of community life and a universal right [6]. As stated by Jah and Polidano [63], “those without necessary skills and qualifications face diminished life prospects and risk alienation from mainstream society”. There is also a particular emphasis on the clear relationship between education and social stability: “increasing access to postsecondary vocational education and training does significantly reduce property crime, drug crime and crime against the person” [63].

Enhancing the qualifications of workers is key to success in all economic sectors, but it is particularly critical in the construction sector. The European construction industry is currently faced with a three-sided challenge:

- Construction is a key component of the Energy Union strategy and as such it faces huge pressure from EU and national regulations. Buildings represent 40% of primary energy consumption in the EU, and between 30 and 40% of CO_2 emissions depending on national energy mixes[64]. Therefore, improving the energy efficiency of European buildings is a key step in achieving the 2020, 2030 and 2050 EU energy and CO_2 emission targets. European energy directives, in particular the Energy-Efficiency Directive (EED) and Energy Performances of Building Directive (EPBD) and related national regulations, set very strict energy-efficiency targets for European buildings, with the aim to generalise Near-Zero Energy Buildings (NZEBs) by 2020. NZEBs are highly complex systems, which call for significant technical progress in several areas, including building envelope performance, energy and comfort monitoring and integration of renewable energy production [24], [65].
- The construction sector is still faced with the consequences of the recent economic crisis, which has reduced the investment capacities of its companies. The European construction sector is a strong economic sector (10% of the EU GDP) but it is also essentially made up of small and very small companies, which have been particularly impacted by the economic downturn. This is one of the reasons why the financing of the required European building stock enhancement through deep renovation (up to 100 billion euros per year until 2020) is recognised as a challenge by the European

Commission [66]. Cost-effectiveness and productivity are therefore two overarching issues for European construction businesses.

- The European construction industry is experiencing a digital revolution, with an intensification of digital support in all stages of building design and construction. In particular, BIM approaches and tools have gained significant interest in the sector [67]. They are recognised as key components of future construction practices, and their benefits on productivity and reliability are widely acknowledged [68]. This evolution contrasts with the original culture and practices of the construction sector, which is widely perceived as a “low-tech” area with a significant proportion of “blue-collar” workers. Therefore, training in construction, even more than in other economic sectors, is one of the most critical challenges of our time [6].

The skills need to be developed to actively promote the widespread use of BIM-based transversal and multidisciplinary collaborative approaches and methods in the European (and beyond) construction industry currently face fragmentation and inadequate training resources. Training and education programmes will raise awareness of stakeholders in the construction value chain about (a) environmental challenges, (b) current and future sustainability scenarios, and (c) energy efficiency targets and EC and governments agendas, with a view of delivering informed built environment interventions across lifecycle and supply chain underpinned by an effective BIM-based training Europe-wide agenda.

1.3.4 BIM Training Approach to the EU-wide Impact

The previous section illustrates some of the intricacies and challenges that the construction industry is facing, including increased pressure from regulations calling for significant gains in energy efficiency, increased economic pressure and competition, and the dramatic evolution of working culture and practices. Therefore, there is a clear need for a game-changing factor that would support the transition to more energy- and cost-efficient practices.

The main objectives for BIM engagement and training are to leverage the take-up of ICT and BIM technologies through a significant upgrade of the skills and capacities of the European construction workforce. This will help to dramatically improve the reliability and effectiveness of design and construction practices, with a view to achieving the objectives of the Energy Union. In the methodology that has been applied to capture the requirements to develop BIM skills for energy efficiency, ICT methods are used to create a dynamic and open community of users that can share experiences and contribute to the process of training and education for BIM in energy efficiency. In this thesis, analysis and consultations are undertaken to determine any gaps in the current BIM for energy practices. It will also emphasise that new skills need to be developed for industry professionals to blue-collar workers to increase BIM for energy efficiency awareness and applicability.

Overall, the qualifications of the construction industry workforces are not good enough to satisfy the work-related demand of BIM for energy efficiency, the main training courses and programmes concentrate on construction and design. In addition, most training courses target more technical participants, and the current training does not appear to address large construction projects.

1.4 Context of the Research: The BIMEET Project

The works in under this research were a part of the researcher's role in the BIMEET project (BIM for Energy Efficiency Training: "BIM-based EU-wide Standardised Qualification Framework for achieving Energy Efficiency Training"), which was funded by the European Commission's H2020 Framework Programme, Executive Agency for SMEs, grant number 753994. The researcher has led dedicated tasks (T2.1 and T2.3) in the project and worked on their deliverables, which are the main works given in Chapters 4 and 5 in this thesis. In addition, the researcher has contributed to all of tasks of this project. The researcher's role was to conduct the literature review and case studies, and he led the consultation through questionnaires, interviews, and workshop, and analysed the data. A brief summary of the BIMEET project follows.

1.4.1 BIMEET Project

BIMEET had many aims, as follows: (a) it paved the way to a fundamental step change in delivering systematic, measurable and effective energy-efficient buildings through BIM training with a view to effectively address European energy and carbon reduction targets; (b) it promoted a well-trained world-leading generation of decision makers, practitioners, and blue collars in BIM for energy efficiency; and (c) it established a world-leading platform for BIM for energy efficiency training nurtured by an established community of interest.

BIMEET endeavoured to enhance the skills, qualifications and capabilities of construction practitioners (from high professionals to blue-collar workers), thus increasing market penetration and adoption of key technological development in BIM, given the timeliness of the need for training in combined green and functional performance engineering.

Table 1-1 BIMEET participant list.

Participant No.	Participant Organisation	Country
1 (Coordinator)	LUXEMBOURG INSTITUTE OF SCIENCE AND TECHNOLOGY (LIST)	LU
2	CARDIFF UNIVERSITY (CU)	UK
3	CENTRE SCIENTIFIQUE ET TECHNIOUE DU BATIMENT (CSTB)	FR
4	BUILDING RESEARCH ESTABLISHMENT LTD (BRE)	UK
5	INES PLATEFORME FORMATION & EVALUATION (INES)	FR
6	TEKNOLOGIAN TUIKIMUSKESKUS VTT OY (VTT)	FI
7	HOUSE OF TRAINING (HOT)	LU
8	METROPOLIA AMMATTIKORKEAKOULU OY (METRO)	FI
9	CENTRE FOR RENEWABLE ENERGY SOURCES AND SAVING FOUNDATION (CRES)	GR

BIMEET is informed by the extensive knowledge of the project participants in the energy efficiency agenda, with a focus on the built environment and the wide range of experiences acquired in recently completed FP7 projects, such as SPORTE2 (Grant agreement n° 260124), KnoholEM (Ref: 609154), as well as ongoing projects such as STREAMER (608739) and PERFORMER (Ref: 609154), which have highlighted the endemic energy performance gap in buildings in requiring a multi-disciplinary and total lifecycle approach [69]. A list of BIMEET's participants is given in Table 1-1.

1.4.2 Expert Panel

An expert panel supported the strategy and subsequent development within the project, helped anticipate business trends, and supported valorisation (including vulgarisation) and take up of the results. BIMEET had already set up a list of high-level experts, which have given, through a signed expert manifestation of interest, their commitment to participate in BIMEET.

1.4.3 Involvement of Relevant Target Groups and Key Actors

The BIMEET consortium engaged with key target groups and stakeholders related to the energy efficiency building value chain across participating countries and beyond, as illustrated in Figure 1-3. In total, 26 experts/organisations had already committed to participate and have sent letters of support for the creation of the BIMEET expert panel. Other organisations and people have already expressed their interest and will be involved. The influence of this group of experts will be amplified by a community of interest, which will involve BIM trainers and national decision makers across Europe leveraged through the BIMEET training platform (200+ users/practitioners are expected).

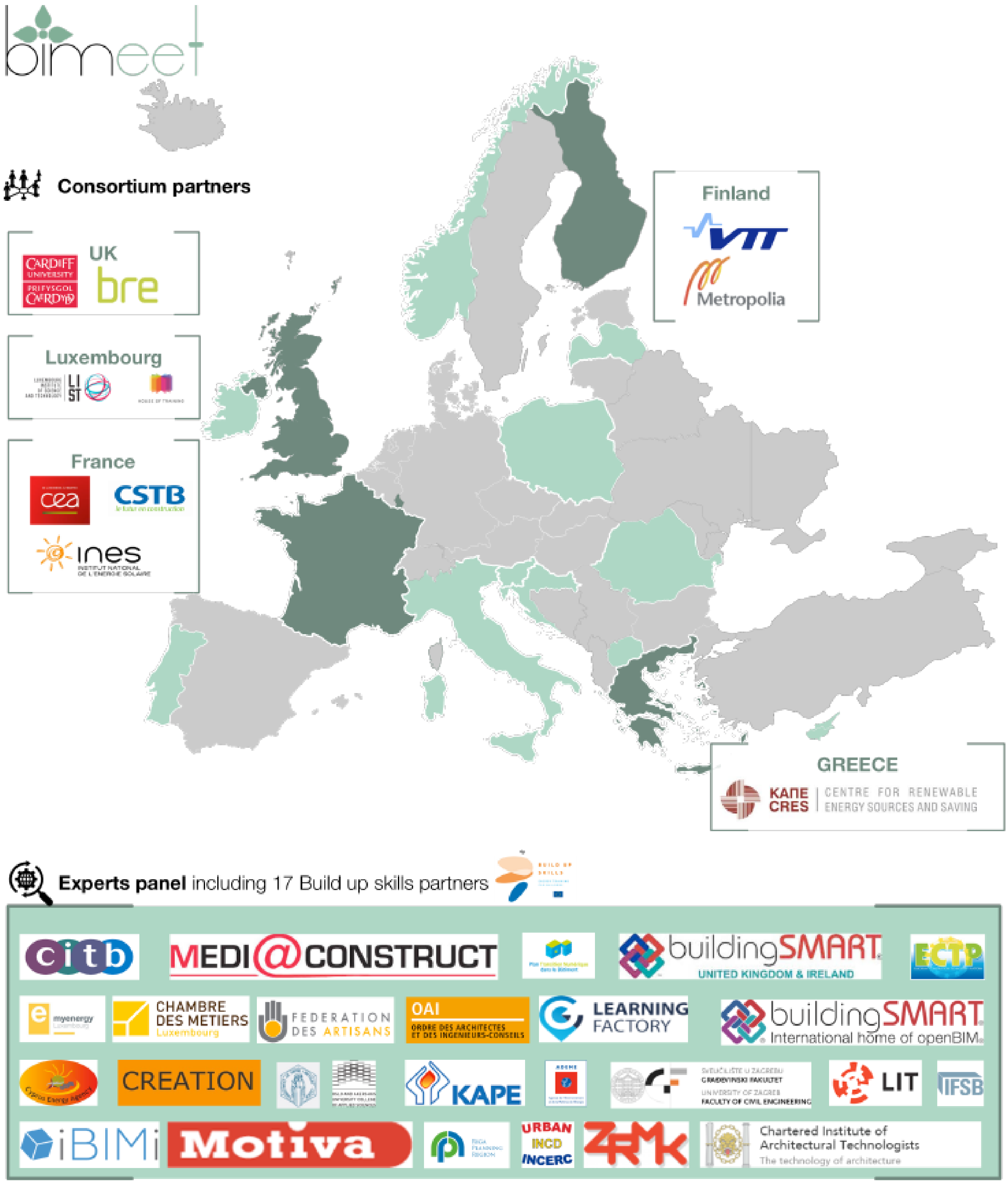


Figure 1-3 BIMEET European network (consortium partners and principal expert panel).

This thesis focuses specifically on objectives 2 and 3 of the BIMEET project, and therefore it provides in-depth analysis and gaps identification in relation to the skills involved in BIM training for energy efficiency, prior to integration with training models and strategies. Mixed methods have been used to understand existing BIM practices, and determine existing requirements and gaps in BIM skills and training. In addition, a framework has been developed to address these requirements.

1.5 Research Objectives

Following the key drivers and global motivation, the aim of the research is to explore the role the digital transformation of the construction industry, with a focus on BIM, in improving energy efficiency in the Construction sector through adapted training and education. The specific target of this thesis is to test a central hypothesis through decomposition into several research questions. The central hypothesis to be tested states:

Adapted training to promote the digital transformation of the construction industry, and in particular to enhance the adoption of Building Information Modelling, can have a positive impact on white and blue-collar work practices to deliver energy efficient interventions.

This hypothesis translates into the following research questions:

Research question 1: What are the requirements, limitations and gaps in the BIM skills and training landscape in Europe?

Research question 2: Which BIM roles and skills are required to achieve energy efficiency via adapted training?

Research question 3: Can changing training requirements as a consequence of the continuous digitalisation of work practices, business processes, and technology evolutions, be captured and managed through a dedicated framework that factors in a wide range of aspects, including roles and skills?

Research question 4: How scalable and adaptable is this standardized qualification framework to other regions and socio-organisation contexts such as in the context of developing economies?

These research questions are addressed through the following objectives:

- Identify the essential gaps and requirements of BIM application in energy efficiency based on the current work and business process practices.
- Identify each role and their qualifications in construction projects. The roles will inform the training process, which can contribute significantly to the education of white and blue collars in the field of BIM and promote energy-efficient practices across organisations and projects.

- Identify the level of skills needed to embed BIM for energy efficiency within work practices for various stakeholders involved in the construction projects during their lifecycle.
- Explore the scalability of the proposed results in a developing economy.

1.6 Contributions

This research has led to a number of contributions to the body of knowledge, including:

- A detailed literature review for BIM training and skills for energy efficiency has been formalised by identify gap in the filed through extensive survey using authentic research databases.
- A skills RIBA map is proposed to define the skills for each different roles' category to handle BIM for energy efficiency through nine stages of the project lifecycle based on the RIBA 2013 Plan of Work.
- A skills matrix for the five main role categories developed based on the skills RIBA map and EQF levels (from 1 - 8) that would be used as a standardised qualification framework for BIM training and education.

1.7 Thesis Outline

This thesis is divided into eight chapters. The contents of each chapter are summarised below to give an overview of the organisation of the thesis.

Chapter 1 Introduction: This chapter has aimed to provide the wider context and background as to the motivation and significance of the research provided in this thesis, and it offers a statement of the problem of the research. In addition, this chapter presents the aim, hypothesis, research questions and objectives. Finally, the contributions to the body of knowledge are outlined.

Chapter 2 Literature Review: This chapter provides a thorough review of the existing body of literature for BIM for energy efficiency in construction sectors. It is split into five main parts: the climate agenda, the construction market, energy efficiency in construction industry, digital transformation of construction industry, and the EU construction energy efficiency training and skills agenda. From this review, the foundation of the research gap will be developed.

Chapter 3 Methodology: This chapter will detail the overarching methodology and approach to carrying out the research described in this thesis. It will discuss the philosophy behind the research, clarify the method by which the research questions will be answered, and report how the work throughout this thesis has been validated. This chapter will also introduce the core theory behind the main components used throughout the thesis, namely interviews, questionnaire, case studies, and social media.

Chapter 4 Requirements and gaps in BIM training and skills for the energy efficiency landscape in Europe: This chapter covers the requirements capture phase. Whereas research aims at offering specialised training and educational programmes to support the BIM implementation agenda for energy efficiency in Europe, this chapter will address the requirements the elicitation phase. This phase collects and analyses the training and skills requirements and gaps to inform the training elaboration phase with regards to skills, roles and required qualifications.

Chapter 5 Knowledge engineering to upskill the construction workforce around BIM for energy efficiency: The chapter covers the requirements capture phase of the research, and it identifies the roles and skills. Based on the requirements elicitation in Chapter 4, this chapter will address the definition of roles and skills for BIM for energy efficiency by using the methodology included a Europe-wide consultation with experts and practitioners, as well as an in-depth analysis of social media sources used across construction communities, informed by a comprehensive literature review. It will also provide consolidation lists of the roles and skills involved in BIM training for energy efficiency.

*Chapter 6 Standardized qualification framework for energy efficiency enhancement***:** The roles and skills list from Chapter 5 and roles categories from Chapter 4 are classified and analysed during the whole lifecycle of a project in terms of relevancy to BIM and energy efficiency in the construction sectors. In this chapter, a standardized qualification framework is then proposed according to RIBA work plan and the EQF recommendations. The skills RIBA plan is used to define the skills for each different roles' category through all stages of the project lifecycle. Then, a skills matrix for each skill level recommended is proposed according to the EQF levels definition. This matrix enables different distinguishing levels for each skill, i.e., senior and technician, and helps to define the level of EQF. The stakeholders' skills levels have been identified to handle BIM for energy efficiency of the building sectors during the lifecycle and supply chain.

Chapter 7 BIM for energy efficiency training requirements in the context of developing countries: Saudi Arabia as a case study: This chapter will endeavour to enhance the skills, qualifications and capabilities of construction practitioners (from high professionals to blue-collar workers). This will increase the market penetration and adoption of key technological development in BIM, given the timeliness of the need for training in combined green and functional performance engineering in the context of developing countries.

Chapter 8 Conclusion: This chapter summarises the research findings and presents how the research questions have been answered through the research stages. In addition, this chapter will describe how this research has met the main aims of the research. Following this, a summary of the key contributions to the body of knowledge will be provided. It will also outline the limitations that have been observed. Finally, this chapter will make several recommendations for future work.

Literature Review

2.1 Introduction

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. BIM provides a unique opportunity to enhance building energy efficiency, 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 aims to improve the whole supply chain related to the design, construction, 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 energy efficiency. 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 energy efficiency practices.

This chapter will assess the gap, or need, for BIM for energy efficiency in the construction sector. It presents a review of recent reports, studies and research related to the subject, and it discusses the contributions and solutions of other researchers. It covers the important issues and aspects investigated in the research, and it details the global and European background to the many different works that contribute to and support research in this field.

2.2 Climate Agenda

Global warming, or the long-term heating of Earth's climate system, has significantly increased the pressure to reduce energy use in the construction sector in recent years. The United Nations Framework Convention on Climate Change [70] and the subsequent Kyoto Protocol [71] called for consumption limits and GHG emission reduction in accordance with agreed national targets. Consequently, the legally binding Paris Agreement was established by 190 parties worldwide, including 27 member states of the European Union (EU-27), with the aim to avoid reaching a 'tipping point' and to keep the global temperature rise worldwide well under 2C, preferably within a maximum rise of 1.5C [72]. Climate Change 2021: The Physical Science Basis mentions that since 1850, the last four decades have been successively warmer than any preceding decade [73]. Today the pressure to avoid reaching this point is still on. This agreement prompted the European construction sector to respond. In addition, the World Green Building Council (WGBC) highlighted in Delivering the Paris Agreement – The Role of the Built Environment, that the Paris Agreement demands a more ambitious built environment strategy [74].

The United Nations (UN) International Development Organisation (UNIDO) 2030 Agenda for Sustainable Development: Goal (7) set the following targets for 2030: to ensure universal access to affordable, reliable and modern energy services; to substantially increase the share of renewable energy in the global energy mix; to double the global rate of improvement in energy efficiency; to enhance international cooperation to facilitate access to clean energy research and technology; and to promote investment, expand and upgrade energy infrastructure and clean energy technology to supply modern and sustainable energy services for all in developing countries [75]. In 2018, a recent European Commission (EC) environmental strategic vision document, A Clean Planet for All, referred to seven strategic building blocks, many of which directly affect the European construction sector [76]. A 2019 report by the WGBC Bringing embodied carbon upfront states that, together, building and construction are responsible for 39% of all carbon emissions in the world, with operational emissions accounting for 28% and the remaining 11% from embodied carbon emissions. Both WGBC and Eurostat Statistics confirm that Europe cannot afford to waste energy [77], [78].

It is evident that the need for the European construction sector to set targets to reduce energy consumption, curb GHG emissions and improve energy efficiency to reduce global warming is well established.

2.2.1 Energy Targets for EU Constructions

The call to improve energy efficiency in construction via targets is well established in Europe. As pointed out in the 2012 EC Energy Roadmap 2050, higher energy efficiency in new and existing buildings is key for the transformation of the energy system of the European Union

(EU) The EC initial mandatory Nationally Determined Contribution (NDC) under the 2015 Paris Agreement was committed to reduce EU GHG emissions by at least 40% by 2030 compared to 1990 levels [79]. The EU's roadmap, or Long-Term Low Emission Development Strategy (LT-LEDS) under that agreement, was published by the UNFCCC in 2020. This strategy endorsed the objective of the 2019 European Green Deal of achieving a climate-neutral, or net-zero, EU by 2050. It set out that the EU-27 should strive to formulate and communicate their long-term low GHG emission national development strategies, which acknowledge their common but differentiated responsibilities and respective capabilities [80].

The current EC 2030 Climate and Energy Framework as part of its 2019-2024 European Green Deal requires the current E-27 member states to contribute to achieving at least 40% cuts in GHS emissions from 1990 levels, at least 32% share for renewable energy and at least 32.5% improvement in energy efficiency [81]. A European Environment Agency 2020 Emission Indicator Assessment summarises that GHG emissions 2030 projections based on current and planned measures of the EU-27 show an emission reduction of only 36%, so further effort will certainly be necessary to achieve climate neutrality by 2050 [82]. Despite setting targets, 2021 data from the Climate Analytics and New Climate Institute Climate Action Tracker (CAT) currently rates the current EU-27 level as insufficient and the pressure is still on for the EU to align actions with intent [83]. Once again, in 2019, the EC suggested in its Clean Energy for all Europeans Package, that by rendering buildings more energy efficient, EU energy and climate goals can be more be more easily achieved. To achieve this, the construction industry, like other sectors, has established targets relating not only to improving energy efficiency but also to reducing energy consumption, and GHG reduction too [84].

2.2.2 EU Environmental and Energy Policies

The energy emission objectives highlighted above are increasingly being translated into stringent policies, directives, regulations and laws. Some of these directly interface with the construction sector. Aligned with the recent digitalisation trend of the construction industry, the EU community has released regulations to promote improved energy performance in buildings, including cost-efficiency, local conditions and requirements (local climates and cultures significantly influence energy consumption in buildings) [52].

The 2019 EC Clean Energy for all Europeans Package [85], enabled the earlier 2015 EU Energy Union Package to be implemented, and eight new or updated related energy emission reduction related laws to be adopted including the (EPBD) 2018/844, energy efficiency Directive (EED) 2018/2002 and Regulation on the Governance of the Energy Union and Climate Action 2018/1999 [86], [87]. The Accounts Modernisation Directive 2005 introduced requirements for companies to include a balanced and comprehensive analysis of the development and performance of the business in their Directors' Report [88]. This analysis should include both financial and, where appropriate, non-financial key performance indicators relevant to a business, including information relating to environmental and employee matters. The 2018 recast of the 2012 EED (2012/27/EU) established a common framework of measures to promote energy efficiency within the EU [89]. According to the Council of European Energy Regulators, the revision sets the EU headline energy efficiency target for 2030 of at least 32.5%, amends certain provisions, and added a requirement for a general Directive review and a possible, upwards revision of the target. It led to a public Consultation on the Review and the Revision of Directive 2012/27/EU on Energy Efficiency [90] and paved the way for further energy efficiency improvements, due to substantial cost reductions, economic or technological development, and an extension to the Energy Savings Obligations scheme, introduced in the 2012 EED. The 2018 recast of the 2010 EPBD (2010/31/EU) imposes stringent energy efficiency requirements for new and retrofitted buildings. It covers a broad range of policies and measures that help boost energy performance of buildings and improve their existing building stock from both a short and long-term perspective [91]. The EU Regulation on the Governance of the Energy Union and Climate Action 2018/1999 led to the requirement for National Energy and Climate Plans (NECPs). The EU-28 submitted Final NECPs for the period 2021-2030 to the EC by the end of 2020 [92]. Following a proposal in 2020, a provisional agreement for the first European Climate Law was established and adopted on the 28 of June 2021 [93]. It is now being updated with a view to implement at least the proposed 55% net GHG emissions reduction target and enshrine its 2050 climate-neutrality target into law. These laws, directives and regulations form the backdrop to the current construction market, both at the global and European scale.

2.3 Construction Market

Global Construction 2025 [94] forecasts that the global construction market will grow by over 70% by 2025. Global Construction 2030 [4] forecasts that global average construction growth would be 3.9% per annum to 2030 driven by developed countries who are recovering from instability and emerging countries who are continuing to industrialise. A recent report Growth Opportunities in the Construction Industry highlights that the future of the global construction industry looks good with opportunities in residential, non-residential, and infrastructure. It goes on to say that the global construction industry is forecast to grow at a Compound Annual Growth Rate (CAGR) of 4.2% from 2018 to 2023 [95]. In addition, the Construction Global Market Report 2021: COVID-19 Impact and Recovery to 2030 [96] forecast that the market is expected to reach US$ 16,614.18 billion in 2025 at a CAGR of 7%. The global construction industry accounts for about 6% of global Gross Domestic Product and is growing [97].

These reports signal various emerging environmental trends that have a direct impact on the construction industry, such as the increasing demand for green construction to reduce carbon footprint and the development of building management information systems. Some countries now have mandatory carbon disclosure requirements for listed companies and have introduced carbon reporting for institutional investors, asset owners and investment managers [98].

2.3.1 EU Construction Market

The 2012 EC European Construction Sector Observatory publication was focussed on the promotion of favourable market conditions for sustainable growth in the construction sector [99]. The following five areas were addressed: a) financing and digitalisation: especially for energy-efficient investments in the renovation of buildings and for research and innovation in a smart, sustainable, and inclusive environment; b) skills and qualifications: workforce and management training for job creation through up-skilling and apprenticeships to meet demands for new competencies; c) resource efficiency: focusing on low emission construction, recycling and valorisation of construction, and demolition waste; d) regulatory framework: emphasis on reducing the administrative burden for enterprises, and particularly small and medium enterprises; and e) international competition: encouraging the uptake of Eurocodes and promoting the spread of new financial tools and contractual arrangements in non-EU countries [99].

According to the Europe Construction Industry Report 2020-2024, this strategy initially appears to have paid off given that the construction industry in Europe is due to record a 7.8% CAGR to reach USD 2707.2 billion by 2024. The residential construction industry increased at a 4.2% CAGR in value terms between 2015 and 2019. However, the report also highlighted the impact of Covid-19 outbreak on the European construction industry. The pandemic is expected to impact the growth across key sectors over the short to medium term, and the recovery is forecast to be slow. Residential and commercial construction sectors are forecast to suffer the most, although the growth of the infrastructure sector is expected to be maintained through public spending [100].

In 2020, during their Annual Conference, Euroconstruct highlighted that the European construction market would not recover completely until 2023, forecasting growth of 4.1% during 2021, 3.4% during 2022 and 2.4% during 2023 [101]. It went on to forecast the civil engineering sector to be least affected by the crisis and infrastructure spending to expand by 5.2% in 2021. Today, the EC says that the construction industry is important to the EU economy, providing 18 million direct jobs contributing to about 9% of EU GDP [102]. The market for the global and European construction sectors therefore looks promising and, from emerging growth and other trend reports, it appears to be increasingly sustainable, but the key to unlocking growth depends on national and organisational ability to meet performance targets and objectives.

2.3.2 Performance Measurement Systems and Targets

Given the backdrop of anticipated sustainable global growth in the sector, several countries, including in Europe, have already setup national growth or performance targets to achieve sizeable overall national short-term and long-term growth objectives [103].

Having a performance measurement system in place provides countries and organisations with reliable information and allows key performance indicators (KPIs), to be set and adjusted over time to meet objectives and implement growth strategies [104].

As a result of the 2005 EU Accounts Modernisation Directive [88], larger European organisations, including construction businesses, have had to take steps to measure their progress to meet targets through environmental KPIs. On environmental matters, this includes environmental impacts, both of a company on the environment (such as GHG emissions, waste to landfill) and of the environment on a company. Project performance itself can be measured and evaluated using performance indicators related to dimensions such as time cost, quality, client satisfaction, client changes, business performance, health and safety [105]–[107]. Time, cost and quality are the three predominant performance evaluation dimensions in the construction industry.

2.4 Construction Energy Efficiency

The construction industry is highly fragmented and subject to poor productivity. It depends on many different professions and trades, most of which tend to respond to local market needs and control only one or a few elements of construction design, construction or maintenance or operational processes.

The construction industry hosts a variety of professional disciplines (such as architecture, civil and structural engineering, and building services). Each has its dedicated codes of practice, regulations and technical jargon. Values, norms and cultures vary from one organisation to another, and increasingly within them, which can reflect in work practices, business processes, communication methods and more. Historically, all of the disciplines involved collaborate poorly, for contractual or other reasons. Projects involve a myriad of stakeholders: contractors, facility managers, product manufacturers and suppliers, user associations, clients and investors, local through to international authorities and others. Firms often appear to be willing to experiment with a suite of tools and techniques, but are either unwilling or unable to instil a culture of collaboration and the potential impact of team building is hindered by the 'formalisation' of collaborative practices [108]. If they do collaborate, then they are faced with multiple and increasingly novel ways of working, such as remote collaboration stimulated by advances in technology. This is compounded by increasing building complexity, new procurement paths, construction technologies, construction methods and materials meeting changing economic, environmental and societal challenges. This requires the involvement not only of those with traditional professional roles and skillsets but also of those in new professions with skills in areas such as energy, environmental, waste, data, communications and smart technology.

2.4.1 Global Construction Challenges

The global construction industry exhibits characteristics that differentiate it from other industrial sectors. Each project is usually a one-off and unique prototype with distinct characteristics, including choice of construction system, materials, site topography and geology, and local environmental factors. Its final products tend to be durable, lasting several decades or more, and represent one of a few non-transportable, predominantly industrial products [109]–[111]. Construction is also highly regulated. Regulations and standards are increasingly rigorous, with the involvement of several levels of regulatory governance (local, regional, national, European, and international) [112]. Beyond this, the sector is still facing the consequences of the economic crisis, and many companies have reduced investment capacities. The entry level for new companies is relatively low because the need for operational capital is small [113]. Research findings suggest that the strength of inter-organisational cooperation may be responsible for its performance in some countries. This includes the relationship of contractors with subcontractors or suppliers of materials, the government, universities, architects or engineers, clients and international collaborations with other contractors [114]. Relationships are often adversarial in nature, temporary and short term, bringing together partners who may never work together again, which can increase the problem. Traditional construction is labour-intensive, with high workforce mobility with contract durations often linked to the length of a single project or design/construction phase.

The design, construction and operation process is often not linear and cannot be viewed in such a functional way. A sequential flow only accentuates the hard breaks between the organisational structure of the industry and contributes to problems of fragmentation, and poor coordination and communication between project team members [115]. This is highlighted by several governmental and institutional reports, as follows: Philips Report [116], Emmerson Report [117], Banwell Report [118], Gyles Report [119], Latham Report [120], and Egan Report [121]. Such issues arising during the traditional construction process often lead to low productivity and profitability, poor project performance and delays, sustainability concerns and construction waste, and skilled labour shortages [122]. Despite lagging industry growth forecasts, a 2017 report titled 'Reinventing Construction: A route to higher productivity' by McKinsey Global Institute found that global labour-productivity growth in construction averaged only 1% a year over the past two decades, compared with 2.8% growth for the total world economy and 3.6% in manufacturing [122]. As a result of these issues, many projects now demand a re-educated and trained workforce as construction technology becomes ever more sophisticated [123], [124].

2.4.2 EU Construction Challenges

Aside from issues affecting the construction sector, there are several other barriers that specifically affect energy efficiency improvement. In Europe these include the following. First, small market size: several EU countries have an established energy efficiency market, but this may be small relative to the size of the opportunity [125]. There are significant economic benefits to be realised from growing these markets and making energy-efficient processes mainstream in construction. Second, SME dominance: over 90% of the industry is dominated by small and medium sized enterprises (SMEs) and many have been impacted by the recent economic downturn due to the COVID-19 crisis [126]. Third, lack of trusted energy efficiency information: there is currently a lack of access to trusted and appropriate energy efficiency information for various European construction trades [127]. Where information is available, it may be generic and not tailored to specific circumstances, which means that construction enterprises are not able to fully assess the benefits of energy-efficient interventions. Fourth, misaligned financial energy incentives: those investing in energy efficiency measures in Europe are not always the ones receiving the direct benefit across the energy value chain [128]. In terms of wider benefits such as improved security of energy supply, the individuals making an investment will not always appreciate the benefit to them. Fifth, undervalued energy efficiency: Partly due to the lack of trusted building information, the long-term benefits of improved building energy efficiency are often regarded as less certain. Consequently, energy efficiency is undervalued relative to other investment options in Europe and not prioritised as it might otherwise be. Finally, a skills gap has, in some cases, prevented businesses from making environmental and energy efficiency improvements [129].

2.4.3 Construction Sustainable Opportunities

The opportunities for sustainable new build and retrofit construction are twofold. First, there is increased interest to find novel technical solutions to decrease energy demand, minimise carbon emissions and improve process efficiency. Industry stakeholders suggest the following for improved process efficiency: a) improving planning and material management; b) using new technologies to reduce inefficient construction practices; c) listening to experienced staff, according to skill sets, across the age spectrum; d) adjusting client expectations; and e) improving communication [130]. In addition, the European Green Deal specifically called for increased green renovation to reduce carbon emissions. The Climate Analytics and New Climate Institute reveal through their CAT that an increase of the renovation rate to 3.5% is necessary to make emissions from the EU building sector compatible with the 1.5°C temperature increase limit [83]. In 2014, 35% of existing European building stock was over 50 years old. Increasing energy efficiency has the potential to reduce EU energy consumption by 5% to 6% and CO2 emissions by 5%. The EC states that currently roughly 75% of buildings in the EU are not energy efficient, yet 85-95% of today's buildings will still be in use in 2050. In 2020, the EC launched its Renovation Wave initiative: A Renovation Wave for Europe - greening our buildings, creating jobs, improving lives. The intention of this initiative is to provide an opportunity for improving energy efficiency of existing building stock [131].

It is thus clear that opportunities exist for improving the energy efficiency of built assets, whether newbuild or retrofit applications. However, there is also a third opportunity: addressing the skills gap and harmonising skills in these domains to counter sectorial challenges and make further energy efficiency again.

2.4.4 Construction Skills for Energy Efficiency

The first principle of the EC European Pillar of Social Rights [132] established as part of EC 2019-2024 priorities states that everybody in the EU has the right to quality and inclusive education, training and lifelong learning. Its Action Plan target is that 60% of all adults should be participating in training every year by 2030, in 2016 only 37% were. Data on the current EU skill landscape is available via the Skills Panorama, an online tool providing central access to data, information and intelligence on skill needs in occupations, sectors (including construction) and countries [133]. It provides information by policy themes and gives a European perspective on trends for skills supply and demand and skill mismatches, while giving information about national data and sources [134]. Inspection of data from this and other sources reveals that deficiencies still exist.

In 2012, Build Up Skills UK National Status Quo research established from employers and industry stakeholders that the following professional occupations and associated skills/knowledge need to be urgently addressed for the UK to meet the requirements of the EU 2020 energy efficiency targets: energy advisor/assessor (wide-ranging skills and knowledge needs), architects (low carbon design skills; whole life costing), construction planners (understanding energy efficiency targets), civil engineers (understanding low carbon materials and installation processes; knowledge of energy efficiency targets), surveyors (understanding of energy efficiency targets and impacts of energy efficiency measures, or lack of them), and site supervisors (understanding the processes and quality standard of completed work needed to meet low carbon requirements). They have since launched a call to reassess the original NCPs and strategic skills roadmaps of the EU countries to include new content mapping the skills needs for white-collar (White-collar workers are suit-and-tie workers who work at a desk and, stereotypically, eschew physical labor. They tend to make more money than blue-collar workers [135]), and professions as well as blue-collar (Blue-collar worker refers to workers who engage in hard manual labour, typically agriculture, manufacturing, construction, mining, or maintenance [135]) trades to reflect the requirements of the whole building value chain. There is increasing alignment of interest, or harmonisation, between those who design and construct a built asset or facility and those who subsequently occupy and manage it [134]. This demands dedicated skills to address lifecycle sustainability requirements across the whole construction industry, incorporating (AEC/FM).

2.4.5 Shifting Construction Disciplines

The process of designing, re-purposing, constructing and operating a building or facility involves not only the traditional disciplines but also many new professions [5], [136]. 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. This requires dedicated qualifications to address multi-objective requirements [57]. European businesses are increasingly integrating energy efficiency into their operating models and traditional AEC/FM disciplines are now sought to be integrated with newer ones from the energy and environmental fields.

2.4.6 Energy Efficiency Solution Agenda

An increasing number of different software solutions are available to the European construction market that are integral to the development of the energy efficiency agenda and which can interface with BIM. Building energy models allow additional information to be embedded to run energy simulations. The objective of these applications is to apply accurate energy-monitoring, provide real-time decision-support system triggers and enable consumption-pattern identification and impact the overall energy profile of a building pilot.

With software interoperability, information can be seamlessly shared between two or more software applications. In 1999, Bazjanac and Crawley showed the tangible benefit of BIM of achieving true interoperability for simulating energy in buildings through a number of case studies [137]. In 2019, Andriamamonjy et al. also highlighted how cost interoperability, time savings and duplicate data and error elimination can be achieved through energy simulation models [138].

In a BIM-based energy simulation, it is possible to satisfy the requirements of energy simulation and pass data flawlessly from BIM to an energy output simulation system, such as EnergyPlus [139] and DOE-2 [140]. EnergyPlus is an energy analysis and thermal load simulation tool that allows performance simulations to be built, such as lighting/daylighting, heating, ventilation and air conditioning, service water heating, and on-site energy generation [141]. Simergy [142] is another BEM tool that facilitates the creation of a digitalised BIM model and also interfaces with EnergyPlus software for simulations. There is also a wide range different environmental and energy-related certification and auditing processes for construction projects, such as LEEDTM and BREEAM (note that BREEAM is the Building Research Establishment Environmental Assessment Method process, whereas LEED is Leadership in Environment and Energy Design certification).

2.5 Digital Transformation in Construction Industry

Recent improvements in ICT have seen the emergence of a plethora of devices, software and communication paradigms that promote a new generation of smart buildings [143]. ICT includes software development, mobile devices, cloud computing, data centres, cyber security, research networks, support and so on [144]. Robotic automation, artificial intelligence, machine learning, the Internet of Things, and 5G technologies also form part of this evolving landscape. Devices such as low-power wireless sensor networks for environmental monitoring, and smart meters for electric load profiling and recognition, give the possibility of monitoring and profiling the energy consumption and overall energy performance of buildings [145].

ICT is an enabling force in a new era for the construction sector. Generally, as Latham explained, information technology can help the coordination and management of a new project if its function and the relationship between the parties are properly stated and understood [120]. It can also play a game-changing role, enabling faster and more reliable design decision making and construction follow-up for construction professionals. Where information was previously managed and communicated via analogue or verbal systems and instructions, today supply chain integration, the use of CAD, BIM and mobile computing development in the sector signify that ICT is becoming an integral part not just of design offices but also of construction sites [146]. ICT has also been recognised as a key player for reducing energy consumption and the progress towards a more sustainable and smart society [147].

In 2006, research by Ruddock revealed that the global construction industry was already beginning to reap the benefits of productivity from the post-1995 surge in ICT investment [148]. However, progress since then has been uneven and affected by external factors. For example, the IDC reports that from 2021 through 2023, overall ICT spending will grow by at least 5% annually due to continued expansion in new technologies [149]. The pressure is still on to accelerate return on ICT investment.

CAD replaces analogue manual draughting design processes. Some, such as Sanders [150], trace the beginnings of CAD to the year 1957, when the first commercial numerical-control program was developed. In 1960, a solution was developed that demonstrated the basic principles and feasibility of computer technical drawing [150]. The increasing use of CAD software in construction design offices from the early-1980s prompted the first efforts in electronic integration and sharing of building information and data [151]. Here, the ability to share information and data electronically through either proprietary drawing formats or via drawing/data exchange format, together with the added dimension of drawing layering, had substantial impacts on business processes and workflows [5]. The use of CAD evolved towards communicating information about a building in ways that a manually drafted or plotted drawing was unable to [152], [153]. Object-oriented CAD was introduced in the early-1990s by companies such as AutoDesk, GraphiSoft, Bentley Systems and others [154]. Data objects in these systems stored non-graphical data and third-party components, which comprise product data, in a logical structure together with the graphical representation of the building. These systems often supported geometrical modelling of the building in 3D, which helped to automate many of the draughting tasks required to produce drawings. When combined with the increasing ubiquity of electronic networking and the Internet, this allowed companies to collaborate and share building information and data, which led to new ways of communicating and working. The opportunities presented by the move towards collaborative working and information sharing led in the early-1990s to the development of frameworks to encourage the migration from document centred approaches towards model based, integrated systems [155], [156] [155], [157]. It is clear that to capitalise on the potential for CAD and object or product model integration, improved standard coordination is needed [158] [159].

In contrast, BIM is the process of generating and managing data and information about a built asset throughout its entire lifecycle. It is defined as a building information generation, storage, management, exchange, and sharing process that is interoperable and reusable [40], [41], [160]. Furthermore, BIM is a procedure that is used in developing and handling project information and data that generates an outcome, which is referred to as the Building Information Model. This requires the development and use of a computer-generated model to simulate planning, design, construction and operational phases of a project [7], as illustrated in Figure 2-1. This model holds the digital information and data of a physical built asset.

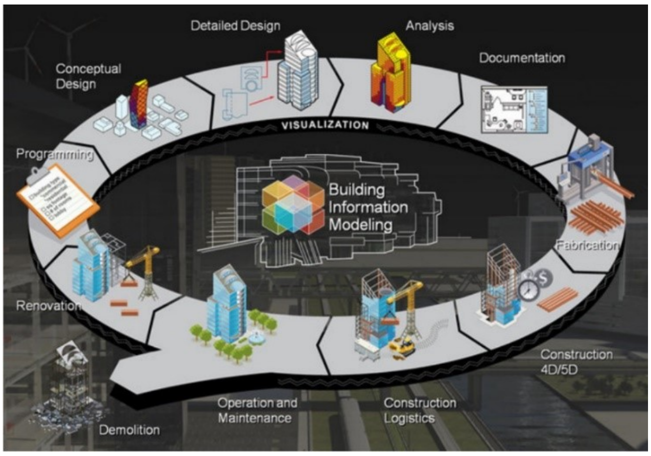


Figure 2-1 Uses of BIM across an asset lifecycle (source: buildipedia.com) .

BIM information and data can be used to illustrate the entire building lifecycle, from inception to completion and beyond, through to demolition and materials reuse. BIM describes the process of designing a building collaboratively using one coherent system of computer models rather than a separate set of drawings [161]. BIM is generated for various strands of issues to be addressed in delivering a scheme. Information flow in each lifecycle stage needs to be planned and managed as per the operational requirements of the asset owner or client. All of this information, including energy efficiency and environment-related information, can be continuously shared and its workflow is managed in a Common Data Environment, as shown in Figure 2-2.

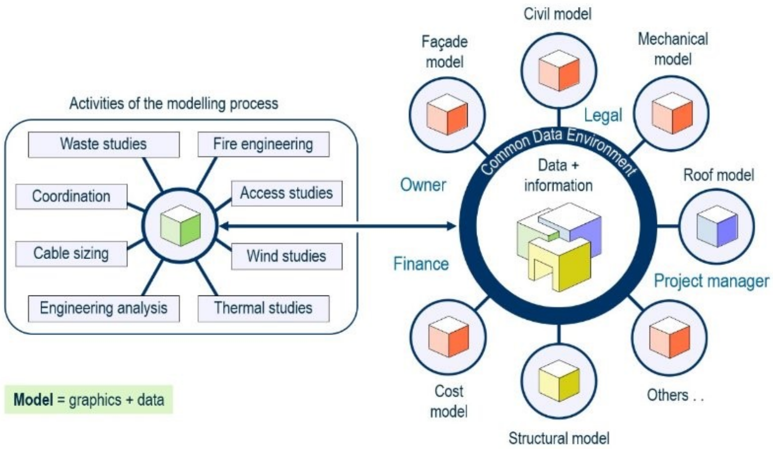


Figure 2-2 Model organisation in a Common Data Environment.

BIM holds plays a critical role in revolutionising the construction industry worldwide. As part of this, the European construction industry is experiencing digital transformation, and digital support is intensifying through all stages of building design and construction. BIM methods and tools are now of significant interest in the sector. They are recognised as key components of future construction practices, and their benefits for productivity and reliability are widely acknowledged. BIM has brought about digital transformation in the construction industry and is of significant interest across Europe [62]. Initially, BIM enhanced design support and construction planning and monitoring. This advanced support from digital tools is likely to enable significant improvements in the quality and performance of buildings or more. Yakami et al. has shown that the use of BIM in projects can have a significant impact on quality, resource efficiency, and reduction in construction time and cost [162]. Yarmohammadi and Ashuri emphasise the roles of BIM qualifications regarding the coordination of building services, and how a team leader with high BIM qualification can have a significant impact on the progress and coordination of a project [163]. Mohd and Latiffi mention that a skilled BIM workforce helps to reduce cost and improve time management through clash detection [164]. Barrett and Sexton say that BIM can support collaboration between employers, designers, suppliers and facilities managers through a range of design and construction tasks [56]. BIM has also been validated in studies by Egan and Bryde et al. [57], [121], as an efficacious instrument for addressing: a) project failure caused by lack of effective project team integration across supply chains; b) Dainty et al. comment on the emergence of challenging new forms of procurement including design–build–operate contracts [165], and c) Becerik-Gerber et al. showed that adopting BIM in FM can decrease the whole life cost of a building [60]. The literature thus shows that BIM enables practitioners to: a) gain efficiency in their individual activities and work more efficiently together with different stakeholders through more seamless information and data exchange, b) have a raft of opportunities for time and cost savings, c) improve natural and human resource efficiency, d) improve quality and productivity through integration of graphical and non-graphical data, e) improve supply chain integration throughout a project lifecycle, f) improve communications and virtual coordination through digital collaboration, g) facilitate opportunities for sustainable construction, h) be of use for a variety of purposes, i) improve organisational, team and individual skills, and j) preserve the competitiveness of European businesses. Managing building information using BIM can lead to significant cost, time and waste reduction throughout the lifecycle of an asset: from inception through to design and construction through to maintenance. Coordination checks become unnecessary, and information generated from a model leads to fewer errors on-site caused by inaccurate and uncoordinated information. Critically, as Boton et al., Petri et al. and Yuce and Rezgui find that BIM represents a game-changing factor that would support the transition to more energy and cost-efficient practices [53], [54], [166].

2.5.1 BIM Applications

During the last decade, BIM has powerfully transformed AEC and FM projects, due to the fact it enables lifecycle and supply chain integration, and facilitates digital collaboration and increased productivity. BIM solutions are vehicles for collaboration and exchange of data. However, to successfully implement BIM processes, AEC/FM construction teams need confidential data security, both externally or internally, within a BIM model. Although a BIM model can be part of an extranet, Christensen et al., Martin 2009 and Udom 2012 say that this may lead to significant legal issues, which should be dealt with through a construction contract [42], [43], [167].

2.5.2 BIM Qualifications

According to Succar and Sher, individual BIM qualifications are the personal traits, professional knowledge and technical abilities required by an individual to perform a BIM activity or deliver a BIM-related outcome [168]. These abilities, activities or outcomes must be measurable against performance standards, and can be acquired or improved through education, training, and/or CPD development.

There is a particular need for technical and collaborative skills because BIM is a relatively new topic in AEC education and best practices in BIM education are yet to emerge, as illustrated in Table 2-1. BIM courses are often taught as technology training, without any theory or collaborative learning. In contrast, industry values both technical as well as collaborative skills because they are the base for better integration and career development of the future employee [169]. Team members from different disciplines also need to collaborate and work together with BIM data, supported by BIM professionals. Many authors highlight that skills such as teamwork and communication are required in the curricula, as well as soft skills such as collaboration and communication, negotiation, teamwork, leadership and conflict management [170]. Similarly, Barison et al. look into individual qualifications such as aptitude, qualifications, skills/abilities, knowledge and attitude, noting the professional need for the position in both foundational and functional ways [171].

Dossick et al. emphasise that BIM curriculum should also include the understanding of computer application concepts and BIM processes [172]. Others, such as Wei et al. [173], emphasise needs such as model management and 3D coordination. Interestingly, Taiebat and Ku report that the construction industry values employees who also have in-depth BIM conceptual skills rather than those with BIM application skills only [174].

Table 2-1 Summary of key BIM skills based on the literature review and on Yakami [162]**.**

No.	Authors	BIM Qualifications
1	Rahimi et al. [175]	Teamwork, communication, understand BIM standards and workflow

2	Succar et al. [168]	Leadership, estimation, documentation and detailing, model management
3	Eadie et al. [7]	Collaboration
4	Murphy [176]	Technical knowledge, planning and administration, strategy and policy, programme management
5	Sturts et al. [172]	Coordination and collaboration
6	Barison et al. [171]	Teamwork, leadership, analytical thinking, BIM applications, creativity
7	Succar and Sher [168]	Leadership, collaboration, facilitation, organisational management
8	Wei et al. [173]	3D coordination, modelling, design review, site utilisation planning
9	Davies et al. [170]	Conflict management, communication, negotiation, teamwork, leadership
10	Dossick et al. [172]	Understand computer application concepts and BIM processes
11	Taiebat and Ku [174]	BIM conceptual skills

2.5.3 BIM Education Practice

Due to the recent and rapid increase in demand for BIM professionals, the current qualification development, training, and educational practices are often based on a reactive approach, while a well-researched and time-tested best practice for diverse BIM skills requirements is yet to emerge [177], [178]. This sector needs structured understanding, assessment, and measurement of BIM qualification of a person or a team, contingent on roles in the BIM ecosystem. It is also essential to improve the breadth, depth, quantity and quality of educated and trained professionals in the built environment to support an effective BIM agenda across Europe.

Yakami et al. have shown that, in this context, BIM education is a critical part of AEC and FM education and should address the individual and team skills. Other authors highlight the need for BIM skills in the AEC/FM sector [162]. Whereas Fan et al. emphasise the need for a relationship between the BIM skills of a person and their understanding of intricacies of the field for which BIM is used [179], research by Kassem et al. reveals the particular value of improving analogue manual processes of information handover, improving the accuracy of FM data and also the efficiency of work orders execution, in terms of speed, data access and intervention location, and the challenges of BIM for FM. This is exemplified through a real-life case study of a UK university complex [180], [181]. BIM is also seen to empower current and future AEC/FM professionals to accomplish increase productivity, reduce waste and create a sustainable future through a combination of technical, methodological, procedural and organisational techniques and skills.

Other research by Kassem et al. suggests that BIM collaborative design protocols can be used at the project level by entire supply chains to increase the efficiency and consistency of information flow and BIM deliverables [180]. In addition to new protocols, new roles are emerging. For example, dedicated BIM managers, BIM coordinators and BIM designers are now often seen as required in construction projects. Project managers are likely to be positioned for roles as BIM managers and, as research by Yakami highlights, their most valuable skills are collaboration, knowledge about BIM development, fluency in BIM applications, and technical skills. However, Rahman et al. state that the skill sets needed for project managers and BIM managers are different [175]. Research by Yakami shows how BIM coordinators require knowledge about BIM standards and recent knowledge about BIM developments, as well as leadership and application skills [162].

2.5.4 BIM Applications for Energy Efficiency

BIM aids the AEC/FM sector and its energy efficiency agenda because digitalisation of product and process information provides a unique opportunity to reduce material waste and duplication of human effort, optimise energy efficiency related decisions across entire building lifecycles and supply chains, and allow opportunities for interface with sustainable construction, design for manufacture and assembly, smart construction processes and IoT. Cerovsek says that BIM also facilitates information collected and stored in a BIM-compliant database, which can often be beneficial for a variety of practices, such as energy management, maintenance and repair, and space management [61]. The implementation of BIM for energy efficiency provides energy savings through a combination of accurate energy monitoring, real-time decision-support systems, and triggers and identification of consumption patterns. Moreover, reliance on a semantic approach, enhanced supervision of energy flows and use in buildings, and new partnerships between energy managers, energy distributors, energy equipment suppliers, and technology optimises energy use management in buildings. This results in quantifiable energy consumption reduction. Petri et al. find that it provides an analytic operating capacity, KPI control, annual consumption forecast progress, reports and personalised alerts. Smart distribution of (reduced) building energy consumption implies economic savings with targeted energy reduction [62].

BIM can facilitate recognised environmental and energy certification processes, including BREEAM and LEED, but not without challenges. The key input to the BREEAM process is building-related data. BIM enables the data location and format to be rationalised and increases the potential for informed decision making compared to traditional approaches to design, construction and management. As its uptake increases, the processes underpinning BREEAM assessments need to be adapted to make use of BIM data, realise performance improvements across a range of metrics and ultimately continue to deliver value to users.

An improved BREEAM rating is a key opportunity offered by increasing BIM use with BREEAM. This offers the potential for digital building data to be processed and analysed to determine when the opportunity to improve performance is most cost effective (e.g., prior to construction or in-use management interventions). Alongside the RegBIM project [182], and utilising learning and output from it, work is underway to develop the IT infrastructure that is required to enable third-party construction software to automatically deliver BREEAM performance feedback to users as the building data models develop. At the heart of this work is the alignment of BREEAM content with industry recognised construction classification systems and interoperable data exchange standards [183].

Data-driven construction and management also presents an unprecedented opportunity to extract building strategy and component data, and then link it to BREEAM performance data to understand successes and failures, and contribute to closing the gap between design intent and in-use performance. In the future, it will become possible to illustrate the relationship between components, strategies and overall building performance against BREEAM requirements, propose improvements, to underpin and inform development BREEAM standards [184].

Wei and Issa highlighted in 2012 that LEED integration is challenged by the wide variety of software applications and domain information that are needed for building simulations and analyses that relate to specific disciplines. Although collaboration between software vendors and file format use can go some way to alleviate this problem, the complexity of LEED projects can cause confusion and miscommunication between project stakeholders. Therefore, care is needed in model information exchange mechanism planning [185].

Level of development requirements and the model view definition are important concepts to grasp when handling BIM-based project information management for LEED. The key is to create an interoperable software environment that is based on open standards, such as industry foundation classes. This facilitates seamless and bidirectional information flow between individual project stakeholders and meets specific model information needs in real time without compromising the overall design process, the model integrity or the anticipated building performance given in the LEED rating system. Consequently, reliance on traditional desktop applications through simple Internet connections with email or file transfer protocol as a major data sharing solution is inadequate [186], [187].

2.5.5 Building Environmental Impact

Based on a building's full lifecycle, the European construction sector is responsible for half of its extracted materials, half of its total energy consumption, a third of its water consumption and a third of waste generation [91]. Consequently, the sector clearly has a responsibility towards setting and meeting environmental standards targets across a building lifecycle, including meeting the requirements set out in the EC's 2020 Circular Economy Action Plan [188]. Therefore, role of construction management plans and frameworks is considered here.

2.5.6 EU Construction Plans and Frameworks

Over the years, several process frameworks for construction project management have been developed, such as the project process [189], Salford process protocol [190], Ministry of Defence 'Working Document' [191], Construction Industry Research and Information Association 113 [192], British Standard 7000 [193], Hubka [194], Pahl and Beitz [195], VDI 2222 [196], French [197], and Royal Institute of British Architects (RIBA) Plan of Work (PoW) [198]. In 1999, through model comparison, Macmillan et al. described the following general criticisms: a) most models describe a sequence of phases that typically imply iteration within phases but not the link between each; b) most models imply starting with an analysis of requirements before the generation of possible solutions (although much design work involves modification of existing solutions, not the invention of new ones); c) most models describe what should be undertaken, not why or how it should be performed; d) most models do not define what is to be carried out by the different team members and what needs to be performed in collaboration; e) and most models do not address the social aspects surrounding team-working, such as the selection and involvement of team members at various stages, the exchange of information, or the promotion of effective collaboration [199].

More recently, to meet the European Green Deal agenda in 2018, the EC launched a test period for its EU Level(s) Framework (Level(s)) [91]. This is a new pan-European approach to assess and report on the sustainability performance of buildings, throughout the full life cycle of buildings. Within Level(s), each indicator is designed to link the impact of an individual building with European sustainability priorities. However, unlike the RIBA PoW, this framework does not include BIM. Evaluation of these plans and frameworks shows that apart from RIBA PoW, none succeed in capturing ways to help a new design team overcome the intense requirements identified at start of a project when team members have conflicting aims, priorities and expectations, and a new way is needed to construct consensus, develop common goals (e.g., more energy-efficient and environmentally friendly processes) and share problem-ownership.

2.5.7 RIBA Plan of Work

The RIBA PoW was originally published in 1964 as a standard process for building and it has become widely accepted as the operational model throughout the UK building industry. The PoW represents a logical sequence of events, which should ensure that sound and timely decisions are made during a project's lifecycle. It is suggested that all decisions, set out or implied, have to be taken or reviewed. It is anticipated that the model will only need adjustments depending upon the size and complexity of the project [200]. The project progresses from inception to feedback, from stages, in a linear fashion, requiring the completion of one stage before proceeding to the next. This provides a shared framework for design and construction that offers both a process map and a management tool. The work stages have been used to designate stage payments and identify the team members' responsibilities when assessing insurance liabilities. In addition, they often appear in contracts and appointment documents.

The RIBA PoW has evolved to reflect the increasing complexity of projects, incorporating increasing and changing regulatory requirements to reflect the demands of industry and the

UK government. It has moved from being a simple matrix representing just the traditional procurement route, to including multiple procurement routes, more diverse roles, multi-disciplinary teams, UK government gateways and has added stages before and after design and construction [201].

In 2011, RIBA published the Green Overlay to the RIBA PoW, which aimed to provide straightforward guidance on the activities needed at each RIBA work stage to ensure that sustainability is at the heart of design and management decisions [202]. In 2012, RIBA published the BIM Overlay to the RIBA PoW, which aimed to provide straightforward guidance on the activities needed at each RIBA work stage to successfully design and manage construction projects in a BIM environment. As well as setting out BIM activities at each work stage, key data drop points were identified within the overall project process. The aim was to assist design and construction teams in using BIM to provide a more efficient, intelligent and cost-effective design process, and to offer enhanced services to clients, particularly in relation to the whole life value of buildings. The 2013 PoW [202] version was even more flexible and reflected increasing requirements for sustainability and BIM, and allows simple, project-specific plans to be created.

The RIBA plan of work is an accepted industry process outlining the critical stages of a construction project. It has eight work stages, as illustrated in Table 2-2. Clear boundaries, and detailed tasks and outputs are required at each stage. It acts across the full range of sectors and project sizes [203].

Table 2-2 RIBA Plan stages of work, 2013.

Stage		Definition
	Stage 0	***Strategic definition*** is a new stage in which a project is strategically appraised and defined before a detailed brief is created. This is particularly relevant in the context of sustainability, when a refurbishment or extension, or indeed a rationalised space plan, may be more appropriate than a new building. Certain activities in Stage 0 are derived from the former (RIBA Outline Plan of Work 2007) Stage A – Appraisal.
	Stage 1	***Preparation and brief*** merge the residual tasks from the former Stage A – Appraisal – with the Stage B – Design Brief – tasks that relate to carrying out preparation activities and briefing in tandem.

	Stage 2	***Concept design*** maps exactly to the former Stage C – Concept.
	Stage 3	***Developed design*** maps broadly to the former Stage D – Design Development – and part of Stage E – Technical Design. The strategic difference is that in the RIBA Plan of Work 2013 the Developed Design will be coordinated and aligned with the **Cost Information** by the end of Stage 3. This may not increase the amount of design work required, but extra time will be needed to review information and implement any changes that arise from comments made before all the outputs are coordinated prior to the **Information Exchange** at the end of Stage 3.
	Stage 4	***Technical design*** comprises the residual technical work of the core design team members. At the end of Stage 4, the design work of these designers will be completed, although they may have to respond to design queries that arise from work undertaken onsite during Stage 5. This stage also includes and recognises the importance of design work undertaken by specialist subcontractors and/or suppliers employed by the contractor (Performance Specified Work in JCT contracts) and the need to define this work early in the process in the design responsibility matrix.
	Stage 5	***Construction*** maps to the former Stage K – Construction to Practical Completion – but also includes Stage J – Mobilisation.
	Stage 6	***Handover and close-out*** maps broadly to the former Stage L – Post Practical Completion – services.
	Stage 7	***In-use*** is a new stage that includes post-occupancy evaluation and a review of project performance, as well as new duties that can be undertaken during the In-Use period of a building.

The BIM overlay to the RIBA Outline Plan of Work provides straightforward guidance on the activities needed at each RIBA work stage to successfully design and manage construction projects in a BIM environment. This version of RIBA (2013) is even more flexible and reflects increasing requirements for sustainability and BIM, and allows simple, project-specific plans to be created.

The RIBA plan has been reviewed by the expert panel to validate and identify the critical stages of the construction projects in this research, starting from strategic definition to in-use stage. An additional stage to reduce the environmental impact of demolition and recycle construction waste was recommended by the experts because in some cases deconstruction works are needed before starting a new project. This plan also helped to classify the skills needed for the category's roles in each stage. This classification provided a clear map to understand which skills are required for each role group during the project lifecycle.

2.6 EU Construction Training Agenda

This section studies the current BIM training and education programmes across Europe, highlighting BIM energy efficiency applications. It also provides an overview for BIM applications in Saudi Arabia.

2.6.1 BIM Training and Education

Education is an overarching social issue worldwide. As the UN Human Rights Office of the High Commissioner stated in 1976, in European societies, as well as in most parts of the world, education is recognised as a key pillar of community life and it is a universal right [6]. Literature shows those without necessary skills and qualifications face diminished life prospects and risk alienation from mainstream society. Jah and Polidano also puts a particular emphasis on the clear relationship between education and social stability: increasing access to post-secondary vocational education and training significantly reduces property crime, drug crime and crime against the person [63]. Enhancing qualifications of workers is therefore key in all economic sectors, but it is particularly critical in the construction sector.

Many of the limitations of the existing BIM training and education provision have been exposed through research. Wu and Issa recognise that the qualifications of fresh graduates are not good enough to satisfy the work-related demand. Offers of education and training focus on only a small subset of the industry. Meanwhile, main courses concentrate on construction and design, not briefing or (construction) planning, which impacts the BIM effect on improving asset operations [173]. Beyond this, research also shows that training courses target more technical participants, rather than blue-collar workers or management teams, and strategic positions within organisations. In addition, BIM training and education does not appear to address large infrastructure projects but predominantly focuses on buildings [173].

Wu and Issa also envisage BIM education as a solution to increase BIM learning and they suggest that BIM education should prepare graduates to be ready enough for organisations to be able to shape their BIM qualifications according to their own need [173]. To meet these aims, BIM training programmes have been established. In some instances, these have been driven by government BIM mandates or national initiatives, while in others they have been driven by non-governmental organisations and industry associations.

Regarding government BIM training initiatives, Hore et al. suggest that if BIM adoption is a requirement, then training must be subsidised by the government to facilitate implementation [51]. Denmark was an early adopter of BIM. In 2013, the government of Denmark mandated BIM in public construction projects that are either fully or partially publicly funded [204]. Since 2020, BIM has been compulsory in all transport projects in Germany [205]. Dobrindt reports that the German BIM Steering Group Planen Bauen 4.0 has set clear guidelines for the practical application of BIM methods by introducing the BIM Level Plan (Stufenplan fur BIM in Deutschland) [206].

The UK and France are leading examples of how the digital skilling of the workforce can be specifically initiated at the government level. One of the priority focus areas of the UK government's Construction Strategy 2016-2020 was the strengthening of the skill base in the sector, particularly digital skills. This strategy sought to support the creation of 20,000 new apprenticeships by 2020, ultimately aiming to integrate and increase the use of digital construction processes (such as BIM) through a skilled workforce [207]. Likewise, in France, the Plan pour la Transition Numérique dans le Bâtiment was launched by the French government in 2018 to foster the adoption and deployment of digital technologies in the construction sector, with a particular focus on improving the digital skill base of construction professionals [208]. This coordinated assessment of available BIM training and benchmarking through international initiatives aims to provide construction professionals with a comprehensive picture of the training opportunities available to them in their digital transition, as well as providing training centres with the opportunity to align their courses with the needs of the industry. A particular focus is also put on strengthening the qualifications of trainers and teaching staff.

Regarding non-governmental BIM training, aside from the strategic direction set out by the public sector, the practical delivery of dedicated training relies on the active involvement of non-governmental institutions, as well as on the cooperation with industry itself. In Ireland, for instance, the Irish Green Building Council offers BIM International training (BIM Level 2), which is a two-day course aiming to train building professionals in BIM by introducing best practices, standards, methods, and procedures [209]. Similarly, in Spain, the Spanish Labour Foundation for Construction (Fundación Laboral de la Construcción) has opened a training centre in Barcelona, aiming to become a benchmark for training in construction innovation with respect to BIM application and new construction methodology (such as lean construction), leveraging tight partnerships with industry [210]. Comparable initiatives can also be found in Eastern European countries. For example, the Latvian Association of Civil Engineers offers a series of seminars to enhance the skills of its members regarding BIM and digital technologies [188].

Private companies also play a role in training and informing construction professionals about BIM. For example, software vendors such as coBuilder and Nemetschek have started educating the Bulgarian construction industry about the advantages of using BIM by organising events such as the Second Scientific-Applied Conference with International Participation - Project management in Construction and the different faces of BIM, which attracted over 150 construction and architecture professionals [211]. In the Netherlands, the uptake of BIM is supported through initiatives that aim to share information and best practices among the community. For instance, the BIM gateway, BIM Loket, is a national portal for information and management of open BIM standards in the Netherlands, which stimulates their use. By bringing together open BIM standards in one coherent system, the BIM Locket will satisfy the need for a good information service that will answer the users' practical questions and facilitate knowledge sharing [212]. Eastern European countries are also implementing initiatives to introduce BIM in the construction sector. In Lithuania, the Lithuanian Association of Builders, together with 12 other relevant associations, launched the Digital Construction action in 2014 to foster the development of BIM and introduce the National Construction Classification and Industry Foundation Classes in the national building sector [213]. In the Czech Republic, the government setup an Interdepartmental BIM Expert Group comprising representatives from various stakeholders (e.g., ministries, universities, construction companies etc.) to foster the exchange of best practices and bring about the implementation of BIM in the construction industry [214] [215].

Therefore, although not strictly skilling initiatives, the schemes implemented in these countries aim to raise awareness, stimulate knowledge sharing and boost the uptake of BIM, thus ultimately leading to higher levels of skills and knowledge of BIM among the construction workforce. Conversely, some countries are directly addressing the need for BIM skilling and training among the workforce, either by explicitly setting training targets in their national strategies or by offering BIM training and learning resources.

Even before work begins on-site, there is an increased demand for low carbon design-related skills to ensure that new buildings are designed for maximum energy efficiency prior to technology being installed and to ensure that they are cost effective. Design and planning considerations relating to the type of material used or aspects of structure can yield cost-effective and appropriate low carbon solutions.

The EED and EPBD and related national regulations that set strict energy-efficiency targets on European buildings, and call for Net Zero Energy Buildings (NZEBs). NZEBs are complex systems that call for significant technical progress and skills in several areas, including building envelope performance, energy and comfort monitoring and integration of renewable energy production.

2.6.2 BIM and energy efficiency training courses

Many European countries have tried to increase the awareness of BIM for energy efficiency amongst construction stakeholders. Training programmes and courses have been established to enhance construction workforces' skills in this area. This section summarises the BIM and energy efficiency training that is currently offered across Europe. This information was supplemented through information obtained from the expert panel and internet search. Five Europe countries have been chosen to investigate their training programs for construction workers to use BIM and energy efficiency, as follows:

Luxembourg: Courses are primarily aimed at BIM co-ordinators and designers with a focus on BIM protocols, modelling issues, BIM management, interoperability and so on. In addition, courses are aimed at all actors to introduce BIM and raise awareness. Completion of all courses will be recognised through a certificate of attendance. None of these current BIM courses in Luxembourg have addressed energy efficiency of buildings. However, one course from the House of Training (HoT) specifically addresses the issue [216], which is aimed at architects, civil engineers, technicians and all actors interested in improving the energy performance of buildings.

Greece: Much of the BIM training programs in Greece are focussed on modelling and using the Revit software at either a basic or advanced level. As such, it is aimed at architects and engineers and is pitched at EQF Level 6. Shorter period courses are aimed at general awareness raising of BIM and addresses all actors. In all cases, recognition is through a certificate of attendance [217]. There is no specific link to energy efficiency [218].

France: Courses address all actors, but they are particularly aimed at architects, engineers and project managers so focus on exchange protocols, design, managing actors in the supply chain and so on. There is a more limited offering to building managers and blue-collar workers, and there are also awareness raising courses including some aimed at clients and building owners [219]. All of the BIM courses are pitched are EQF Level 5-6, but there are five Level 7 master's degree courses offered to students that cover BIM concepts, modelling and management [220].

None of these courses directly address energy efficiency. However, INES has recently launched a 3-day Level 5/6 course: *BIM au service de l'efficacité énergétique des bâtiments* [221], which is aimed at all stakeholders and the learning objectives are to understand: the energy efficiency of buildings, the BIM process, and how BIM can improve the energy performance of buildings. Despite this activity, the integration of BIM in these contexts is in its infancy, and not all schools and training courses are at the same level in the use and integration of BIM. Much depends on the experience of teachers and the linkages between schools and access to existing training materials.

Finland: Various software companies offer short BIM training courses which are related to using their software in different contexts and are targeted at construction professionals. None of them specifically address energy efficiency, except for one from a Swedish company, EQUA [222], which has developed IDA ICE (Indoor Climate and Energy), an annual dynamic multi-zone simulation application to assess the thermal indoor climate and energy consumption of a building. The aim is to integrate the tool with BIM to reduce energy consumption, assess lifecycle costs, application to LEED and so on. Similarly, Oulu, Tampere, Saimaa, Turku, Lapland and Savonia Universities all offer BIM related courses primarily focussing on planning and design at Levels 5 to 7. However, energy efficiency is not generally addressed.

UK: The two key areas where BIM is currently offered are in university degree courses and CPD training (with the potential for certification) for construction professionals. Energy efficiency or, more broadly, sustainability is addressed in some of these courses, although the focus appears to be on the design stage of construction [223]. Their qualification(s) are also aimed at a broader base including: mechanical, electrical and plumbing services engineers, heating, ventilation and air-conditioning engineers, technicians, contractors, subcontractors, fabricators and manufacturers, facilities and operations managers, and quantity surveyors [224].

The key planks of BRE's training are BIM (Level 2) Essentials and BIM (Level 2) Information Manager. Both are offered in a short period classroom format each with a multiple-choice exam at the end, but both can be taken online instead [225]. Delegates must pass the Essentials course before proceeding to the Information Manager course. CPD certificates are awarded, but successful delegates can also become certified as:

- **BIM Informed Professional**. This certification is suitable for those wishing to demonstrate their knowledge of the BIM process. Certification audits require demonstration of the detailed knowledge and understanding gained through training and experience on Information Management.
- **BIM Certificated Practitioner (Project/Task Information Manager or PIM/TIM)**. This certification is suitable for those wishing to demonstrate their application of the BIM process on live projects. Certification audits cover the detailed knowledge and understanding gained through training and experience.

These courses do not directly address energy efficiency. However, BRE also offers a short BIM course for site managers which targets the implications of BIM for those responsible for managing sites [226]. The course does not address energy efficiency explicitly but does highlight how BIM can help effective management and minimise risk which can improve efficiency and reduce the performance gap.

In conclusion, key insights into the overview of BIM and energy efficiency training programmes offered across Europe are as follows:

- Raising awareness of BIM across the supply chain is reasonable, particularly amongst designers, contractors and clients, but there could be improvements amongst sub-contractors and facility/asset managers. With regard to BIM/energy efficiency awareness raising, the provision is limited across the supply chain.
- Similarly, designers and contractors are well-served by BIM training across the concept, design, construction and handover phases. This is usually provided by private

training organisations. In this they are supported by certification schemes offered by these bodies, such as those in France and the UK, whereby they can demonstrate their knowledge and competence. Such courses are often focussed on modelling software, as in Greece for example, which emphasises the planning and design aspects.

- Students also appear to be well-served, at least those taking bespoke BIM degree courses such as a masters (Level 7) in the UK, or the Level 5 and 6 courses offered by universities in Finland. Bachelor degrees in traditional construction areas such as architecture, civil engineering, surveying, planning and construction management are increasingly integrating BIM.
- Conversely, the extent of integrated BIM and energy efficiency training is either poor or limited in these areas. Some of the Finnish courses incorporate aspects of energy and use well-established software tools to undertake energy simulations, overheating assessments and so on. Similarly, some of the UK masters degrees include treatment on the delivery and performance of low energy/sustainable buildings, but these are in the minority.
- Software providers are helping to fill this void, and provide courses aimed at modellers and designers helping them to integrate BIM and energy performance tools with the intention to streamline the process and avoid duplication. There is certainly scope to integrate BIM into national calculation methodologies for energy performance certification, thermal bridge assessment and so on.
- Clients, facility managers and sub-contractors do not appear to have sufficient BIM training across many of the plan of works stages, and such training is largely absent for BIM/energy efficiency. The situation is much the same for students outside of the brief, concept and design stages.
- Overall, the position is developing rapidly with the proposed establishment of courses across the project partners, particularly courses in Luxembourg and France, university courses in the UK and so on but there needs to be a more focussed effort in those areas where the main gaps have been identified.

2.6.3 BIM for Energy Efficiency

The previous section shows that there is a need for a combined strategy in Europe for training, education and Continuing Professional Development (CPD) for BIM and energy efficiency. A virtual collaborative platform that provides integrated access to BIM resources in the form of interactive, dynamic, and user-oriented services that fully exploit latest advances in computing technologies may help to address these barriers [52]. BIM training and education can be taken at the individual or collective level, depending on the experience of the team and project-based requirements. These 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.

The UK construction skill gap and training agenda is a case in point. The Build Up Skills UK project, which is an alliance of four sector skills councils (i.e., Asset Skills, Construction Industry Training Board (CITB)-ConstructionSkills, Energy & Utility Skills and SummitSkill) was setup to meet EU 2020 energy efficiency targets [134], [227]–[230]. It identified skills gaps and implemented long-term training infrastructure to improve the skills related to the installation and maintenance of building energy efficiency technologies. Efforts are also being made to ensure that all organisations responsible for the delivery of national energy efficiency policies have the appropriate qualifications and certifications. The UK government also commissioned the British Standards Institute to develop the PAS 51215:2014 energy efficiency assessment of the qualification of the lead energy assessor [231]. This provides a benchmark setting for the level of qualification of the lead energy efficiency auditors who are deemed to be qualified to conduct energy efficiency audits in compliance with the implementation of the EED in the UK. Also in the UK, research has been carried out to inform a 2011 report Delivering Low Carbon Skills Wales – Low Carbon New Build Learning Project, which included a workshop with built environment sector stakeholders to discuss the skills issues associated with low carbon building projects in Wales [232]. This workshop revealed the following: a) better knowledge is needed rather than skills with respect to low carbon building; b) skills around quality requirements and checking could be improved across the board; c) architects' skills for low carbon residential developments require improvement; d) Standard Assessment Procedure Assessors do not always have knowledge outside of the assessment and may not be able to help with practical achievement; e) site agents need to adopt a different approach to the traditional methods; f) designers need to be fully knowledgeable about how to create buildable standard details that meet the requirements of the code (these details ultimately need to be shared with the trades). This workshop has also identified opportunities for improvement by g) bringing a code assessor onboard at an earlier stage to simplify design and build; h) creating details in a format that can be easily understood on-site; i) providing more site-based time for trainee architects; and j) employing a low carbon coordinator on-site from day 1.

According to Alhamami et al. [136] a broad range of training and education suppliers and opportunities are available to the European construction industry to fill the gaps in BIM and energy efficiency. Furthermore, BIM training, education and CPD courses are available, either online or offline, from a range of providers, such as universities, institutions, research establishments and other professional organisations. These courses aim to improve communication processes through new virtual educational methods to create skilled and deep-seated groups. They also seek to improve the quantity and quality of educated and trained built environment professionals to support the ambitious BIM agenda across Europe. These opportunities can also be provided by solution providers and via social media platforms, as well as IT and BIM Peer to Peer networks [136]. In addition, these courses can be provided within the context of a European Qualification Framework (EQF) on BIM for energy efficiency.

2.6.4 The European Qualification Framework

Figure 2-3 A holistic approach to BIM and energy efficiency training [62]**.**

A BIM-based standardised EQF for achieving energy efficiency training is proposed by this research, which acknowledges the predecessors of the current EPBD 2018/844/EU and EED 2018/2002/EU and RIBA PoW 2020 and legislation carried out during the research period. Through this research, several European countries seek to develop a standardised BIM framework for energy efficiency training, education and CPD across Europe. This framework aims to broaden the BIM training and education agenda to holistically support the current and future EU building energy efficiency training and education agenda, see Figure 2-3. It seeks to capture and manage the changing requirements of BIM and energy efficiency training and education needs through a dedicated framework, which includes a wide range of aspects such as roles, and skills. To be of value, this requires broad awareness and engagement with BIM and energy efficiency practice across different asset types, project scales and roles in the industry.

The main objective of this literature review was to address the BIM engagement and training process by leveraging the take-up of ICT and BIM technologies through a significant upgrade of the skills, roles and capacities of the European construction workforce, to dramatically improve the reliability and effectiveness of design and construction practices, with a view to achieving the objectives of the Energy Union. In the methodology applied for determining BIM skills and roles for energy efficiency, ICT based qualitative and quantitative methods can be used to create a consolidated database of skills and roles that contributes to the process of training and education for BIM in energy efficiency. A key factor of consideration for this sort of framework for BIM for energy efficiency is understanding the best scales for workers, to ensure that it can be adapted to cater for different levels of understanding and skill. A BIM for energy efficiency qualification framework is expected to be disseminated and used by organisations such as the Chamber of Commerce. Representatives of these governing bodies will be invited to join the expert panels of the project. The suitability of scaling and adapting the BIM for energy efficiency framework for other regions and socio-organisational contexts, such as developing economies like Saudi Arabia, is also being considered.

The EQF is a European-wide qualifications framework that joins the qualifications of different European Union members [233]. The EQF acts as a translation device to make national qualifications more readable across Europe. This scheme aims to promote mobility and relate different countries' national qualifications systems to a common European reference framework. Since 2012, all new qualifications that have been issued in Europe carry a reference to an appropriate EQF level [234].

The EQF is used to identify levels of qualification that would enhance the knowledge and skills balance between supply and demand [233]. The EQF levels are rated from 1 to 8 and they describe all levels of qualifications defined in terms of knowledge, skill and responsibility acquired in general, vocational as well as academic education and training; as presented in Table 2-3. The EQF shifts the focus from educational inputs to what a person holding a particular qualification knows and is able to do.

Table 2-3 Definitions of EQF levels.

Levels	Knowledge	Skills	Responsibility and autonomy
Level 1	Basic general knowledge	Basic skills required to carry out simple tasks	Work or study under direct supervision in a structured context
Level 2	Basic factual knowledge of a field of work or study	Basic cognitive and practical skills required to use relevant information in order to carry out tasks and to solve routine problems using simple rules and tools	Work or study under supervision with some autonomy
Level 3	Knowledge of facts, principles, processes and general concepts, in a field of work or study	A range of cognitive and practical skills required to accomplish tasks and solve problems by selecting and applying basic methods, tools, materials and information	Take responsibility for completion of tasks in work or study; adapt own behaviour to circumstances in solving problems
Level 4	Factual and theoretical knowledge in broad contexts within a field of work or study	A range of cognitive and practical skills required to generate solutions to specific problems in a field of work or study	Exercise self-management within the guidelines of work or study contexts that are usually predictable, but are subject to change; supervise the routine work of others, taking some responsibility for the evaluation and improvement of work or study activities

Levels	Knowledge	Skills	Responsibility and autonomy
Level 5	Comprehensive, specialised, factual and theoretical knowledge within a field of work or study and an awareness of the boundaries of that knowledge	A comprehensive range of cognitive and practical skills required to develop creative solutions to abstract problems	Exercise management and supervision in contexts of work or study activities where there is unpredictable change; review and develop performance of self and others
Level 6	Advanced knowledge of a field of work or study, involving a critical understanding of theories and principles	Advanced skills, demonstrating mastery and innovation, required to solve complex and unpredictable problems in a specialised field of work or study	Manage complex technical or professional activities or projects, taking responsibility for decision making in unpredictable work or study contexts; take responsibility for managing professional development of individuals and groups
Level 7	Highly specialised knowledge, some of which is at the forefront of knowledge in a field of work or study, as the basis for original thinking and/or research Critical awareness of knowledge issues in a field and at the interface between different fields	Specialised problem-solving skills required in research and/or innovation in order to develop new knowledge and procedures and to integrate knowledge from different fields	Manage and transform work or study contexts that are complex, unpredictable and require new strategic approaches; take responsibility for contributing to professional knowledge and practice and/or for reviewing the strategic performance of teams
Level 8	Knowledge at the most advanced frontier of a field of work or study and at the interface between fields	The most advanced and specialised skills and techniques, including synthesis and evaluation, required to solve critical problems in research and/or innovation and to extend and redefine	Demonstrate substantial authority, innovation, autonomy, scholarly and professional integrity and sustained commitment to the development of new ideas or processes at the forefront of work or

Levels	Knowledge	Skills	Responsibility and autonomy
		existing knowledge or professional practice	study contexts including research

This research mainly concerns the skills that cover the technical information for each actor that should know in their domain (from the thesis objectives). The use of EQF levels enables comparative scoring criteria within a BIM competency framework to appraise levels of skills for BIM for energy efficiency stakeholders. The EQF qualification levels cover the whole supply chain and aim to set a common framework for the EU to support the skilled BIM workforce, the labour market, as well as a common way of working with BIM for energy efficiency.

2.7 BIM for Energy Efficiency in Developing Economies: Saudi Arabia

The building sector accounts for more than 40% of global primary energy demand and up to 30% of global carbon dioxide emissions, and therefore it has a significant role in addressing climate change. Meanwhile, Saudi Arabia uses 345.1 TWh of power, 0.5 million barrels of fuel oil per day, and 10.6 billion cubic feet of natural gas per day, according to the International Energy Agency (IEA) [235], [236]. In Saudi Arabia, just two primary energy sources are used to meet energy needs: oil (51%) and natural gas (49%), [237]. It is therefore essential to develop and implement policies to minimise Saudi Arabia's primary energy use. Possible interventions include implementing energy-saving policies and public support for the use of alternative energy in Saudi Arabia's buildings [238].

Rapid information and technology developments are paving the way for the adoption of Building Information Modelling (BIM) technology. There is also evidence of widespread BIM adoption in buildings that are being developed by major construction companies in the United Kingdom and the United States. However, despite these signs of progress, understanding and execution across the entire construction sector and markets in these countries are still relatively poor [239]. Meanwhile, although BIM is being introduced in Saudi Arabia but is still considered to be in its infancy [240], [241]. Few Saudi project owners have begun to recognise the advantages associated with BIM implementation, such as the potential to produce several design alternatives, the ability to perform multiple experiments on a BIM platform, and the ability to allow for early identification of design defects to avoid expensive reworks [242].

BIM solutions and applications have continued to expand over time, which has led to more efficient multidisciplinary collaborations aimed at the entire lifecycle and supply chain integration [243]. In addition, BIM includes the process of producing and maintaining data and information about the built environment throughout its lifecycle, from concept design to decommissioning [244]. Over the past decade, BIM technology has brought significant transformative power to the architecture, engineering and construction/facility management domain (AEC/FC) regarding its whole lifecycle, integration of the supply chain and digital collaboration [7]. This can enact and reveal technologies and strategies that can disrupt the construction industry, which is expected to surpass $11 trillion in annual spending by 2020 [3].

Several studies have attempted to harmonise energy-related BIM knowledge and skills in developed countries, as well as achieving global unity through developing a BIM for energy efficiency (EE) [245], [246]. These studies have focused on establishing a framework of reciprocal recognition for qualifications and certifications among member states, as well as developing an effective policy to ensure that qualification and training methods are preserved and consolidated [247].

Recently, the building industry has undergone significant changes in the field of BIM as a result of innovation, and global technological and management advances [248]. The recognition of this transition remains a key area for the industry to consider. In particular, current training programmes should be adapted to introduce these new skills and competencies for construction workers.

According to the origin and filed of expertise, the researcher has implemented the developed framework on Saudi Arabia as case study in order to broaden the BIM training agenda to support Saudi Arabia's building energy efficiency agenda and also to provide opportunities for future research in this country.

2.8 Conclusion

The market for the global and European construction sectors looks promising and, from emerging growth and other trend reports, it appears to be increasingly sustainable. However, the key to unlocking growth depends on national and organisational ability to meet performance targets and objectives. It is evident that the need for the European construction sector to set targets to reduce energy consumption, curb GHG emissions and improve energy efficiency to reduce global warming is well established.

The global construction industry exhibits characteristics that differentiate it from other industrial sectors. Each project is usually a one-off and unique prototype with distinct characteristics, including choice of the construction system, materials, site topography and geology, and local environmental factors. The construction industry is highly fragmented and subject to poor productivity. It also depends on many different professions and trades, most of which tend to respond to local market needs and control only one or a few elements of construction design, construction or maintenance or operational processes. In addition, the construction industry hosts a variety of professional disciplines (e.g., architecture, civil and structural engineering, and building services).

BIM aids the AEC/FM sector and its energy efficiency agenda because digitalisation of product and process information provides a unique opportunity to reduce material waste and duplication of human effort, optimise energy efficiency related decisions across entire building lifecycles and supply chains, and allow opportunities for interface with sustainable construction, design for manufacture and assembly, smart construction processes and IoT. However, there is a particular need for technical and collaborative skills because BIM is a relatively new topic in AEC education and best practices in BIM education are yet to emerge. Although designers and contractors are well-served by BIM training across the concept, design, construction and handover phases, the extent of integrated BIM and energy efficiency training is either poor or limited in these areas. Clients, facility managers and sub-contractors do not appear to have sufficient BIM training across many of the plans of works stages, and such training is largely absent for BIM/energy efficiency.

It is thus clear that opportunities exist for improving the energy efficiency of built assets, whether new-build or retrofit applications. There are also promising opportunities for addressing the skills gap and harmonising skills in these domains to counter sectorial challenges and make further energy efficiency gains. These opportunities demand dedicated skills to address lifecycle sustainability requirements across the whole construction industry, incorporating (AEC/FM), which require dedicated qualifications to address multi-objective requirements. European businesses are increasingly integrating energy efficiency into their operating models and traditional AEC/FM disciplines are now seeking to be integrated with newer ones from the energy and environmental fields.

Raising awareness of BIM across the supply chain is reasonable, particularly amongst designers, contractors and clients, but there could be improvements amongst sub-contractors and facility/asset managers. Regarding BIM/energy efficiency awareness-raising, the provision is limited across the supply chain. In this thesis, the need to address these gaps and counter the limitations in BIM and energy efficiency training, education and CPD was found during the project lifecycle in Europe. This research shows that training and education, either mandated by governments or driven by national initiatives, can assist in addressing gaps. They should also be systematically revisited and updated to address the continuously changing requirements due to the evolution of BIM for energy efficiency technology, as well as the BIM for energy efficiency regulatory landscape, through closer consideration of skills in both domains and development of tailormade provision through an accessible platform.

These changing requirements and training/education needs may be captured and managed through a dedicated framework, such as the proposed EQF, which is based upon an existing comprehensive process framework that has BIM and sustainability embedded in it, such as the RIBA PoW 2013 and its subsequent versions (e.g., RIBA PoW 2020).

It remains to be seen exactly how scalable and adaptable such a standardised qualification framework for achieving energy efficiency training for BIM could be in a developing economy, such as Saudi Arabia. However, preliminary research of the dual opportunity that the country presents in terms of its need for a more diverse and cleaner energy portfolio, and a more digitally-transformed industry suggests that it could hold potential, at a basic level at least.

Methodology

This chapter presents the methodology that has been adopted in this research, describing each task, its applied methodology and the justification for its application.

3.1 Introduction

In this chapter, an overview of the methodology that will be used to achieve the objectives of this thesis will be outlined. This overview will include the procedures that are used to undertake the research, as well as the philosophical assumptions and design strategies that underpin the study. In addition, the data collection and analysis procedures will be documented. The aim of this research is to explore the role the digital transformation of the construction industry, with a focus on BIM, in improving energy efficiency in the construction sector through adapted training and education. The specific target of this thesis is to test a central hypothesis through decomposition into several research questions. The central hypothesis to be tested is:

Adapted training to promote the digital transformation of the construction industry, and in particular to enhance the adoption of Building Information Modelling, can have a positive impact on white- and blue-collar work practices to deliver energy-efficient interventions.

To evaluate the central hypothesis, the following research questions have been formulated:

1. What are the requirements, limitations and gaps in the BIM skills and training landscape in Europe?
2. What are the BIM roles and skills required to achieve energy efficiency via adapted training?
3. Can changing training requirements as a consequence of the continuous digitalisation of work practices, business processes, and technology evolutions, be captured and managed through a dedicated framework that factors in a wide range of aspects, including roles and skills?
4. How scalable and adaptable is this standardized qualification framework to other regions and socio-organisation contexts such as in the context of developing economies?

The origin and relevance of these research questions has been made clear in Chapter 2 through a review of the literature review. The method by which they will be answered will be detailed in following objectives:

- Identify the essential gaps and requirements of BIM application in energy efficiency based on the current work and business process practices.
- Identify each role and its qualifications in construction projects. These roles will inform the training process, which can contribute significantly to the education of white- and blue-collar workers in the field of BIM, and promote energy-efficient practices across organisations and projects.
- Identify the level of skills needed to embed BIM for energy efficiency within work practices for various stakeholders involved in the construction projects during their lifecycle.
- Explore the scalability of the proposed results in a developing economy.

In the rest of this chapter, the researcher will discuss and justify the methodological framing of the research to address these research questions.

3.2 Philosophical Research Paradigms and Research Methods

The research methodology that was used in this thesis can be described as an outline of the strategy that is used to collect and analyse data with the aim of addressing the research questions and achieving the research objectives. Although there is no universal philosophical paradigm in terms of research method, various universal schools of thought exist. For example, [249] cites positivism, interpretivism and pragmatism as the three predominant schools.

Positivism is strongly related to the concept of objectivism. In this paradigm, the concern of the researchers is to collect data from a large sample rather than focusing on specific research details [250]. Within the social sciences, positivism considers human behaviour to result from a reaction to external stimuli in the environment, which means that it can be assessed using deductive methods [251].

In contrast, **interpretivism** is said to be "predicated upon the view that a strategy is required that respects the differences between people and the objects of the natural sciences" [252]. Under this paradigm, one person's reality is believed to be different from another's as a result of their varied social perspectives. This means that it is important for interpretivist researchers to outline the truth from each participant's perspective. Interpretivism largely uses qualitative research methods, such as interviews, focus groups and observations [253].

Pragmatism is a combination of both positivism and interpretivism, and has experienced a recent revival after having declined in use for some time. Giacobbi Jr et al. [254] describe pragmatism as "a philosophy of knowledge construction that emphasises practical solutions to applied research questions and the consequences of inquiry." Thus, according to Saunders et al. [255], pragmatism is a useful philosophical approach for mixed-methods research. Therefore, this approach will be used in this thesis.

Based on these paradigms, the next section will focus on the two primary classifications of research methods: quantitative and qualitative. According to Bryman [252], it is important to distinguish between these two basic strategies in research to resolve any methodological issues.

3.2.1 Quantitative Research

Quantitative research entails the collection of numerical data with the aim of explaining a particular phenomenon [255]. Researchers carrying out quantitative research largely depend on statistical and numerical measurements, which help to develop or expand knowledge of social life. Saunders and Tosey [256] note that quantitative research largely uses surveys (both descriptive and analytic), experimental design (quasi-experiments) and classic experiments (studies with control and experimental groups).

3.2.2 Qualitative Research

In contrast, qualitative research primarily depends on human experience and knowledge, and is strongly linked to cultural and social investigations. Qualitative research is favoured in the social sciences because of its ability to systematically help researchers to understand various sociocultural problems [257], [258]. This type of research tends to be inductive and interpretivist, relying largely on ethnography (observation), interviews, focus groups and case studies [252].

3.2.3 Mixed Methods

A mixed-methods approach (triangulation) has been shown to be very advantageous thorough investigation [249], [259]. Triangulation can be defined as the use of various research methods for various purposes within the same research investigation [255]. According to Bryman and

Bell [260], triangulation employs more than one specific research framework or data collection method within the same study. Employing both approaches may reduce or eliminate disadvantages of each individual approach, while gaining benefits from using both of them together [259]. A mixed-method approach is increasingly selected as the main research approach in various disciplines of research (e.g., management, science and engineering) [261], [262]. In the area of computing and engineering research, developing technological innovation not only involves technical aspects but also includes social, legal and financial perspectives [263].

According to Creswell [264], data collection timing in mixed-method research may take the form of a sequential, concurrent or transformative process. In a sequential process, both qualitative and quantitative data are collected in the same phase. Either starts by collecting qualitative data first followed by quantitative, or vice versa. In a concurrent process, qualitative and quantitative data are collected and analysed concurrently by the researcher. However, in the concurrent form both qualitative and quantitative data are concurrently collected and the analysis gives equal priority to both data types, whereas in the sequential form priority is given to the collected data type. This kind of form gives equal priority to both types. Therefore, triangulation is very effective when investigating the research topic by adopting several, alterative paradigms or methods [259]. Table 3-1 illustrates the differences among these research approaches.

Table 3-1 Comparison among three research approaches adopted from [264]**.**

	Quantitative	Qualitative	Mixed-methods
Philosophical assumptions	Post-positivism	Inter positivism	Pragmatism
Strategies	Survey Experiments	Phenomenology Case study Narrative research	Sequential Concurrent Transformative
Data collection	Closed-ended question Predetermined approaches	Open-ended questions Emerging approaches	Both open-and closed-ended question Both emerging and predetermined approaches

Nature of data	Performance data Attitude data Observational data Census data	Interview data Observation data Document data Audio-visual data	Multiple forms of data drawing on all possibilities
Data analysis	Statistical analysis Statistical interpretation	Test and image analysis Theme, patterns interpretation	Statistic and text analysis Across databases interpretation

Johnson and Onwuegbuzie [265] define mixed-methods research as “the class of research where the researcher mixes or combines quantitative and qualitative research techniques, methods, approaches, concepts or language into a single study.” With this in mind, mixed methods can be considered as “the third major research approach or research paradigm, along with qualitative research and quantitative research” [266]. The mixed-methods approach has many advantages, including the ability to answer research questions that other methodologies cannot, to provide stronger inferences and to open up a broader range of perspectives [267]. In particular, Saunders [255] argues that mixed methods is a stronger approach to qualitative or quantitative approaches alone because it can help achieve different objectives, which improve the strength of findings, and it can allow triangulation, due to the combination of different methods (i.e., interviews and questionnaires). Bowling [251] lists a large number of mixed-methods approaches, such as case studies, consensus methods, action research, rapid appraisal techniques and document research.

According to a discussion with experts’ panel, a mixed-methods approach has been adopted as the most relevant approach to accomplish this research requirements, which will include data collection, case studies analysis, interviews, questionnaires, and social-media analysis. In addition, the final framework in this study needs to be validated. However, this is one of the major challenges of using assessment frameworks because there is no simple way to obtain scientific validation of a particular framework [268], and therefore the absence of empirical validation is a concern. In many circumstances, frameworks rely on empirical data that is far from perfect. While the best way for any type of metric related to the BIM for energy efficiency field to be validated would be to test it continually after major events and refine it accordingly, this would take a considerable amount of time [269]. In addition, the lack of data is considered another obstacle to validate this framework. Therefore, the standardized qualification framework has been validated through a questionnaire with the expert panel, while semi-structured interviews with the expert panel has been used to validate different phrases of this study.

3.3 Overarching Methodology for the Research

The research questions that were formulated in the last section translate into the research objectives that are illustrated in Figure 3-1. Within each of the objectives, the specific methods used are described and justified.

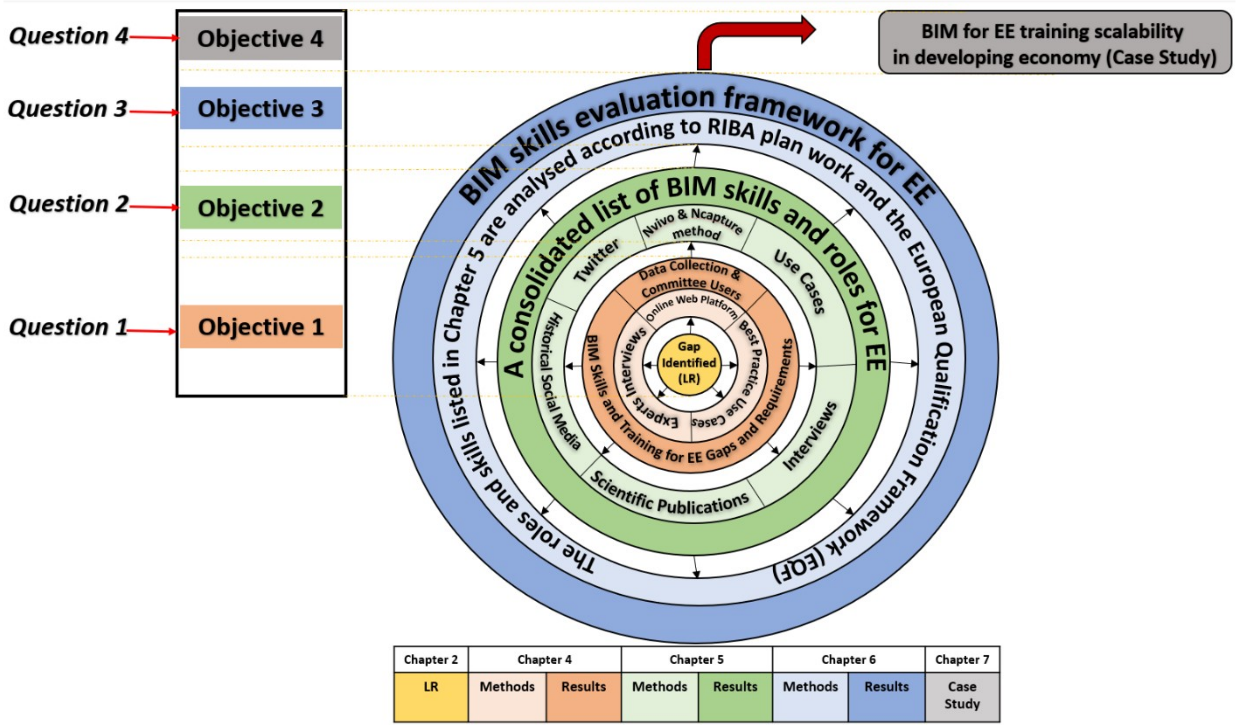


Figure 3-1 Overall research approach.

3.4 Research Instruments to Be Used for the Research.

This section will provide an overview of the instruments that are used in this research. Followed by a detailed description regarding the research design.

3.4.1 Questionnaires

A questionnaire is a predefined set of questions (items), which is assembled in a predetermined order prepared for respondents to answer the questions, thus providing the researcher with data that can be analysed and interpreted [249]. Questionnaires are frequently associated with the survey research strategy and often a questionnaire is sent out by post to a sample of people, who are asked to complete it and return it to the researcher or sometimes it is developed using web-based survey websites [270]. A questionnaire can be used within other research strategies such as an interview, case studies, action research or design and creation [249]. This research instrument is widely used in research because it can provide an efficient way of collecting data from many respondents in geographically diverse locations [263]. Questionnaires obtain the same kind of data from a large group of people in a standardised and systematic way [259]. It can also be used with interpretive and critical research [271]. Questionnaires are widely accepted and used in the IS field and they have been used in many IS journals [249]. In computing, a common use of a survey is in the user evaluation of a software system, although it must be said that many such surveys appear to have been tagged on at the end of system development given that they are often poorly designed and executed [249].

There are many advantages for using questionnaires in research, as reported in [249], which are: (a) to obtain data from a large from people; (b) to obtain relatively brief and uncontroversial information from people; (c) obtain standardised data by posting identical questions to each respondent and pre-defining the answers; (d) can expect respondents to be able to read and understand questions and possible answers; (e) time and cost effective, especially when using web-based questionnaires; (f) the results of the questionnaires can usually quickly and easily quantified by the researcher or through the use of a analytical software package; (g) the results can be analysed more scientifically and objectively than other forms of research; (h) the quantified results can be used to compare and contrast other research, and may be used to measure changes; and (j) positivists believe that quantitative data can be used to create new theories and/or test existing hypotheses.

There are, however, some drawbacks to using questionnaires, as reported in [15] and [24], which are: (a) ambiguous and poorly-worded questions could be problematic, especially when the researcher is not there to clarify the meaning; (b) the targeted respondents may have no time to fully complete the questionnaire; (c) questionnaires are not suitable for some information forms (e.g. emotions, behaviour, feelings, etc.); (d) questionnaires lack validity and it is difficult to tell how truthful a respondent is being; and (e) the respondents might interpret each question differently and then reply based on their own understanding of that question, and hence the questionnaire does not acknowledge the level of subjectivity.

Several researchers have used questionnaires in BIM research. For example, Khosrowshahi and Arayici [273] have used a mixed-method that includes a questionnaire to establish a BIM implementation guidance at strategic and operational levels. Furthermore, their study presents a review of the literature on the use of the questionnaire as a tool for collecting energy data in residential buildings. Numerous studies have used a questionnaire to gather necessary information for different purposes [274].

Data collection was conducted in this research by questionnaire to validate and collect details regarding the skills matrix from the experts because many experts prefer to fill in a questionnaire rather than participating in interviews because of their Ito limited schedule.

3.4.2 Semi-structured Interviews

An interview from a research perspective is a particular kind of conversation between people but which has a set of unspoken assumptions that do not apply to normal conversations [249]. Usually, the researcher has a purpose for undertaking the interview because they want to gain information from a targeted group of people [249]. This means that the discussion does not occur by chance but has been planned in some way by the researcher [249]. There are three types of interviews: (a) structured interviews, which contain predetermined, standardised, identical questions for every interviews; (b) semi-structured interviews, where the researcher has a list of themes to be covered and questions to be asked; (c) unstructured interviews, where the researcher has less control over the conversation, starts by introducing the topic and allows the interviewees to develop their ideas [249], [259]. Interviews are commonly used in case studies and ethnographies as well as a questionnaire to obtain more detail about some questionnaire responses (e.g., from BIM experts) [249].

Oates [249] stated that interviews are suitable data generation methods when the researcher wants to: (a) obtain detailed information; (b) ask questions that are complex, or open-ended, or whose order and logic might need to be different for different people; (c) explore emotions, experiences or feelings that cannot easily be observed or described via predefined questionnaire responses; and (d) investigate sensitive issues or privileged information that the respondents may be unwilling to write about on paper for a researcher that they have not met.

Sem-interviews have several other advantages, as reported by [260], [275], [276] which are: (a) they offer a freedom for interviewees to answer in their own way in their familiar language so they provide a natural response; (b) they encourage the interviewee to take time in giving detailed responses to questions and probes hence add more contribution to the discussion; (c) they allow the interviewee to share their own particular viewpoints; (d) they give the researcher an opportunity to bring fresh inquiries within the same interview based on the interviewee's replies; (e) they provides massive and rich data in the form of detailed responses. Meanwhile, semi-structured interviews do have some drawbacks. According to Brewerton and Millward, these drawbacks are: (a) an interview should be conducted by a well-trained researcher; (b) an interview can take very long time in forming the discussion and data analysis; and (c) many bias factors could affect the reliability of an interview [277].

In this research, semi-structured interviews are used to determine a set of questions to be investigated with regard to focus on understanding and utilising BIM as a toolset to optimise energy in the industry field during the lifecycle of the activity. This set of questions comprises major themes, topics, gaps, and areas related to the BIM for energy efficiency research. In particular, semi-structured interviews are chosen for the following reasons: (a) they can gather the required information and knowledge that exists with the BIM for energy efficiency experts; (b) the researcher is willing to change the question order depending on the conversation, it is consequently possible to ask additional questions if an expert brings up issues that have no prepared questions; and (c) they allow the experts to speak in more detail on the issues that the research raises, as well as introduce new issues that are relevant to the research theme [249].

After conducting the interviews, a transcription of the interview record must be made because it is much easier to search and code through and analyse the interview data once it is in written form [249]. The responses of the interviewees might be affected by the researcher’s role and identity (e.g., the interviewees' answers might differ depending on their feelings about the researcher). Therefore, the researcher must always aim to be professional, polite, punctual, receptive and neutral [249].

3.4.3 Case Study

Case studies are used as a tool for intensive description and analysis of a single individual or group with the aim of exploring and understanding complex issues within their real-world context [278]. Case studies are an appropriate research method when a holistic, in-depth investigation is needed [278]. Case studies were defined by Yin [258] as an empirical inquiry about a contemporary phenomenon (e.g., a case) set within its real-world context, especially when the boundaries between phenomenon and context are not clearly evident. Furthermore, there are three main reasons for choosing case study as a research method [258], as follows: (a) if the research contains descriptive questions or explanatory questions; (b) the case study method favours other research methods in collecting data in natural settings by emphasising the study of a phenomenon within its real-world context; and (c) when a researcher wants to conduct pilot study.

There are several advantages for using case studies in research, as reported in [258], which are: (a) it simplifies complex concepts by exposing the researcher to real life situations, which can sometimes be difficult; (c) it helps to add new knowledge to the researcher through discussion on concrete subjects; (d) it aids the development of analytical thinking, communication, tolerance for difficult views on the same problem; (e) it offers the researcher an opportunity to innovate; and (g) data collection and interpretation might help to avoid biases.

There are, however, several drawbacks for a case study, as reported in [258], which are: (a) it might be difficult to find an appropriate case study to suit all subjects; (b) cases studies contain the study observation and perception of one person, thus the person presenting the case study may missing some aspects completely; (c) case studies generally consume more time when compared to other instruments; (D) since there is no right answer, validation of the solution can be a problem because there are many viewpoints of the same problem; (e) a case study it depends on the participants' level of maturity. Therefore, the researcher has aimed to define the best practices, regulatory awareness and BIM skills gaps for the energy efficiency domain through a case studies analysis to determine a collection of training requirements.

3.4.4 Social Media

With the advent of the world as a global village, there has been a widespread growth in the use of social media. Social media provides an intimate look into to the lives of individuals, and offers large amounts of information. Qualitative analysis of social-media content has potential value in many fields [279]. For example, the personal nature of these posts can give researchers far greater insight into the information seeking and sharing behaviours of individuals with chronic disease [280].

Twitter provides individuals with a platform to communicate and interact with a wider community. Understanding the content of tweets can allow improved utilisation of Twitter in the construction industry. Several studies have examined quantitative data, including the number of tweets as well as a qualitative analysis of tweets, coding them into categories based on their content. In particular, it has been observed that the Twitter interaction remained within a close-knit network of people rather than the broader community [281]. Therefore, this approach was utilised in this research to provide more insights into construction sectors during the lifecycle of the projects to extract more information about BIM skills for energy efficiency.

3.4.5 A Community Platform

To support the process of content mining and analysis for BIM training, the researcher has monitored the web presence and activity for the BIMEET platform that provides integrated access to BIM resources. The platform was published in November 2017 and is an open, scalable and polymorphic context-based solution with modules enabling serendipitous BIM information and knowledge discovery by utilising a symbiosis of technologies, such as the semantic web and social networks [243].

The expert panel have been used directly to upload the selected use cases to the platform. Then, the researcher has obtained the required information for use cases from the platform as a tool for collecting data and run the analysis process.

The researcher has used the platform as tool to aggregate new use cases, BIM communities and more information about BIM for energy efficiency. The experts panel have used directly to upload the selected use cases to the platform. Then the researcher has obtained the required information for use cases from the platform as tool for collecting data, and run the analysis process.

This platform has helped in the process of content mining by informing on the portfolio of companies, institutions and organisations from Europe that has a particular interest in the field of BIM for energy efficiency [247]. The role of the platform was to facilitate the identification of roles and skills, to aggregate content for the analysis, and to support the construction project implementation phase in providing construction professionals with the necessary training to offer useful BIM expertise for energy efficiency and low carbon solutions, while also enabling them to utilise the latest best practice and regulations; as illustrated in Figure 3-2.

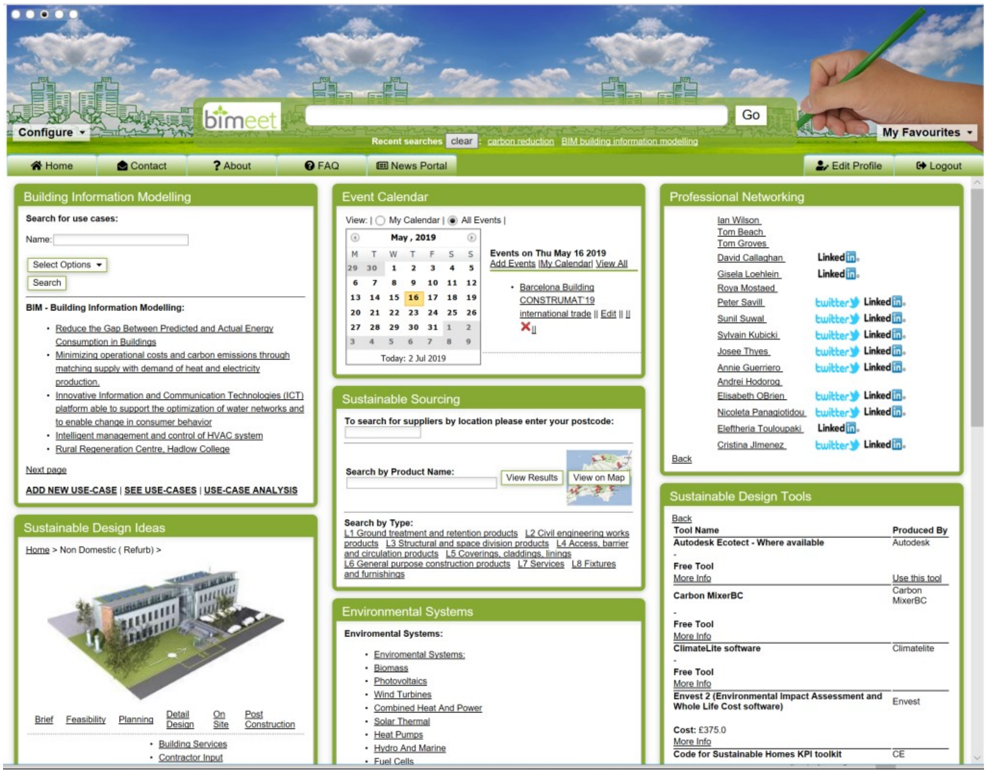


Figure 3-2 The BIMEET platform: [www.energy-bim.com].

The search service: As part of the platform, experts' panel implemented a search service that performs semantic searching on the platform's BIM knowledge base from a set of authoritative URIs. The submitted BIM query has a set of associated ontological concepts to improve the precision and recall of the returned results. The search service also provides an aggregation of data from a variety of trusted sources related to BIM via web-crawling. These sources can be proposed by users and are validated by a group of experts according to their relevance to BIM for energy efficiency (see Figure 3-3).

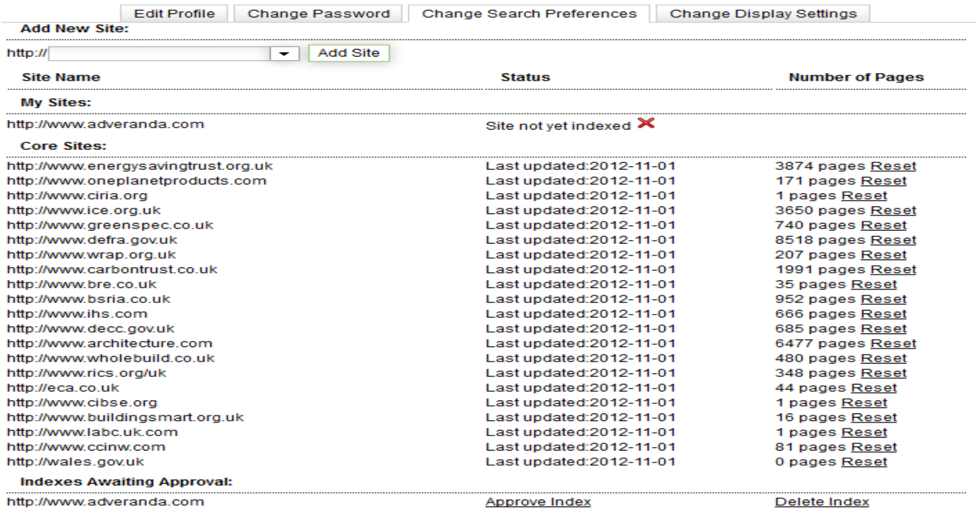


Figure 3-3 Sources Aggregation: These sources can be proposed by users and validated by a group of experts according to their relevance to sustainable construction.

To test and validate the searching system, the researcher relied on the group of experts (External Experts Advisory Board) and partners involved in the requirement assessment phase. In addition, as the platform is extended to further users, an increasingly expanding constituency is formed. To collect best practice use-cases in the field of BIM for energy, a template has been designed, implemented and exposed online for users to submit their cases.

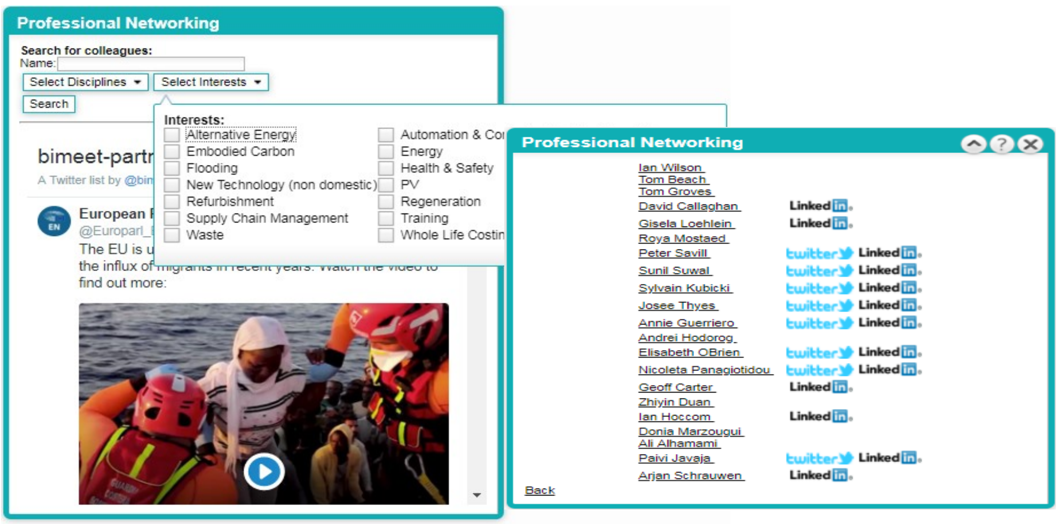


Figure 3-4 Professional networking service: An illustration of the associated interface of the professional networking service is provided.

The Professional Networking Service: This service enables users to collaborate using social networks such as LinkedIn and Twitter by aggregating associated data. This service also allows users to search for partners and colleagues, and identify the corresponding networking profiles based on a set of interests and disciplines (as illustrated in Figure 3-4).

3.4.6 Experts' Profiles

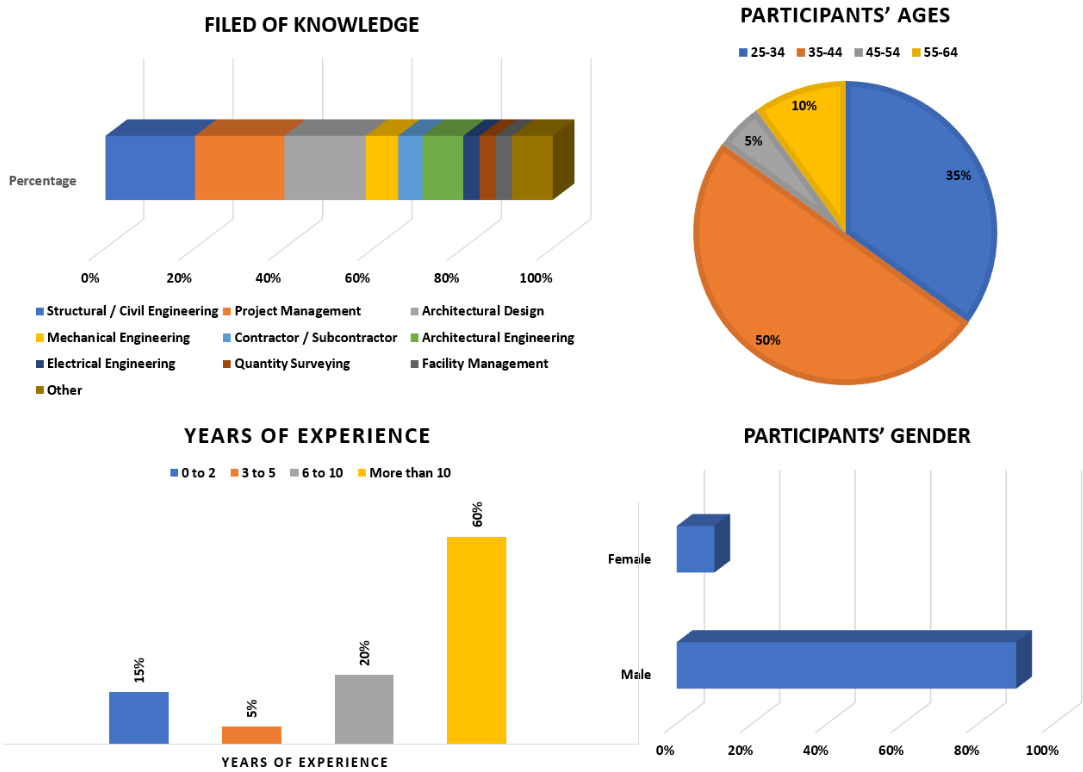


Figure 3-5 Profile of the expert panel.

The data collection and validation tools (e.g., interviews, semi-structured interviews, and questionnaire) were carried out with the expert panel that includes participants from 25 to 64 years old, and which includes the two genders, as shown in Figure 3-5. A collaboration between the researcher and the experts' panel to fill out the use cases, interviews, questionnaire and the validation process. The strength of the expert panel is that it has experts from many different areas, such as structural/civil engineering and project management (who represented 40% of the participants), while approximately 18% of participants are from architectural design. As can be seen in Figure 3-5, the experts also came from mechanical engineering, electrical engineering, facility management, and others (i.e., environment science and education, energy management in industrial, executive management, building and district energy management, ICT, and energy optimisation). Finally, Figure 3-5 shows the years of experience for the expert panel, and it can be seen that most experts have more than 10 years of experience.

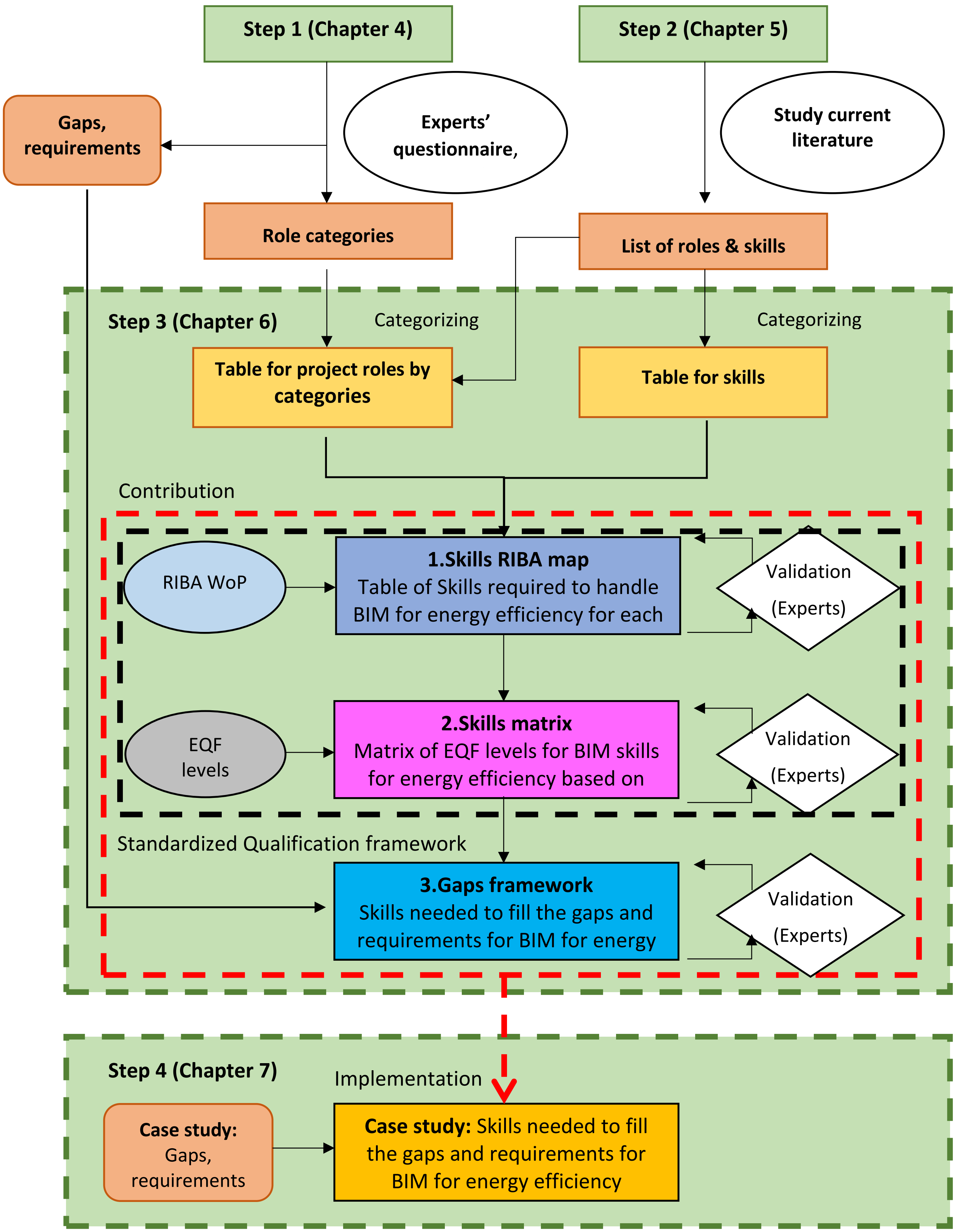


Figure 3-6 Methodology framework structure of the research contributions and objectives.

3.5 Detailed Overall Methodology

In this section, the researcher will describe more details about the methodology steps that has been adopted to address the research questions, as shown in Figure 3-7.

3.5.1 step 1:

The methodology that will be used to conduct the analysis has 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 energy efficiency theme.
- An online web-based, Europe-wide BIM use cases collection template and questionnaire, from which the 41 best practice case studies have been collected. Prepared invitations were sent to the experts panel in order to select and share the most relevant use-cases in their countries across Europe that used BIM for energy efficiency applications.
- An expert panel consultation process in Europe that consists of one workshop (around 40 participants in total), a series of 15 semi-structured interviews with key industry representatives, and other study partners meetings.

The researcher has adopted an incremental methodology that is 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, the researcher aimed to define the best practices, regulatory awareness and BIM gaps for the energy efficiency domain, and to determine a collection of training requirements. These consultations have been facilitated through a series of workshops to discuss the stakeholders' awareness, perception and behaviour with a view to identifying the primary obstacles to BIM applicability for energy efficiency. The identified barriers were discussed and debated from a variety of socio-technical perspectives. This first phase of this step aimed to identify the gaps and requirements in the field of BIM for energy efficiency by leveraging on the quantitative analysis process facilitated through the use of web technologies via the platform and a portfolio of use cases.

In the second phase of the consultations, the researcher focused on a qualitative analysis by validating the outcome of the analysis process that was undertaken in the first phase of the consultations. This phase aimed to identify any relevant gaps and requirements based on intensive discussions and debates within the consortia members, and with our EU and international experts in relation to the project's 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, as presented in Figure 3-8.Figure 3-8 General requirements methodology for Step 1. The experts' panel have undertaken a set of actions that 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 the lifecycle (from briefing to recycling) and the supply chain (from architects and structural engineers to blue-collar workers); and (vi) create a structure for the selected use cases that can be implemented directly on the study web portal. These measures lead to increased group visibility by publishing use case research and encouraging individuals to register if they wish to access study materials that focus on BIM for energy efficiency.

The platform has helped to identify the BIM training requirements for energy efficiency. It 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 in the initial phase and 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, while also enabling them to access and use the current best practices and regulations in the field of BIM for energy efficiency.

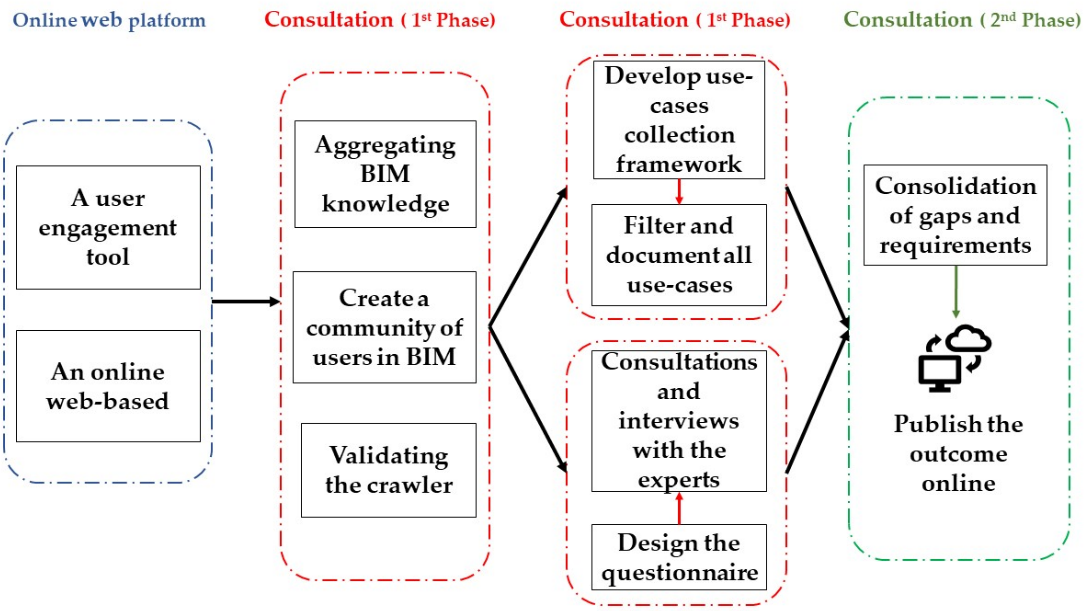


Figure 3-8 General requirements methodology for Step 1.

3.5.1.1 Evidencing BIM for Energy Efficiency via Industry Best Practice

This methodology has focused on community knowledge extraction involving project consortia partners, expert panel members and skilled BIM experts. These experts have engaged in validating the use case collection template and they have 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. This is 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 set of requirements for BIM training. A 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 this workshop, brainstorming sessions with experts were organised with a view to understanding the current gaps in BIM for energy efficiency, while also aggregating new best practice use cases.

3.5.1.2 Evidencing BIM for Energy Efficiency via Industry via Authoritative Web Portals

The partners and experts of the research have been asked to contribute and register a list of authoritative Uniform Resource Identifier (URI) sources to support the process of use case collection. These sources have been stored within the platform and indexed for crawling with a view to generating BIM knowledge for the community. These sources have been integrated into the searching service, which enables 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 used to validate these relevant sources and to search URIs based on specialised keywords, which have been verified by experts in the field of BIM and supported by the consortium partners. The keywords include BIM, energy efficiency, best practice, case study, training and education.

3.5.1.3 Evidencing BIM for Energy Efficiency in Industry via Research Engines

To support the process of requirement elicitation, the researcher has 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 researcher 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 energy efficiency, as an emerging field, covers many other areas and requires a well-considered scope. Hence, the researcher disregarded papers that focused on national or building level energy management, or which only considered the design phase of energy systems.

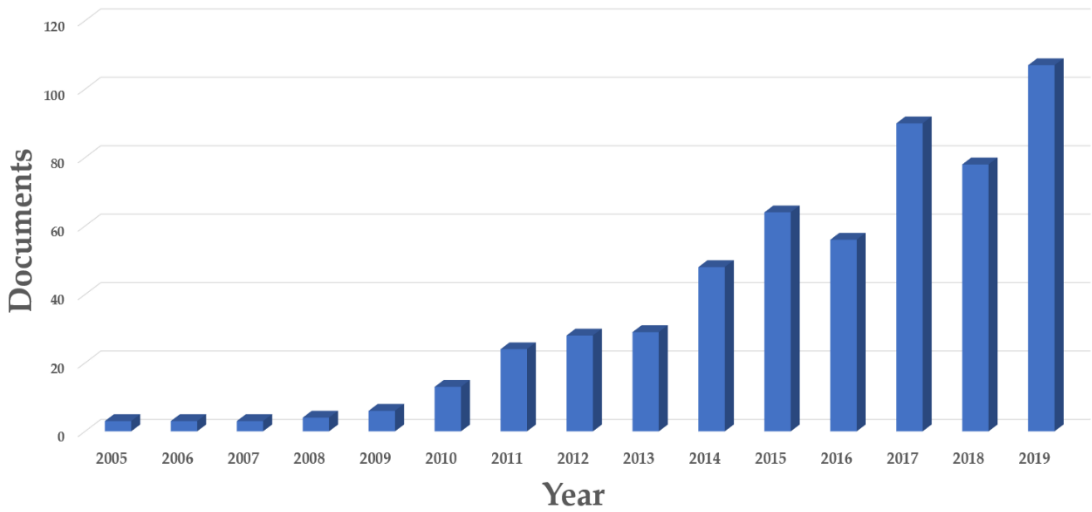


Figure 3-9 BIM's success over time as seen in the number of relevant Scopus publications per year for energy efficiency analysis.

To capture the recent technological change in the construction industry, the researcher has only considered recent publications and concentrated the analyses on BIM training for energy efficiency. As shown in Figure 3-9, 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, which led to a final bibliography of circa 547 references. The results for this step are discussed in Chapter 4.

3.5.2 step 2:

This step aims to address research question 2, restated here as:

What are the BIM roles and skills required to achieve energy efficiency via adapted training?

To address this question, a qualitative methodology will be used that focuses on primary sources of evidence (i.e., interviews, industry best practice use-cases, and social media content) and secondary sources of evidence drawn from the scientific literature. Primary sources of evidence are used to understand the dependencies and associations between BIM for energy-related concepts primarily related to roles and skills.

For the analysis, two main methods that facilitate text crawling and mining are used. NVivo analysis will be used to retrieve new skills and roles. NVivo has facilitated rich text-based and/or multimedia information analysis, where deep levels of analysis on small or large volumes of data are required. NVivo is used predominantly by the academic community, governments, health and commercial researchers across a diverse range of fields, including social sciences such as anthropology, psychology, communication, sociology, as well as in forensics, tourism, criminology and marketing [282]. NVivo accommodates a wide range of research methods, including network and organisational analysis, action or evidence-based research, discourse analysis, grounded theory, conversation analysis, ethnography, literature reviews, phenomenology, and mixed methods research [283]. The second source is heuristic content mining and expression analysis. Due to the noisy nature of social media, where short, informal spellings and grammar are often used, the researcher developed a set of RegEx and pattern matching rules from the researcher's own collection of BIM-related posts that were collected from social networking profiles. These were annotated as part of the human annotation process with language introduced from short informal text related to the BIM-related categories to assist the analysis process.

The identification of roles and skills in the context of BIM for energy efficiency has been elaborated based on:

- Consolidation of BIM for energy efficiency best practice case studies collected in the requirements capture process, and presented in the evaluation and discussion sections. A higher-order analysis has been applied to the consolidated repository of case studies to determine the skills and roles that are specific for BIM implementation for energy efficiency.
- Consolidation of 15 interviews conducted with industry experts in BIM. A similar analysis has been applied to the consolidated repository of interviews to determine skills and roles specific for BIM training for energy efficiency.
- A scientific literature repository formed of 66 key publications relevant to BIM and associated analytics has been applied to identify the set of roles and skills necessary for the training elicitation process.
- A social media repository formed of around 40 million of tweets crawled from key actors in the field of BIM for energy and training. This repository has been analysed through:
    - Regular NVivo social media analysis.
    - Heuristics expression analysis and mining of social media content.

The entire analysis process and methodology has been facilitated by using the energy-bim.com portal, which was developed by the researcher and supported by a community of interest of 200+ members. The web presence of the energy-bim.com portal has been monitored for six months. Using forensics methods, a portfolio of companies and users active in the field of BIM have been identified. The social media profiles of these companies have been inferred, and public domain content produced by these companies has been collected and analysed with the objective of creating a comprehensive list of roles and skills.

For elaborating the list of roles and skills, the following steps have been followed; as illustrated in Figure 3-10.

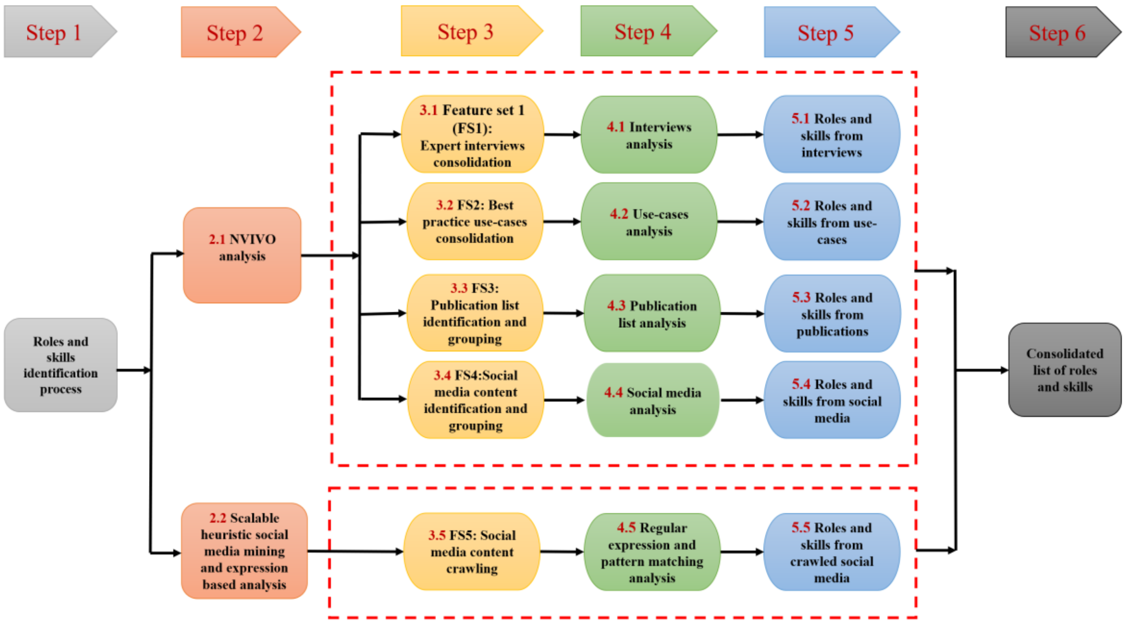


Figure 3-10 The overall BIM knowledge mining methodology.

Step 1: Using of the portal and monitoring of the web activity, including visits and accessed content.

Step 2.1: Configuration and preparation of NVivo software for running analysis of interviews, use-cases, scientific publications, and social media content.

Step 2.2: Scalable heuristic social media source identification and content consolidation.

Steps 3.1–3.4: Preparation of the content to analyse: interviews, use-cases, training descriptions, publications and social media facilitating compliance with NVivo environment and overall importing.

Step 3.5: Implementation of automated crawling techniques from Twitter based on several identified Twitter accounts, which resulted in a repository of more than 40 million tweets.

Steps 4.1–4.4: Apply analytics algorithms and mining methods on the consolidated content for skills and roles identification.

Step 4.5: Implementation of expressions and pattern matching algorithms to be applied to the consolidated content.

Steps 5.1- 5.5: Roles and skills identification with associated interests and key directions in the field of BIM for energy as resulted from interviews, use-cases, scientific publications and social media content analysis.

Step 6: Consolidation of BIM skills and roles.

In the following subsections, the researcher presents in detail the way in which each type of analysis has been conducted, identifying use-cases, interviews, scientific publications and social media analysis. The researcher has combined static skills and roles that are identified from traditional sources such as case studies, interviews, and publications, together with the more dynamic part from social media content. The researcher has adopted these approaches starting from the hypothesis that social media analysis can address the more dynamic part of the skills and roles identification because BIM for energy and construction is a dynamic process where new concepts are disseminated and spread on social media. The next step involves preparing the content for analysis, including interviews, use-cases, training descriptions, publications, and social media, to facilitate compliance with the NVivo environment and overall import process. Below the researcher presents the analysis scenarios implemented for skills and roles identification.

Published Data Sources

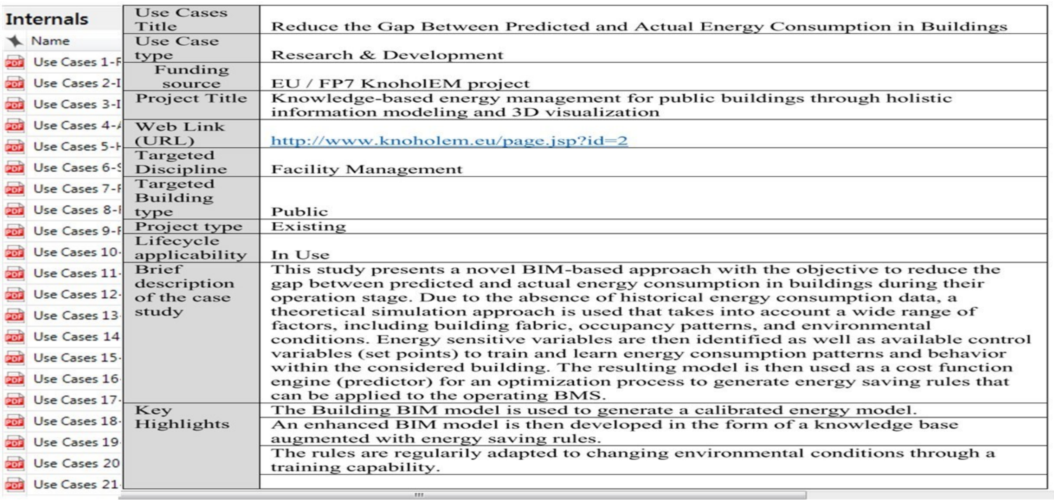
Best Practice Case Studies Analysis

Based on a requirement to capture a use-cases template, the researcher has aggregated 41 best practice case studies from the field of BIM for energy efficiency [284], [285]; as shown in Figure 3-11. The entire portfolio of case studies can be accessed online, and the results of these analyses are presented in the evaluation section. The other case studies are listed in Appendix A.

For the use-case analysis phase—and similarly, for interviews, publications and social media the researcher has adopted the following objectives:

Objective: Identification of skills and roles based on NVivo analysis.

Outcome: A consolidated list of skills and roles with regards to BIM for energy.



Use Cases Title	Reduce the Gap Between Predicted and Actual Energy Consumption in Buildings
Use Case type	Research & Development
Funding source	EU / FP7 KnoholEM project
Project Title	Knowledge-based energy management for public buildings through holistic information modeling and 3D visualization
Web Link (URL)	http://www.knoholem.eu/page.jsp?id=2
Targeted Discipline	Facility Management
Targeted Building type	Public
Project type	Existing
Lifecycle applicability	In Use
Brief description of the case study	This study presents a novel BIM-based approach with the objective to reduce the gap between predicted and actual energy consumption in buildings during their operation stage. Due to the absence of historical energy consumption data, a theoretical simulation approach is used that takes into account a wide range of factors, including building fabric, occupancy patterns, and environmental conditions. Energy sensitive variables are then identified as well as available control variables (set points) to train and learn energy consumption patterns and behavior within the considered building. The resulting model is then used as a cost function engine (predictor) for an optimization process to generate energy saving rules that can be applied to the operating BMS.
Key Highlights	The Building BIM model is used to generate a calibrated energy model.
	An enhanced BIM model is then developed in the form of a knowledge base augmented with energy saving rules.
	The rules are regularily adapted to changing environmental conditions through a training capability.

Figure 3-11 Use-cases template and list from NVivo.

The process that we adopted identifies three phases, as presented in Figure 3-10, starting with the consolidation in NVivo import, and followed by an analysis where the roles and skills are determined.

Analysis of the Interviews

Interviews and consultations with industry experts and project partners have been utilised as a means to infer new BIM skills and roles, and to capture a more country-specific understanding of the use of BIM and energy efficiency in all of the consortium's countries [136]. NVivo analysis has been applied to determine new skills and roles in the field of BIM for energy efficiency.

The researcher used two criteria to choose a panel of experts of BIM for energy efficiency. In the first criterion, the researcher has selected the panel of expert interviewees who provide broad coverage of representation of the entire lifecycle of the construction project and the supply chain. They represent the blue-collar workers, designers, contractors and manufacturers. The second criterion focuses on the credibility of experts. The researcher has targeted interviewees for credibility and invention in the field of BIM, and they either play roles in BIM agenda or BIM training agenda within European countries.

Based on the interviews that were conducted with 15 BIM industry experts from more than 40 project partners from Europe, the researcher has determined the skills and roles reported in the results section (more details about the interviews are given in Appendix B).

Scientific Publications Analysis

A comprehensive literature search based on the 'title/abstract/keyword' search method was first conducted through the Scopus scholarly publication search engine. Scopus is chosen because it covers a wide journal range (i.e., over 22,000 journals) [286]. It also allows a multidisciplinary search and offers author profiles that include affiliations, number of publications and their bibliographic data, references, and details on the number of citations that each published document has received [287]. Scopus also leads over other search engines in indexed documents, as well as citations in all research fields. This is especially evident in the discipline of engineering and technology [288]. The keywords used in the literature search included 'building information modelling', 'energy efficiency', 'role', 'skill', 'training', 'education', and 'competencies'. Articles and technical papers in refereed journals that included these particular terms in their titles, abstracts or keyword lists, covering various stages in the entire building lifecycle were considered. Given that BIM for energy efficiency is a relatively new technology, this review surveyed articles published between 2009 and 2019.

The article categories including editorials, book reviews, letters to the editor or discussions/closures and comments were excluded. In total, 1,180 papers were scanned during this process, and 66 BIM-energy-efficiency-related papers were used in the analysis [138], [226], [273], [289]–[351].

Social Media Analysis

A social media analysis has been used by capturing the Twitter activity of the identified company profiles. In this part, only tweets posted by companies have been used and analysed, while an extension of this analysis has been provided within the scalable heuristic social media analysis. In total, for this phase of the study, the researcher has utilised 50,000 tweets that were posted by the portfolio of companies.

This process identifies three phases, from social media aggregation using NCapture (a browser extension which allows tweets download) to NVivo import and analysis, where roles and skills are determined; as illustrated in Figure 3-12.

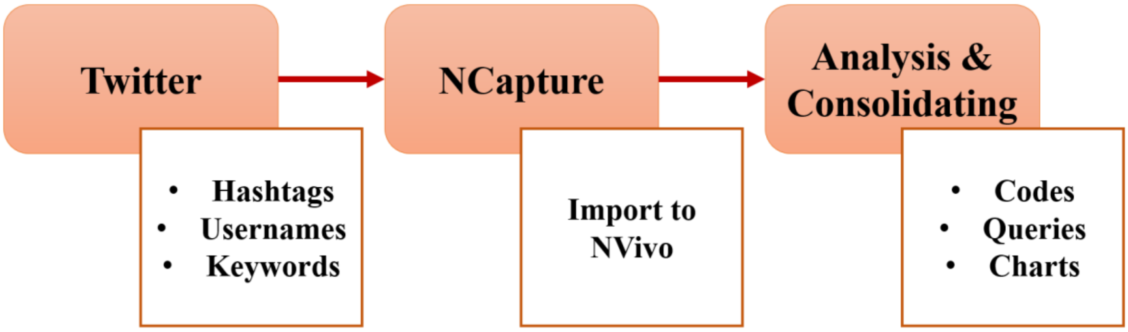


Figure 3-12 Progress of capture data from social media (Twitter).

The list of the organisations that were utilised for the capturing process has been obtained from three sources: (i) forensics algorithms with IP detection and organisation identification, (ii) followers of the @BIMEET project Twitter account and (iii) partners' indication of known BIM training institutions (see Table 3-2).

Scalable Heuristic Social Media Analysis

The researcher has used forensics algorithms to determine what companies, organisations and users from the field of BIM and energy visit the www.energy-bim.com platform [146]. the researcher has recorded all the visit logs. Based on the list of visitors, the researcher has selected profiles of the most relevant companies that activate in the field of BIM for energy efficiency. The researcher has identified other key Twitter profiles, and followers relevant for the researcher analysis from the Twitter followers list of the @BIMEET project; as shown in Table 3-2.

The list of organisations was selected based on the visitors of the energy-bim.com web platform. The names of the organisations were discovered based on forensic investigation of the IP addresses of the visitors of energy-bim.com. Each IP address was looked up via the reverse WHOIS protocol to determine the organisations and/or ISPs that they were likely to belong to. The list was then shortened to BIM-related organisations and training providers.

Table 3-2 List of organisations and their Twitter accounts.

Name of organisations	Twitter account
Group CSI	https://Twitter.com/groupecesi
INEs Solaires	https://Twitter.com/ines solaire
BRE Academy	https://Twitter.com/BREAcademy
Ecoles des Ponts Paris Tech	https://Twitter.com/EcoledesPonts

ESTP	https://Twitter.com/estpparis
Universite de Liege	https://Twitter.com/UniversiteLiege
UC Louvain	https://Twitter.com/UCLouvain_be
Citt`a di Modena	https://Twitter.com/cittadimodena
ORSYS Formation	https://Twitter.com/ORSYS
BEC partners SA	https://Twitter.com/becpartners
Middlesex University	https://Twitter.com/MiddlesexUni
House of Training	https://Twitter.com/Houseoftraining
Sapienza Universita	https://Twitter.com/sapienzaRoma
Scuola Master F.lli Pesenti, Politecnico di *M*ilano	https://Twitter.com/master pesenti
Le Moniteur	https://Twitter.com/Le Moniteur
Technical University of Denmark	https://Twitter.com/DTUtweet
Norwegian University of Science and Technology	https://Twitter.com/ntnu
UIC Barcelona	https://Twitter.com/UICbarcelona
Mensch und Maschine	https://Twitter.com/MuMDACH
Zigurat	https://Twitter.com/Ziguratdigital
BIMEET EU	https://Twitter.com/bimeetEU
H2020EE	https://Twitter.com/H2020EE
H2020 BIM plement	https://Twitter.com/H2020BIMplement
ECTP Secretariat	https://Twitter.com/ECTPSecretariat

In the analysis, the following sequence of steps has been applied (as shown in Figure 3-13):

Fetching friends and followers from the list of Twitter accounts (using the friend’s ids and followers’ ids Twitter APIs);

Fetching timeline tweets from all the friends and followers determined at step 1 using the user timeline Twitter API;

Importing all the tweets collected at step 2 in a MySQL database during collection;

Querying the SQL database using the regular expressions that are presented in the list;

Exporting the SQL results in Excel format;

Importing the results determined at step 5 into NVivo;

Generating word clouds and word trees from NVivo;

Consolidating the final list of roles and skills.

The BMEET researchers have fetched a total of 40 million tweets with text associated and description, based on which the BMEET researchers conduct text analysis and expression mining to determine the skills and roles for BIM for energy. The set of expression utilised to identify skills and roles are presented below:

+((contractor/manager/designer/engineer/client/)/skills/).+ (/energy/construction)

+((/BIM/construction/energy)/skills/).+ (/need/require)

+((/BIM/construction/energy)/roles/).+ (/need /require)

+((/BIM/construction/energy)/actors/).+ (/skills /competencies)

+((/BIM/construction/energy)/knowledge/).+ (/requirements /require)

+((/BIM/construction/energy)/skills/).+ (/need /require)

+((/BIM/construction/energy)/competencies/).+ (/need /require)

+((/skills/competencies/knowledge/expertise)/BIM/).+ (/energy /construction)

The regular expressions that are included are built around the concepts of skills and roles. The overall objective was to create an expression for filtering the wrong Twitter context before skills and roles identification. Keywords such as ‘construction’, ‘skills’, ‘energy’ were frequently associated with roles, whereas terms such as ‘training’ and ‘knowledge’ were more likely to be included in tweets where a skill or role is reported.

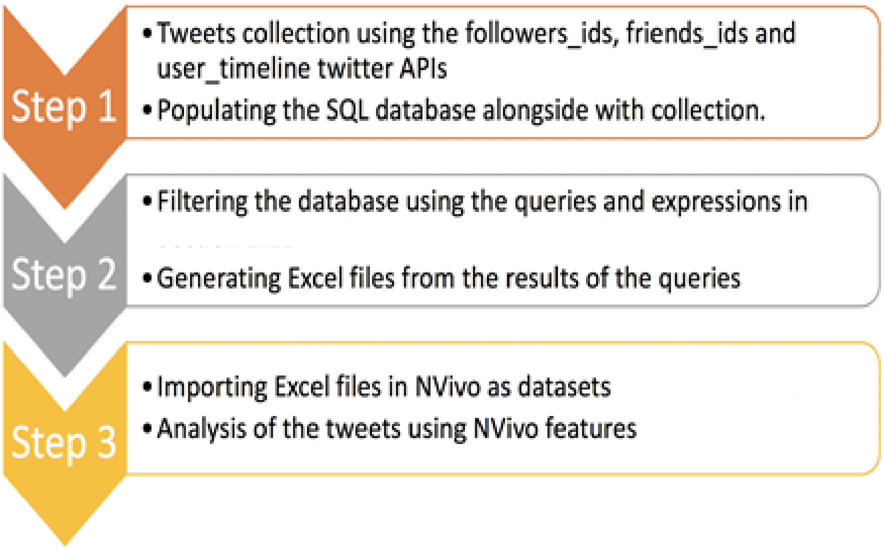


Figure 3-13 The progress of collecting the tweets.

3.5.2.2 Classifying Roles and Skills

The key objective is to determine the frequency of each BIM role and skill in the corpus of 41 use-cases, 15 interviews, scientific publications with Twitter and scalable heuristic social media mining. The equation has been used (1):

(Equation 1) $\boldsymbol{TF(T)} = \frac{\boldsymbol{number\ of\ times\ the\ t\ appears}}{\boldsymbol{total\ number\ of\ terms\ of\ the\ same\ type\ of\ t}}$

where *t* is either skill of a role and the type of *t* can be either a skill or a role.

Our final objective was to determine the importance of each role and skill, while taking into account the average of the number of occurrences in conjunction (association) with all its counterparts, by equations (2) and (3):

(Equation 2) $\boldsymbol{Importance\ (skill)} = \frac{\boldsymbol{1}}{\boldsymbol{n}} \sum_{\boldsymbol{n=1}}^{\boldsymbol{n}} (\boldsymbol{no.of\ occurences}(\boldsymbol{association}(\boldsymbol{skill} + \boldsymbol{role})))$

where *n* is the number of different associations between that skill and different roles.

(Equation 3) $\boldsymbol{Importance\ (role)} = \frac{\boldsymbol{1}}{\boldsymbol{n}} \sum_{\boldsymbol{n=1}}^{\boldsymbol{n}} (\boldsymbol{no.of\ occurences}(\boldsymbol{association}(\boldsymbol{role} + \boldsymbol{skill})))$

where *n* is the number of different associations between that role and different skills.

The results for this step are discussed in Chapter 5.

3.5.3 step 3:

This step is aims to address research question 3, which asks:

Can the evolving BIM for energy efficiency training landscape be captured and managed through a dedicated framework that factors in a wide range of aspects, including roles and skills?

To achieve this objective, a methodology framework has been developed; as shown in Figure 3-7. Several steps have been adopted to address the contribution of this chapter, as follows:

Stage 1: Develop a classification for project roles by categories that include all of the roles aggregated in Chapter 4. In addition, summarise the gaps and requirements of skills and training for BIM for energy efficiency.

Stage 2: Summarise detailed lists for all of the roles involved in construction projects and skills needed for BIM for energy efficiency from Chapter 5.

Stage 3: Develop a Skills RIBA map that distributes skills (from stage 2) required to handle BIM for energy efficiency for each role category (from stage 1) based on the RIBA Plan during the lifecycle of a project. The map was reviewed by the expert panel by applying a validation method (i.e., selective questionnaire) as a part of the whole validation process of the framework. The questionnaire was sent to 50 experts, and 20 responses were received. The researcher has addressed the expert consultation to validate the matrix, as illustrated in Appendix D.

Stage 4: Based on the previous step, develop a skills matrix for aggregated skills in the project lifecycle for each role group, with the level of skills recommended based on EQF levels. This is one of the main contributions of this research and will be used as a framework for BIM training and education. The matrix was validated by the expert panel and wide-context experts by applying a similar validation method to that used in the previous step, as a part of the process of validating the research.

Stage 5: From the skills matrix and skills RIBA map, a framework for skill allocations is required to address the gaps and requirements for BIM for energy efficiency that were identified by Chapter 4 (from stage 1) through BIM training and education. This stage is aligned with the previous stage as an attempt to address the main research gaps.

Stage 6: The standardized qualification framework is then implemented on gaps and requirements concluded from the case study in Chapter 7. This is one of the main research outputs and recommendations.

The results for this step are discussed in Chapter 6.

3.5.4 step 4:

Specifically, this step aims to address research question 4, which asks:

How scalable and adaptable is this training framework to other regions and socio-organisation contexts such as in the context of developing economies?

To address this question, the researcher will use quantitative and qualitative analyses to identify the gaps and skills required to improve BIM practices for energy efficiency. In particular, this chapter aims to address the following sub-research questions:

What are the requirements, limitations and gaps in BIM training?

What strategies are required to promote BIM for energy efficiency in Saudi Arabia?

To address these questions, the researcher proposes a methodology to capture the industrial trends, requirements, and gaps; as illustrated in Figure 3-15. They will also show what strategies and training are required to ensure the effective implementation of BIM for energy efficiency. The methodology that is adopted in this chapter utilises results data analysis of interviews and consultations to determine the requirements and specifications. The interviews will include construction companies and professionals, advisory governments, consultants, and educational and training bodies who deliver adapted BIM training and education in the construction industry.

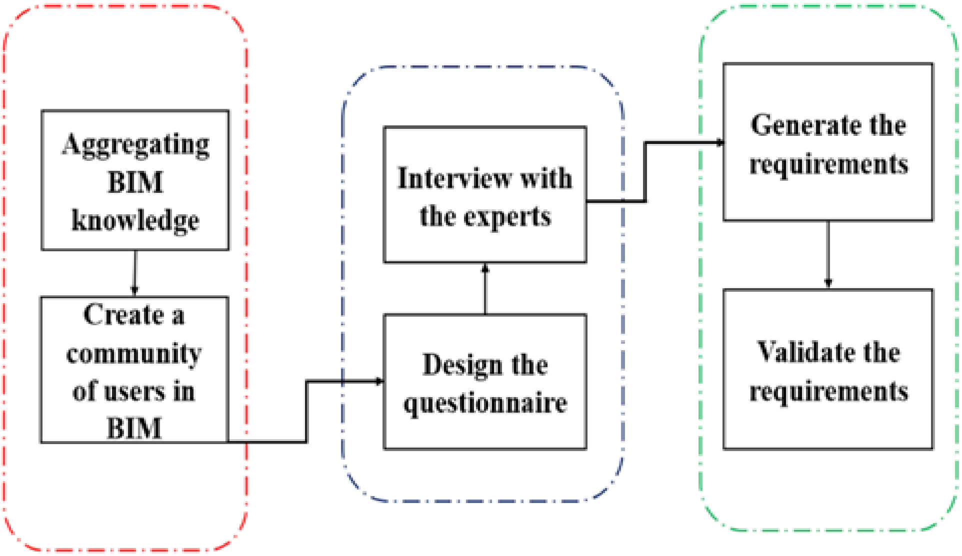


Figure 3-15 General requirements methodology.

This research followed a convenience sampling method by contacting the most accessible 35 organisations related to BIM applications. The responses from 16 experts, who replied to the request, were collected through structured interviews that cover various questions related to BIM for energy efficiency in buildings, see Table 3-3.

Table 3-3 Profile of The Experts Interviewed in Saudi Arabia.

Category	Interviewee	Type of occupation	Years of experience in using BIM
Government	1	Advisory council	7
	2	Advisory council	8
	3	Advisory council	6
Academia &Training Institution	4	Professor	11
	5	BIM Researcher	5
	6	Teaching Assistant	8
	7	BIM and software training expert	10
Construction Companies	8	Project Manager	12
	9	Project Manager	7
	10	Project Manager	9
	11	Project Manager	4
	12	Project Manager	3
Consultant	13	Structure Consultant	6

	14	Construction Consultant	6
	15	Architecture Consultant	3
	16	HVAC Consultant	4

The main objective of the consultation process was to define regulatory awareness and BIM gaps for the energy efficiency domain to collect the training requirements. The identified barriers were then discussed and debated from a variety of socio-technical perspectives. A mixed-methods analysis for outcomes of the interviews was undertaken in the first phase of the consultations, which included identifying the relevant gaps and requirements based on intensive discussions and debates in the case study, Saudi Arabia, with international experts in relation to the project's objectives. Finally, the BIM skills evaluation framework from Chapter 6 has been used to fill the identified requirements and gaps.

3.5.4.1 Analysis Index

A convenience sampling method was used to select respondents who have participated in construction projects for the questionnaire interview. The questionnaires were administered to experts who had participated in construction projects in different regions and organisations in Saudi Arabia.

The collected feedback provided qualitative and quantitative information that helped to build an initial understanding of the problems, limitations, and requirements of BIM training for energy efficiency for building industry stakeholders, and design the other research instruments (including the interview guide and questionnaire). Pattern coding is used to identify any emergent themes, patterns, or explanations suggested by the qualitative information gathered from the selected instruments [352]. Pattern coding reduces large amounts of data into a smaller number of analytic units and helps to structure the investigated issues. The quantitative analysis (questionnaire) helped to corroborate the qualitative issues that emerged from the research. It is, however, essential that the limits of this chapter be recognised. The researcher relied on questionnaires and interviews. Consequently, it is always possible that pertinent information might have been withheld for commercial, strategic, or political reasons. The impact of this limitation has been anticipated through the development of converging lines of inquiry (i.e., triangulation). The results for this step are discussed in Chapter 7.

3.6 Conclusion

The relationship between each of the philosophical research paradigms reviewed in Section 3.4, the tasks constituting this research, and the role of the researcher are shown in Table 3-4, constituting a wider research philosophy of pragmatism, accounting for multiple methods contributing to a holistic research programme around the subjects explored.

Table 3-4 Philosophical research paradigms applied to specific tasks defined within this research.

Research Questions	Objectives	Research Paradigm	Applied Methodology	Role of the Researcher
Research Question 1	Objective 1	Mixed Method	Literature review, Interviews, Case studies	The researcher has conducted the literature review and case studies, and led the consultation through questionnaires, interviews, and workshop; Analysed the data.
Research Question 2	Objective 2	Mixed Method	Interviews, Case studies, Scientific publications, social media	The researcher has aggregated all of the data from different sources and analysed the data by NVivo.
Research Question 3	Objective 3	Mixed Method	Questionnaire	The researcher has developed a framework that includes the skills RIBA map, the skills matrix, and the validation process.
Research Question 4	Objective 4	Mixed Method	Literature review, Interviews	The researcher has conducted the literature review and led the consultation through questionnaires, interviews, and analysed the data and fill the gaps.

Given the scope of the wider subject domain and the need to focus on the specific topics identified in Chapter 2, a clear definition of the methodologies to be applied at research commencement is required. However, the concurrent evolution of the subject area and exploration of these meant that flexibility in methods adopted was also necessary. Finally, more details or the application of the methods described here and the research outcomes are included in following chapters.

Requirements and Gaps in BIM Training for Energy Efficiency

In this chapter, the researcher will present quantitative and qualitative analyses to identify the gaps and skills required to improve BIM practices for energy efficiency. The methodology adopted in this study utilises computing data analysis techniques, including interviews and consultations and case studies, to determine the requirements and specifications to deliver adapted BIM training and education in the construction industry.

4.1 Introduction

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% [2]. The reductions in energy consumption and carbon emissions have become essential objectives that are 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 requirements for new and retrofitted buildings.

Some previous studies have looked for solutions that will pave the way for a fundamental change in the systematic delivery of observable and productive energy-efficient buildings through BIM training to achieve the European energy and carbon reduction objectives [353]. Engineering actors need to develop into a well-trained, world-leading generation of BIM decision-makers, professionals and blue-collar workers for energy efficiency [354]. Moreover, a world-leading BIM training platform for energy efficiency is needed, nurtured by an established community of interest [355]. Research and related assessments have been discussed in Europe across the building value chain (including lifecycle and supply chain), highlighting energy efficiency linkages, qualification priorities, distribution networks, skills and accreditation processes, while also highlighting training deficiencies and the potential areas for progress [354]. 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 last few years, intending to encourage more successful multidisciplinary partnerships to complete lifecycle and supply chain integration [52]. BIM includes the process of producing and maintaining data and information about the built environment throughout its lifecycle, from concept design to decommissioning [244] (see Figure 4-1). Over the past decade, BIM technology has brought significant transformative power to AEC/FC in terms of its fundamental lifecycle and integration of the supply chain and digital collaboration [7]. This 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 [3].

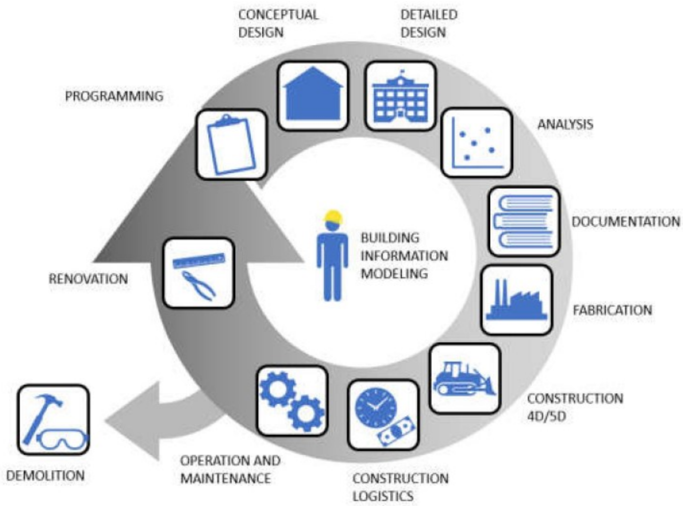


Figure 4-1 BIM applications across buildings' lifecycles.

Several studies have tried to harmonise energy-related BIM expertise and skills available in Europe and to achieve a global consensus through a BIM for the energy efficiency External Expert Advisory Board (EEAB) [245], [356], [357] . The emphasis is on developing a mutual recognition system for qualifications and certifications between different member states, accompanied by an effective strategy to ensure that methods of qualification and training are retained and unified [354].

The construction industry has experienced constant change in the last few decades thanks to BIM, and advances in global technical and management [248]. Identifying this change and the corresponding adjustment of existing training programmes to develop new skills for construction professionals is a critical area to address in the industry.

This chapter will explore the gaps and requirements for the implementation of BIM for energy efficiency with associated BIM training by identifying the relevant skills. Consultations and interviews were used to collect the requirements. 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.

This chapter makes the following contributions:

- Adapts and uses an online web portal to collect and analyse best practice case studies with a view to delivering BIM for energy efficiency training and education in EU construction projects;
- Conducts a consultation process involving key BIM experts and training organisations within the EU construction sector around BIM for energy efficiency;
- Elaborates a comprehensive set of requirements to inform future BIM training for upskilling the next generation of construction professionals to implement energy efficiency for the construction sector.

4.2 Revisiting the Research Question

This chapter aims to address research question 1, which states:

What are the requirements, limitations, and gaps in the BIM training landscape in Europe?

To address this question, the researcher proposes a methodology to capture the industrial trends, requirements and gaps, and will show what strategies and training are required to ensure the effective implementation of BIM for energy efficiency. The researcher adopts a use-case based approach within a community of BIM stakeholders and experts with a view to contribute to the digitization of the construction industry and associated high-level BIM strategy evaluation.

4.3 Method

Initially, a more theoretical analysis of the existing research gaps was conducted through a thorough literature review, as provided in Chapter 2. This process aimed to synthesise the existing body of work, highlighting the strengths and weaknesses, and crucially pinpointing the research gaps. This stage of the research methodology largely framed the development of the central hypothesis and research questions. Consequently, answering the hypothesis and research questions formed the main basis for the remainder of the work described in this thesis. The literature review consisted of an extensive search of the related literature around the fields of BIM for energy efficiency. Common themes between these topics indicated the need for triangulation of a wide range of methods to explore the topic to the extent required to advance one particular aspect. The output from this task is included in Chapter 2.

In Chapter 4, the researcher will present quantitative and qualitative analyses for the identification of the gaps and skills required to improve BIM practices for energy efficiency. The methodology adopted in this study utilises computing data analysis techniques, including interviews and consultations, to determine the requirements and specifications for delivering adapted BIM training and education in the construction industry. This objective aims to address the following sub-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, the researcher proposes a methodology to capture the industrial trends, requirements and gaps, and show what strategies and training are required to ensure the effective implementation of BIM for energy efficiency. The researcher adopts a use case-based approach within a community of BIM stakeholders and experts with a view to contributing to the digitalisation of the construction industry and associated high-level BIM strategy evaluation. The methodology that is utilised to conduct the analysis has three main parts, as follows:

- 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 energy efficiency 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), and a series of 15 semi-structured interviews with key industry representatives and other study partners meetings.

The researcher has adopted an incremental methodology underpinned by the platform[2] as tool to enable the management and exchange of data resources and experiences relevant to BIM training.

4.4 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, which was supported by consultations and interviews.

4.4.1 Collection of Case Studies

Based on the repository of use cases, the researcher aims to determine how BIM can support the development of energy-efficient designs, and the construction and maintenance of buildings. For example, 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 energy efficiency 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 4-1 provides two best practice use cases as examples where the lifecycle applicability is aligned with eight work stages of the 2013 RIBA work plan. Many variables were evaluated, and they are listed in the table based on the usage cases. The structure of the best practice use cases collection template has been elaborated during the consultation and workshop sessions. Each parameter and variable that has been included in the collection template has been discussed and validated by the project partners, construction stakeholders and BIM for energy efficiency experts from the European countries in relation to the project's objectives. The entire portfolio of use-cases can be accessed online. The status at the time that this thesis is submitted is presented in Appendix A.

[2] www.energy-bim.com

Table 4-1 Examples of BIM for energy efficiency best practices (BIMEET Platform).

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 & 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”.
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. These facilities are distinctive because of their physical nature, their energy consumption profiles, people's usage patterns within, ownership criteria, and comfort needs [358]. 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 [54].	This project is a large shopping and commercial development centre that is 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 [359].

Impacts	Energy savings up to 30 % Emission reduction up to 30 %	BIM was used 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. Measured power output from geothermal heat pumps and free energy benefits for heating and cooling have also exceeded expectations.

A set of automated analyses has been applied using the web platform on 40 use cases that were collected from a European community of BIM experts in the construction industry. These cases have been provided by Cardiff University experts and they have been elicited as examples because these cases have shown more benefits through using BIM for energy efficiency. The results show the distribution of impacts according to criteria such as discipline, the type of building and the lifecycle stage.

4.4.2 Challenges and Initial Results of Use Cases

The premise of this project is that BIM can significantly support energy-efficient design, construction and building maintenance in many ways. Principally, BIM can boost and ease energy-efficient building on the basis of better data exchange and communication flows, and in practice (for example) by accelerating energy simulations and searching for beneficial solutions, supporting end users' involvement, requirement setting and commissioning, and by providing an opportunity for systematic maintenance management. This study has demonstrated the strengths of BIM in energy-efficient building by collecting and providing use cases. Several examples of use cases where lifecycle applicability is aligned with eight work stages of RIBA Plan of Work 2013 follow.

Use Case 1: Reduce the Gap between Predicted and Actual Energy Consumption in Buildings. KnoholEM project

Use Case Type: Research & Development

Target Discipline: Facility Management

Target Building Type: Public

Lifecycle Applicability: In Use

Brief Description of The Use Case: This study presents a novel BIM-based approach to reduce the gap between predicted and actual energy consumption in buildings during their operation stage. Due to the absence of historical energy consumption data, a theoretical simulation approach is used that takes into account a wide range of factors, including the building's fabric, occupancy patterns, and environmental conditions. Energy sensitive variables and available control variables (set points) are then identified to train and learn energy consumption patterns and behaviour within the considered building. The resulting model is then used as a cost function engine (predictor) for an optimisation process to generate energy saving rules that can be applied to the operating Building management System (BMS).

Impacts: The use of BIM has helped achieve a reduction of 25% energy compared to baseline figures.

Use Case 2: BIM-based Parametric Building Energy Performance Multi-objective Optimisation

Use Case Type: Research & Development

Target Discipline: Architectural Design

Target Building Type: Domestic

Lifecycle Applicability: Concept Design, Developed Design

Brief Description of The Use Cases: An integrated system is developed to enable designers to optimise multiple objectives in the early design process. A prototype of the system is created in an open-source visual programming application, Dynamo, which can interact with a BIM tool (Autodesk Revit®) to extend its parametric capabilities. The aim is to maximise the number of rooms of the residential unit that satisfy the requirements of the LEED IEQ Credit 8.1 for Daylighting while minimising the expected energy use. The geographic location of the home is in the city of Indianapolis, Indiana, USA.

Impacts: The use of a BIM model to generate a multiplicity of parametric design variations for simulated and procedural analysis is a viable workflow for designers who seek to understand trade-offs between daylighting and energy use.

Use Case 3: Intelligent Services for Energy-efficient Design and Lifecycle Simulation: ISES project.

Use Case Type: Research & Development

Target Discipline: Architectural design, Structural engineering, HVAC engineering, Electrical engineering, Builders, Construction companies, Building managers

Target Building Type: Public

Lifecycle Applicability: In Use

Brief Description of The Use Cases: Intelligent Services For Energy-Efficient Design and Lifecycle Simulation is developing ICT building blocks to integrate and complement existing tools (STEP and BIM) for design and operation management into a Virtual Energy Lab that is capable of evaluating, simulating and optimising the energy efficiency of products and facilities, in particular components for buildings and facilities, before their realisation and taking into account their stochastic lifecycle nature.

Impacts: A combination of energy profile models with product development STEP models, and building and facility BIM models

Use Case 4: Robust Decision Making for Building Efficiency and Occupant Comfort.

Use Case Type: Real-world Application

Target Discipline: Facility Management

Target Building Type: Public

Lifecycle Applicability: In Use

Brief Description of The Use Cases: Ingenuity House is a 12,000m2 highly sustainable building that is currently under construction adjacent to Birmingham’s International Airport and Railway Station. The building will be Interserve's new regional HQ and is being used a test bed to start to go beyond BIM Level 2 (BS 1192: 2007).

Impacts: Delivery of SMART building.

Use Case 5: Use of BIM for ESD analysis of BCA Academic Tower.

Use Case Type: Real-world Project

Target Discipline: Architectural, Mechanical & Structural

Target Building Type: Public

Lifecycle Applicability: Concept Design and Developed Design

Brief Description of The Use Cases: BCA Academy Project consists of a new 10 floor academic block, with an adjoining new six floor training workshop block and new pavilion. The design aims to be climatically responsive, and will incorporate active and passive features wherever possible to lower energy consumption. These include proper orientation of the building, appropriate choice of materials, use of energy fittings, fixtures and devices (such as light fittings), good fenestration and daylight design, and so on. Vertical greenery and a roof garden should be provided, where possible. BIM plays a pivotal role in achieving the required sustainable design features.

Impacts: BIM plays a pivotal role in achieving energy efficiency by leveraging the BIM model and performing several types of energy analysis and simulations.

BIM has been implemented with increasingly powerful results for some building types. In particular, certain cases of retail and office buildings provide good examples how BIM has supported demanding requirement management, simulations and searching solutions for ambitious energy targets. For instance, BIM has been effectively used in a shopping centre to use around half the energy of a typical development. The results associated with commercial buildings report about 50% energy saving and 50% saving in water consumption.

The RIBA Plan of Work for lifecycle applicability shows some of the associations between lifecycles and BIM impact on energy efficiency. The RIBA Plan of Work organises the design process into different stages, including briefing, designing, constructing, maintaining, operation and use of the building. According to these stages, various ways of use and levels of impact can be identified for the use of BIM for energy efficiency.

4.4.2.1 Analysis of Use Cases Type

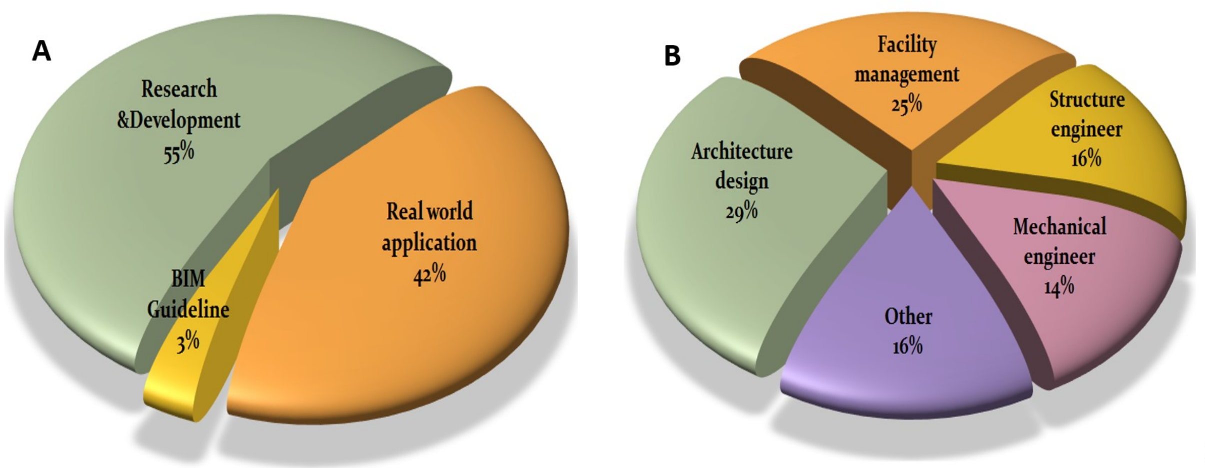


Figure 4-2 Use-case type analysis (A) & Target discipline analysis (B).

Based on the data that was collected over four months in a portfolio of 40 best practice use cases around BIM for energy efficiency, the researcher has applied statistics as part of the requirements elicitation process. The researcher 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 4-2 shows the distribution of different BIM for energy efficiency projects, utilising the use case type as an evaluation criterion. This figure 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. It was found that research and development has 17 use cases, the real-world framework has 13 use cases and the BIM guideline has only one use case. Similarly, Figure 4-2 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 others.

4.4.2.2 Analysis by Targeted Discipline

The use cases portfolio is organised according to the target discipline. Figure 4-2 provides the use case distribution based on the target discipline. It can be seen that BIM is used more commonly in architectural design and facilities management projects, while it is used to a lesser extent in structural engineering and mechanical engineering projects. This analysis has determined that various targeted disciplines utilised BIM for energy efficiency, such as architectural design, facility management, structural engineering and mechanical engineering, and others. Architectural designers were determined by 29% and facility management 25%, while structural and mechanical engineers were mentioned by 16% and 14%, respectively.

4.4.2.3 Evaluation per Building Type

In this section, the researcher will analyse the use cases based on the type of building projects that have adopted BIM for energy efficiency. According to Figure 4-3, 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 4-3, BIM is applied in 7.65% of these case studies to public buildings, 17.5% to domestic buildings and the rest is applied to commercial and industrial buildings.

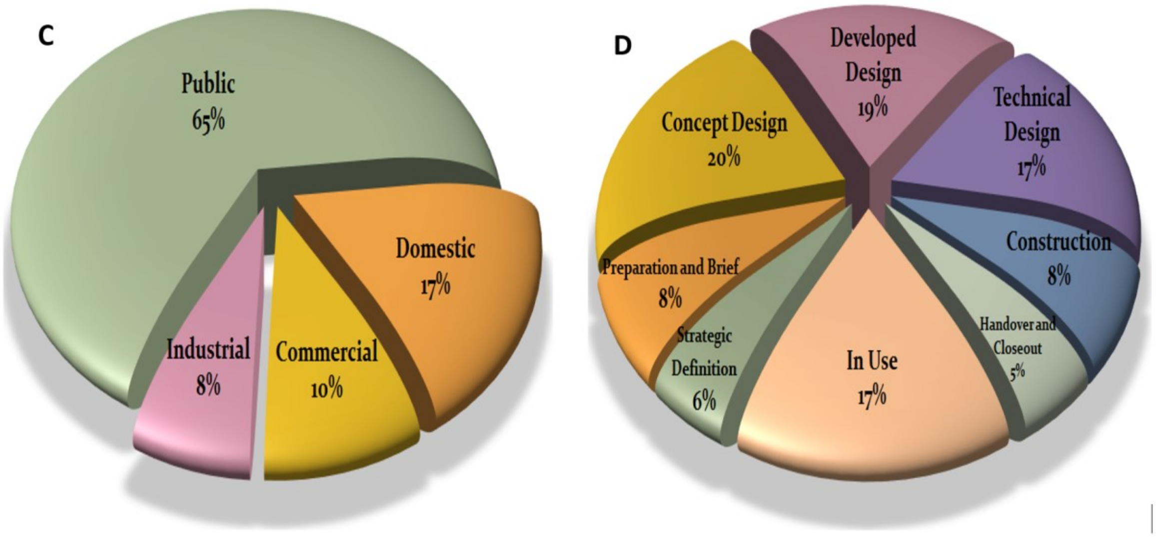


Figure 4-3 Building-type analysis (C) & Lifecycle stages analysis (D).

4.4.2.4 Analysis per Lifecycle Stage

Given that the researcher has used RIBA stage lifecycles for the study, this section will evaluate the relationship between the lifecycle stages for every best practice use case. Figure 4-3 shows that 56% of the projects are reported to use BIM for energy efficiency in the design phases during the project's lifecycle, while the in-use process represents 13% of the project lifecycle.

4.4.2.5 Analysis per Project Type

The researcher investigates the set of use cases that have adopted BIM and classifies them based on the project-type variable. From the study reported in Figure 4-4, it can be seen that the 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, while the remaining project types are renovation and extension projects.

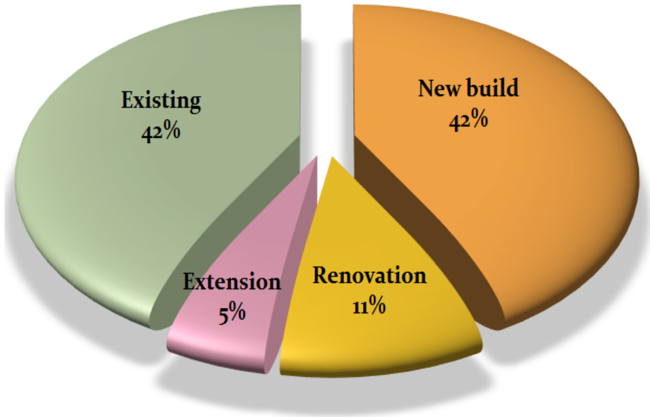


Figure 4-4 Analysis of project type.

4.4.3 Relationships Between the Variables and the Impacts

4.4.3.1 Analysis by Impact and Target Discipline

The first variable used that will be used in this study is the target discipline, which the researcher compared with the impacts to find the corresponding association between the target discipline and the impacts of use cases. Table 4-2 presents the majority of use cases that implement BIM for energy efficiency associated with the facility management discipline. However, some use cases implement a BIM for energy efficiency methodology for multiple disciplines, with significant impacts being seen in energy and water savings. BIM has been further implemented with more convincing results for some building types. In particular, some 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 contributes 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. The results associated with commercial buildings report energy savings of about 50% and water consumption savings of 50%.

Table 4-2 Discipline relevance and impacts (Examples of use cases).

Use-cases	Target disciplines					Impacts
	Architecture	Facility	Structure	Mechanical	Other	

Reduce the gap between energy consumption expected and real in buildings [360]		✓				A 25% drop in energy compared to baseline estimates.
Minimise operational costs and carbon emissions by matching supply with demand for heat and electricity production [361]		✓				Leading to a 32% increase in profit and a 36% reduction in CO2 emissions.
Intelligent management and control of a HVAC system [362]		✓				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 [363]		✓				GWP reduction of 60%. Operational energy consumption reduction of 35%
(FASUDIR)- Budapest Residential District [363]		✓				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) [364]		✓				Achieve building energy performance
Parametric design of a shelter roof in an urban context [365]	✓	✓	✓	✓	✓	Early BIM for parametric optimisation through simulations
Building as a Service [366]	✓	✓	✓	✓		Optimise energy performance in the application domain of non-residential buildings
Delivering highly energy-efficient hospital centre [367]		✓				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 [368]	✓	✓	✓	✓	✓	50 % energy savings, 50 % savings in water consumption

Design of energy-efficient library with high architectural goals [368]	✓	✓	✓	✓	✓	Energy optimisation results impacted the building and HVAC design
Use of Optimisation tool to compare hundreds of concepts energy efficiency before the actual design [369]		✓				Use of 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, the researcher can also observe the associations between lifecycles and the impact of BIM on energy efficiency. This reflects the increasing 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 energy efficiency. A taxonomy of the different evaluation criteria used in the use cases analysis is presented in Figure 4-5.

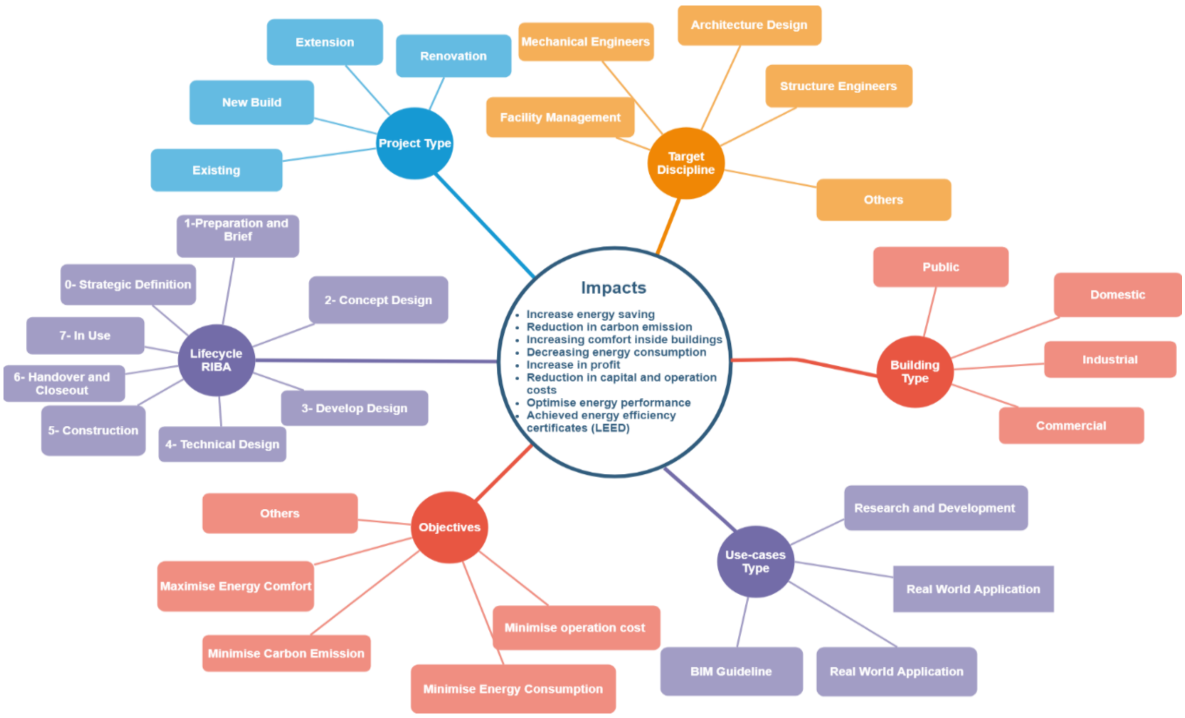


Figure 4-5 Taxonomy of use-case concepts of BIM for energy efficiency.

4.4.3.2 Building Type and Impacts

Building type is another variable that is used in our analysis. When compared with the impacts, it has provided significant insights in identifying gaps. From Table 4-3, it can be concluded that BIM for energy efficiency has been applied in the majority for public buildings.

Table 4-3 Relationship between building type and the impact (Examples of use cases).

Use cases	**Building Type**				**Impacts**
	Public	Domestic	Commercial	Industrial	
Reduce the gap between predicted and actual energy consumption in buildings	✓				Reduction of 25% energy compared to baseline figures.
Minimising operational costs and carbon emissions through matching supply with demand of heat and electricity production.	✓				Leading to a 32% increase in profit and 36% reduction in CO2 emissions.
Intelligent management and control of HVAC system	✓				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	✓				GWP reduction of 60%. Operational energy consumption reduction of 35%
Friendly and Affordable Sustainable Urban Districts Retrofitting (FASUDIR): Budapest Residential District	✓				Operational energy reduced by 35% and energy running costs reduced by 35%
An innovative integrated concept for monitoring and evaluating building energy performance (the gap between predicted and actual building energy performance is addressed by the project).	✓				Achieve building energy performance
Parametric design of a shelter roof in urban context	✓				Early BIM for parametric optimisation through simulations
Building as a service	✓				Optimise energy performance in the

					application domain of non-residential buildings
Delivering highly energy-efficient hospital centre	✓				41% reduction in fabric loss heat, 29% reduction in carbon emissions,15% reduction in overall energy usage
Shopping centre using around half the energy of a typical development	✓				50 % energy savings, 50 % savings in water consumption
Design of energy-efficient library with high architectural goals			✓		Energy optimisation results impacted for the building and HVAC design
Use of optimisation tool to compare hundreds of concepts energy efficiency before actual design	✓				Use of Optimisation tool has the potential to save money and time while directing to more optimal energy efficiency solutions.

4.4.3.3 Project Type and Impacts

In this section, we will try to determine the dependencies between project type and impact, where project types can be: existing project, new builds, renovation and extension. From Table 4-4, it can be concluded that a greater impact is recorded when applying BIM for existing and new build projects. One use-case has been recorded as applying BIM for a renovation project, with a significant impact in energy and water savings.

Table 4-4 Dependencies between project type and the impacts (Examples of use cases).

No	Use cases	Project type				Impacts
		Existing	New Build	Renovation	Extension	
1	Reduce the gap between predicted and actual energy consumption in buildings	✓				Reduction of 25% energy compared to baseline figures.
2	Minimising operational costs and carbon emissions through matching supply with demand of heat and electricity production.		✓			Leading to a 32% increase in profit and 36% reduction in CO2 emissions.

3	Intelligent management and control of HVAC system	✓			Up to 30% of energy saving up to 30% emission reduction
4	Friendly and Affordable Sustainable Urban Districts Retrofitting (FASUDIR): Heinrich-Lubke housing area, Frankfurt, Germany	✓			GWP reduction of 60%. Operational energy consumption reduction of 35%
5	Friendly and Affordable Sustainable Urban Districts Retrofitting (FASUDIR): Budapest Residential District	✓			Operational energy reduced by 35% and energy running costs reduced by 35%
6	An innovative integrated concept for monitoring and evaluating building energy performance (the gap between predicted and actual building energy performance is addressed by the project).	✓			Achieve building energy performance
7	Parametric design of a shelter roof in urban context		✓		Early BIM for parametric optimisation through simulations
8	Building as a service	✓			Optimise energy performance in the application domain of non-residential buildings
9	Delivering highly energy-efficient hospital centre		✓		41% reduction in fabric loss heat, 29% reduction in carbon emissions,15% reduction in overall energy usage
10	Shopping centre using around half the energy of a typical development			✓	50 % energy savings, 50 % savings in water consumption
11	Design of energy-efficient library with high architectural goals		✓		Energy optimisation results impacted for the building and HVAC design
12	Use of optimisation tool to compare hundreds of concepts energy efficiency before actual design		✓		Use of optimisation tool has the potential to save money and time while directing to more optimal energy efficiency solutions.

4.4.3.4 The Relation Between the Lifecycle of the Project and the Impact

This section explores the relationship between project lifecycle and impacts. As reported in Table 4-5, the highest impact is recorded for projects that are ‘in-use’ (stage 7 from RIBA). However, the portfolio includes project use-cases where BIM is applied at all stages cycle, with a great impact on energy and water savings in the shopping centre using around half the energy of a typical development.

Table 4-5 Dependencies between lifecycle and high impacts (Examples of use cases).

Use cases	Lifecycle applicability (RIBA)								Impacts
	0	1	2	3	4	5	6	7	
Reduce the gap between predicted and actual energy consumption in buildings								✓	Reduction of 25% energy compared to baseline figures.
Minimising operational costs and carbon emissions through matching supply with demand of heat and electricity production.								✓	Leading to a 32% increase in profit and 36% reduction in CO2 emissions.
Intelligent management and control of HVAC system								✓	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								✓	GWP reduction of 60%. Operational energy consumption reduction of 35%
Friendly and Affordable Sustainable Urban Districts Retrofitting (FASUDIR): Budapest Residential District								✓	Leading to a 32% increase in profit and 36% reduction in CO2 emissions.
An innovative integrated concept for monitoring and evaluating building energy performance (the gap between predicted and actual building energy performance is addressed by the project).								✓	Achieve building energy performance
Parametric design of a shelter roof in urban context			✓	✓					Early BIM for parametric optimisation through simulations

Building as a service								✓	Optimise energy performance in the application domain of non-residential buildings
Delivering highly energy-efficient hospital centre					✓				41% reduction in fabric loss heat, 29% reduction in carbon emissions,15% reduction in overall energy usage
Shopping centre using around half the energy of a typical development	✓	✓	✓	✓	✓	✓	✓	✓	50 % energy savings, 50 % savings in water consumption
Design of energy-efficient library with high architectural goals		✓	✓	✓	✓	✓			Energy optimisation results impacted for the building and HVAC design
Use of optimisation tool to compare hundreds of concepts energy efficiency before actual design			✓						Use of optimisation tool has the potential to save money and time while directing to more optimal energy efficiency solutions.

4.5 Interviews Analysis

This chapter provides an in-depth analysis and gap identification of the skills involved in BIM training for energy efficiency 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.

Given that it was not simple to obtain access to use cases in BIM and energy efficiency in all of the consortiums' countries, it was apparent that this trending topic was not sufficiently mature in many European countries. Therefore, the researcher 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 energy efficiency, and to determine the gaps and requirements in this field. The interview was designed using a questionnaire with three sections, which are the experiences of BIM and energy, BIM for energy efficiency skills and using BIM for energy efficiency in projects.

For the selection of interviewers, the researcher used two criteria in order to choose a panel of experts of BIM for energy efficiency. In terms of the first criteria, the researcher has 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 blue-collar workers, designers, contractors, and manufacturers. For the second criteria, the credibility of experts, the researcher targeted interviewees for credibility and invention in the field of BIM. They play roles either in the BIM agenda or the BIM training agenda within European countries. The results of these interviews are reported below, and a full repository of the interviews is provided in Appendix B.

4.5.1 Experience of BIM and Energy

Figure 4-6 shows the BIM expertise of the experts, which includes research in BIM assessment, architecture service, design and construction, and energy efficiency training and durability of construction. In addition, the researcher interviewed experts with different levels of expertise in applied technology for design and engineering project delivery, sustainable designs and physical buildings.

The main aim of the interviews was to approach 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 4-6 presents the experts' historical experience. It can be seen that two-thirds of the experts have experience using BIM in multiple ways, and they also have extensive experience with BIM software.

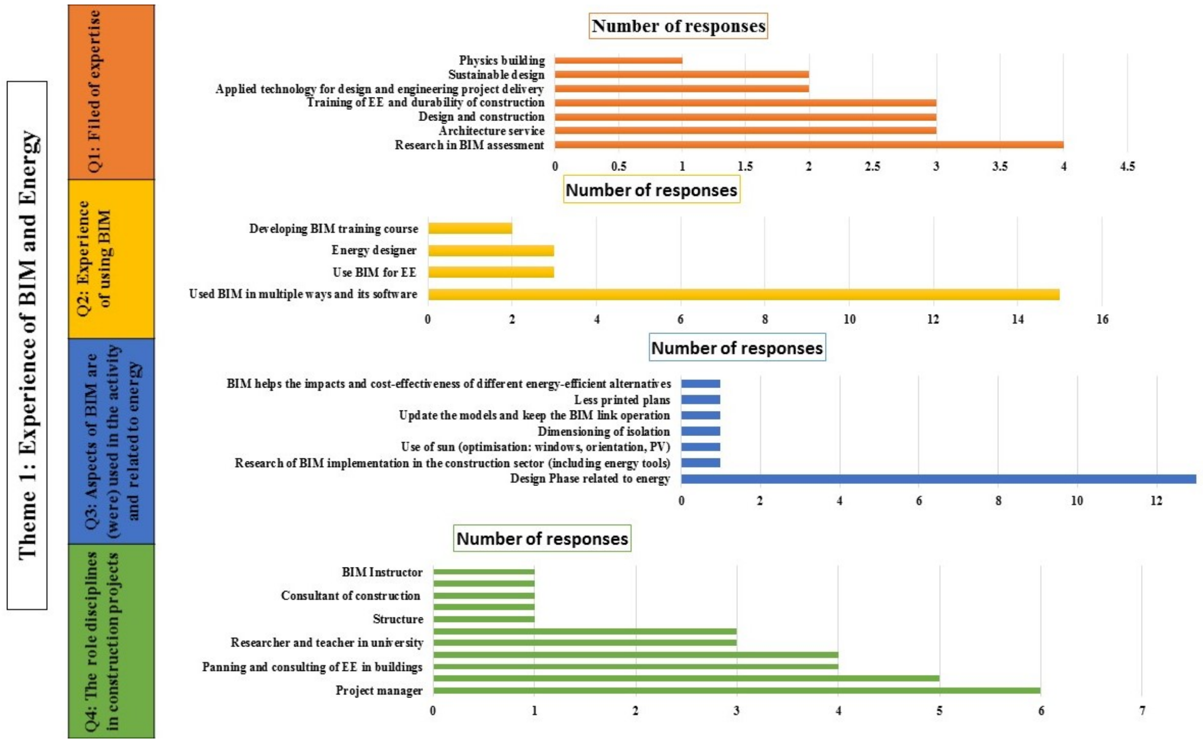


Figure 4-6 The number of responses for experiences of BIM and energy.

4.5.2 BIM for Energy Efficiency Skills

Experts were asked to specify the skills required to improve BIM management, with an emphasis on energy efficiency. The skillsets that were identified by the experts as being necessary for handling BIM data for energy efficiency associated with the role of designers, contractors and blue-collar workers. Several skills are highlighted by the experts for designers (see Figure 4-7), as follows: (1) ability to use CAD programmes and other energy efficiency software; (2) knowledge of the principle of energy efficiency and sustainability; (3) maintaining data of different varieties and solutions; (4) formulating the model using energy efficiency simulation programmes; and (5) good communication between designers, clients and suppliers. A high percentage of feedback identifies the ability to use CAD programmes and other energy efficiency software, as well as a knowledge of the principles of energy efficiency and sustainability, as essential skills for managing BIM for energy efficiency.

The identified contractor skills (see Figure 4-7) in BIM for energy efficiency 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. These 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 to improve BIM qualifications in the field of energy efficiency.

Some of the primary tasks in industrial construction activity are carried out by blue-collar workers, as presented in Figure 4-7. 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.

The researcher also observed a set of common gaps for which recommendations are made to improve BIM for energy efficiency. These common skills are related to knowledge about the principles of BIM and energy efficiency, skills to separate the information needed and to realise good communication between the disciplines in projects.

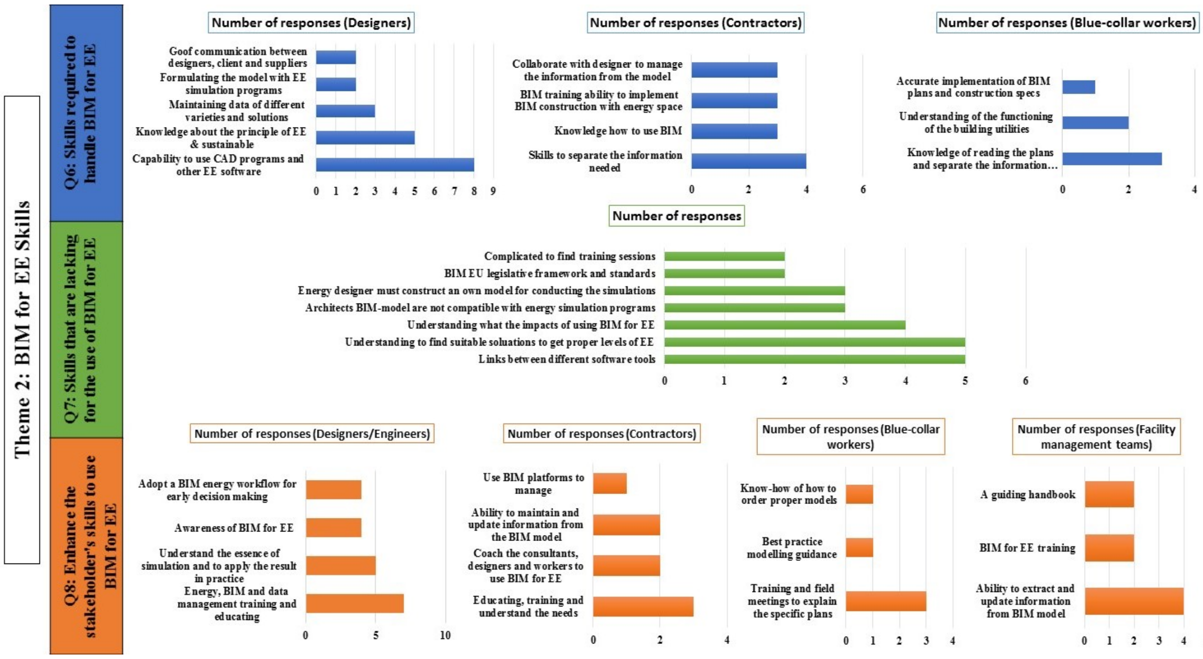


Figure 4-7 The number of responses for BIM for energy efficiency skills.

Based on the experience of the interviewed experts, Figure 4-7 shows the skills that are currently lacking for the use of BIM to achieve energy efficiency 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 energy efficiency, and understanding the impacts of using BIM for energy efficiency.

Almost 40% of the experts highlighted the following gaps and limitations against using BIM in energy efficiency: a) architects' BIM models that are not compatible with energy simulation programs, b) energy designers who should construct their models to conduct the simulations, c) BIM EU legislative frameworks and standards, and d) the difficulty of finding a location for training sessions. These gaps, limitations and the lack of skills need to be addressed by developing appropriate training programmes in the use of BIM to achieve energy efficiency. The experts highlighted several groups where the stakeholders' skills for using BIM for energy efficiency in projects can be enhanced, as follows: (1) blue-collar workers: workers, technicians, and so on; (2) designers and engineers; (3) contractors; and (4) facility management teams. For blue-collar workers, the experts reported that hosting training and field meetings to explain the specific plan can be an efficient way of improving the BIM skillset. The experts also reported the "know-how" of how to order proper models, finding best practice modelling guidance and the ability to change old attitudes as essential skills to add value obtained from using BIM. One of the experts highlighted that blue-collar worker 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' and 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 energy efficiency, and adopting a BIM energy workflow for early decision making.

Moreover, based on the experts' consultations in Figure 4-7, there are several ways to enhance the contractors' skills. A third of the experts have listed education and training as a key requirement to understanding BIM and improve its use. Meanwhile, other experts have highlighted novel methods to improve skills, including encouraging consultants, designers, and workers to use BIM for energy efficiency, maintaining and updating information from the BIM model, visualising the model and using BIM platforms to manage product data. Finally, the facility management teams require different methods to develop their skills for the use of BIM for energy efficiency. The experts considered that the ability to extract and update information from the BIM model is important. 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 energy efficiency.

The experts have provided several insights to support BIM training for energy efficiency on an organisational level. As shown in Figure 4-7, the experts have reported that organisations should support BIM training for energy efficiency. More than 60% of the experts reported that their organisations undertake training programmes on the use of BIM in energy design. More than 20% of the experts consider that the teaching of software programmes for the use of BIM for energy efficiency is important, alongside continuous learning on the issue of standardisation and to improve the skills of BIM coordinators.

4.5.3 Using BIM for Energy Efficiency in Projects

The experts reported that there are many benefits to using BIM for energy efficiency during the lifecycle of the project. Figure 4-8 shows that several benefits are to be realised during the design phase. In particular, BIM can improve the design process and increase energy performance. Other advantages include managing banks of materials, analysing them and giving better information, and as a result there will be fewer mistakes. The linking of monitoring operations and maintenance measurements to BIM was mentioned by four of the experts as significant benefits. Others highlighted the ability to collaboratively work on the same model version, the ability to link the building system with future users' behaviour, and the 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.

Based on the questionnaire, there are many benefits to using BIM for energy efficiency. However, there are several barriers to using BIM for energy efficiency in real industrial applications. Figure 4-8 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 programs. Some barriers are listed twice, such as tight schedules, the high cost of programs, Internet connectivity issues, achieving a proper BIM model and a lack of fundamental skills. Other experts mentioned the absence of information management standards and the lack of real case studies where BIM and energy efficiency were successfully implemented.

Figure 4-8 highlights that the majority of experts identify the need to carry out performance evaluations and to institute appropriate training mechanisms for BIM. Therefore, BIM tools should be utilised in the early stage of the project. Incentives on the adoption of BIM for energy efficiency are also determined to be essential. These recommendations will feed into the implementation phase of the study and will be considered when developing training programmes for using BIM for energy efficiency.

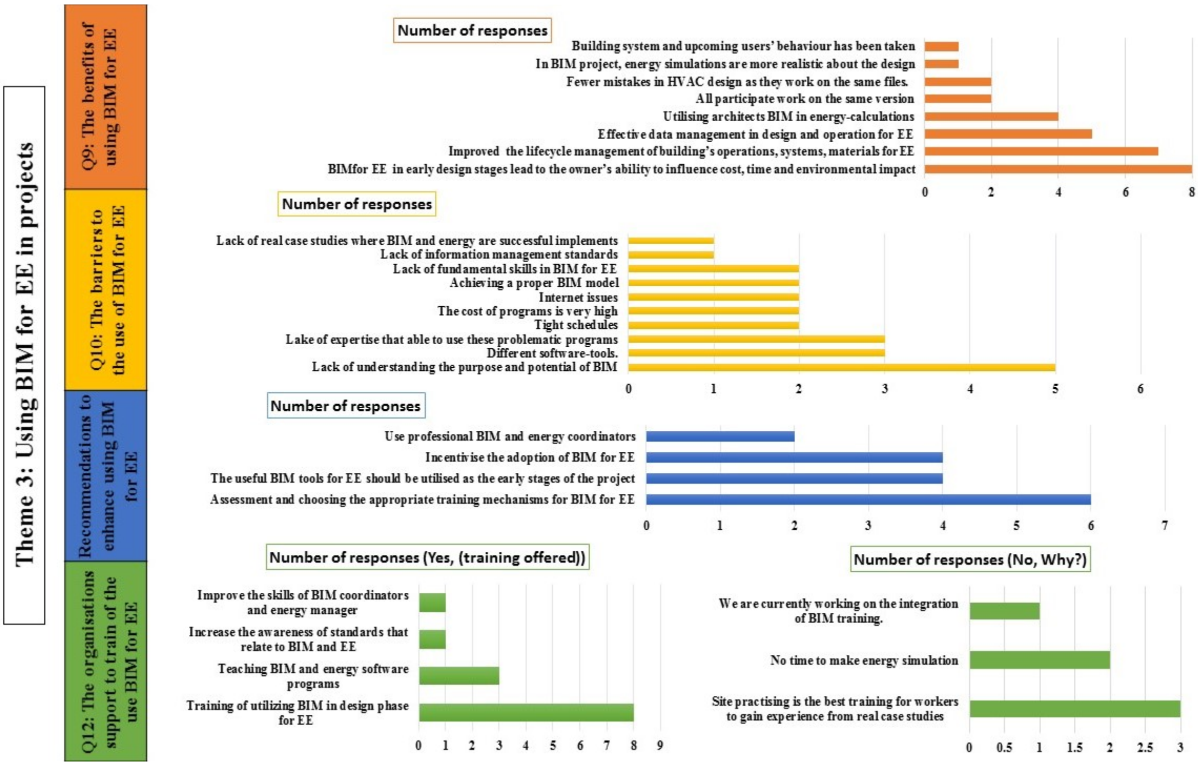


Figure 4-8 The number of responses for using BIM for energy efficiency in projects.

As shown in Figure 4-8, some of the organisations have no training programmes for their staff and (as mentioned in the interviews) experienced staff are used to train the other members of the team. Other organisations appear not to have time to provide energy simulation training. Meanwhile, 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.

4.6 Gaps of BIM Training for Energy Efficiency

Table 4-6 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 (e.g., designers, blue-collar workers and contractors). A particular emphasis was placed on the BIM software tools and the need to deliver specialised training programmes that can help the actors to understand and use these tools. At the organisational level, the experts have presented several strategies that can be adopted to improve the BIM skills and practices of the staff.

Table 4-6 Gaps identified in the interviews.

No.	Parameters	The Gaps
1	Skills required to handle BIM for energy efficiency	Designer: Formulating the model with energy efficiency simulation programs, 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 ensur1e best practice. Contractors: Knowledge of how to use BIM and training ability to implement BIM for energy efficiency, collaborate with the designer to manage the information from the model (See Figure 4-7).
2	Skills that are lacking for the use of BIM for energy efficiency	Understanding the link between different software tools, finding suitable solutions to promote BIM in energy efficiency, understanding the impacts of using BIM for energy efficiency (See Figure 4-7).
3	Specific ways of enhancing the stakeholders' skills for the use of BIM for energy efficiency	Blue-collar workers: Training and field meetings to explain the specific plans. Designers/Engineers: Energy, BIM, data management training and education, and understand the essence of simulation and how to apply the results in practice (See Figure 4-7).
4	BIM training for energy efficiency by organisation	Designers: Teaching software programs, BIM for energy efficiency. Continuous learning: issue with standardisation, skills of BIM coordinators and BIM managers should be defined. Contractors: Education and training should be adapted based on specific requirements. Facility management teams: This group need the ability to extract and update information from BIM models (see Figure 4-8).
5	Common barriers to the use of BIM for energy efficiency	Lack of understanding of the use of BIM, limitations in the use of different software tools, lack of expertise in using BIM programs (see Figure 4-8).
6	Recommendations to enhance the use	Assess the performance and appropriateness of the training mechanisms; tools should be utilised in the early stage of the

of BIM for energy efficiency	project; incentivise the adoption of BIM for energy efficiency (see Figure 4-8).

This analysis has shown 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 energy efficiency. In addition, this analysis has also revealed some key strategies 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 that we 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 is the case for both new build and refurbishments, and should cover the design, construction and management. These outcomes have informed the development of learning objectives and associated skills matrix that are now adopted by the European Commission to deliver BIM training and education around BIM for energy efficiency in the construction industry.

Given that construction projects involve multi-discipline and 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 results of the analysis, most respondents agreed that project managers are responsible for preparing the construction project's collaborative environment. They were also 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 the end users and their access to resources. With the proposed the platform, the researcher intends 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 this system. This will also help to overcome some of the restrictions to sharing and information exchange, which is a significant problem in the context of online communities. For instance, in this 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 (e.g., 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.

4.7 BIM Training for Energy Efficiency Requirements

In this chapter, the researcher has critically reviewed and investigated the current BIM practices landscape and has determined the requirements for developing a BIM training scheme informed by the above consultation and review of primary sources of evidence to address current industry collaboration problems on projects. This solution aims to facilitate and guide the collaboration processes of construction teams, while 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 experts and BIM specialists in the project consortia. This second validation consultation phase has focused on qualitative analysis with a view to filtering and consolidating the list of requirements for delivering BIM for energy efficiency in the European construction sector.

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 will identify a set of general and specific requirements for developing BIM skills and training, with a particular emphasis on energy efficiency, 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. Table 4-7 presents the gaps identified in the study of the use cases.

Table 4-7 Identified requirements based on use-case analyses.

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

4.8 Conclusion

In this chapter, the researcher has addressed the requirement elicitation criteria phase to identify gaps and new strategies for delivering BIM for energy efficiency. The researcher used a participatory and incremental approach and involved an expert panel with a view to reaching key stakeholder communities to help identify, and then screen and analyse past and ongoing projects related to energy efficiency involving aspects of BIM.

This work aimed at assembling evidence-based quantitative and measurable scenarios and use cases that demonstrate the role of BIM in achieving energy efficiency in buildings across the whole value chain. The researcher has recorded 40 best practice use cases from the field of BIM for energy efficiency, and has conducted an in-depth analysis to determine the gaps in BIM for energy efficiency training and any 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, while highlighting stakeholder targets, ranging from blue-collar workers to decision-makers.

The primary objective of this chapter was to identify the gap between the demand for skills and the learning for BIM application in energy efficiency. The researcher 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, to identify BIM training requirements across the value chain (from blue-collar workers to middle and senior level workers). In this chapter, the researcher has 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.

The researcher has identified the need to establish an open BIM community of BIM actors with access to resources, and to facilitate training and education programmes to overcome some of the constraints around sharing and exchanging BIM information, which is a significant problem in the field. Specifically, the researcher has identified that BIM is only applied for certain public building types and disciplines, whereas commercial and industrial buildings seem to require more skills on how to adopt BIM for energy efficiency. Similarly, the researcher has 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, the researcher has observed that the implementation of BIM can significantly reduce energy and water, but other construction domains require additional expertise for integrating BIM. At the discipline level, the researcher has identified that blue-collar workers and engineers need training in BIM for energy efficiency, as well as at the organisational level, where designers, contractors and facility management teams should be integrated into future BIM training.

In this chapter, the researcher has analysed the specific context of the EU to understand the current state-of-the-art around BIM for energy efficiency, which reflects the construction industry within developed economies because 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 they emphasised that the outcomes in developed economies around the world will extend to another context. In following chapter, the research will conduct and analysis knowledge mining to identify new skills and roles to address BIM training requirements and gaps for energy efficiency.

Upskilling the Construction Workforces Around BIM for Energy Efficiency

This chapter will provide an in-depth analysis of BIM-related roles and skills for construction professionals to inform current and future training strategies, and with a view to deliver energy-efficient buildings. The methodology included a Europe-wide consultation with experts and practitioners, as well as an in-depth analysis of social media sources used across construction communities, informed by a comprehensive literature review. This has helped to infer the roles and skills that are necessary in delivering a BIM-based project, as well as informing future BIM training and education needs. One of the main findings is that these roles, skills and associated training needs are not static but evolve to reflect the maturity and evolution of technology and the construction workforce.

5.1 Introduction

The construction industry is highly fragmented and it is often portrayed as involving a culture of adversarial relationships and risk avoidance, which is exacerbated by a linear workflow. This often leads to low efficiency, delays and construction waste [130]. 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 energy and environment [130]. There is currently an increasing alignment of interest between those who design and construct a facility, and those who subsequently occupy and manage it. The latter demands dedicated skills and competencies to address multi-objective sustainability (including energy) requirements [57]. While low carbon construction and energy-efficient buildings represent substantial opportunities in the sector, particularly with the fast adoption of ICT, there are (a) substantial low training among self-employed and (b) skills shortages among trade and professional occupations that inhibit technology deployment and innovation [370].

The current training system is perceived as confusing because it has multiple entry points, a plethora of qualifications, a wide variety in the quality of training provision, and complicated funding options can overwhelm and confuse businesses and individuals. Tough economic conditions have led to a substantial fall in apprenticeship completions in construction related industries (e.g., from about 22,000 in 2008/09 to about 16,000 in 2011/12 in the UK) [371]. Moreover, uncertainty in the market has led employers to reduce the number of workers on the books and use a more flexible self-employed workforce. In fact, the industry is currently dominated by a high number of self-employed who often face an ‘earn or learn’ dilemma [372]. In this context, the challenge facing the industry is to identify and target new recruits for skilled trades and the professions, and address training and development needs on a more strategic basis [373]. The transient nature of the workforce and the changing nature of the industry make this issue particularly important. Finally, there is a need to address the issues associated with career planning, and to change training and development from a supplier led to a demand-led model. There is also a need to encourage a more strategic approach to CPD and Continuing Craft Development (CCD) across the industry [373].

This chapter aims to analyse and infer BIM roles and skills for construction professionals as a means to inform BIM training programmes and to promote informed energy-efficient practices. This chapter will use data science techniques to identify BIM trends and practices for education and training, aiming to address the increased demand for professionals who have BIM skills.

5.2 Method

In this chapter, the proposed methodology is qualitative and involves primary sources of evidence (i.e., interviews, industry best practice use-cases, and social-media content; and secondary sources of evidence drawn from the scientific literature).

Primary sources of evidence are used to understand the dependencies and associations between BIM for energy-related concepts, primarily related to roles and skills. For the analysis, two main methods that facilitate text crawling and mining are used. First, NVivo analysis has been used to retrieve new skills and roles. NVivo has facilitated rich text-based and/or multimedia information elicitation, where deep levels of analysis on small or large volumes of data are required. NVivo is used predominantly by the academic community, governments, health and commercial researchers across a diverse range of fields, including social sciences such as anthropology, psychology, communication, sociology, as well as fields such as forensics, tourism, criminology and marketing [282]. NVivo accommodates a wide range of research methods, including network and organisational analysis, action or evidence-based research, discourse analysis, grounded theory, conversation analysis, ethnography, literature reviews, phenomenology, and mixed-methods research [283]. Second, heuristic content mining and expression analysis is used. Due to the noisy nature of social media, where short, informal spelling and grammar are often used, the researcher developed a set of regular expressions (RegEx) and pattern matching rules from the collection of BIM-related posts collected from social networking profiles. These were annotated as part of the human annotation process with language introduced from short informal text related to the BIM-related categories to assist the analysis process.

5.3 Results and Discussions

In this section, the researcher will present the findings of the analysis, while highlighting the resulting roles and skills. The methods utilised for the identification of the skills and roles are summarised below:

Word count and frequency analysis: This method explores the appearance of the key terms in a document and the associated frequency. This can be effective in determining when specific “keywords” appear in a data repository and in which frequency. Frequency analysis also enables the determination of the degree of importance for each analysed concept, which has served as a preliminary step to conduct the next analysis.

Word cloud analysis: This a more visual representation of “keywords” based on their frequency and position on a graph of concepts. Based on the word cloud analysis, a selection of central key terms has been identified and used to run the “tree” analysis.

Word tree analysis: This a method for exploring the maps of concepts associated with a repository of data. For the analysis, this method has been employed to observe dependencies between concepts and determination of roles and skills as presented in Figure 5-1 and Figure 5-2. The researcher has applied analysis on a database of use-cases, interviews, scientific publications, and Twitter, which was filtered by the expressions/queries reported earlier. The figures present the information connected to the roles and skills in the form of word trees. The context of these trees was extended to 25 words.

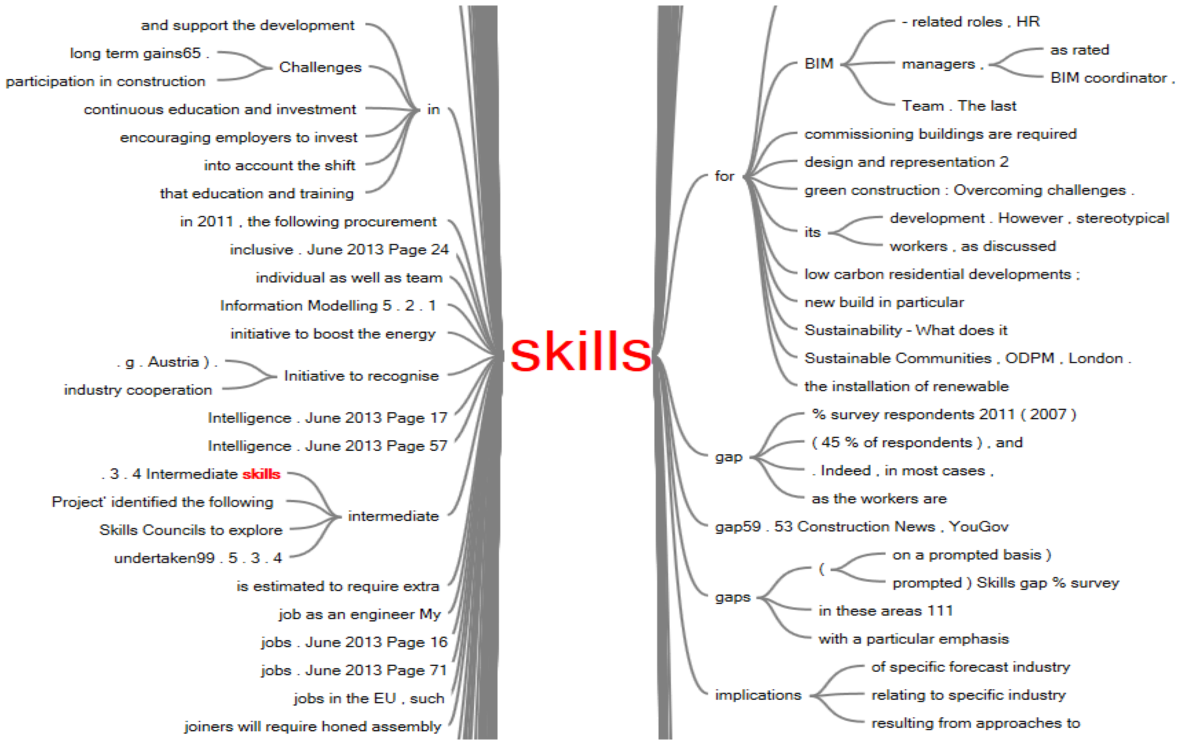


Figure 5-1 Word tree illustration for skills.

Figure 5-2 Word tree illustration for roles.

5.3.1 Use Cases Analysis

A set of analyses have been applied to the portfolio of use-cases to identify the skills and roles for BIM for energy efficiency. The overall methodology has been presented in the Chapter 3 (Step2), and the portfolio of use-cases is illustrated in Figure 3-11. The NVivo tf-idf (frequency-inverse document frequency) technique has been applied to find the most relevant "keywords" in the search space. By using the word cloud method for the use-cases, concepts can be emphasised, and new roles and skills can be identified with corresponding dependencies.

The Word cloud feature is also representative for this type of analysis because it determines the degree of importance between two concepts, significantly reflecting existing dependencies. The NVivo word tree technique has also been used to create a higher order of formalism throughout the portfolio of use-cases and to identify visual relationships between different concepts. NVivo trees can group together key terms that frequently appear before and after a pre-determined interrogation, and they can provide the means to assess a particular scenario and isolate the area of interest; as illustrated in Table 5-1.

Table 5-1 Consolidated list of skills and roles that were extracted from the word tree of the use cases .

NO.	Roles
1	Architect designer
2	Construction engineer
3	Facility manager
4	Mechanical engineer
5	Structure engineer
6	HVAC engineer
7	Worker in ceramic sector
8	BIM modeller

NO.	Skills
1	Optimal decision making
2	Collaborative design open ICT platform
3	Operation energy running costs
4	Operational energy demand
5	Interaction between the project managers
6	Data management
7	Adapted to changing environment conditions
8	Performance measuring, monitoring and optimisation

9	Steel Contractor
10	Electrical engineer
11	Builder
12	Supply manager
13	Energy modeller
14	Construction engineer
15	Energy simulation experts
16	Operation engineers
18	Electrical engineers

9	Integrated information management framework
10	Establish energy modelling
11	Achieve energy "LEED" certification
12	ICT skills
13	Teamwork skills
14	Understand BIM standards
15	Understand energy efficiency principle
16	BIM tools updates skills
18	Searching and BIM development skills

5.3.2 Interviews Analysis

In the next round, the analysis has been applied to 15 interviews; as gathered from the requirements elicitation phase. The input preparation phase has been necessary for importing the interviews into NVivo, where they have been modelled as word files and configured for successive evaluations. For the interviews, the researcher has applied word frequency queries leveraging NVivo advantages to enable words frequency determination with an associated percentage. This method has facilitated a better understanding of the key concepts and their correlation in the interview's portfolio. For instance, the most frequent words as derived from the interviews are BIM, energy, efficiency, construction, skills, but other relevant word dependencies have been determined and are presented in Table 5-2.

Table 5-2 Consolidated list of skills and roles that were extracted from the word tree of the interviews.

NO.	Roles
1	Architect
2	Project manager

NO.	Skills
1	Educating on BIM
2	BIM training

3	BIM instructor
4	Training instructor
5	Consultant of constructor
6	Energy expert
7	BIM manager
8	Planner and consultant of energy-efficient buildings
9	Real estate maintenance data management consultant
10	Structure engineer
11	BIM coordinator
12	Facility manager
13	University researchers and teachers
14	Contractor manager
15	Site manager
16	HVAC engineer
17	Civil engineer
18	

3	Practice Energy Modelling
4	Link between different software
5	Understanding of graphical information
6	Enhance the stakeholders' skills of BIM for energy efficiency
7	Site meeting for the comprehension of BIM data and energy features implementation
8	Capability to use CAD programs and other energy efficiency software
9	Knowledge about the principle of energy efficiency & sustainable construction
10	Formulating the model with energy efficiency simulation programs
11	Good communication between designers, client, supplier
12	Skills to separate the information needed
13	Knowledge how to use BIM
14	BIM training ability to implement BIM construction with energy space
15	Collaborate with designer to manage the information from the model
16	Strategy management skills
17	Managing and updating BIM data
18	Data management skills

19		19	Information managements standards

To continue with the analysis, the researcher has chosen to apply methods related to word queries to explore a map of dependencies between different BIM-related “keywords”. Terms such as “skills, roles and training” are central. Therefore, the analysis of the interviews was based on an exploration of the skills, roles and training. The word tree methods can also group words that appear frequently, which supports the exploration of dependencies for skills, roles and competencies. For example, in the determination of the roles, the researcher has used the term “role” as a central “keyword” when compiling the tree dependencies analysis. All of the Word trees are illustrated in Appendix C.

5.3.3 Analysis of the Scientific Publications

In this section, more than 66 scientific publications have been found and imported into NVivo to identify the roles and skills as required for the study of BIM for energy efficiency. In addition, international standards for BIM and energy efficiency have been provided to get more skills and roles. Mendeley was chosen to collect the scientific publications, which has also facilitated an orchestrated selection of the most relevant scientific studies before integration with NVivo. The data has been imported from Mendeley to NVivo, where various visualisation and concept retrieval methods have been used to determine the roles and skills that are relevant in BIM for energy efficiency. In the first round, the researcher has applied the word cloud analysis to identify key concepts with an associated degree of importance, as derived from the portfolio of scientific publications. This word cloud illustrates not only the most frequent words but also dependencies between concepts and keywords, such as building, energy, construction and design.

Table 5-3 Consolidated list of skills and roles that were extracted from the word tree of the scientific publications.

NO.	Roles	NO.	Skills
1	Facilitator of sustainable [design]	1	Simulation programs
2	BIM manager	2	BIM education

3	BIM modeller
4	Facility manager
5	Energy manager
6	Training and informing consultation professionals about BIM
7	BIM consult
8	Structure Engineers
9	Regulators
10	HVAC engineers
11	Technical manager
12	Contract manager
13	Finance manager
14	Maintenance manager
15	Quality assurance (QA) manager
16	Facility administration

3	Assess [respondents'] perception of BIM competence and prerequisite skills
4	Knowledge of BIM standards
5	Applying theoretical knowledge
6	Developing contractual specifying owner's BIM requirements
7	Training should be developed in BIM for energy efficiency
8	Knowledge about BIM standards
9	Update knowledge about BIM developments
10	An imbalance between the demand and supply of skilled labour in construction sector
11	Focus on soft skills like collaboration and communication, negotiation, teamwork, leadership and conflict management
12	Knowledge of building commissioning and building commissioning strategies
13	BIM model review – Automatic model check
14	Drawing skill with BIM tools
15	Practices in facilitating information exchange to meet stakeholders' business needs in BIM execution
16	Perspective with LCA and LCC applications

17	Sale manager
18	Production manager
19	Purchasing manager
20	Store manager
21	Safety manager
22	Construction manager
23	Acetic Designers
24	Mechanical engineers
25	Electrical engineers
26	Team manager
27	Built environment experts
28	Operation engineer

17	Increase the awareness of energy consumption
18	Increase the awareness of building regulations and how they will continue to evolve over time
19	Understanding of the principles of heat loss, heat gain and moisture movement
20	Knowledge of different types of low carbon materials – including the design lifecycle
21	QA specifically in relation to energy efficiency
22	BIM competence certification. Others suggest EU level certifications
23	Transfer of BIM Training Tool for Increasing Competence of Building Sector Competence
24	Educational programmes and training
25	Teamwork skills
26	Understand BIM workflow
27	Understand BIM standards
28	Leadership skills
29	Estimation skills
30	Documentation and detailing
31	Strategy and policy
32	Programme management
33	Technical knowledge

34	Planning and administration
35	Model management
36	Collaboration skills
37	Model coordination and collaboration
38	Analytical thinking
39	BIM applications
40	Creativity skills
41	Facilitation skills
42	Organisational management
43	3D coordination
44	Design review
45	Site utilisation planning
46	Conflict management
47	Negotiation skills

To identify new skills and roles, the researcher utilised similar techniques as in previous cases using central concepts such as “role, skills and training” because these concepts have proven to provide the best results in the initial tests. New skills were retrieved and added to the overall list presented in Table 5-3. The main differentiation factor from the skills identified from use-cases and interviews is that skills identified based on the scientific publications are more generic and cover a large segment of applications for the use of BIM. However, the researcher considers that presentation of all skills and roles is important, especially for the following analysis to be conducted in future work where associations between skills and roles can be undertaken with a higher order of accuracy.

Table 5-4 Consolidated list of skills and roles that were extracted from the word tree of the international standards.

NO.	Roles
1	Energy auditors
2	Energy manager
3	Maintenance engineer
4	Operation engineer
5	Project manager
6	Electrical engineer
7	Mechanical engineer
8	Civil engineer

NO.	Skills
1	Energy auditor's skills
2	Communication skills
3	Moderation skills
4	Presentation skills
5	Capacity for observation
6	Measurement skills
7	Analysis skills
8	Synthesis skills
9	Ability to articulate concepts and ideas
10	Ability to encountered situations
11	Ability to encountered situations
12	Ability to make concrete proposals for improvements
13	Project management and methodology skills
14	Decision-making skills
15	Problem solving skills
16	Demonstration skills
17	Energy saving technologies skills
18	Maintenance of suitable and recognized skills

19	Improvement of suitable and recognized skills
20	Level of defining the energy efficiency improvement opportunities
21	Energy auditing training skills
22	Clear understanding between the organisation and the energy auditing skills
23	Create confidence and minimises risks
24	Adequate manner on all aspects (technical, economic and others) of the energy audit
25	Energy production skills
26	Transmission and distribution processes
27	General understanding of the energy market
28	Tariffs and tariff structures
29	Ability to apply knowledge to complete tasks and solve problems
30	Actual performance or observation conducted in the work environment resulting in the acquisition of knowledge
31	Knowledge of physical principles related to energy (thermal, electrical, thermodynamics, heat transfer, fluid mechanics, etc.)

32	Capable of making a measuring/ metering plan for the data

5.3.4 Social Media (Twitter) Analysis

To increase the list of skills and roles, the researcher has extended the analysis to a social media content domain. This social media analysis includes the search for tags and ids as a first step of the process to identify new BIM skills and roles. Social media analysis addresses the more dynamic part of the skills and roles identification because BIM for energy and construction is a dynamic process where the majority of new concepts are disseminated and spread on social media. The data has been gathered from Twitter, including the organisation name and their Twitter accounts with the associated list of tweets.

NCapture has been used to gather all tweets, mentions and retweets. Almost 50,000 tweets have been captured, which has represented the knowledge base repository for the analysis conducted in this instance. The analysis has been performed around the same concepts of "skills, roles and training", with the overall objective of retrieving novel skills and roles relevant to the process of BIM for energy efficiency. In the analysis of social media content, the researcher has observed significant un-relevant concepts, which have been eliminated with the mechanism of exclusion facilitated by NVivo. However, the social media analysis led to the identification of new skills and roles. This proves that BIM for energy involves a dynamic and evolving dimension, whereby skills, roles and technologies are continuously updated. The identification of skills has reported a similar problem in terms of the "noise" existing in the results. After several rounds of filtering on social media content, the researcher has managed to increase the relevance of the results, and to determine new skills that have been reported by organisations and users that are active in the field of BIM and energy efficiency (as illustrated in Table 5-5). Because it was not trivial to get access to all social media content for BIM and energy efficiency in all of the countries involved in the study, the researcher has conducted extensive and scalable social media analysis to increase the social media database from which more skills and roles can be identified.

Table 5-5 Consolidated list of skills and roles that were extracted from the word tree of Twitter.

NO.	Roles
1	Architect
2	Energy manager
3	Construction information manager
4	BIM manager
5	Digital technology designer
6	Facility manager
7	Designer
8	Energy expert
9	Project manager
10	Construction manager
11	EE expert
12	Human resource manager
13	Team manager
14	Researches
15	Water manager
16	Structure engineers

NO.	Skills
1	BIM education programme
2	Certification scheme
3	Good communication
4	Increase the awareness about BIM for energy efficiency
5	Training for energy efficiency skill
6	Build up energy efficiency core skill in construction
7	E-learning training courses
8	Understand the standards in construction supply chain
9	Skills and knowledge needed to ensure building and renovation projects meet stringent energy efficiency requirements
10	Scientific skills and technical knowledge in the field of communication with respect to sustainability
11	EE skills certification scheme for EU
12	Cooperation skills
13	Modelling skills
14	Digital skills
15	Sustainability skills
16	Construction skills training material

17	Mechanical engineers		17	Management skills
18	Electrical engineers		18	ICT skills
19	ICT experts		19	Scientific skills and technical knowledge
20	Researchers and developers		20	Leadership skills
21	Supply chain managers		21	Teamwork skills

5.3.5 Scalable Heuristic Social-Media Mining

To increase the data repository, the researcher has extended the social media analysis by implementing a social media crawler that has retrieved friends' and followers' activity based on the list of accounts presented in Table 5-6. The researcher has applied similar analysis but on a database of 40 million tweets, which was filtered by the expressions/queries reported earlier. Table 5-6 presents the roles and skills that have been recorded during the scalable heuristic social media mining process. Figure 5-3, Figure 5-4, and Figure 5-5 present the information connected to the roles, skills and training in the form of word trees. The context of these trees was extended to 25 words. Also, the tables show and summarise the most common roles and skills from the word trees.

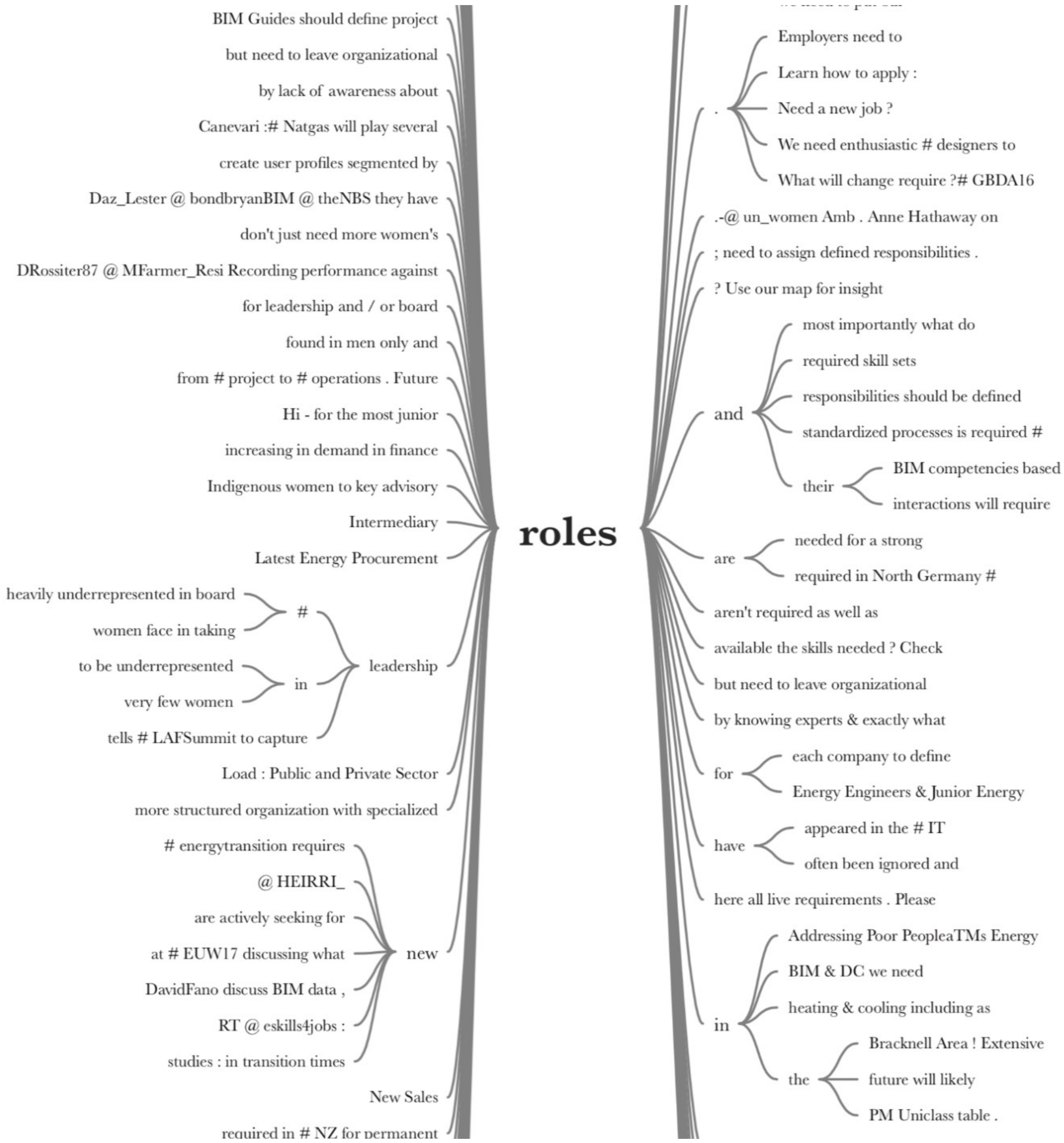


Figure 5-3 Role word tree in scalable social media mining.

When applying analysis on the central concept of ''roles'', numerous skills and roles have been identified. An improvement to the previous analysis was the exclusion of ''neutral terms'' and linking words, which has improved the accuracy of the results, and increased the list of skills and roles. Figure 5-3 presents a sequence of the tree, which is presented in Appendix C.

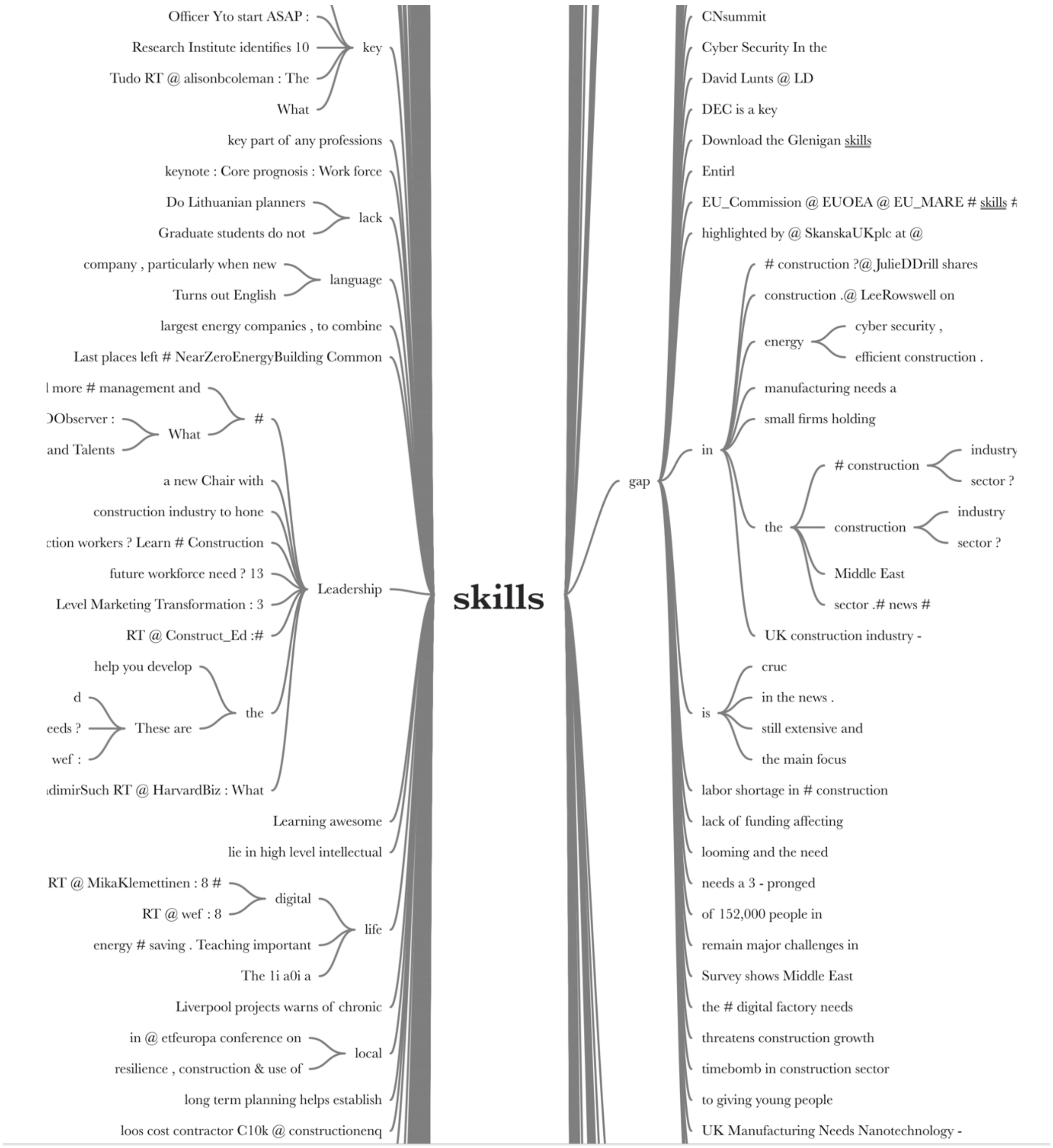


Figure 5-4 Skills word tree in scalable social media mining.

To determine the skills, analysis have been conducted by utilising the central concept ‘’skills’’, which led to relevant results and increased the list of skills. Figure 5-4 presents an instance of the word tree, which is extensively presented in Appendix C and in the results in Table 5-6.

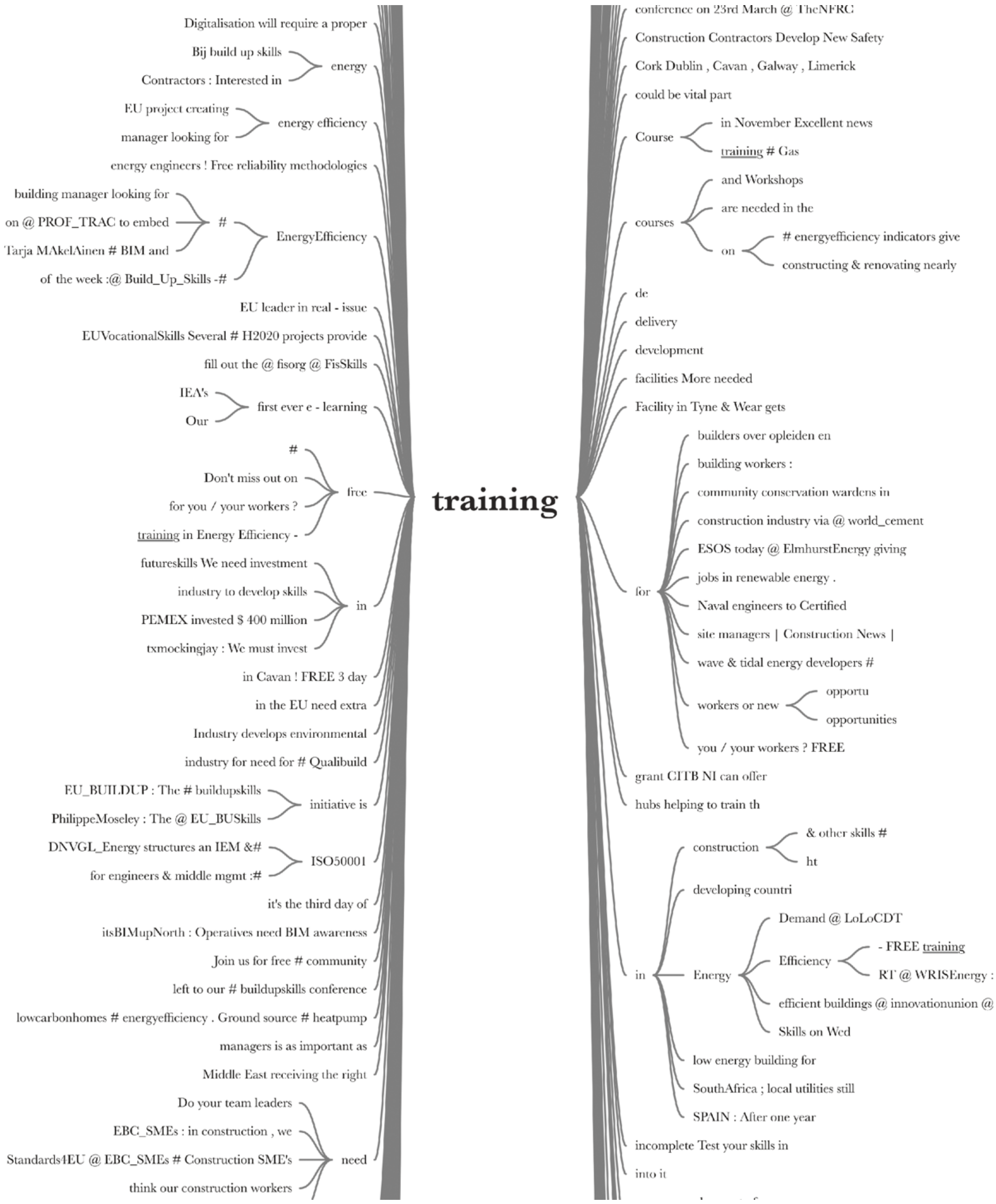


Figure 5-5 Training word tree in scalable social media mining.

For the ''training'' key concept analysis, a large set of dependencies have been determined that have not only improved the identification of skills and roles but also provided new insights for the main interests and directions that are now active in the field of BIM for energy efficiency. An extract of the training tree is given in Figure 5-5, while the whole view is provided in Appendix C.

Table 5-6 Consolidated list of skills and roles that were extracted from the word tree of the scalable heuristic social media mining.

No.	Roles
1	Architect
2	Energy Analyst
3	Advisory roles
4	Construction Managers
5	Data Protection Officers
6	Designers
7	Digital energy economist
8	Extensive Sales experience required in Bracknell
9	Energy procurement
10	Finance
11	HMI Operator
12	Human resources for Big Data professions
13	Information coordinator & information facilitator
14	Information Management in Construction
15	Nanotechnology
16	Supervisors
17	Technicians
18	Senior organisational roles
19	aerospace engineer
20	architecture & construction project manager
21	building professional
22	chemical engineer
23	communication officer

No.	Skills
1	IoT, ICT
2	AEC organisations need to understand the power of Analytics
3	Negotiation, social, Building the bridge between the worlds of education and work
4	Timber frame construction, Educational game construction, Solar panels
5	Lifelong learning
6	Construction, IoT, ICT
7	Negotiation, social skills
8	4D simulation
9	augmented reality
10	automation skills
11	construction skills
12	cooperation skills
13	coordination skills
14	data science skills
15	digitisation in construction
16	digital & urban skills
17	entrepreneurial skills
18	energy harvesting
19	energy law
20	energy performance
21	energy storage committee
22	energy transition
23	e-learning skills

24	data protection officer
25	designer
26	energy engineer
27	environmental scientist
28	government affairs manager
29	information facilitator
30	market acquisition manager
31	nuclear energy expert
32	private science panellist
33	researcher
34	solar energy specialist
35	technical manager
36	alternative energy
37	automotive engineer
38	business unit director
39	circular economy specialist
40	construction health & safety
41	data scientist
42	electrical engineering
43	engineering, procurement and construction service provider
44	expert in timber engineering
45	human resources for big data professions
46	innovation manager
47	mechanical engineer
48	passive house designer
49	Professor
50	robotics specialist
51	sustainability specialist, advocacy & policy design
52	timber frame and joinery

24	energy policy decision making
25	engineering skills
26	ICT skills
27	labour work skills
28	leadership skills
29	low - zero energy buildings
30	management skills
31	Energy management skills
32	marketing skills
33	math skills
34	pooling skills
35	Python programming skills
36	Revit programming skills
37	renovation skills
38	SEO skills
39	socioeconomics development
40	speaking skills
41	structural analysis skills
42	technological skills
43	training skills
44	structural engineering software operation skills
45	virtual reality operation skills
46	4D simulation
47	augmented reality
48	automation skills
49	construction skills
50	cooperation skills
51	coordination skills
52	data science skills

53	architectural engineer
54	BIM teaching assistant
55	carpenter
56	civil engineer
57	cyber security specialist
58	digital marketing
59	energy consultant
60	environmental engineer
61	GEF small grants programme coordinator
62	Information coordinator
63	inventor
64	Nanotechnology engineer
65	PMP - Energy Oriented Business Developer
66	programme manager
67	sales engineer
68	T.C. Engineer
69	Installers
70	Advanced service-oriented roles
71	Collar's craftsmen
72	Construction workers

53	digitisation in construction
54	digital & urban skills
55	entrepreneurial skills
56	energy harvesting
57	energy law
58	Interdisciplinary
59	Green energy
60	NZEB design
61	Building
62	Writing

When applying analysis on the key concepts of "role" and "skills", the emerging skills and roles that institutions and users from the BIM domain broadcast on social media have been identified, respectively. The previous analysis was improved by the exclusion of "neutral terms" and linking words, which has improved the accuracy of the results and also increased the list of skills and roles. For the training analysis, a larger set of dependencies have been determined, which have not only improved the identification of skills and roles but also provided new insights for the main interests and directions that are now active in the field of BIM for energy efficiency.

5.4 Consolidating Skills and Roles

A list of skills and roles has been obtained from the analyses applied to the portfolio of use-cases, interviews, publications and social media, and are presented in Table 5-7 and Table 5-8. Reflecting the diversity of roles and skills in this area, the table contains roles such as architect, project manager and BIM coordinator, and skills such as training of BIM and understanding of how graphical information can help to inform appropriate training programme, which are all related to addressing the process of BIM for energy efficiency. The "training" concept has returned results that facilitated the identification of new skills and roles, creating new correlations between terms that exist in the same semantical space.

Table 5-7 A consolidated list of BIM roles for energy efficiency from different sources (A: Use-cases, B: Interviews, C: Scientific publication, D: Twitter analysis, E: Scalable heuristic social media mining).

Roles	A	B	C	D	E
(Construction, Architect, Mechanical, Structure, HVAC, Electrical, Civil, Automotive, Environment, Aerospace, Energy, Chemical, and Nanotechnology) Engineers	✓	✓	✓	✓	✓
(Facility, Team, Supply chain, O&M, Contracts, Site, Technical, Finance, QA, sale, Production, Purchasing, Store, Health & Safety, HR, Water, Market acquisition, Innovation, Programme, Energy, BIM, Government Affairs, Construction, and Project) Managers	✓	✓	✓	✓	✓
Blue-Collar such as (technicians, ceramic worker, steel, builder, supervisors, and carpenter)	✓				✓
(Modeller, Instructor, Coordinator, Consultant, and Training and informing consultation professionals) about BIM	✓	✓	✓	✓	✓
(Simulation expert, expert, Planner and consultant of energy-efficient buildings, energy efficiency expert, Digital energy economist, procurement, nuclear energy, solar energy specialist, and alternative) Energy	✓	✓	✓	✓	✓
Real estate maintenance data management consultant		✓			
University researchers and teachers		✓		✓	✓
Facilitators of sustainability			✓		
Decision-makers "Advisory roles, Regulators, Senior Organisational roles, and Policy designers"			✓		✓
Facility administration			✓		

Built environment experts			✓		
Technology specialists "Digital technology designer, ICT experts, Data Protection Officers, Information coordinator & information facilitator, data scientist, robotics specialist, and cybersecurity specialist"				✓	✓
Building professional					✓
Communication officer					✓
Environmental scientist					✓
Private science panellist					✓
Business unit director					✓
Circular economy specialist					✓
Engineering, procurement and construction service provider					✓
Expert in timber engineering					✓
Passive house designer					✓
Sustainability specialist					✓
Timber frame and joinery					✓
GEF small grants programme coordinator					✓
PMP - Energy Oriented Business Developer					✓

It should be noted here that data from best practice use-case studies and interviews has delivered several state-of-the-art roles and skills for energy efficiency, whereas scientific publications reported more traditional and fewer new BIM roles and skills as disseminated in the field of research; as illustrated in Table 5-7 and Table 5-8. The novelty in terms of new skills and roles was identified when conducting analysis on social media data based on the list of Twitter accounts (as presented previously). By combining such diverse data sources, the researcher has managed to address the two main objectives for this study: (i) determine skills and roles required for the implementation of BIM for energy efficiency and (ii) capture the dynamic nature of BIM to keep up with new industry requirements and trends. Given that BIM relies on data and the AEC industry represents a sector where new technical solutions are now implemented, especially with the emergence of IoT discoveries, approaching BIM training for energy efficiency holistically can give the industry sector a significant advantage to absorb innovations and shift towards sustainability in the overall landscape of climate change.

Table 5-8 A consolidated list of BIM skills for energy efficiency from different sources (A: Use-cases, B: Interviews, C: Scientific publication, D: Twitter analysis, E: Scalable heuristic social media mining).

Skills	A	B	C	D	E
Data management	✓	✓		✓	✓
An integrated information management framework	✓	✓			
ICT skills	✓			✓	✓
Teamwork skills	✓		✓	✓	✓
Understand BIM standards	✓		✓		
Understand energy efficiency principle	✓	✓		✓	
BIM tools updates skills	✓	✓	✓		
BIM education		✓	✓	✓	
BIM training		✓	✓		
Links between different software		✓			
Enhance the stakeholders' skills of BIM for energy efficiency		✓	✓		✓
Capability to use CAD programs and other energy efficiency software		✓		✓	
Formulating the model with energy efficiency simulation programs		✓	✓		
Good communication between designers, client, supplier		✓		✓	
Increase the awareness of energy consumption			✓	✓	
Increase the awareness of building regulations and how they will continue to evolve over time			✓	✓	
BIM competence certification. Others suggest the EU level certifications			✓	✓	
Focus on soft skills like collaboration and communication, negotiation, teamwork, leadership and conflict management		✓	✓	✓	✓
Programme management			✓	✓	
Conflict management			✓		✓
Negotiation skills			✓		✓
Build up energy efficiency core skill in construction			✓	✓	
E-learning training courses				✓	✓
Understand the standards in construction supply chain			✓	✓	
EE skills certification scheme for EU	✓	✓		✓	

Cooperation skills				✓	✓
Operation energy running costs and operational energy demand	✓				
Performance measuring, monitoring and optimisation	✓				

5.5 Classification of Roles and Skills

The resulting list of roles and skills are classified using frequency analyses applied to the repository of tweets that have been retrieved. In this section, a selection of roles and skills have been classified to understand the degree of importance of each skill and role, with a view to understanding which BIM areas are more dynamic and require training strategies.

In this experiment, the equation (1) has been used to determine the frequency of skills and roles from different sources.

(Equation 4) $$\boldsymbol{TF(T)} = \frac{\boldsymbol{number\ of\ times\ the\ t\ appears}}{\boldsymbol{total\ number\ of\ terms\ of\ the\ same\ type\ of\ t}}$$

where *t* is either skill of a role and the type of *t* can be either a skill or a role.

Frist of all, the roles were analysed based on their frequency in the document corpus. Figure 5-6 presents a classification of roles based on frequency, where roles such as energy analyst, energy consultant, energy developer, energy procurement specialist have been identified as important by the community of interest. In contrast, a lower frequency has been attached to roles such as HR specialist, finance specialist, communication officer. This demonstrates the future areas of interest for developing BIM competencies and educational programmes.

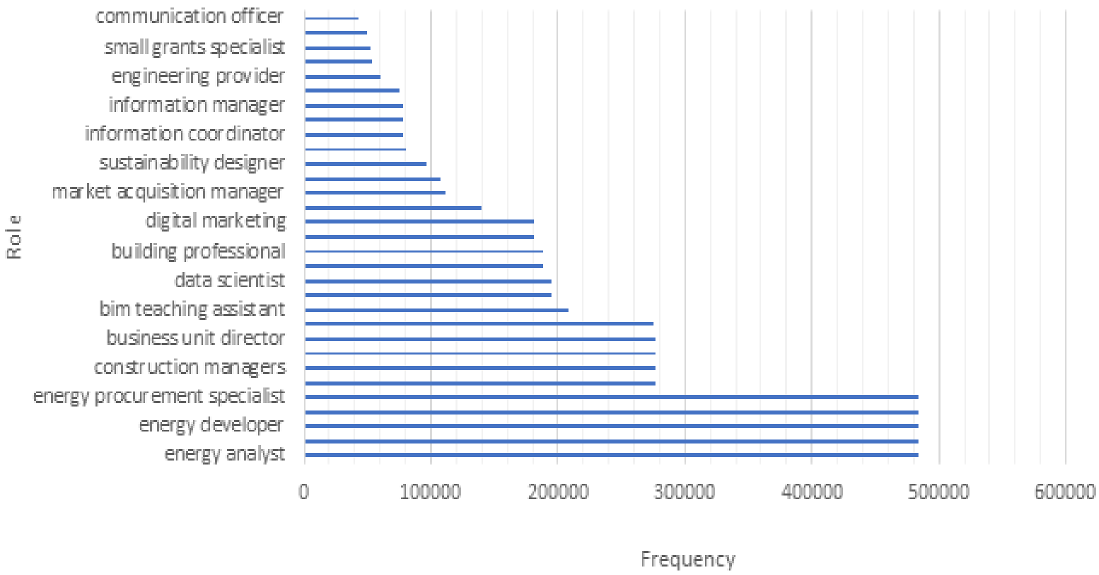


Figure 5-6 Frequency of BIM roles.

From Figure 5-6 it can also be observed that BIM has an impact on different areas of practice, ranging from clerical roles to scientists, which brings a relatively high diversity of BIM roles.

In addition, the skills were analysed based on their frequency in the document corpus. Figure 5-6 presents a classification of skills based on frequency, where skills such as 4D simulation, construction, digital and urban, and training have been identified as important by the community of interest. In contrast, a lower frequency has been attached with skills such as structural engineering software, structural analysis, and mathematics. This demonstrates the future area of interest for developing BIM competencies and educational programmes.

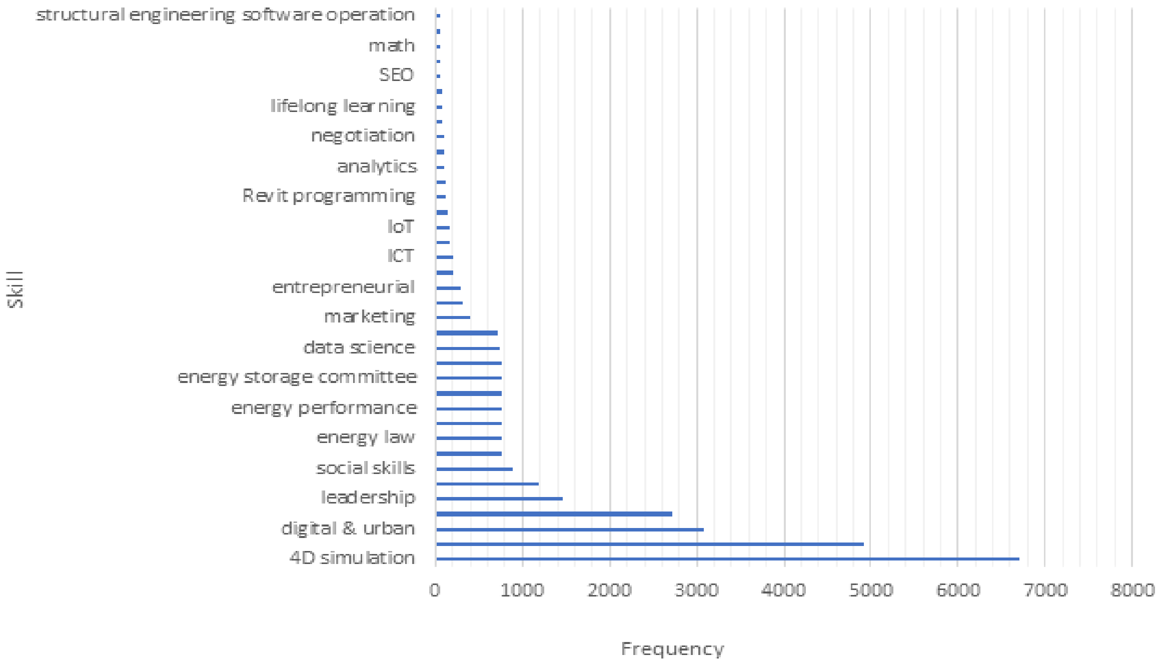


Figure 5-7 Frequency of BIM skills.

From Figure 5-7, it can also be observed that BIM has an impact on different areas of practice, ranging from basic mathematical and computer literacy to advanced skills such as digital and urban 4D simulation, which brings a relatively high diversity of BIM skills.

Furthermore, the importance level of skills and roles have analysed by using equations (2&3):

(Equation 5) $\boldsymbol{Importance\ (skill)} = \frac{\mathbf{1}}{\boldsymbol{n}} \sum_{\boldsymbol{n}=\mathbf{1}}^{\boldsymbol{n}} (\boldsymbol{no.of\ occurences}(\boldsymbol{association}(\boldsymbol{skill} + \boldsymbol{role})))$

where *n* is the number of different associations between that skill and different roles.

(Equation 6) $\boldsymbol{Importance\ (role)} = \frac{\mathbf{1}}{\boldsymbol{n}} \sum_{\boldsymbol{n}=\mathbf{1}}^{\boldsymbol{n}} (\boldsymbol{no.of\ occurences}(\boldsymbol{association}(\boldsymbol{role} + \boldsymbol{skill})))$

where *n* is the number of different associations between that role and different skills.

Figure 5-8 and Figure 5-9 have presented many of skills and roles with demonstrated the correlation between frequency and importance. The main objective of this experiment was to determine a correlation between the importance and the frequency of each role and skill—note that importance and frequency are defined by the formulas presented in the methodology section.

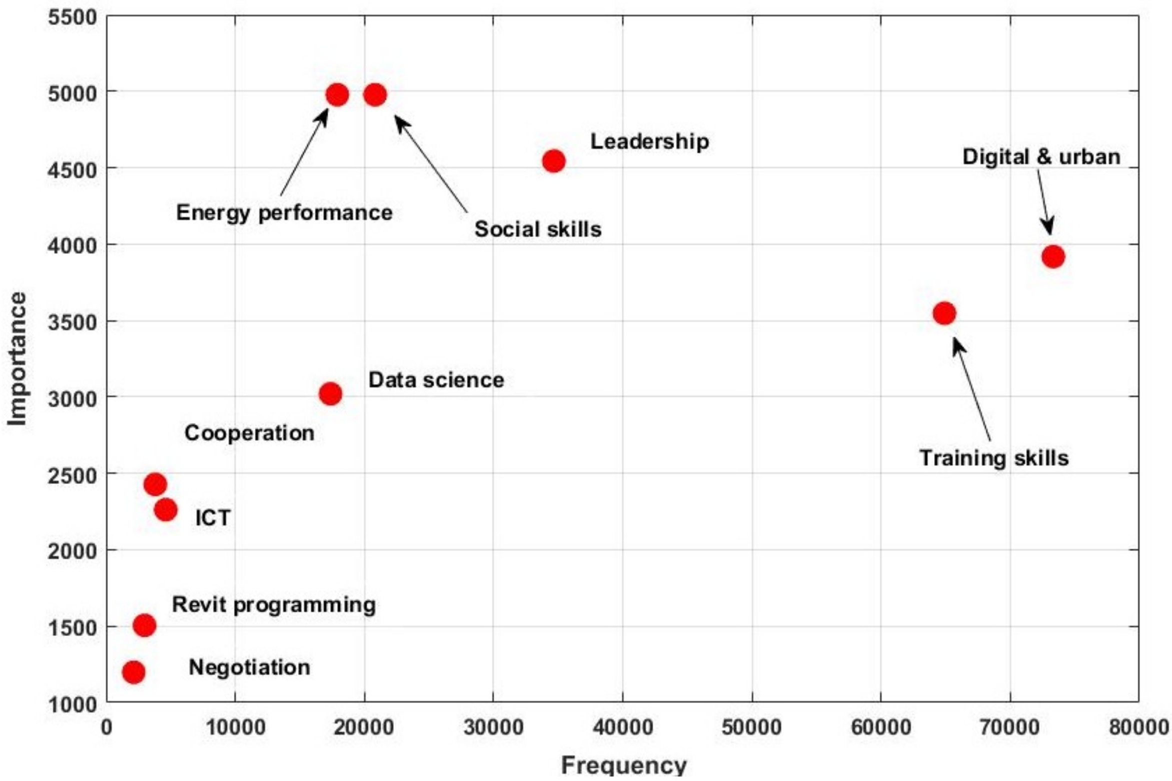


Figure 5-8 Frequency and importance of skills.

As shown in Figure 5-8, the skills can have different levels of importance in relation to the construction industry domain. From the list of tweets, skills such as “energy performance” and “leadership” have the highest ranking, whereas “negotiation” and “Revit programming” are less important.

The experiment shown in Figure 5-9 also investigates the classification of roles based on their level of importance. It can be observed that “Information Coordinator”, “Finance Specialist” and “Environmental Engineer” are also frequent and important, whereas roles such as “Mechanical Engineering” and “Automotive Engineer” are less frequent and important. These results show that there is a change of the dynamics in the construction industry.

Classifying roles and skills represents a key advantage for construction professionals because new industry trends can be identified and new fields of interest can be addressed by devising adequate training programmes.

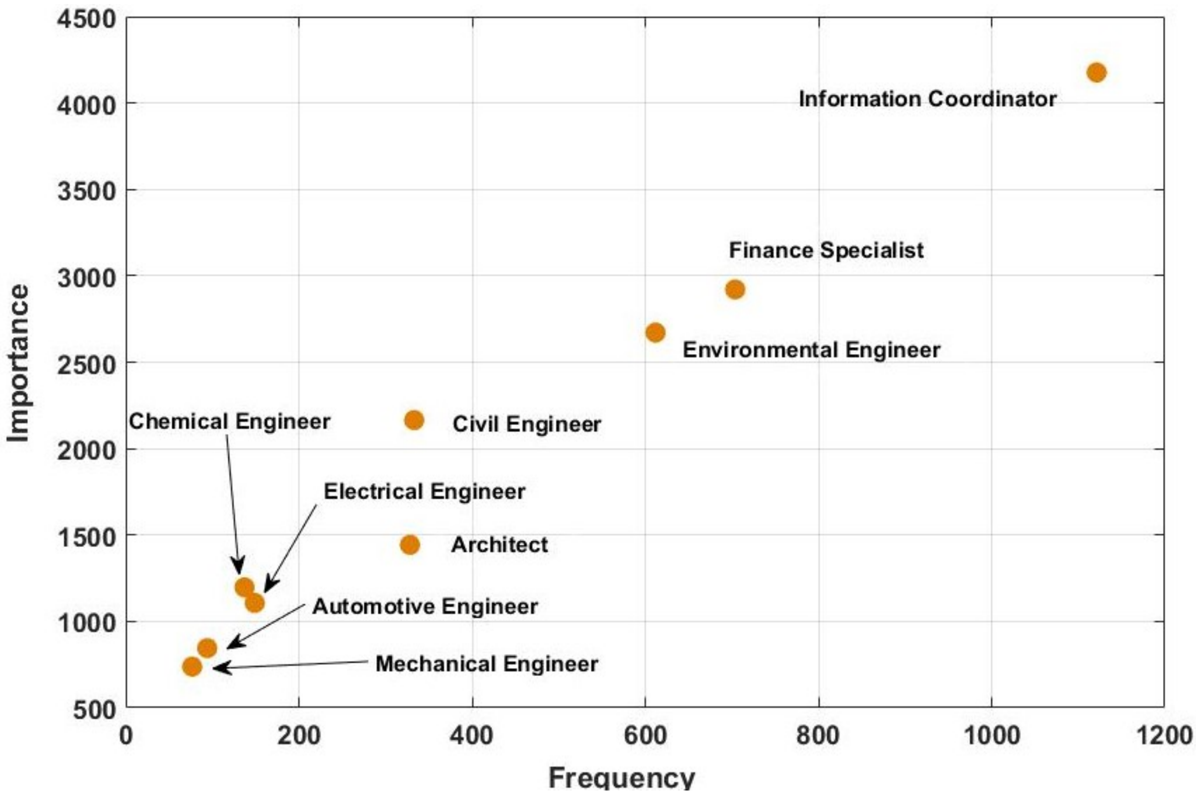


Figure 5-9 Frequency and importance of roles.

5.6 Conclusion

This chapter has conducted knowledge mining and analysis to identify new skills and roles to address BIM training for energy efficiency. From the evaluation section, the researcher has implemented four analysis scenarios: use-cases analysis, interviews analysis, scientific publication analysis and Twitter analysis. The findings show that BIM is dynamic in nature and requires new training programmes to cover the gaps in the training of BIM for energy efficiency. The evaluation of the social media analysis stage shows that the resulting list of roles and skills is novel and can bring new insights into the process of BIM training and education. The new technological capabilities proposed by social media give a unique opportunity to re-engineer and improve the existing methodology, and to extend on the current state of knowledge for BIM application in energy efficiency. In addition to the acknowledged importance of social media, the analysis has suggested that some organisational characteristics have had to adapt to facilitate change and support the implementation of the new BIM processes. This leads to the conclusion the BIM is a dynamic process that cannot be captured with traditional analysis methods. The analysis has also shown that this stage was crucial because of the number of supporting concepts that play a significant role in the BIM process characterisation. In addition, a holistic methodology is required for the assessment of BIM with associated competencies and training programmes.

Finally, the analysis has also demonstrated that an organisation in the field of BIM for energy and construction needs to pay attention to organisational and human skills involved in the BIM process and should adopt a continuous improvement approach to change. From the related work, it was determined that the role of these BIM roles and skills concepts is very often neglected in the existing BIM studies. For example, all of the studies reported the urgent need for training to use the existing BIM skills and competencies efficiently and utilise the full potential of the new system to increase productivity and improve quality. In addition, the analysis of the research results showed that there is a potential danger of resistance to change, which might constrain the overall BIM development process. Consequently, the researcher has demonstrated a need to involve the end-users more closely in the decision-making process, as well as in the implementation process.

The researcher’s approach has started from the consultations process that identified, analysed, and assessed construction sector stakeholders’ requirements for BIM training to ensure engagement with energy management in construction. From these consultations and use-cases, the researcher has applied NVivo qualitative and quantitative analysis to determine the skills and roles of BIM for energy efficiency. This chapter, ultimately, aims to identify skills and roles that will inform the training process, which can significantly educate a community of users in the field of BIM and promote energy-efficient practices among companies and users. These skills and roles will be used in the next chapter to develop a Standardized Qualification Framework that to be adopted by training programs to address the increased demand for stakeholders requiring BIM skills.

Standardized Qualification Framework for Energy Efficiency

This chapter will provide an in-depth analysis of BIM-related roles and skills for construction professionals to inform current and future training strategies with a view to delivering energy efficiency. In this chapter, the roles and skills list from Chapter 5, and the roles categories from Chapter 4 are classified and analysed during the whole lifecycle of a project in terms of relevancy to BIM and energy efficiency in the construction sectors. The RIBA plan will also be used to develop the skills RIBA map that defines for each role category through all of the stages of the project lifecycle. Then, a matrix for each skill level that is recommended will be proposed according to the European Qualifications Framework (EQF) levels definition. This skills matrix enables different levels to be distinguished for each skill (e.g., senior and technician). It also helps to define the level of EQF. Finally, the stakeholders' skill levels will be identified, which will enable them to handle BIM for energy efficiency in the building sector during the lifecycle and in the supply chain.

6.1 Introduction

By 2025, the global construction market is expected to rise by more than 70% compared to 2013 [2] [3]. Several countries, such as the United Kingdom, have already established a target to attain significant goals, such as: (i) a 33% decrease in both the initial cost of construction and the total cost of assets throughout their entire life cycle; (ii) a 50% reduction in the overall time from inception to final for new and refurbished assets; (iii) a 50% decline in GHG emissions in the built environment; and (iv) a 50% decrease in the trade deficit between total exports and total imports for construction products [3], [4].

The previous chapters have highlighted the importance of BIM in facilitating more effective energy modelling and multi-disciplinary collaborations from a total lifecycle and supply chain integration perspective. They explored the results of a survey of BIM and energy efficiency experts about the training and skills agenda in this area. They also summarised the BIM and energy efficiency training that is currently offered in the five partner countries (i.e., Luxembourg, United Kingdom, France, Finland, and Greece), as follows:

- A lack of awareness within the supply chain with regards to BIM for the energy efficiency of buildings.
- Most existing training and certification schemes focus on designers and contractors, and often focus on the modelling software.

- Bachelor's degrees in traditional construction areas tend to increasingly integrate BIM.
- The extent of integrated BIM and energy efficiency training is either poor or limited in these areas. However, some courses have been developed (e.g., in Finland and the United Kingdom) that incorporate aspects of energy and use well-established software tools to undertake energy simulations, overheating assessments and so on.
- Software providers are helping to fill this void and are providing courses aimed at modellers and designers, helping them to integrate BIM and energy performance tools with the intention of streamlining the process and avoiding duplication. There is certainly scope to integrate BIM into national calculation methodologies for energy performance certification, thermal bridge assessment and so on.

A skill is defined as the technical and detailed information that each actor should know in their domain (i.e., the know-how) [374]. The key point is to identify the skills to be integrated as a cross-cutting theme into apprenticeships that will help to fill the training gaps among (for example) facility managers and subcontractors (including blue-collar workers and technicians) who are responsible for the design, installation and maintenance of fabric measures, building services, and so on. This will improve the integration of BIM in the whole project lifecycle and increase the energy efficiency.

The RIBA plan of work is a well-known guideline for construction in the EU, which is published by the RIBA [375]. The RIBA plan of work integrates the BIM to support design and construction teams to implement an efficient, intelligent and cost-effective design process and to provide better services to clients, particularly in relation to the whole life-value of buildings. This framework was followed to conduct construction project stages and relevant tasks to identify the skills that are needed for each stakeholder to deliver all of the required outputs during the project stages.

The EQF, which was produced by the European Commission in 2013, is the main tool to be used for mobility and lifelong learning. It has been used with variable success to support the development or referencing of sectoral qualifications frameworks through allocating levels for individual qualifications [376]. This tool was selected in this study to extract the skill levels that are required to handle tasks and outputs based on the RIBA plan stages for construction projects.

This chapter aims to analyse and infer BIM roles and skills for construction stakeholders as a means to inform BIM training programmes and to promote informed energy-efficient practices. In particular, this chapter uses data science techniques to identify the level of skills needed to handle BIM for energy efficiency for various stakeholders involved in the construction projects during their lifecycle to be adopted by training programs and thus address the increased demand for stakeholders requiring BIM skills.

Methodology

This chapter uses data science techniques to identify the level of skills that are required to handle BIM for energy efficiency for various stakeholders involved in the construction projects during their lifecycle to be adopted by training programs and address the increased demand and gaps for stakeholders requiring BIM skills. In addition, the framework followed in Chapter 6 highlights the general methods that are used to develop a standardized qualification framework for BIM for energy efficiency. Then, the analysis results and discussion for skills, roles, and the proposed skills RIBA map and skills matrix are given.

6.2 Results and Discussion

The outputs of the research methodology framework were concluded in four main outputs, as follows: a detailed list of project roles, a detailed list of skills, roles and skills RIBA map, and the skills matrix by project roles. These outputs will be discussed in detail in the following subsections.

6.2.1 Role Categories and Role List

The most common role categories in construction projects were identified in Chapter 4 by the expert panel and consultation interview, which contains five main categories, including client/advisor, engineer/designer, facility management team, and blue-collar workers. A systematic analysis to identify the skills and roles involved in the construction sector needed for the BIM for energy efficiency process was conducted in Chapter 5. This data was collected from several sources, including use-cases, interviews, scientific publications and standards reports, and social media (Twitter).

According to these categories, all of the roles involved in a construction project were classified and allocated under the role groups (as listed in Table 6-1). For example, the client and advisors groups can include client, project manager, and BIM manager, and so on. Meanwhile, the design and engineering group covers disciplines such as architectural, structural, mechanical, electrical and plumbing. The contractor group includes the site manager, construction engineer, and so on. The facility management team can include a facility manager and maintenance operator. Finally, construction workers were listed under the blue-collar group. This role classification helps to clearly and simply identify the target groups and the tasks of the project stakeholder to allocate skills required to enhance BIM for energy efficiency according to the RIBA plan.

Table 6-1 List of project roles.

General roles by category				
Client/advisor/ admin	Engineer/designed	Contractor	Facility Management team	Blue-collar
Project manager	Architect designer	A Human-Machine Interface (HMI) operator	Facility manager	Workers in different disciplines (ceramic, glass, painting, etc)
BIM instructor	Construction engineer	Steel Contractor	Operation engineers	building professional
Training instructor	Mechanical engineer	Construction engineer	Maintenance manager	timber frame and joinery
Planner and consultant of energy-efficient buildings	Structure engineer	Contractor manager	Facility administration	Carpenter
Energy expert	HVAC engineer	Site manager	Maintenance engineer	Collars craftsmen

General roles by category				
Client/advisor/ admin	Engineer/designed	Contractor	Facility Management team	Blue-collar
Real estate, developer, and data consultant	BIM modeller	Technical manager	Operation manager	Construction workers
Researcher, academic and private science panellist	Electrical engineer	Contract manager	Water manager	
Training and informing consultation professionals about BIM Regulators	Energy modeller	Production manager	Energy manager	
Finance manager	Energy simulation experts	Construction manager	Information coordinator & information facilitator	
Sales manager	Energy expert	Construction information manager		
QA manager	BIM manager	ICT technicians		
Purchasing manager	Planner and consultant of energy-efficient buildings	Supply chain managers		
Store manager	BIM coordinator	Information Management in Construction		
Team manager	Civil engineer	Technical manager		
Safety manager	Facilitator of sustainable [design]	Supervisors		

General roles by category				
Client/advisor/ admin	Engineer/designed	Contractor	Facility Management team	Blue-collar
Energy auditors	BIM consult	Technicians		
Human resource manager	Built environment experts	Construction health & safety		
Advisory roles	Digital technology designer	Installers		
Government affairs manager	EE expert			
Data Protection Officers	ICT experts			
Energy procurement	Energy analyst			
Finance	Aerospace engineer			
Market acquisition manager	Architecture & construction project manager			
Human resources for Big Data professions	Chemical engineer			
Business unit director	Nuclear energy expert			
Circular economy specialist	Solar energy specialist			
Human resources for big data professions	Alternative energy			
Innovation manager	Automotive engineer			

General roles by category				
Client/advisor/ admin	Engineer/designed	Contractor	Facility Management team	Blue-collar
Sustainability specialist, advocacy & policy design	Data scientist			
Digital marketing	Timber engineering experts			
Energy consultant	Passive house designer			
PMP: Energy Oriented Business Developer	Robotics specialist			
Programme manager	Environmental engineer			
Sales engineer	Nanotechnology engineer			
Communication officer	Cybersecurity specialist			
Information facilitator/coordinator	Advanced service-oriented roles			

6.2.2 Skills Needed for BIM for Energy Efficiency

Many skills have been aggregated and conducted from different sources, as explained in Chapter 5. These skills are required to enhance the stakeholder's (from professionals to blue-collar workers) qualifications in construction sectors for using BIM for energy efficiency during the lifecycle of a project. These skills also provide a wide and comprehensive vision of all stakeholders for the whole construction process to improve the efficiency of resources, energy, materials, construction, cost, and performance, and so on.

Approximately 200 skills were collected, as mentioned in the previous section. The lists of roles and skills were sent to the expert panel and the most common and relevant roles and skills related to BIM for energy efficiency were selected.

The final list includes 59 skills. These skills are related to management and administration (as listed in Table 6-2), such as optimal decision making, integrating information and data management framework and risk management. Other skills were related to software, such as information and communication technology (ICT), using BIM tools and applications (Revit, etc.), and working with energy simulation programs. Some skills were related to engineering and design disciplines, such as achieving BIM and energy efficiency certifications (LEED, BREEM, etc.), adapting to environmental conditions changes, and reviewing design and coordination. Finally, the general skills included teamwork and collaboration, communication (speaking and presentation), and technical writing.

These skills are used to identify the qualifications that are required for stakeholders in construction projects to improve their understanding of BIM for energy efficiency. In the following section, the RIBA plan will be used to map the distribution of these skills in each role category in the whole project lifecycle stages.

Table 6-2 List of skills required for BIM for energy efficiency (Chapter 5).

Label	Skill
S1	Understanding BIM workflow and standards
S2	Recognising graphical engineering information (architecture, structure, etc.)
S3	Understanding energy efficiency principle & sustainable construction
S4	Implementing building regulations and development awareness
S5	Understanding energy policies, market, and tariffs structures
S6	Recognising low carbon materials through the supply chain and the project lifecycle
S7	Creativity and analytical thinking
S8	Observing and separating the information needed
S9	Defining opportunities for energy efficiency improvement
S10	Knowing physical principles related to energy (thermal, electrical, thermodynamics, heat transfer, fluid mechanics, etc.)
S11	Understanding construction supply chain standards
S12	Communication (speaking and presentation)
S13	Technical writing
S14	Developing collaborative ICT platform
S15	Adapting to environmental conditions changes

Label	Skill
S16	Energy performance measuring, monitoring and optimisation
S17	Establishing energy models
S18	Achieving BIM and energy efficiency certifications (LEED, BREEM, etc.)
S19	Reviewing BIM models and performing automatic model checks
S20	Math and estimation
S21	BIM and energy models management
S22	Reviewing design and coordination
S23	Energy auditing
S24	Extracting measures and data from plans
S25	Understanding BIM technologies with respect to sustainability
S26	Energy harvesting and production (renewable energy sources implementations)
S27	Energy-saving technologies, NZEB and low-zero energy building designing
S28	Information and communication technology (ICT)
S29	Using BIM tools and applications (Revit, etc.)
S30	Linking between different software
S31	Using CAD programs
S32	Applying energy simulation programs
S33	3D software usage and coordination
S34	4D software usage and coordination
S35	Using BIM tools for energy efficiency
S36	Computer programming (Python, MatLab, etc.)
S37	Virtual reality operation
S38	Implementing energy efficiency applications in construction and renovation projects (materials, system, etc.)
S39	Installing renewable energy systems (Solar panels, heat pumps, etc.)
S40	Optimal decision making
S41	Integrating information and data management framework
S42	Teamwork and collaboration
S43	Establishing onsite/off-site meetings to comprehend BIM data and energy efficiency features
S44	Handling communications and interactions between project managers (client, designer and constructor)

Label	Skill
S45	Exchanging and extracting model information with designers
S46	Facilitating information exchange to meet stakeholders' business needs in BIM execution
S47	Understanding life cycle assessment (LCA) and life cycle costing (LCC) applications
S48	Leadership
S49	Strategy and policy management
S50	Planning, administration and organisational management
S51	Demonstrating concrete proposals for improvements
S52	Risk management
S53	Manging transmission and distribution processes
S54	Applying knowledge to complete tasks and solve problems
S55	Ensuring construction/renovation projects meet stringent energy efficiency requirements
S56	Energy costs operation
S57	Energy demand operation
S58	QA specifically in relation to energy efficiency
S59	EE implementations marketing

6.2.3 Skills RIBA Map

For each of the role categories for construction projects that was mentioned in Section 6.3.1, different skills were suggested to improve role qualifications for using BIM for energy efficiency. Based on project lifecycle stages conducted from the RIBA plan, the recommended skills were identified from the final list of skills (S1-S59) in the previous section for each stakeholder category according to their roles in each project stage.

The client group is involved in all of the project stages because they are considered to be the main stakeholders in the project and they represent the owner. Meanwhile, engineering disciplines engage in projects from concept design to in-use stages, as well demolition stage if required. The contractor group is considered in only two main stages: construction, and handover and close-out; it also appears in the demolition stage. Generally, facility and management teams are involved in handover and close-out, in-use phases for new buildings, while they are involved from the first stage of renovation and extension projects (as highlighted in Table 6-3). In addition, blue-collar workers group are required in construction, in-use and demolition stages. The stages that do not require roles are left blank.

Table 6-3 Skills for each role category through the RIBA plan of work.

RIBA plan	General roles by category / Skills required (S1-S59)				
	Client/advisor/admin	Engineer/designer	Contractor	Facility management team	Blue-collar
Strategic definition	3, 4, 5, 9, 12, 13, 40, 49, 51			3, 4, 5, 9, 12, 13,23, 40, 49, 51	
Preparation and brief	3, 4, 5, 7, 9, 12, 13,40, 42, 49, 51, 59			3,4 5, 7, 9, 10, 12, 13, 23, 26, 27, 40, 42, 49, 51, 59	
Concept design	2, 3, 4, 7, 9, 12,21, 22, 29, 31, 40, 42, 55	1, 3,4, 7, 8, 9, 12,17, 19, 22, 26, 27, 28, 33 ,30, 31, 33, 35, 40, 42,51, 54, 55		2, 3, 4, 7, 8, 9, 12,19, 21, 22, 26, 27, 29, 31, 35, 40, 42, 45	
Developed design	2, 3, 4, 5, 7, 9, 12,18, 19, 21, 22,24, 29, 31, 35, 40, 42, 45, 46, 47, 55, 59	1,3,4, 7, 8, 9, 12,15,16, 17, 19, 21, 22, 25, 26, 27, 28, 33 ,30, 31,32, 33, 35, 40, 42,51, 54, 55		2, 3, 4, 5, 7, 8, 9, 10, 12,15, 16, 19, 21, 22,23,24, 26, 27, 28, 29, 31, 32, 35, 40, 42, 45, 46, 47, 52, 53, 55, 56, 57, 58	
Technical design	1, 2, 11, 12,18, 19,21, 24, 29, 31, 35, 40, 42, 45, 46, 55	1,2, 6, 7, 10, 12,13, 14, 15,16, 17, 19, 21, 26, 27, 28, 33 ,30, 31,32, 33, 34, 35, 36,37, 40, 42,51, 54, 55		1, 2, 6, 10, 12, 14,15, 16, 19, 21, 23,24, 28, 29, 31, 32, 35, 37, 40, 42, 45, 46, 47, 53, 55, 56, 57, 58	

RIBA plan	General roles by category / Skills required (S1-S59)				
	Client/advisor/admin	Engineer/designer	Contractor	Facility management team	Blue-collar
Construction	1, 2, 11, 12,13, 19, 21, 29, 30, 31, 35, 40, 42, 43, 44, 45, 48, 52, 53, 54, 56, 57, 58	1, 12, 13, 16, 19, 21, 28, 29, 30, 31, 33, 34, 35, 40, 42, 43, 51, 54, 55	1, 2, 5, 6, 8, 10, 11, 12, 16, 19, 20, 21, 24,28, 29, 30, 31, 33, 34, 35, 38, 39, 40, 41, 42, 43, 45, 47, 48, 52, 53, 55, 56, 57, 58	1, 2, 6, 10, 12, 13, 16, 19, 21, 28, 29, 31, 32, 33, 35, 37, 40, 41, 42, 43, 45, 48, 50, 52, 53, 54, 56, 57, 58	3, 8, 12, 20, 24, 38, 39, 42, 43
Handover and close-out	2, 18, 19, 24, 29, 40, 42, 46, 55	19, 29, 55	12, 13, 51	2, 8, 10, 19, 21, 24, 28, 29, 40, 41	
In-use	40, 52	2, 19, 42		1, 2, 3, 5, 9, 10, 12, 15, 16, 19, 21, 23, 28, 29, 30, 32, 37, 35, 39, 40, 41, 42, 43, 45, 47, 48, 50, 52, 53, 54, 56, 57, 58, 59	3, 8, 20, 24, 39
Demolition	4, 40, 42, 49, 51, 52, 54	19, 42, 51, 54	3, 11, 12, 19, 20, 40, 42, 43, 45, 48, 52		3, 8, 12, 20, 24, 38, 39, 42, 43

The skills RIBA map has been developed based on the main five categories of roles. However, each role group has many specific roles that need to be trained well to enhance their skills to use BIM for energy efficiency. Each stage has several skills for a single role category, for example: strategic definition, and preparation and brief stages only include the client group, while the management team are involved in these stages in the renovation of existing buildings. In other stages, skills were distributed on all categories, such as the construction stage. Few stages require many skills for all role groups unless it is an unused group in this stage. For example, the blue-collar workers' group does not work during the handover and close-out stage. Skills in the demolition stage are distributed in all role categories, except for the facility management team group who is not active in this stage of the project. Furthermore, the in-use stage includes all of the stakeholders' groups, but the contractor group is unneeded in this stage (as well as unneeded skills).

From the map it can be seen that three stages (i.e., design development, technical and construction stages) require many skills due to the technical complexity of the task and responsibilities during these stages. Other stages required fewer skills from some role categories; for example, the handover stage does not require many skills from client, engineering, contractor and management groups, while in-use stages only require skills for management team because the project is completed.

Some skills appear in different role categories in the same stage. For instance, S3 was required for engineers, clients, management groups in the concept design stage because of the importance of understanding the fundamental concepts of energy efficiency and sustainable construction for these groups to increase the awareness about energy efficiency in the construction sector.

Some skills are commonly required in all categories and stages. For instance, S3 is one of the most common skills in all categories and during the whole lifecycle of projects, except in a few advanced project stages, which should be learned by the client, engineer, facility management team and workers during the design phases, the construction phases, and the in-use phase. Other skills have been listed in most role groups and lifecycle stages to enhance the qualification of stakeholders for using BIM for energy efficiency, such as S2, S12 and S40. Nevertheless, some of the role categories have few skills that have been considered once in a particular stage. For instance, S59 is only listed in the preparation stage for client and management groups.

Some role categories have frequent skills in different project stages because these skills need to be adopted in different stages for the same or different roles under this category. For example, optimal decision making (S40) has appeared frequently in all stages among the client’s group that includes client, project manager, etc.

Overall, a list of common skills needed for each role category throughout the project lifecycle stages is identified based on the proposed skills RIBA map. To understanding the skills level required for each role in the project, the EQF levels have been adopted (as will be shown in the following section).

6.2.4 Skills Matrix (EQF Levels)

From the skills RIBA map that has been illustrated in Table 6-3, all of the skills needed for BIM for energy efficiency have been conducted for each role group during the lifecycle stages of the projects. Several skills are required for at least one role group and are recommended in one or more stages during the lifecycle of the buildings. The EQF levels have been adopted, as discussed in Section 6.1.2, to identify the levels of the skills that are required to achieve efficient building energy levels using BIM. For each role category, main common roles have been selected by the expert panel. These main roles are important in all projects, and the rest of the roles could follow the main roles with the skills required. Based on this information, the skills matrix for BIM for energy efficiency has been developed for each of the role categories in Table 6-4 to Table 6-8, which describe the skills and their recommended levels for these groups. Each skill has been given a qualification level for all of the main roles; the levels are based on the EQF levels in . The skills matrix has been validated by the expert panel, which is described in Section 6.2, to extract more details and perspectives from the experts in the field. The validation matrix has been explored in Table 6-4 to Table 6-8.

6.2.4.1 Client Skills Matrix

The first part of the skills matrix for the client and client advisors' group—which includes clients (C), project managers (PM), and BIM managers (BM)—is developed in Table 6-4. More than 60% of skills listed in Table 6-2 are required for the group of clients to improve these role skills to use BIM for energy efficiency throughout the whole lifecycle and supply chain of the projects. The skills required for the client are at lower EQF levels when compared to the other roles because they do not need high qualification levels to seek the energy efficiency requirements. However, they still need to increase their awareness and qualifications of some skills, such as understanding energy efficiency principle and sustainable construction, understanding construction supply chain standards, and energy efficiency implementation marketing. A few skills need to be at high levels (2-3) for the clients because they have significant benefits of using BIM for energy efficiency in the projects (e.g., optimal decision making, and teamwork and collaboration). Meanwhile, several skills are not relevant to the clients, so these skills should not be considered by them (e.g., BIM and energy model management, using BIM tools and applications (Revit, etc.), and facilitating information exchange to meet stakeholders' business needs in BIM execution).

The experts consented about the levels of the skills to increase the qualification of stakeholders in the construction sector to use BIM for energy efficiency among the lifecycle stages. For example, S1 has been identified for all three roles with different levels. The majority of experts have mentioned that the client should have level 1 to be able to understand the work process. They also said that the BIM manager needs have advanced knowledge of a field of work involving a critical understanding of principles, therefore level 7 has been selected (as seen in Table 6-4). Furthermore, technical writing skill (S13) is required at a high level (5) for the project and BIM managers because they need to provide concrete reports regarding their work but is needed at a low level (2) for the clients because they need basic cognitive and practical technical writing skills to write their requirements and to give feedback during the work process.

The project managers need a level 5 of achieving BIM and energy efficiency certifications (LEED, BREEM, etc.) (S18), and a basic level for both clients and BIM managers. The client should be level 1 as a basic level to achieve the energy efficiency certifications because the focus on green certifications could lead to an increase in the project budget and risks. This will help in making the right strategic decisions and capturing them in a business case.

S40 is another important skill, so the experts have agreed to qualify all three roles with at least level 3 and above. In this context, the project managers should have level 6 for this skill because it requires them to manage complex and unpredictable work contexts. In addition, the BIM managers should have level 6 to be able to make optimised decisions. The leadership skill (S48) is also needed for both project managers and BIM managers because it helps them to lead the project tasks to successful achievements, so the levels of this skill are 6 and 4, respectively. However, this skill is not relevant to the clients.

Finally, S52 is one of the skills required for all the roles but with different levels. The clients should have basic risk management skills because it may cause more cost or delay of the project. The other roles should have a higher level to deal with risks that may occur during the project phases.

Table 6-4 EQF levels for BIM skills for energy efficiency are recommended for the project client group (i.e., clients, project managers and BIM managers)..

Label	Skills	EQF level		
	Client & Client advisors Client (C), Project manager (PM), BIM manager (BM)	C	PM	BM
S1	Understanding BIM workflow and standards	1	5	7
S2	Recognising engineering graphical information (architecture, structure, etc.)	1	7	6
S3	Understanding energy efficiency principle & sustainable construction	1	6	5
S4	Implementing building regulations and development awareness	1	6	4
S5	Understanding energy policies, market, and tariffs structures	1	6	3
S7	Creativity and analytical thinking	2	5	5
S9	Defining opportunities for energy efficiency improvement	1	5	4
S11	Understanding construction supply chain standards	1	6	2
S12	Communication (speaking and Presentation)	2	6	4
S13	Technical writing	2	5	5
S18	Achieving BIM and energy efficiency certifications (LEED, BREEM, etc)	1	5	3
S19	Reviewing BIM models and preforming automatic model checks	-	5	6
S21	BIM and energy models management	-	4	5
S22	Reviewing design and coordination	1	5	2
S24	Extracting measures and data from plans	-	5	4
S29	Using BIM tools and applications (Revit, etc)	-	4	6
S31	Using CAD programs	-	4	6
S35	Using BIM tools for energy efficiency	-	4	5
S40	Optimal decision making	3	6	6
S42	Teamwork and collaboration	3	6	4

S43	Establishing onsite/off-site meetings to comprehend BIM data and energy efficiency features	-	5	5
S44	Handling communications and interactions between project managers (client, designer and constructor)	1	6	5
S45	Exchanging and extracting model information with designers	-	5	5
S46	Facilitating information exchange to meet stakeholders' business needs in BIM execution	-	5	4
S47	Understanding life cycle assessment (LCA) and life cycle costing (LCC) applications	1	6	2
S48	Leadership	-	6	4
S49	Strategy and policy management	1	6	1
S51	Demonstrating concrete proposals for improvements	-	5	4
S52	Risk management	1	5	4
S53	Manging transmission and distribution processes	-	5	1
S54	Applying knowledge to complete tasks and solve problems	2	5	4
S55	Ensuring construction/renovation projects meet stringent energy efficiency requirements	2	6	4
S56	Energy costs operation	3	5	4
S57	Energy demand operation	1	5	3
S58	QA specifically in relation to energy efficiency	-	5	3
S59	EE implementations marketing	1	5	2

6.2.4.2 Engineering Skills Matrix

The second part of the skills matrix is dedicated to the design and engineering group as identified in Table 6-5, which includes Architectures (ARCH), Structures (SE), and Mechanical, Electrical & Plumbing (MEP)—who need approximately 65% of the whole skill list. The roles of this group need to be highly qualified, so most skills levels are above level 4. For example, S3, which is understanding energy efficiency principles and sustainable construction, has high levels for all roles. However, communication (speaking and presentation) (S12) is required level 2 for the SE and MEP, which is a low level in comparison.

ARCH and SE are required level 4 for implementing building regulations and development awareness skill (S4) because working with the building regulations is important for both roles and where the regulations are specified at the design stage. In addition, the experts have consented that level 5 is required for all the roles for S8 because observing and separating the information is a key skill to use BIM for energy efficiency.

Moreover, ARCH and MEP have level 5 of S18 because the architects need to practice and education in these certifications and to keep up with these important standards. This requires cognitive and practical skills to ensure that the design is in line with LEED and BREEAM. In addition, skill (S27) related to energy-saving technologies, NZEB and low-zero energy building design has the same level of qualification for ARCH and MEP.

Finally, ensuring construction/renovation projects meet stringent energy efficiency requirements (S55) has a significant value for all roles in this section due to the importance of the skill to handle BIM for energy efficiency during the lifecycle stages and supply chain of the project. Consequently, all roles required level 5 in this skill.

Table 6-5 EQF levels for BIM skills for energy efficiency are recommended for the project engineering group (i.e., architecture, structure, and mechanical, electrical and plumbing).

Label	Skills	EQF level		
	Design and engineering Architectural (ARCH), Structural (SE), Mechanical, electrical and plumbing (MEP)	ARCH	SE	MEP
S1	Understanding BIM workflow and standards	6	5	5
S3	Understanding energy efficiency principle & sustainable construction	6	6	5
S4	Implementing building regulations and development awareness	4	4	3
S6	Recognising low carbon materials through the supply chain and the project lifecycle	4	4	4
S7	Creativity and analytical thinking	6	5	4
S8	Observing and separating the information needed	5	5	5
S9	Defining opportunities for energy efficiency improvement	6	3	6
S10	Knowing physical principles related to energy (thermal, electrical, thermodynamics, heat transfer, fluid mechanics, etc.)	5	4	7

S12	Communication (speaking and Presentation)	4	2	2
S13	Technical writing	3	3	3
S14	Developing collaborative ICT platform	1	1	2
S15	Adapting to environmental conditions changes	4	2	4
S16	Energy performance measuring, monitoring and optimisation	4	2	5
S17	Establishing energy models	3	1	6
S18	Achieving BIM and energy efficiency certifications (LEED, BREEM, etc)	5	3	5
S19	Reviewing BIM models and preforming automatic model checks	4	4	4
S21	BIM and energy models management	5	4	4
S22	Reviewing design and coordination	6	4	4
S25	Understanding BIM technologies with respect to sustainability	4	4	5
S26	Energy harvesting and production (renewable energy sources implementations)	3	2	6
S27	Energy-saving technologies, NZEB and low-zero energy building designing	5	3	5
S28	Information and communication technology (ICT)	2	2	4
S29	Using BIM tools and applications (Revit, etc)	6	4	6
S30	Linking between different software	5	2	4
S31	Using CAD programs	6	6	6
S32	Applying energy simulation programs	4	2	6
S33	3D software usage and coordination	5	3	4
S34	4D software usage and coordination	2	3	3
S35	Using BIM tools for energy efficiency	4	3	5
S36	Computer programming (Python, MatLab, etc.)	2	2	4
S37	Virtual reality operation	1	1	3
S40	Optimal decision making	5	5	5
S42	Teamwork and collaboration	4	4	4
S43	Establishing onsite/off-site meetings to comprehend BIM data and energy efficiency features	2	2	2
S51	Demonstrating concrete proposals for improvements	5	4	5
S54	Applying knowledge to complete tasks and solve problems	4	4	4

S55	Ensuring construction/renovation projects meet stringent energy efficiency requirements	5	5	5

6.2.4.3 Contractor Skills Matrix

More than half of the skills in Table 6-2 are included in this part of the skills matrix, which is recommended for the contractor group—including the site manager (SM) and construction engineer (CE)—who are most likely working in the construction stage (as seen in Table 6-6). Due to the late-stage of the project, there are particular skills that need to be adopted and the level of skills depends on the project's requirements.

An advanced level of skills is needed for both SM and CE; for example, S2 required level 4 for SM and level 6 for CE because it is very important to recognise graphical engineering information (e.g., architecture, structure, etc.). In addition, a range of cognitive and practical skills is required to accomplish tasks and solve problems, therefore S10—which is knowing the physical principles related to energy like thermal, electrical, thermodynamics, heat transfer, fluid mechanics, and so on—is required at level 3 for both roles.

S30 and S34 are needed at a basic level for SM because they are basic skills of linking between different software programs, and 4D software usage and coordination. The CE are not required at any level of these skills to accomplish their work, so it is not necessary to have a budget for training the CE any of these skills or hiring highly qualified staff in this field.

Installing renewable energy systems (solar panels, heat pumps, etc.) (S39) is a skill that needs to be considered by the contractor group because they deal with these systems during the construction phase. The level of skill that is required for both of these roles needs to be above the basic level, so the experts have agreed that level 4 is required for this skill. Meanwhile, some skills are necessary for both roles, but may be more important for one role rather than the other. For instance, S40 is required at a high level (5) for the SM to be able to make decisions for the important tasks that need decisions to be made on the site.

The SM also need to have level 4 of energy demand operation skill (S57) to deal efficiently with energy supply during the construction stage, in addition to QA. Specifically, in relation to energy efficiency skill (S58), this needs to be adopted with level 4 for SM. However, both skills could have low levels for the CE.

Table 6-6 EQF levels for BIM skills for energy efficiency are recommended for the project construction group (i.e., Site manager and Construction engineer).

Label	Skills	EQF level	
	Contractor Site manager (SM), Construction engineer (CE)	SM	CE
S1	Understanding BIM workflow and standards	4	3
S2	Recognising graphical engineering information (architecture, structure, etc.)	4	6
S3	Understanding energy efficiency principle & sustainable construction	4	3
S6	Recognising low carbon materials through the supply chain and the project lifecycle	4	3
S8	Observing and separating the information needed	4	5
S10	Knowing physical principles related to energy (thermal, electrical, thermodynamics, heat transfer, fluid mechanics, etc.)	3	3
S11	Understanding construction supply chain standards	4	3
S12	Communication (speaking and Presentation)	5	3
S13	Technical writing	4	3
S16	Energy performance measuring, monitoring and optimisation	3	2
S19	Reviewing BIM models and preforming automatic model checks	4	2
S21	BIM and energy models management	4	2
S24	Extracting measures and data from plans	4	5
S28	Information and communication technology (ICT)	2	1
S29	Using BIM tools and applications (Revit, etc)	4	3
S30	Linking between different software	1	-
S31	Using CAD programs	4	3
S33	3D software usage and coordination	2	-
S34	4D software usage and coordination	1	-
S35	Using BIM tools for energy efficiency	4	2
S38	Implementing energy efficiency applications in construction and renovation projects (materials, system, etc)	2	3
S39	Installing renewable energy systems (Solar panels, heat pump, etc)	4	4
S40	Optimal decision making	5	4
S41	Integrating information and data management framework	4	1
S42	Teamwork and collaboration	4	2

S43	Establishing onsite/off-site meetings to comprehend BIM data and energy efficiency features	4	3
S45	Exchanging and extracting model information with designers	4	1
S47	Understanding life cycle assessment (LCA) and life cycle costing (LCC) applications	2	-
S48	Leadership	3	3
S51	Demonstrating concrete proposals for improvements	4	3
S52	Risk management	5	2
S53	Manging transmission and distribution processes	4	3
S55	Ensuring construction/renovation projects meet stringent energy efficiency requirements	4	3
S56	Energy costs operation	2	1
S57	Energy demand operation	4	2
S58	QA specifically in relation to energy efficiency	4	3

6.2.4.4 Management Skills Matrix

The matrix in this section describes the skill levels for the project management and operation group, including facility manager (FM), and maintenance operator (MO). This matrix includes approximately 85% of the skills from Table 6-2 because these roles are mainly responsible for the in-use stage, the longest of the project. Consequently, they need to adopt more skills with different levels, as shown in Table 6-7. For example, S13 is needed at level 3 for the FM and MO to report about technical issues in the project.

Several skills need to be adopted by training and educating to increase the qualification of stakeholders to deal with BIM for energy efficiency in the buildings. For example, adapting to changes in the environmental conditions, measuring energy performance, monitoring and optimisation, energy auditing and energy-saving technologies, NZEB and low-zero energy building designing (S15, S16, S23, S27) are required for the project management and operation teams. Both FM and MO are needed at level 4 for these skills to help them to accomplish the tasks to understand the behaviour of the energy appliances and to find the opportunities to minimise energy consumption in the building designing, and also improve its capacity during the lifetime of the project.

Some skills need to be considered with above average levels for one role but may not be relevant to the other roles, such as S43 and S50. For example, establishing onsite/off-site meetings to comprehend BIM data and energy efficiency features and planning, administration and organisational management are important for the FM to be able to use BIM for energy efficiency in the buildings. However, these skills are not recommended for the MO teams. In addition, S59 is recommended at level 3 for the FM but is not required for the MO because the FM needs to consider energy efficiency implementations marketing.

Table 6-7 EQF levels for BIM skills for energy efficiency are recommended for the project management group (i.e., Facility manager and Maintenance operator).

Label	Skills	EQF level	
	Management and operation Facility manager (FM), Maintenance operator (MO)	FM	MO
S1	Understanding BIM workflow and standards	4	3
S2	Recognising graphical engineering information (architecture, structure, etc.)	4	3
S3	Understanding energy efficiency principle & sustainable construction	3	2
S4	Implementing building regulations and development awareness	3	-
S5	Understanding energy policies, market, and tariffs structures	5	3
S6	Recognising low carbon materials through the supply chain and the project lifecycle	3	1
S7	Creativity and analytical thinking	3	1
S8	Observing and separating the information needed	4	3
S9	Defining opportunities for energy efficiency improvement	4	1
S10	Knowing physical principles related to energy (thermal, electrical, thermodynamics, heat transfer, fluid mechanics, etc.)	4	2
S12	Communication (speaking and Presentation)	3	2
S13	Technical writing	3	3
S14	Developing collaborative ICT platform	4	3
S15	Adapting to environmental conditions changes	4	4
S16	Energy performance measuring, monitoring and optimisation	4	4
S19	Reviewing BIM models and preforming automatic model checks	5	3
S21	BIM and energy models management	5	2
S22	Reviewing design and coordination	3	-
S23	Energy auditing	4	4

S24	Extracting measures and data from plans	4	3
S26	Energy harvesting and production (renewable energy sources implementations)	4	3
S27	Energy-saving technologies, NZEB and low-zero energy building designing	4	4
S28	Information and communication technology (ICT)	4	2
S29	Using BIM tools and applications (Revit, etc)	3	1
S30	Linking between different software	3	-
S31	Using CAD programs	2	2
S32	Applying energy simulation programs	4	1
S33	3D software usage and coordination	1	-
S35	Using BIM tools for energy efficiency	3	1
S37	Virtual reality operation	2	2
S39	Installing renewable energy systems (Solar panels, heat pump, etc)	3	4
S40	Optimal decision making	4	1
S41	Integrating information and data management framework	4	1
S42	Teamwork and collaboration	3	2
S43	Establishing onsite/off-site meetings to comprehend BIM data and energy efficiency features	4	-
S45	Exchanging and extracting model information with designers	3	1
S46	Facilitating information exchange to meet stakeholders' business needs in BIM execution	3	-
S47	Understanding life cycle assessment (LCA) and life cycle costing (LCC) applications	4	2
S48	Leadership	3	-
S49	Strategy and policy management	3	1
S50	Planning, administration and organisational management	4	-
S51	Demonstrating concrete proposals for improvements	3	1
S52	Risk management	4	1
S53	Manging transmission and distribution processes	4	1
S54	Applying knowledge to complete tasks and solve problems	3	1
S55	Ensuring construction/renovation projects meet stringent energy efficiency requirements	3	1
S56	Energy costs operation	5	3

S57	Energy demand operation	5	3
S58	QA specifically in relation to energy efficiency	5	3
S59	EE implementations marketing	3	-

6.2.4.5 Blue-Collar Skills Matrix

The last part of the skills matrix is for the project blue-collar workers group, such as construction workers (CW). The blue-collar workers need to develop some skills because it is one of the main groups in the project. To increase the energy efficiency in building, more than 15% of skills in Table 6-2 need to be adopted at various levels. Table 6-8 shows that basic levels are required for all skills because the CW need basic skills required to carry out simple tasks. For example, understanding energy efficiency principles and sustainable construction (S3), extracting measures and data from plans (S24), and implementing energy efficiency applications in construction and renovation projects (materials, system, etc.) (S38).

A few skills need to be adopted at a higher level (level 2) to enhance the qualification of the CW to save energy in the building. For instance, level 2 is required for S12 for the CW to improve their communication skills, which will increase the efficiency of the work. In addition, the CW need to have level 2 of S39 due to the importance of this skill in both new and renovation projects. However, S8 is considered to be the highest skill needed for CW required with a medium EQF level (3) because they should have a good level of ability to observe and separate the information that they need.

Table 6-8 EQF levels for BIM skills for energy efficiency recommended for the blue-collar workers' group (i.e., construction workers).

Label	Skills	EQF level
	Blue-collar Construction worker (CW)	CW
S3	Understanding energy efficiency principle & sustainable construction	1
S8	Observing and separating the information needed	3
S12	Communication (speaking and Presentation)	2
S20	Math and estimation	1
S24	Extracting measures and data from plans	1
S38	Implementing energy efficiency applications in construction and renovation projects (materials, system, etc)	1

S39	Installing renewable energy systems (Solar panels, heat pump, etc)	2
S42	Teamwork and collaboration	2
S43	Establishing onsite/off-site meetings to comprehend BIM data and energy efficiency features	1

The validation skills matrix for each of the stakeholder categories has been provided in Table 6-4 to Table 6-8 which includes the different levels of qualification for each skill for all the roles in the construction sector during the lifecycle stages. The matrices will help to address the shortage of qualifications for all roles groups throughout the project phases. Good training and education programs to learn or enhance these skills will help the stakeholders to handle the use of BIM for energy efficiency during the whole lifecycle and supply chain of the project.

Finally, the standardized qualification framework included the skills matrix and the skills RIBA map has been sent to the expert panel to validate all of the skills, roles, and EQF levels during the RIBA stages. First, to ensure that the scope of the matrix was applicable to EU countries and to a wider context. The experts gave positive feedback, including:

1. The uniqueness of the proposed skills matrix is that it covers the five most common groups of roles to improve their skills to use BIM for energy efficiency, which was mentioned by the majority of experts.
2. More than half of experts highly recommended adopting this skills matrix in their companies and organisations because it has given a more comprehensive emphasis to improve the construction industry to use BIM for energy efficiency.
3. Having the EQF levels of each skill for each role will enable companies to identify the level of training that their staff require.

Although several experts agree with applying the skills matrix, they also stated that:

4. This skills matrix is applicable but it needs to be translated into education courses and training programs to test them and see the outcomes.
5. The skills matrix is applicable widely but it should be continuously updated with upcoming skills in the construction sectors.
6. The case study of Saudi Arabia proves that the skills matrix is scalable for different contexts; however, it needs to be adopted and tested on further case studies in different countries to give more comprehensive results.

To ensure the completeness and relevance of skills for the whole lifecycle of projects, many experts said that:

7. The skills RIBA map has identified all of the skills that are required in all stages for each role group to use BIM for energy efficiency. This will increase the QA, specifically in relation to energy efficiency.
8. Based on the skills matrix and skills RIBA map, construction companies are able to hire or train workers who are needed with specific qualification levels at any stage of the project to avoid wasting money and time.

Some experts noted highlights to give proposed EQF levels for all skills and include all of the roles:

9. The skills matrix has used the EQF levels to weigh the skills required for each role and this leads to the design of appropriate training programmes or university courses.
10. The skills matrix has included blue-collar workers, who play a key mission to achieve the goals of using BIM for energy efficiency.

Nevertheless, the skills matrix could face issues in addressing and challenging policy implementation, as some experts said:

11. The skills matrix has 59 skills that need to be adopted for all of the roles in the project lifecycle with different levels of qualification to use BIM for energy efficiency, which requires more money and time to consider the skills. However, increasing the awareness about using BIM for energy efficiency has a significant impact on budget and the environment in the long term.
12. The implementation of the skills matrix may face some challenges in different countries outside Europe due to the fact that this matrix data depends on the construction sectors in the EU countries, but at the same time using this skills matrix will help to address other countries requirements.
13. Governments play a key role in adopting this kind of matrix by establishing the regulations and standards that encourage or enforce the construction industry to use BIM for energy efficiency. However, in the developing countries, the regulations are not good enough to increase the use of BIM for energy efficiency, but the

environmental challenges might lead them to adopt such regulations in building projects.

These discussions illustrate the experts' level of agreement of the skills matrix and the skills RIBA map applicability in the EU countries. Moreover, many experts accepted that the skills matrix is applicable to other developing countries. For instance, many of the experts highly recommended adopting this qualification framework in their own companies and organisations. However, others mentioned that the standardized qualification framework needs to be translated into education courses and training programs to test them and see the outcomes. In addition, many experts noted that the skills matrix, which has EQF levels of each skill for each role, will enable companies to identify the level of training that is required for their staff. Similarly, many experts proposed that the skills matrix has used the EQF levels to weigh the skills required for each role and that this can lead to the design of appropriate training programs or university courses. However, it is also important to note that the standardized qualification framework could face several challenges in implementation. For example, one expert said that the implementation of the qualification framework might face some challenges in countries outside the EU because this framework data depends on the construction sectors in the EU countries, but at the same time using this standardized qualification framework will help many to address other countries requirements. Nevertheless, the experts confirmed that the standardized qualification framework had been validated for enhanced construction stakeholders to use BIM for energy efficiency throughout the lifecycle stages.

6.3 BIM Skills for Gaps and Requirements

In In this section, based on the proposed standardised qualification framework and according to the methodology framework in Section 6.2, a consolidated list of skills has been adopted to address the gaps to enhance workforce skills for using BIM for energy efficiency, as concluded from Chapter 4. The proposed framework has been sent to the expert panel for validation. The experts made some specific inputs for BIM training for industrial roles (e.g., designers, blue-collar workers and contractors). The researcher has assigned the relative skills for the validation framework to fill the gaps to enhance the stakeholders' qualifications to use BIM for energy efficiency in the construction sectors. Many skills have been distributed, as listed in Table 6-9.

Table 6-9 Skills required to fill the gaps for BIM for energy efficiency.

No.	Parameters	Roles Categories	Gaps	The Skills Requirements
1	Skills required to handle BIM for energy efficiency	Designer	Formulate the model with energy efficiency simulation programs.	S16, S17, S19, S21, S30, S32, S36
			Maintain data of different varieties and solutions.	S28, S37, S40, S43, S51, S54
			Good communication between designers, clients, and suppliers.	S12, S13, S22, S28, S37, S40, S42, S43, S51
		Blue-collar worker	Simulate use-case scenarios for the design.	S3, S24, S38, S39
			Communication with clients and contractors to ensure best practice.	S12, S42, S43
		Contractors	Knowledge of how to use BIM and training ability to implement BIM for energy efficiency	S1, S3, S11, S16, S21, S29, S30, S35, S38, S55
			Collaborate with the designer to manage the information from the model.	S8, S12, S13, S19, S28, S30, S40, S41, S42, S45, S48, S51, S53, S55
2	General skills for all roles that are lacking for the use of BIM for energy efficiency		Understanding the link between different software tools	S1, S8, S16, S21, S28, S29, S30, S31, S33, S35, S41, S42, S45, S46, S53, S58
			Finding suitable solutions to promote BIM in energy efficiency	S3, S4, S5, S7, S9, S11, S18, S40, S44, S46, S47, S49, S54, S55, S56, S57, S59
			Understanding the impacts of using BIM for energy efficiency on projects	S3, S4, S5, S6, S7, S9, S10, S26, S40, S47, S49, S51, S56, S57, S59

No.	Parameters	Roles Categories	Gaps	The Skills Requirements
3	Specific ways of enhancing the stakeholders' skills for the use of BIM for energy efficiency	Blue-collar workers	Training and field meetings to explain the specific plans.	S3, S20, S24, S43
		Designers/ Engineers	Energy, BIM, data management training and education	S1, S3, S10, S16, S18, S21, S25, S26, S27, S36, S43, S54
			Understand the essence of simulation and how to apply the results in practice.	S1, S2, S8, S15, S18, S22, S25, S30, S51, S55
4	BIM training for energy efficiency by organisation	Designers	Teaching software programs, BIM for energy efficiency.	S17, S18, S21, S25, S27, S28, S30, S31, S32, S33, S34, S36
			Continuous learning: issue with standardisation, skills of BIM coordinators and BIM managers should be defined.	S1, S3, S4, S7, S18, S19, S21, S29, S35, S43, S55
		Contractors	Education and training should be adapted based on specific requirements.	S3, S6, S8, S10, S11, S16, S28, S29, S30, S35, S38, S39, S47, S52, S53, S56, S57, S58
		Facility manageme nt team	This group needs the ability to extract and update information from BIM models.	S1, S2, S8, S12, S14, S19, S21, S22, S24, S28, S29, S37, S40, S41, S45, S46, S53
5	Common barriers to the use of BIM for energy efficiency	-	Lack of understanding of the use of BIM	S1, S18, S19, S21, S25, S29, S31, S33, S34, S35
			Limitations in the use of different software tools	S17, S19, S20, S21, S27, S28, S29, S30,

No.	Parameters	Roles Categories	Gaps	The Skills Requirements
				S31, S32, S33, S34, S35, S36, S37

Overall, the need for awareness-raising across all stakeholders in the building lifecycle to establish the basis of initial training and more comprehensive education programmes around BIM for energy efficiency is required to fulfil the required skills in the previous table. This analysis has also revealed some key strategies to tackle performance gaps 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 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), and unable to use models (extract data from and enter data into).

The standardized qualification framework has been adopted to address all of the requirements. For example, formulating the model with energy efficiency simulation programs has been identified as a requirement for the designer role, which has been fitted by skills such as establishing energy models (S17) and applying energy simulation programs (32). In addition, several skills have been adopted to fill the requirement of communication between designers, clients, and suppliers, such as communication (speaking and presentation) (S12), technical writing (S13), and teamwork and collaboration (S42).

Several requirements and gaps have been identified as general requirements or for specific roles group. Based on the skills matrix, the EQF levels of each skill are defined for each role in Table 6-4 to Table 6-8. The companies and organisations are able to identify the skills needed and their qualification levels to enhance the ability of the company's workers (from professionals to blue-collar workers) to use BIM for energy efficiency in the construction industries. Furthermore, to save money and time, the owners are able to hire and train workers at specific stages with the qualification levels that are required during the projects according to the skills RIBA map proposed in Table 6-3.

6.4 Conclusion

In this chapter, an in-depth analysis of BIM-related roles and skills for construction professionals was presented to inform current and future training strategies with a view to delivering energy efficiency. Data science techniques were used to identify the level of skills that are required to handle BIM for energy efficiency for various stakeholders involved in the construction projects during their lifecycle. This will enable these skills to be adopted by training programs to address the increased demand for stakeholders requiring BIM skills.

Chapter 5 classified 106 of the most common roles involved in construction projects distributed into five main categories: client/advisor, engineer/designer, facility management team, and blue-collar workers. This helps to clearly and simply identify the target groups and tasks of the project stakeholder to allocate the skills that are required to enhance BIM for energy efficiency. Based on several sources (e.g., interviews, case studies, scientific publications, standard reports, and social media), a list of 59 skills has been developed in this chapter (e.g., skills related to management and administration, software skills, engineering and design disciplines, and other general skills). These skills are then used to identify the qualifications required for stakeholders in construction projects to improve understanding of BIM for energy efficiency.

According to skills and roles lists, a skills RIBA map was proposed to define the skills for each of the role categories to handle BIM for energy efficiency through nine stages of the project lifecycle based on the RIBA 2013 work of plan (i.e., strategic definition, preparation and brief, concept design, developed design, technical design, construction, handover and close-out, in-use, and demolition stages). In addition, a skills matrix for the five main role categories was developed based on the skills RIBA map and EQF levels (from 1 - 8) that can be used as a standardized qualification framework for BIM training and education. The developed standardized qualification framework has been validated through the expert panel. The matrices will help to enhance the shortage of qualifications for all of the role groups through the project phases. Good training and education programs to learn or enhance these skills will help the stakeholders to handle the use of BIM for energy efficiency during the whole lifecycle and supply chain of their projects.

From the proposed skills RIBA map and skills matrix, we can observe that some skills are needed in certain project stage for a roles group. These skills levels vary according to each role in the group, which means that this person may not be involved in that particular project stage. Otherwise, some skills may not be needed in earlier stages of the project. This offers an opportunity and gives time for training to prepare the role (person) to be eligible to handle the project responsibilities in the advanced stages of the project (e.g., hiring, training and termination).

Finally, the standardized qualification framework has been used to address the requirements and gaps in BIM for energy efficiency in the EU countries through assigning and a consolidating list of skills from the skills matrix to enhance the stakeholders' qualifications to use BIM for energy efficiency in the construction sector. The analysis has revealed some key strategies to tackle the performance gaps, 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, which highlights the need for establishing the fundamental training and education programmes around BIM for energy efficiency. The qualification framework will be used in the next chapter to analyse the requirements in the case study, Saudi Arabia, and to develop a framework to address the gaps in the construction sector related to BIM for energy efficiency.

Skills Requirements in the Context of a Developing Country

This chapter aims to broaden the BIM training agenda to support Saudi Arabia’s building energy efficiency agenda. This requires a broad awareness and expertise in BIM practice across different asset types and different roles in the industry. This chapter will endeavour to enhance the skills, qualifications and capabilities of construction practitioners (from highly-specialised professionals to blue-collar workers). This will increase the market penetration and adoption of key technological development in BIM, given the timeliness of the need for training in combined green and functional performance engineering. The interviews focus on understanding and utilising BIM as a toolset to optimise energy in the construction industry across the lifecycle of a building. Consequently, the researcher focusses on demonstrating the benefits of BIM in maximising energy efficiency and sustainable outcomes.

7.1 Introduction

Just two non-renewable or clean primary energy sources (oil and natural gas) are used to meet energy needs in Saudi Arabia. It is therefore essential to develop and implement policies to minimise Saudi Arabia's primary energy use, including in Saudi Arabia’s buildings [237]. Furthermore, BIM is being introduced in Saudi Arabia but is still considered to be in its infancy. Few Saudi project owners have begun to recognise the advantages associated with BIM implementation, such as the potential to produce several design alternatives, the ability to perform multiple experiments on a BIM platform, and the ability to allow for early identification of design defects to avoid expensive rework. The combined environmental, energy and BIM development needs in Saudi Arabia point to its potential for a BIM for energy efficiency qualification framework application.

According to the origin and filed of expertise, the researcher has implemented the developed framework on Saudi Arabia as a case study in order to broaden the BIM training agenda to support Saudi Arabia’s building energy efficiency agenda besides, provides opportunities for future research that benefits his country.

This chapter will explore the gaps and requirements for the implementation of BIM for energy efficiency, together with associated BIM training, by analysing and identifying the relevant skills and competencies. Consultations and interviews were used to collect the requirements to understand existing BIM practices, and to identify the current limitations and shortcomings in BIM training in Saudi Arabia. This chapter makes the following contributions:

- It conducts a consultation process involving key BIM experts and training organisations within the Saudi Arabia construction sector around BIM for energy efficiency;
- It elaborates a comprehensive set of requirements to inform future BIM training to upskill the next generation of construction professionals who will implement energy efficiency in the construction sector.

7.2 Methodology

In this section, the researcher presents quantitative and qualitative analyses to identify the gaps and skills required to improve BIM practices for energy efficiency. The methodology adopted in this study utilises computing data analysis techniques, including interviews and consultations to determine the requirements and specifications through utilising the proposed standardized qualification framework from Chapter 6 to deliver adapted BIM training and education requirements in the construction industry.

7.3 Analysis Results

The researcher conducted interviews with 16 BIM industry experts from Saudi Arabia to obtain a more global understanding of the maturity associated with the application of BIM to energy efficiency, and to determine any gaps and requirements in this field. Table 3-3 summarises the profiles of the participants in the study. The interview was designed using a questionnaire with three sections, which are: "experience of BIM for energy efficiency", "BIM for energy efficiency skills", and "using BIM for energy efficiency" in the construction projects, as listed in Appendix E. Table 7-1 shows the participants’ BIM expertise, which includes BIM applications, architecture service, project management and electrical services in the field. In addition, the interviewees had different levels of expertise in applied BIM for design and engineering project delivery, providing training on BIM software, and helping engineers in implementing BIM in projects.

7.3.1 Experience in BIM and Energy

The primary objective of the interviews was to target experts with experience in a wide range of BIM activities, so the aggregated feedback was expected to be comprehensive and inspired by industrial expertise. Table 7-1 presents the experts' historical experience. Two-thirds of the experts have experience using BIM in a wide range of areas, and they also have extensive experience with BIM software.

Table 7-1 The number of experts’ responses for several codes under the theme “Experience of BIM and Energy”.

Theme	Coding	Perspectives of the experts	Number of responses (1:16)
1-Experience of BIM and Energy	1-Experience field	Architecture	■■■■■■■□□□□□□□□□
		BIM applications	■■■□□□□□□□□□□□□□
		Project management	■■□□□□□□□□□□□□□□
		Electrical services	■■■□□□□□□□□□□□□□
		BIM for infrastructure	■□□□□□□□□□□□□□□□
		Civil	■■□□□□□□□□□□□□□□
		Planning and design	■□□□□□□□□□□□□□□□
	2-Experience in using BIM	Using BIM in projects for several years	■■■■■■□□□□□□□□□□
		Provide training on BIM software	■■■■□□□□□□□□□□□□
		Helps engineers in implementing BIM in projects	■■■□□□□□□□□□□□□□
		Autodesk Revit structure certified	■■■□□□□□□□□□□□□□
	3-Aspects of BIM are (were) used in the activity and related to energy	Used BIM for energy efficiency in the design stage	■■■■■■□□□□□□□□□□
		BIM for energy efficiency in education courses	■□□□□□□□□□□□□□□□
		Used BIM to meet LEED certification requirements	■■□□□□□□□□□□□□□□
		System control	■□□□□□□□□□□□□□□□
		HVAC (design and operation)	■■□□□□□□□□□□□□□□
		Lighting, curtains	■■□□□□□□□□□□□□□□
		To choose the appropriate materials to achieve the energy efficiency in the buildings	■■□□□□□□□□□□□□□□

4-The role disciplines in construction projects	Architecture	■	■	■	■	■	■										
	Structure	■	■														
	Electrical	■	■	■													
	Civil	■	■														
	Mechanical	■	■														
	Plumbing	■	■														
	Researching in universities	■															
	BIM	■															
5-Roles	Project manager	■	■	■	■												
	Architect	■	■	■	■	■	■										
	BIM consultant	■	■	■	■												
	Site manager	■															
	Construction consultant	■															

7.3.2 BIM for Energy Efficiency Skills

The researcher asked the experts to specify the skills required to improve BIM management, with an emphasis on energy efficiency. The skill sets that were identified by the experts as being necessary for handling BIM data for energy efficiency are associated with the roles of the designers, contractors, and blue-collar workers. Several skills for designers are highlighted by experts, which are presented in Table 7-2, as follows: (1) knowledge of how to use BIM and energy efficiency software and its updates, (2) knowledge of the principle of energy efficiency and sustainability, (3) BIM and energy certificates, (4) recognise BIM guidelines, and (5) good communication between designers, clients and suppliers. A high percentage of feedback is identified as an essential skill for managing BIM. For energy efficiency, essential skills include the ability to use BIM programs and other energy efficiency software, as well as a knowledge of the principles of energy efficiency and sustainability.

The contractor skills in BIM for energy efficiency that were identified are: (1) knowledge of how to use BIM for energy efficiency, (2) skills to select the materials that led to energy efficiency, (3) skills to separate the information needed and (4) follow energy efficiency standards. These 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 to improve BIM competencies in the field of energy efficiency.

Some of the primary tasks in industrial construction activities are carried out by blue-collar workers and are presented in Table 7-2. The identified skills are: (1) knowledge of how to read the plans and separate the information needed, (2) knowledge of the principle of BIM and energy efficiency, and (3) accurate implementation of BIM plans and construction specifications. To enhance the stakeholders' skills for using BIM for energy efficiency in projects, the experts highlighted several methods to improve these skills according to: 1) blue-collar workers and technicians, 2) designers/engineers, 3) contractors, and 4) facility management teams. For blue-collar workers, the experts mentioned that hosting training and field meetings to explain the specific plans is an efficient way of improving the BIM skillsets. The experts also reported the "know-how" of how to order proper models and find best practice modelling guidance as essential skills. One of the experts highlighted that blue-collar worker should not be held responsible for this sort of work, and they added 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, increasing the awareness of BIM for energy efficiency, and adopting a BIM energy workflow for early decision making (see Table 7-2).

Table 7-2 The number of experts' responses for several codes under the theme "BIM for energy efficiency Skills".

Theme	Coding	Sub-coding	Perspectives of experts	Number of responses (1:16)
2-BIM for energy efficiency Skills	6-Skills required to handle BIM for energy efficiency	Designers	Knowledge of how to use BIM and energy efficiency software and its updates	8
			Knowledge about the principles of energy efficiency and sustainability	7
			Get BIM and energy certificates	2
			Recognise BIM guidelines	2

		Good communication between designers, client and suppliers	■■□□□□□□□□□□□□□□
	Contractors	Knowledge of how to use BIM for energy efficiency	■■■□□□□□□□□□□□□□
		Skills to select the materials that led to energy efficiency	■■□□□□□□□□□□□□□□
		Skills to separate the information needed	■■□□□□□□□□□□□□□□
		Follow energy efficiency standards	■■□□□□□□□□□□□□□□
	Blue-collar workers	Knowledge of reading the plans and separate the information needed	■■□□□□□□□□□□□□□□
		Knowledge of principle of BIM and energy efficiency	■■□□□□□□□□□□□□□□
		Accurate implementation of BIM plans and construction specs	■□□□□□□□□□□□□□□□
7-Enhance the stakeholder's skills to use BIM for energy efficiency	Designers and engineers	Energy, BIM and data management training and education	■■■■■■■■□□□□□□□□
		Awareness of BIM for energy efficiency	■■□□□□□□□□□□□□□□
		How to follow an execution plan	■□□□□□□□□□□□□□□□
		Adopt a BIM energy workflow for early decision making	■□□□□□□□□□□□□□□□
	Contractors	Educating, training and understand BIM for energy efficiency tools	■■■■■■■■□□□□□□□□
		Provide guidance for the project to support building performance	■■■■□□□□□□□□□□□□
		Ability to maintain and update information from the BIM model	■□□□□□□□□□□□□□□□

		Blue-collar workers: workers, technicians	Training and field meetings to explain the specific plans	■■■■■■
			Best practice modelling guidance	■
			Know-how of how to order proper models	■
		Facility management teams	BIM for energy efficiency training	■■■■■
			Ability to extract and update information from the BIM model	■■
			A guiding handbook	■■
			Know the benefits of using BIM for energy efficiency	■■■■
			Improve the capabilities in maintenance management	■
			Not important	■
	8-BIM for energy efficiency Use-	Yes	Number of use-cases that you have been used BIM for energy efficiency	■■■■■■■
		No	Never used	■■■■■■■■■

Based on the experts' consultations in Table 7-2, there are several ways to enhance the contractors' skills. In particular, half of the experts listed education and training as requirements to understanding BIM and improve its use. Meanwhile, other experts have highlighted providing BIM for energy efficiency guidance for the project to support building performance, and the ability to maintain and update information from the BIM model. Furthermore, the facility management teams require different ways to develop their skills for the use of BIM for energy efficiency. Based on the experts' recommendations, BIM for energy efficiency training is considered by many to be a solution. Furthermore, other experts said that increasing the awareness of the benefits of using BIM for energy efficiency is an essential condition.

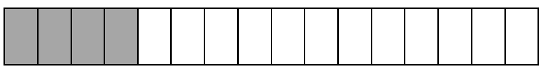
7.3.3 Using BIM for Energy Efficiency in Projects

According to the experts, there are many benefits to using BIM for energy efficiency during the lifecycle of a project. Table 7-3 lists several advantages that can be realised during the design phase, as follows: understanding the energy consumption of the building from the early stages of the design and helping to save the energy; using BIM for energy efficiency may offer alternatives and solutions to reduce energy consumption and increase energy efficiency of buildings during the lifecycle of projects; O&M phases offer significant benefits; and it is easy to assess the energy efficiency in buildings.

Based on the questionnaire, there are many benefits to using BIM for energy efficiency. However, there are several barriers to using BIM for energy efficiency in real industrial applications. Table 7-3 illustrates that a lack of understanding of the purpose and potential of BIM can be a significant obstacle (i.e., lack of experience). In addition, the training programmes need additional cost, which many projects may not be able to afford.

Some barriers are listed many times, such as the high cost of these programmes, different and complex software, and a lack of sufficient awareness of BIM for energy efficiency. Other experts mentioned barriers such as lack of fundamental skills in BIM for energy efficiency and BIM is a new technology in Saudi Arabia. Consequently, many construction stakeholders do not know the benefits of using BIM for energy efficiency. Incentives on the adoption of BIM for energy efficiency are determined to be essential. These recommendations will feed into the implementation phase of the study and will be considered when developing training programmes for using BIM for energy efficiency.

Table 7-3 The number of experts' responses for several codes under the theme "Using BIM for energy efficiency".

Theme	Coding	Sub-coding	Perspectives of experts	Number of responses (1:16)
3-Using BIM for	9-The benefits of using BIM for	-	Understand the energy consumption of the building from the early stages of design and help to save energy	

		Using BIM for energy efficiency may offer alternatives and solutions to reduce energy consumption and increase energy efficiency of buildings during the lifecycle of a project	■■□□□□□□□□□□□□□□
		Significant benefits of O&M phases and accessibility to assessment of energy efficiency in buildings	■■□□□□□□□□□□□□□□
10-The barriers to the use of BIM for energy efficiency	'	Lack of understanding the purpose and potential of BIM (shortage of experience)	■■■■■□□□□□□□□□□□
		Additional cost for training	■■■□□□□□□□□□□□□□
		Different software tools	■■■□□□□□□□□□□□□□
		Insufficient awareness	■■□□□□□□□□□□□□□□
		The cost of software is very high	■■□□□□□□□□□□□□□□
		Owners do not allow us to pay for that	■■□□□□□□□□□□□□□□
		BIM is a new technology in Saudi Arabia, so many people do not know the benefits of using BIM for energy efficiency	■■□□□□□□□□□□□□□□
		Lack of fundamental skills in BIM for energy efficiency	■■□□□□□□□□□□□□□□
		Government does not require BIM for energy efficiency in its projects, so there are no commitments from the contractors	■■□□□□□□□□□□□□□□
		Lack of actual case studies where BIM and energy are successfully implemented	■□□□□□□□□□□□□□□□
		Lack of standards and enforcement	■□□□□□□□□□□□□□□□

11-Recommendations to enhance using BIM for energy efficiency	-	Good training and education of BIM for energy efficiency	4
		Increase the stakeholders' awareness around BIM for energy efficiency	3
		Update the standards	2
		Companies should transfer to BIM technology and incentive their workers to adopt BIM for energy efficiency	2
12- The organisations support a train of the use of BIM for energy efficiency	Yes (training offered)	Regular software courses	4
		Introduction to BIM	2
		Site visits to new projects and companies that adopt BIM for energy efficiency	1
	No, why?	Planning to train in future	3
		Must learn by yourself and pay from your own pocket	1
		The government does not require these technologies, so the organisations are not training their staff	3
		A small organisation that cannot offer any kind of training	1

As shown in Table 7-3, some of the organisations have no training programmes for their staff and, as mentioned in the interviews, they are planning to train in the future. Other organisations said that the stakeholders must learn by themselves and pay from their own pocket. In addition, the government does not require these technologies, so many organisations do not train their staff. Although some organisations do not support the training, considering it to be unimportant, other institutions provide introductory courses to BIM and the software that is used.

7.4 BIM Training Requirements and Gaps

In this chapter, the researcher has critically reviewed and determined the requirements for developing a BIM training scheme to address current industry collaboration problems in projects. This solution aims to facilitate and guide the collaboration processes of construction teams, while taking into account the requirements of construction practitioners. Furthermore, 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 chapter underlines the importance of BIM training as the foundation for future research and development in this area.

Table 7-4 presents a summary of the study 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 placed on BIM software tools and the need to deliver specialised training programmes that can help the actors to understand and utilise these tools. At the organisational level, the experts have presented several strategies that can be adopted to improve the BIM skills and practices of the staff.

Table 7-4 The requirements for developing a BIM training scheme to address current industry collaboration problems on projects.

No.	Parameters	Requirements for:
1	Skills required to handle BIM and energy efficiency (see Table 7-2)	Designer: 1- Knowledge of how to use BIM and energy efficiency software and its updates, 2- Knowledge about the principle of energy efficiency and sustainability Blue-collar worker: 1- Knowledge of reading the plans and separate the information needed, 2- Increase the awareness of the principle of BIM and energy efficiency Contractors: 1- Skills to select the materials that lead to energy efficiency., 2- Knowledge of principles of BIM and energy efficiency
3	Specific ways of enhancing the stakeholders' skills for the use of	Designers/Engineers:1- Energy, BIM and data management training and education. 2-

	BIM for energy efficiency (see Table 7-2)	Increase the awareness of BIM for energy efficiency. Contractors: 1- Education, training and understanding of BIM for energy efficiency tools, 2- Ability to maintain and update information from the BIM model Blue-collar workers: 1- Training and field meetings are needed to explain the specific plans; 2- Best practice modelling guidance. Facility management team: 1- BIM for energy efficiency training, 2- Ability to extract and update information from BIM model
4	BIM training for energy efficiency by the organisation (see Table 7-3)	Introductory courses for the software Introduction to BIM
5	Common barriers to the use of BIM for energy efficiency (see Table 7-3)	Lack of understanding the purpose and potential of BIM (shortage of experience) Additional cost for training and adoption Different software tools Not enough awareness The government does not require BIM for energy efficiency in its projects, so there are no commitments from the contractors BIM is a new technology in Saudi Arabia, so many people do not know the benefits of using BIM for energy efficiency Lack of fundamental skills in BIM for energy efficiency
6	Recommendations to enhance the use of BIM for energy efficiency (see Table 7-3)	Good training and education of BIM for energy efficiency. Increase the stakeholders' awareness around BIM for energy efficiency. Companies should transfer to BIM technology and incentivise their workers to adopt BIM for energy efficiency. The government should update the standards and enforce the contractor companies to adopt them.

7.5 BIM Skills for Energy Efficiency in Saudi Arabia

According to the origin and field of expertise, the researcher has implemented the developed framework on Saudi Arabia as a case study in order to broaden the BIM training agenda to support Saudi Arabia's building energy efficiency agenda and also to provide opportunities for future research.

To aggregate wide details about using BIM for energy efficiency in projects in developing countries rather than the EU context, more investigation has been done in the developing countries and especially in Saudi Arabis, which was the case study. In the previous section, many gaps and requirements had been identified to understand the lack of using BIM for energy efficiency in the industry, which directly related to the construction stakeholders in Saudi Arabia. A summary of the most common requirements and gaps is given in Table 7-5, which lists the general requirements and gaps for all roles group, many of which have been identified for specific groups.

Regarding the methodology framework in Chapter 6, the requirements and gaps of the case study have been addressed according to the standardized qualification framework that was developed in the previous chapter. The qualification framework was selected to fill the gaps for this case study and could apply for other case studies in different regions to enhance the construction workers skills (from professionals to blue-collars) to handle BIM and energy efficiency.

Table 7-5 The skills required to fill the gaps for BIM for energy efficiency.

No.	Parameters	Role Categories	Requirements and Gaps	Skill Requirements
1	Skills required to handle BIM and energy efficiency	Designer	Knowledge of how to use BIM and energy efficiency software and its updates	S1, S17, S18, S21, S25, S28, S30, S31, S32, S33, S34, S35, S36
			Knowledge about the principle of energy efficiency and sustainability	S3, SS6, S10, S15, S16, S17, S18, S27, S55
		Blue-collar worker	Knowledge of reading the plans and separate the information needed	S8, S12, S20, S24, S38

			Increase the awareness of the principle of BIM and energy efficiency	S3, S39, S43
		Contractors	Skills to select the materials that lead to energy efficiency	S3, S6, S10, S11, S38, S39, S40, S45, S47, S58
			Knowledge of principles of BIM and energy efficiency	S1, S3, S10, S29, S38, S43, S53, S55, S58
3	Specific ways of enhancing the stakeholders' skills for the use of BIM for energy efficiency	Designers/ Engineers	Energy, BIM and data management training and education	S1, S3, S10, S16, S18, S21, S25, S26, S27, S36, S43, S54
			Increase the awareness of BIM for energy efficiency	S3, S4, S6, S7, S9, S10, S12, S13, S15, S25, S26, S27, S43, S55
		Contractors	Education, training and understanding of BIM for energy efficiency tools	S3, S6, S8, S10, S11, S16, S28, S29, S30, S35, S38, S39, S47, S52, S53, S56, S57, S58
			Ability to maintain and update information from the BIM model	S1, S2, S8, S11, S12, S16, S19, S21, S24, S28, S38, S40, S41, S45, S53
		Blue-collar workers	Training and field meetings are needed to explain the specific plans	S3, S12, S43
			Best practice modelling guidance	S38, S39
		Facility manageme nt teams	BIM for energy efficiency training	S1, S3, S6, S9, S10, S21, S23, S26, S27, S28, S29, S30, S31, S32, S33, S35, S40, S43, S46, S54, S55

4	BIM training for energy efficiency by organisation		Lack of introductory courses for the software	S28, S29, S30, S31, S32, S33, S34, S36
5	General barriers to the use of BIM for energy efficiency		Lack of understanding the purpose and potential of BIM (shortage of experience)	S1, S19, S21, S25, S29, S41, S42, S44, S45, S46
			A complex combination of different software tools	S28, S30, S31, S32, S33, S34, S35, S36
			The government does not require BIM for energy efficiency in its projects, so there are no commitments from the contractors	S3, S4, S5, S6, S9, S11, S40, S41, S49, S50, S52, S56, S57, S59

Regarding the identified requirements and gaps of using BIM for energy efficiency in the previous chapter and in this case study, it is clear that the most of requirements and gaps identified in EU countries are also seen in the case study. However, the construction sectors in Saudi Arabia have identified more gaps than in the EU. Based on the state-of-art in Chapter 2, the construction industry in the developing countries is found to still be in the early stages of using BIM in their projects, which still have more requirements and gaps when compared to the developed countries.

In Saudi Arabia's construction sectors, there is a lack of awareness about using BIM for energy efficiency because the shortage of understanding the purpose and potential of BIM. Consequently, many construction companies do not offer enough training for their workers because they wish to avoid the training costs. In addition, the government does not require the use of BIM for energy efficiency in its projects, consequently there are no commitments from the contractors. However, the qualification framework has provided many skills that can help to increase the awareness of using BIM for energy efficiency, such as understanding energy efficiency principles and sustainable construction (S3), implementing building regulations and development awareness (S4), and energy efficiency implementations for marketing (S59), as shown in Table 7-5.

The increase of the energy costs and the new building regulations in Saudi Arabia have encouraged the construction sectors to adopt BIM for energy efficiency in several projects, where the number of projects using BIM for energy efficiency is currently growing. However, as the number of projects rises, many requirements and gaps need to be addressed by skills to handle BIM for energy efficiency. Consequently, many skills were selected from the qualification framework to fill these gaps, as presented in Table 7-5. For example, knowledge of how to use BIM and energy efficiency software, and its update requirements for the engineering and design team to use BIM for energy efficiency. Many skills are selected from the standardized qualification framework to address this requirement, such as understanding BIM workflow and standards (S1), understanding BIM technologies with respect to sustainability (S25), and using BIM tools for energy efficiency (S35). Moreover, blue-collar workers require knowledge of how to read the plans and separate the information needed. Many skills were identified to cover this requirement, such as observing and separating the information needed (S8), math and estimation (20), and extracting measures and data from plans (S24).

Based on the skills matrix, the EQF levels of each skill are defined for each role in Chapter 6. The standardized qualification framework will help the construction companies to identify the needed skills and the qualification levels to enhance the companies' stakeholder qualifications to use BIM for energy efficiency during the lifecycle and supply chain of their projects.

7.6 Conclusion

The researcher has addressed the requirements elicitation phase to determine any gaps and new strategies in delivering BIM training for energy efficiency. The researcher has used a participative and incremental approach that involves Saudi experts, with a view to reaching key stakeholder communities to help identify and then analyse past and ongoing projects related to energy efficiency involving aspects of BIM.

The main objective was to identify the gap between the demand for skills and the learning for BIM application in energy efficiency. The researcher has used a consultation-driven methodology. The consultation process has helped both in defining skills related to BIM technology and associated application for energy efficiency in buildings, and in identifying the BIM training requirements across the value chain (from blue-collar workers to middle/senior level workers).

In this chapter, the researcher has addressed three primary objectives:

1. Identify critical gaps in terms of BIM skills and related training offers based on an assessment of the current situation.
2. Deliver a set of requirements as derived from an analysis of the consultations and interviews.
3. Using the standardized qualification framework that was developed in Chapter 6 to address the gaps and requirements.

Our approach started with a consultation process that identified, analysed, and assessed the construction sector stakeholders' requirements for BIM training to ensure engagement with energy management in construction. This research revealed a set of perceived barriers to engagement at the individual, organisational, and wider industry levels. Based on the research results, it was found that an online training repository that provides integrated access to BIM resources (i.e., knowledge, expertise, best practice, and software tools and applications) in the form of interactive, dynamic, and user-oriented services may help to address these barriers.

From the analysis of the consultation results and the associated literature review, the initial specification of BIM training and education for the energy environment have been described, including the general service requirements, and skills to address and organisational policies. Compared to the requirements of EU countries for BIM for energy efficiency training, Saudi Arabia’s construction sectors need to adopt more training programmes to enhance their worker's skills to handle BIM for energy efficiency. The biggest limitation is the readiness of the industry to adhere to such changes. The researcher hopes that this chapter will provide future research opportunities by extending the investigation of various BIM applications in different case studies in developing countries (e.g., the MENA region) to identify a set of requirements for BIM training in a broader context to achieve energy-efficient buildings. In addition, the standardized qualification framework that was developed in the Chapter 6 was selected to fill the gaps and requirements to improve the construction worker’s (from professionals to blue-collar) skills for using BIM for energy efficiency in Saudi Arabia.

Conclusion

This chapter concludes this thesis by revisiting the research questions that were provided in Chapter 1 and summarising how they were addressed by this research. The explorations for each research question will be combined to address the main hypothesis at the centre of this research. Following this, a summary of the key contributions to the body of knowledge will be provided. The limitations of this work will then be identified. Finally, some recommendations for future research will be outlined.

8.1 Main Research Finding

The primary objective of this study was to develop a standardized qualification framework to enhance the use of BIM for energy efficiency in the construction sector. To this end, several research questions were developed, ensuring that a stepwise approach was employed to achieve this primary objective. The research questions will be addressed in the following subsections.

8.1.1 Research Question 1

What are the requirements, limitations and gaps in the BIM skills and training landscape in Europe?

This research question was largely the target of Stage 1 of the research methodology, which aimed to identify the requirements and gaps in the BIM training and skills for energy efficiency landscape in Europe. Creating the expert community in the field was one of the major objectives because it allowed the researcher to address the requirement elicitation criteria phase to identify gaps and develop new strategies for delivering BIM for energy efficiency. The researcher used a participatory and incremental approach, and involved an expert panel with a view to reaching key stakeholder communities to help identify, and then screen and analyse past and ongoing projects related to energy efficiency involving aspects of BIM.

The researcher has recorded 40 best practice use cases from the field of BIM for energy efficiency, and has conducted an in-depth analysis to determine the gaps in BIM for energy efficiency training and any 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, while highlighting stakeholder targets, ranging from blue-collar workers to decision-makers.

The researcher used a consultation-driven approach and use-case aggregation techniques, assisted by a semantic search engine, to promote the submission of BIM questions with the collection 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, to identify BIM training requirements across the value chain (from blue-collar workers to middle and senior-level workers). In this chapter, the researcher has 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 total, 19 gaps were identified related to five parameters, including: (a) skills required to handle BIM for energy efficiency; (b) general skills for all roles that are lacking for the use of BIM for energy efficiency; (c) specific ways of enhancing the stakeholders' skills for the use of BIM for energy efficiency; (d) BIM training for energy efficiency by organisations; and (e) common barriers to the use of BIM for energy efficiency. These gaps are required for different roles categories in construction projects included designers, blue-collars, contractors, and facility managers. For each role category, a set of requirements and gaps were identified, such as:

(1) Designers: Formulate the model with energy efficiency simulation programs; maintain data of different varieties and solutions; good communication between designers, clients, and suppliers; energy, BIM, data management training and education.
(2) Contractor: Knowledge of how to use BIM and training ability to implement BIM for energy efficiency; collaborate with the designer to manage the information from the model; and education and training should be adapted based on specific requirements.
(3) Blue-collar: Simulate use-case scenarios for the design; communication with clients and contractors to ensure best practice and training; and field meetings to explain the specific plans.
(4) Facility management team: This group mainly needs the ability to extract and update information from BIM models.

Otherwise, some skills that are lacking for the use of BIM for energy efficiency were generally determined for all roles, such as finding suitable solutions to promote BIM in energy efficiency and understanding the positive impacts of using BIM for energy efficiency on projects. The proposed skills RIBA map and skills matrix in Chapter 6 provide a promising approach to enhance these issues according to the expert panel validation.

8.1.2 Research Question 2

Which BIM roles and skills are required to achieve energy efficiency via adapted training?

To address this question, several sources have been utilised to explore the existing skills and roles for using BIM for energy efficiency in this research, including use cases, interviews, scientific publications, standard reports, and social media (Twitter). The findings show that BIM is dynamic in nature and requires new skills and training programmes to cover the gaps in BIM for energy efficiency. All of the use cases and interview outcomes from the previous question and scientific publication and standards reports about BIM for energy efficiency have been used as a source to conduct more of skills and roles. In addition, social media (Twitter) has been used to identify more roles and skills, which proved that it could bring new insights into the process of BIM skills and training. The data that have been aggregated from the above sources have been analysed to determine the skills and roles of BIM for energy efficiency using NVivo, and quantitative and qualitative analysis.

This thesis has classified 106 roles that represent the most common roles involved in construction projects, which are distributed in five main categories, as follows:

- Client/advisor category: Client, project manager, BIM manager, etc.
- Engineer/designer: Architectural, structural, mechanical, electrical and plumbing, etc.
- Contractor: Site manager, construction engineer, etc.
- Facility management team: Facility manager, maintenance operator, etc.
- Blue-collar workers: Construction worker, etc.

A list of 59 different skills related to management and administration, software skills, engineering and design disciplines, and other general skills has been developed. These skills are used to identify the qualifications required for stakeholders in construction projects to improve their understanding of BIM for energy efficiency, such as: skills related to management and administration, optimal decision making, integrating information and data management framework, and risk management. Other skills are related to software, such as ICT, using BIM tools and applications (Revit, etc.), and applying for energy simulation programs. Skills related to engineering and design disciplines include achieving BIM and energy efficiency certifications (LEED, BREEM, etc.), adapting to environmental conditions changes, and reviewing design and coordination. Other general skills include teamwork and collaboration, communication (speaking and presentation), and technical writing.

8.1.3 Research Question 3

Can changing training requirements as a consequence of the continuous digitalisation of work practices, business processes, and technology evolutions, be captured and managed through a dedicated framework that factors in a wide range of aspects, including roles and skills?

Data science techniques were used to identify the level of skills that are required to handle BIM for energy efficiency for various stakeholders involved in the construction projects during their lifecycle to be adopted by training programmes and address the increased demand for stakeholders requiring BIM skills. From the classification roles and the list of skills that have been identified in the previous question, standardized qualification framework has developed. A RIBA skills map was proposed to define the skills for each of the different role categories to handle BIM for energy efficiency through nine stages of the project lifecycle based on the RIBA 2013 work of plan, including strategic definition, preparation and brief, concept design, developed design, technical design, construction, handover and closeout, in-use, and demolition stages. In addition, a skills matrix for the five main role categories was developed based on the RIBA skills map and EQF levels (from 1 - 8), which would be used as a framework for BIM training and education.

From the proposed RIBA skills map and skills matrix, it can be observed that some skills are required in certain project stages for a role group. The level of these skills varies according to each role in the group, which means that this person may not be involved in that particular project stage. Otherwise, some skills may not be needed in earlier project stages, which offer an opportunity and time for training to prepare the role (person) to be eligible to handle the project responsibilities at advanced project stages and support decision making, such as hiring, training and termination. For example, within the client and advisor group, 36 skills were identified to improve these roles' skills to use BIM for energy efficiency throughout the whole lifecycle and supply chain of the projects. Most of these skills are required at lower EQF levels compared to the other roles because this group do not need high levels of qualification to seek the energy efficiency requirements. However, most of these skills are needed with high EQF levels for project managers and BIM managers.

Finally, a consolidating list of skills has been adopted to address BIM for energy efficiency requirements and to identify gaps through assigning the relative skills from the skills matrix to enhance the stakeholders' qualifications to use BIM for energy efficiency in the construction sectors. For example, formulating the model with energy efficiency simulation programs has been identified as a requirement for the designer role, which has been fitted by several skills, such as by establishing energy models, and applying energy simulation programs. In addition, several skills have been adopted to fill the requirement of communication between designers, clients, and suppliers, such as communication (speaking and presentation), technical writing, and teamwork and collaboration.

8.1.4 Research Question 4

How scalable and adaptable is this standardized qualification framework to other regions and socio-organisation contexts, such as in the context of developing economies?

A case study in a developing country was selected to identify the requirements and gaps in BIM skills and training for energy efficiency, which were then compared with the EU outcomes. Saudi Arabia as a case study has proven the ability to adapt the developed framework to address the case study's requirements and fill the gaps of using BIM for energy efficiency. In addition, critical gaps were identified in terms of BIM skills and related training offers based on an assessment of the current situation. Then a set of requirements and gaps were delivered, as derived from an analysis of the consultations and interviews.

In total, 17 gaps were identified, related to four parameters, as follows: (1) skills required to handle BIM and energy efficiency; (2) specific ways of enhancing the stakeholders' skills for the use of BIM for energy efficiency; (3) BIM training for energy efficiency by organisations; and (4) general barriers to the use of BIM for energy efficiency. These gaps are required for different roles categories in the projects included designers, blue-collars, contractors, and facility managers.

Finally, a framework to address the gaps and requirements has been developed by using the proposed skills matrix and skills RIBA map, which shows the potentials to enhance parameters 1 and 2 through the awareness of using BIM for energy efficiency and focusing on enhancing understanding energy efficiency principle and sustainable construction, implementing building regulations and development awareness, and energy efficiency implementations marketing.

Parameters 3 and 4 were addressed through the standardized qualification framework, which provided several skills, such as linking between different software, using CAD programs, and learning computer programming (Python, MATLAB, etc.).

8.2 Revisiting the Hypothesis

The discussion surrounding the four research questions has laid the basis for a final evaluation of the main research hypothesis, which is restated here as follows:

Adapted training to promote the digital transformation of the construction industry, and in particular to enhance the adoption of Building Information Modelling, can have a positive impact on white and blue-collar work practices to deliver energy efficient interventions.

To address the research hypothesis, the outcomes of the four research questions have been combined. First, through case studies and expert interviews, significant requirements, and gaps in the EU construction sector to handle BIM for energy efficiency have been identified, as demonstrated in Chapter 4. Second, several sources have been used to identify the skills and roles related to construction projects, which help to reduce and address those requirements and gaps through an appropriate training programme. Third, the RIBA plan and EQF levels have been utilised to develop a matrix that combines the skills and roles in a standardized qualification framework for BIM training, which would directly enhance the qualifications of the stakeholders in the construction projects to handle BIM for energy efficiency. Finally, a consultation process has been conducted with an expert panel from the EU and Saudi Arabia to validate the positive impacts of the proposed framework to solve the research gaps, conducted from Chapter 4, in the EU and a developing county outside the EU, as discussed in Chapters 6 and 7, respectively. The panel agreed on the significant contributions of the framework and capabilities to fill these gaps. The combination of the results demonstrated throughout this thesis clearly confirm the central research hypothesis.

8.3 Research Contributions

This research has contributed to the body of knowledge by introducing several outcomes. The contributions from each work stage were provided in the relevant chapters. They will be briefly restated here to illustrate the main contributions of this thesis, as follows:

Data collection

- Applying new channels of data collection, such as social media, which provided a unique opportunity to re-engineer and improve the existing methodology, and showed the new technological capabilities to extend the current state of knowledge for BIM application in energy efficiency.
- Using the platform as tool to collect the case studies gives an opportunity to dynamically update requirements, skills, roles, and gaps. A case study template has been developed in the platform to allow the expert community to participate in adding BIM for energy efficiency case studies directly.

List of roles and skills

- Unique equations have been developed within the research framework to identify the importance and the frequency of the skills and roles, while considering the frequency of occurrences in conjunction with all its counterparts.
- The evaluation of the social media analysis showed that the resulting list of roles and skills is novel and can bring new insights into the process of BIM training and education.

Standardized qualification framework for each role during the lifecycle of a project:

- A skills map was developed to define the skills required for each of the role categories to handle BIM for energy efficiency through nine stages of the project lifecycle based on the RIBA 2013 work of the plan.
- Develop a skills matrix for the five main role categories developed based on the RIBA skills map and EQF levels (from 1 to 8), which will be used as a standardized qualification framework for BIM training and education.

Fill the gaps and requirements:

- A framework was developed to enhance the shortage of qualifications for all role groups through the project phases based on EQF levels and the RIBA plan for the EU context.

8.4 Limitations and Future Work

Despite the contributions made during this research, the following limitations have been observed:

The limitations:

- Given that this study was a part of the EU H2020 BIMEET project, the scope of the research was focused on building construction in the EU.
- For the same reason, the expert panel was mostly drawn from the EU countries.
- Although high numbers of invitations have been sent, the number of experts who participated in the study is still not wide.
- The EQF covers personal responsibilities and skills, but this research was only focused on the skills because the personal qualifications are the main drivers to handle the required responsibilities.

Recommendations for future work:

This research provides further opportunities for future research, as follows:

- A framework should be developed for training and education programmes that focus on improving the key skills for each stakeholder for BIM for energy efficiency during the lifecycle of a project.
- Extend the investigations in further developing countries or regions to identify more requirements and to explore more skills.
- The BIM skills were identified with the aim of enhancing the energy efficiency; therefore, the impact of the key skills on other project aspects, such as cost and time, might be explored.
- New approaches should be explored to address further key skills and identify the construction sector gaps.

- This research was focused on building construction, so further implementations for the framework to identify the skills required in different sectors might be required (e.g., infrastructure).
- Future research should expand the scope of this work to support the legislative changes that will stimulate the demand for energy skills across lifecycle and supply chains.

Overall, this research provides a standardized qualification framework that includes: (1) a skills matrix related to BIM and energy efficiency, harmonised thanks to the European Qualifications Framework standard, to assess and support energy efficient handling of BIM projects; and (2) a skills map that will help to widely distribute the BIM skills required during the project lifecycle to achieve energy efficiency based on the Royal Institute of British Architects Plan of Work. The proposed framework provides a promising approach to promote the use of BIM in energy efficiency and understand the positive impacts of BIM in projects.

References

[1] European Commission, “Challenging and Changing Europe’s Built Environment A vision for a sustainable and competitive construction sector by 2030,” 2005. Accessed: Dec. 20, 2017. [Online]. Available: https://www.certh.gr/dat/79DC02A3/file.pdf.

[2] E. European Construction Technology Platform, “Challenging and Changing Europe’s Built Environment A vision for a sustainable and competitive construction sector by 2030,” 2005, Accessed: Jan. 26, 2018. [Online]. Available: https://www.certh.gr/dat/79DC02A3/file.pdf.

[3] D. Cummings and K. Blanford, “Global Construction Outlook: Executive Outlook,” 2013. Accessed: Dec. 20, 2017. [Online]. Available: https://www.ihs.com/pdf/IHS_Global_Construction_ExecSummary_Feb2014_140852110913052132.pdf.

[4] Global Construction Perspectives and Oxford Economics, “Global Construction 2030 A global forecast for the construction industry to 2030,” 2015.

[5] Y. Rezgui and J. Miles, “Exploring the Potential of SME Alliances in the Construction Sector,” *J. Constr. Eng. Manag.*, vol. 136, no. 5, pp. 558–567, May 2010, doi: 10.1061/(asce)co.1943-7862.0000150.

[6] United Nations Human Rights Office of the High Commissioner, “International Covenant on Economic, Social and Cultural Rights,” no. January, p. Article 12, 1976, Accessed: Jan. 27, 2018. [Online]. Available: http://www.ohchr.org/EN/ProfessionalInterest/Pages/CESCR.aspx.

[7] R. Eadie, M. Browne, H. Odeyinka, C. McKeown, and S. McNiff, “BIM implementation throughout the UK construction project lifecycle: An analysis,” *Autom. Constr.*, vol. 36, pp. 145–151, Dec. 2013, doi: 10.1016/J.AUTCON.2013.09.001.

[8] EU Commission, “Harrison Management Plan 2021 – 2026,” pp. 1–60, 2021.

[9] A. Alhamami, I. Petri, and Y. Rezgui, “Use-case analysis for assessing the role of Building Information Modeling in energy efficiency,” in *eWork and eBusiness in Architecture, Engineering and Construction*, CRC Press, 2019, pp. 31–38.

[10] S. Suwal and V. Singh, “Assessing students’ sentiments towards the use of a Building Information Modelling (BIM) learning platform in a construction project management

course," *https://doi.org/10.1080/03043797.2017.1287667*, vol. 43, no. 4, pp. 492–506, Jul. 2017, doi: 10.1080/03043797.2017.1287667.

[11] ADC, "Building Information Modelling (BIM) - The Automatic Door Company," 2020. https://www.theautomaticdoorco.com/about/bim/ (accessed May 08, 2021).

[12] P. Rajendran, C. G.-2nd international conference on, and undefined 2012, "Implementing BIM for waste minimisation in the construction industry: a literature review," *academia.edu*2012 ,.

[13] O. O. Akinade *et al.*, "Designing out construction waste using BIM technology: Stakeholders' expectations for industry deployment," *J. Clean. Prod.*, vol. 180, pp. 375–385, Apr. 2018, doi: 10.1016/J.JCLEPRO.2018.01.022.

[14] J. K.- Buildings and undefined 2018, "Design for deconstruction in the design process: State of the art," *mdpi.com*, vol. 8, no. 11, Nov. 2018, doi: 10.3390/buildings8110150.

[15] S. Azhar, M. Khalfan, and T. Maqsood, "Building Information Modeling (BIM): Now and Beyond," 2012, doi: 10.3316/INFORMIT.013120167780649.

[16] JPF Systems Ltd, "BIM | JPF Systems Ltd," 2020. https://www.jpf-systems.co.uk/bim/ (accessed May 08, 2021).

[17] B. Succar, "Building information modelling framework: A research and delivery foundation for industry stakeholders," *Elsevier*, 2009, Accessed: May 27, 2021. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S0926580508001568?casa_token=SWB5tfaWTKcAAAAA:h5MGHEJkMWuAqeJeFarU_wAnldTbKTu88OhUeRLdK-OjQtufoW03h1Tkw8PobSnXNnKOUynnow.

[18] A. Medina, Á. Cámara, and J.-R. Monrobel, "Measuring the Socioeconomic and Environmental Effects of Energy Efficiency Investments for a More Sustainable Spanish Economy," *mdpi.com*, 2016, doi: 10.3390/su8101039.

[19] J. Viholainen, M. Luoranen, S. Väisänen, and A. Niskanen, "Regional level approach for increasing energy efficiency," *Elsevier*, 2016, Accessed: May 05, 2021. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S0306261915013288?casa_token=jsBvDbIcZ6YAAAAA:TGMxRXGJzNSfHu0EoZ1Lru6sfbe9r3LJ-

C0UL0J9Fmqu3aw6fPM5EoZ8WBZo6UXF_zCV1i-hfw.

[20] H. Geller, P. Harrington, A. H. Rosenfeld, S. Tanishima, and F. Unander, “Polices for increasing energy efficiency: Thirty years of experience in OECD countries,” *Energy Policy*, vol. 34, no. 5, pp. 556–573, Mar. 2006, doi: 10.1016/J.ENPOL.2005.11.010.

[21] D. Ürge-Vorsatz and B. Metz, “Energy efficiency: how far does it get us in controlling climate change? The mitigation challenge,” 2009, doi: 10.1007/s12053-009-9049-7.

[22] L. Pérez-Lombard, J. Ortiz, R. González, and I. R. Maestre, “A review of benchmarking, rating and labelling concepts within the framework of building energy certification schemes,” *Energy and Buildings*, vol. 41, no. 3. Elsevier, pp. 272–278, Mar. 01, 2009, doi: 10.1016/j.enbuild.2008.10.004.

[23] EU Commission, “2020 targets | European Commission,” 2007. https://ec.europa.eu/info/energy-climate-change-environment/overall-targets/2020-targets_en (accessed May 06, 2021).

[24] The European parliament and the council of the European union, “Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010 on the energy performance of buildings,” *Off. J. Eur. Union*, 2010, Accessed: Jan. 28, 2018. [Online]. Available: http://www.buildup.eu/sites/default/files/content/EPBD2010_31_EN.pdf.

[25] A. J. Marszal *et al.*, “Zero Energy Building - A review of definitions and calculation methodologies,” *Energy Build.*, vol. 43, no. 4, pp. 971–979, Apr. 2011, doi: 10.1016/j.enbuild.2010.12.022.

[26] A. Oladosu, “Concepts in education. fundamental principles and practice of instruction. ,” 2009. Accessed: May 18, 2021. [Online]. Available: https://scholar.google.co.uk/scholar?hl=en&as_sdt=0%2C5&as_ylo=2009&as_yhi=2009&q=Oladosu%2C+A.+%282009%29.+Concepts+in+education.+fundamental+principles+and+practice+of+instruction.+Ilorin.+University+of+Ilorin.&btnG=.

[27] T. N. Garavan, “Training, development, education and learning: different or the same?,” *J. Eur. Ind. Train.*, vol. 21, no. 2, pp. 39–50, Mar. 1997, doi: 10.1108/03090599710161711.

[28] A. Karina, S. Rodriguez, and D. Heesom, “BIM Education Framework for Clients and

Professionals of the Construction Industry," *Int. J. 3-D Inf. Model.*, vol. 6, no. 2, 2017, doi: 10.4018/IJ3DIM.2017040104.

[29] M. Masadeh, "TRAINING, EDUCATION, DEVELOPMENT AND LEARNING: WHAT IS THE DIFFERENCE? ," *Eur. Sci. J. May Ed.*, vol. 8, no. 10, 2012, Accessed: May 18, 2021. [Online]. Available: https://www.researchgate.net/publication/279480522.

[30] K. P. Kisi, N. Mani, ; Eddy M Rojas, and E. T. Foster, "Optimal Productivity in Labor-Intensive Construction Operations: Pilot Study," *ascelibrary.org*, vol. 143, no. 3, p. 04016107, Mar. 2016, doi: 10.1061/(ASCE)CO.1943-7862.0001257.

[31] Y. Wang, P. M. Goodrum, C. T. Haas, and R. W. Glover, "Craft Training Issues in American Industrial and Commercial Construction," *J. Constr. Eng. Manag.*, vol. 134, no. 10, pp. 795–803, Oct. 2008, doi: 10.1061/(asce)0733-9364(2008)134:10(795).

[32] S. Durdyev, M. Omarov, and S. Ismail, "Causes of delay in residential construction projects in Cambodia," *Cogent Eng.*, vol. 4, no. 1, 2017, doi: 10.1080/23311916.2017.1291117.

[33] L. Le-Hoai, Y. Dai Lee, and J. Y. Lee, "Delay and Cost Overruns in Vietnam Large Construction Projects: A Comparison with Other Selected Countries," *KSCE J. Civ. Eng.*, vol. 12, no. 6, pp. 367–377, 2008, doi: 10.1007/s12205-008-0367-7.

[34] S. Zafar, S. Tabish, and K. N. Jha, "Success Traits for a Construction Project," *ascelibrary.org*, vol. 138, no. 10, pp. 1131–1138, Oct. 2012, doi: 10.1061/(ASCE)CO.1943-7862.0000538.

[35] C. Forde and R. MacKenzie, "Cementing skills: Training and labour use in UK construction," *Hum. Resour. Manag. J.*, vol. 14, no. 3, pp. 74–88, 2004, doi: 10.1111/j.1748-8583.2004.tb00127.x.

[36] L. S. Marín and C. Roelofs, "Promoting Construction Supervisors' Safety-Efficacy to Improve Safety Climate: Training Intervention Trial," *ascelibrary.org*, vol. 143, no. 8, p. 04017037, Aug. 2017, doi: 10.1061/(ASCE)CO.1943-7862.0001330.

[37] D. Cooper, "Measuring and improving safety culture," 1996.

[38] AACIF, "A framework for the adoption of project team integration and building information modelling.," 2014. Accessed: May 18, 2021. [Online]. Available:

https://scholar.google.co.uk/scholar?hl=en&as_sdt=0%2C5&q=A+framework+for+the+adoption+of+project+team+integration+and+building+information+modelling.&btnG=.

[39] M. Kanellakis, G. Martinopoulos, and T. Zachariadis, "European energy policy-A review," *Energy Policy*, vol. 62, pp. 1020–1030, Nov. 2013, doi: 10.1016/J.ENPOL.2013.08.008.

[40] R. Vanlande, C. Nicolle, and C. Cruz, "IFC and building lifecycle management," 2008, doi: 10.1016/j.autcon.2008.05.001.

[41] S. Azhar, M. Hein, and B. Sketo, "Building Information Modeling (BIM): Benefits, Risks and Challenges," 2008, Accessed: Jan. 25, 2018. [Online]. Available: http://ascpro.ascweb.org/chair/paper/CPGT182002008.pdf.

[42] S. Christensen, J. McNamara, and K. O'Shea, "Legal and contracting issues in electronic project administration in the construction industry," *Struct. Surv.*, vol. 25, no. 3/4, pp. 191–203, Jul. 2007, doi: 10.1108/02630800710772791.

[43] J. Martin, "e-Procurement and Extranets in the UK Construction Industry," 2009, Accessed: Jan. 25, 2018. [Online]. Available: https://www.fig.net/resources/proceedings/fig_proceedings/fig_2003/TS_6/TS6_4_Martin.pdf.

[44] K. Udom, "Building Information Modelling," 2012. https://www.thenbs.com/knowledge/bim-mapping-out-the-legal-issues (accessed Jan. 25, 2018).

[45] S. Azhar, W. A. Carlton, D. Olsen, and I. Ahmad, "Building information modeling for sustainable design and LEED® rating analysis," *Autom. Constr.*, vol. 20, no. 2, pp. 217–224, Mar. 2011, doi: 10.1016/J.AUTCON.2010.09.019.

[46] R. Crotty, *The Impact of Building Information Modelling: Transforming Construction - Ray Crotty*. 2013.

[47] Efficiency and Reform Group, "Government Construction Strategy," 2011. Accessed: Jan. 25, 2018. [Online]. Available: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/61152/Government-Construction-Strategy_0.pdf.

[48] B. Giel, R. Issa, and S. Olbina, “Return on investment analysis of building information modeling in construction2009 , ”,.

[49] K. Thomsen and K. Wittchen, “European national strategies to move towards very low energy buildings,” 2008. Accessed: Jun. 05, 2017. [Online]. Available: http://vbn.aau.dk/ws/files/14019804/sbi-2008-07.pdf.

[50] H. Yan and P. Damian, “Benefits and Barriers of Building Information Modelling,” pp. 16–18, 2008, Accessed: Jan. 25, 2018. [Online]. Available: https://dspace.lboro.ac.uk/2134/23773.

[51] A. Hore and K. Thomas, “Advancing the Use of BIM Through a Government Funded Construction Industry Competency Centre in Ireland,” *Conf. Pap.*, Jan. 2011, Accessed: Jan. 25, 2018. [Online]. Available: https://arrow.dit.ie/beschreccon/30.

[52] I. Petri, T. Beach, Y. Rezgui, I. E. Wilson, and H. Li, “Engaging construction stakeholders with sustainability through a knowledge harvesting platform,” *Comput. Ind.*, vol. 65, no. 3, pp. 449–469, Apr. 2014, doi: 10.1016/J.COMPIND.2014.01.008.

[53] C. Boton, S. Kubicki, and G. Halin, “Designing adapted visualization for collaborative 4D applications,” *Autom. Constr.*, vol. 36, pp. 152–167, Dec. 2013, doi: 10.1016/J.AUTCON.2013.09.003.

[54] B. Yuce and Y. Rezgui, “An ANN-GA Semantic Rule-Based System to Reduce the Gap Between Predicted and Actual Energy Consumption in Buildings,” *IEEE Trans. Autom. Sci. Eng.*, vol. 14, no. 3, pp. 1351–1363, Jul. 2017, doi: 10.1109/TASE.2015.2490141.

[55] I. Petri, H. Li, Y. Rezgui, Y. Chunfeng, B. Yuce, and B. Jayan, “A modular optimisation model for reducing energy consumption in large scale building facilities,” *Renew. Sustain. Energy Rev.*, vol. 38, pp. 990–1002, Oct. 2014, doi: 10.1016/J.RSER.2014.07.044.

[56] P. Barrett and M. Sexton, “Innovation in Small, Project-Based Construction Firms,” *Br. J. Manag.*, vol. 17, no. 4, pp. 331–346, Dec. 2006, doi: 10.1111/j.1467-8551.2005.00461.x.

[57] D. Bryde, M. Broquetas, and J. M. Volm, “The project benefits of Building Information Modelling (BIM),” *Int. J. Proj. Manag.*, vol. 31, no. 7, pp. 971–980, Oct. 2013, doi: 10.1016/J.IJPROMAN.2012.12.001.

[58] J. Egan, "Rethinking Construction," 1998. Accessed: Mar. 08, 2018. [Online]. Available: http://constructingexcellence.org.uk/wp-content/uploads/2014/10/rethinking_construction_report.pdf.

[59] A. Dainty, D. Moore, and M. Murray, *Communication in Construction: Theory and Practice - Andrew Dainty, David Moore, Michael Murray - كتب Google*. 2006.

[60] B. Becerik-Gerber, F. Jazizadeh, N. Li, and G. Calis, "Application Areas and Data Requirements for BIM-Enabled Facilities Management," *J. Constr. Eng. Manag.*, vol. 138, no. 3, pp. 431–442, Mar. 2012, doi: 10.1061/(ASCE)CO.1943-7862.0000433.

[61] T. Cerovsek, "A review and outlook for a 'Building Information Model' (BIM): A multi-standpoint framework for technological development," *Adv. Eng. Informatics*, vol. 25, no. 2, pp. 224–244, Apr. 2011, doi: 10.1016/J.AEI.2010.06.003.

[62] I. Petri, S. Kubicki, Y. Rezgui, A. Guerriero, and H. Li, "Optimizing Energy Efficiency in Operating Built Environment Assets through Building Information Modeling: A Case Study," *Energies*, vol. 10, no. 8, p. 1167, Aug. 2017, doi: 10.3390/en10081167.

[63] N. Jha and C. Polidano, "Vocational Education and Training: A Pathway to the Straight and Narrow," *SSRN Electron. J.*, Aug. 2016, doi: 10.2139/ssrn.2814748.

[64] Communication and from the Commission, "'A Framework Strategy for a Resilient Energy Union with a Forward-Looking Climate Change Policy,'" 2015. http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM:2015:80:FIN (accessed Jan. 28, 2018).

[65] European Commission, "Energy Efficiency Directive," 2013. https://ec.europa.eu/energy/en/topics/energy-efficiency/energy-efficiency-directive (accessed Jan. 28, 2018).

[66] European Commission, "Review of the Energy Performance of Buildings Directive, including the 'Smart Financing for Smart Buildings' initiative," 2015, Accessed: Jan. 28, 2018. [Online]. Available: http://ec.europa.eu/smart-regulation/roadmaps/docs/2016_ener_001_epbd_smart_buildings_en.pdf.

[67] Centre for Digital Built Britain, "This trend is well illustrated by the recent creation of BIM incentivizing and regulatory schemes in EU member states, e.g. BIM 2016 in the UK," 2016. https://www.cdbb.cam.ac.uk/ (accessed Jan. 28, 2018).

[68] M. Petrullo *et al.*, “SmartMarket Report Measuring the Impact of BIM on Complex Buildings SmartMarket Report,” 2015, Accessed: Jan. 28, 2018. [Online]. Available: https://c.ymcdn.com/sites/www.nibs.org/resource/resmgr/Docs/BIMSmartMarketReport.pdf.

[69] B. Yuce and Y. Rezgui, “An ANN-GA Semantic Rule-Based System to Reduce the Gap Between Predicted and Actual Energy Consumption in Buildings,” *IEEE Trans. Autom. Sci. Eng.*, vol. 14, no. 3, pp. 1351–1363, Jul. 2017, doi: 10.1109/TASE.2015.2490141.

[70] UNFCCC, “United Nations Framework on Climate Change,” vol. 62220, 1992.

[71] UNFCCC, “United Nations Framework on Climate Change Kyoto Protocol,” *Conf. PARTIES Third Sess. Kyoto, 1-10 December 1997 Agenda item 5*, pp. 1–24, 1997.

[72] Official Journal of the European Union, “United Nations Framework on Climate Change Paris Agreement,” pp. 1–15, 2016.

[73] IPCC, “Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change,” 2021.

[74] World Green Building Council, “World Green Building Council 2018. Delivering the Paris Agreement – The Role of the Built Environment - بحث Google2018 ”,.

[75] UNIDO, “The Sustainable Development Goals,” 2015.

[76] European Commission, “A Clean Planet for All: A European strategic long-term vision for a prosperous, modern, competitive and climate neutral economy,” 2018.

[77] World Green Building Council, “Bringing embodied carbon upfront,” 2019.

[78] Eurostat, *Energy data 2020 edition*. 2020.

[79] European Commission, “Update of the NDC of the European Union and its Member States,” 2020.

[80] UNFCCC, “Long-term low greenhouse gas emission development strategy of the European Union and its Member States,” 2020.

[81] European Commission, “2030 climate & energy framework ,” *Climate Action*, 2021. .

[82] European Environment Agency, “Total greenhouse gas emission trends and projections

in Europe," 2020.

[83] Climate Analytics and New Climate Institute, "Climate Action Tracker," 2009. .

[84] European Commission, "Clean energy for all Europeans package," *Energy*, 2019. .

[85] European Commission, "Energy Union Package: A Framework Strategy for a Resilient Energy Union with a Forward-Looking Climate Change Policy ," 2015.

[86] European Parliament and Council of the European Union, "Energy Performance of Buildings Directive (EPBD) 2018/844," May 2018.

[87] European Parliament, "DIRECTIVE (EU) 2018/2002 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL," *Off. J. Eur. Union*, vol. 328, no. November, pp. 210–230, 2018.

[88] Trucost, "EU Accounts Modernisation Directive," no. November, pp. 1–5, 2005.

[89] European Union, "Regulation (EU) 2018/1999 on the Governance of the Energy Union and Climate Action," *Off. J. Eur. Union*, vol. 328, no. 1, pp. 1–77, 2018.

[90] E. Commission, "Consultation on the Review and the Revision of Directive 2012 / 27 / EU on Energy Efficiency," pp. 1–42, 2021.

[91] European Commission, "Energy performance of buildings directive," 2018.

[92] European Commission, "National energy and climate plans (NECPs) ," 2019.

[93] European Parliament and Council of the EU, "European Climate Law," 2020.

[94] Global Construction Perspectives and Oxford Economics, "Global Construction 2025," 2013.

[95] Lucintel, "Growth Opportunities in the Global Construction Industry," Oct. 2021.

[96] Business Research Company, "Construction Global Market Report 2021: COVID-19 Impact and Recovery to 2030," Mar. 2021.

[97] World Economic Forum, "Shaping the Future of Construction: A Breakthrough in Mindset and Technology," 2016. doi: 10.1061/9780784402474.

[98] Climate Disclosure Standards Board, "CDSB Framework for reporting environmental & climate change information," 2019.

[99] European Commission, "European construction sector observatory | Internal Market,

Industry, Entrepreneurship and SMEs,” 2012.

[100] ConsTrack360, “Europe Construction Industry Report 2020-2024 ,” 2020.

[101] EUROCONSTRUCT, “The 91st EUROCONSTRUCT Conference streamed Report,” Vienna, Jun. 2021.

[102] European Commission, “The European construction sector - A global partner ,” 2021.

[103] World Economic Forum, “Ranking of National Key Performance Indicators,” 2017.

[104] The KPI Working Group, “KPI Report for The Minister for Construction,” *Dep. Environ. Transp. Reg.*, no. January, p. 34, 2000.

[105] A. Enshassi, S. Mohamed, and S. Abushaban, “Factors affecting the performance of Construction projects in the Gaza Strip,” *J. Civ. Eng. Manag.*, vol. 15, no. 3, pp. 269–280, Sep. 2009, doi: 10.3846/1392-3730.2009.15.269-280.

[106] S. O. Cheung, H. C. H. Suen, and K. K. W. Cheung, “PPMS: a Web-based construction Project Performance Monitoring System,” *Autom. Constr.*, vol. 13, no. 3, pp. 361–376, May 2004, doi: 10.1016/J.AUTCON.2003.12.001.

[107] A. Enshassi, J. AlNajjar, and M. Kumaraswamy, “Delays and cost overruns in the construction projects in the Gaza Strip,” *J. Financ. Manag. Prop. Constr.*, vol. 14, no. 2, pp. 126–151, Jul. 2009, doi: 10.1108/13664380910977592.

[108] M. Suprapto, H. L. M. Bakker, and H. G. Mooi, “Relational factors in owner-contractor collaboration: The mediating role of teamworking,” *Int. J. Proj. Manag.*, vol. 33, no. 6, pp. 1347–1363, Aug. 2015, doi: 10.1016/J.IJPROMAN.2015.03.015.

[109] R. Vrijhoef and L. Koskela, “Revisiting the Three Peculiarities of Production in Construction,” 2005.

[110] Y. Rezgui, “Text-based domain ontology building using Tf-Idf and metric clusters techniques,” *Knowl. Eng. Rev.*, vol. 22, no. 4, pp. 379–403, Dec. 2007, doi: 10.1017/S0269888907001130.

[111] I. Petri, T. Beach, Y. Rezgui, I. E. Wilson, and H. Li, “Engaging construction stakeholders with sustainability through a knowledge harvesting platform,” *Comput. Ind.*, vol. 65, no. 3, pp. 449–469, 2014, doi: 10.1016/j.compind.2014.01.008.

[112] S. Henson and J. Humphrey, “Understanding the Complexities of Private Standards in

Global Agri-Food Chains as They Impact Developing Countries," *http://dx.doi.org/10.1080/00220381003706494*, vol. 46, no. 9, pp. 1628–1646, 2010, doi: 10.1080/00220381003706494.

[113] M. Ball, "Rebuilding construction (Routledge Revivals): Economic change in the British construction industry," *Rebuilding Constr. (Routledge Revivals) Econ. Chang. Br. Constr. Ind.*, pp. 1–241, Mar. 2014, doi: 10.4324/9781315816715/REBUILDING-CONSTRUCTION-ROUTLEDGE-REVIVALS-MICHAEL-BALL.

[114] M. Miozzo and P. Dewick, "Networks and innovation in European construction: Benefits from inter-organisational cooperation in a fragmented industry," *Int. J. Technol. Manag.*, vol. 27, no. 1, pp. 68–92, 2004, doi: 10.1504/IJTM.2004.003882.

[115] D. M. Sheath, H. Woolley, R. Cooper, J. Hinks, and G. Aouad, "The development of a generic design and construction process protocol for the UK construction industry," *Natl. Conf. Publ. Eng. Aust. Ncp*, no. February 1996, pp. 85–90, 1996.

[116] A. Wild, *The Working Party Report to the Minister of Works: The Phillips Report on Building (1948–50)*. John Wiley & Sons, Ltd, 2003.

[117] Emmerson H, "Ministry of Works Survey of Problems before the Construction Industries (Emmerson Report)," 1962.

[118] C. Hardcastle, P. Kennedy, and J. Tookey, "The Placing and Management of Contracts for Building and Civil Engineering Work: The Banwell Report (1964)," *Constr. Reports 1944–98*, pp. 55–68, Jan. 2003, doi: 10.1002/9780470758526.CH5.

[119] Gyles R, "Final report / Royal Commission into Productivity in the Building Industry in New South Wales.," 1992.

[120] M. Latham, "Constructing the team," 1994.

[121] J. Egan, "Rethinking Construction: The Report of the Construction Task Force," *Constr. Task Force*, 1998.

[122] McKinsey & Company, "Reinventing Construction: A Route To Higher Productivity," 2017.

[123] R. Marciniak, P. Móricz, and M. Baksa, "Promotion of an Industry – Trends and Expectations of Digital Transformation in the Hungarian Business Services Sector," pp.

1–16, 2017.

[124] M. A. Silverio-Fernández, S. Renukappa, and S. Suresh, “Strategic framework for implementing smart devices in the construction industry,” *Constr. Innov.*, vol. 21, no. 2, pp. 218–243, Mar. 2021, doi: 10.1108/CI-11-2019-0132/FULL/XML.

[125] A. Bisello, V. Antoniucci, and G. Marella, “Measuring the price premium of energy efficiency: A two-step analysis in the Italian housing market,” *Energy Build.*, vol. 208, p. 109670, Feb. 2020, doi: 10.1016/J.ENBUILD.2019.109670.

[126] M. Iqbal, N. Ahmad, M. Waqas, and M. Abrar, “COVID-19 pandemic and construction industry: Impacts, emerging construction safety practices, and proposed crisis management,” *Brazilian J. Oper. Prod. Manag.*, vol. 18, no. 2, pp. 1–17, Jun. 2021, doi: 10.14488/BJOPM.2021.034.

[127] P. Tuominen, K. Klobut, A. Tolman, A. Adjei, and M. De Best-Waldhober, “Energy savings potential in buildings and overcoming market barriers in member states of the European Union,” *Energy Build.*, vol. 51, pp. 48–55, 2012, doi: 10.1016/j.enbuild.2012.04.015.

[128] J. J. Hunhevicz and D. Hall, “Crypto-Economic Incentives in the Construction Industry,” 2020, doi: 10.3929/ethz-b-000420837.

[129] P. Schroeder, K. Anggraeni, and U. Weber, “The Relevance of Circular Economy Practices to the Sustainable Development Goals,” *J. Ind. Ecol.*, vol. 23, no. 1, pp. 77–95, Feb. 2019, doi: 10.1111/JIEC.12732.

[130] Y. Rezgui, *Harvesting and Managing Knowledge in Construction: From Theoretical Foundations to Business Applications*. Routledge, 2011.

[131] European Commission, “A Renovation Wave for Europe - greening our buildings, creating jobs, improving lives ,” 2020.

[132] European Commission, “The European Pillar of Social Rights Action Plan,” 2019.

[133] European Commission, “Skills Panorama,” 2020. .

[134] European Commission, “BUILD UP Skills – rebooting the National Platforms and Roadmaps,” 2021.

[135] M. Parietti, “Blue-Collar vs. White-Collar: What’s the Difference?,” *Investopedia*, 2021.

https://www.investopedia.com/articles/wealth-management/120215/blue-collar-vs-white-collar-different-social-classes.asp (accessed Jan. 25, 2022).

[136] A. Alhamami, I. Petri, Y. Rezgui, and S. Kubicki, "Promoting Energy Efficiency in the Built Environment through Adapted BIM Training and Education," *Energies 2020, Vol. 13, Page 2308*, vol. 13, no. 9, p. 2308, May 2020, doi: 10.3390/EN13092308.

[137] V. Bazjanac and D. Crawley, "INDUSTRY FOUNDATION CLASSES AND INTEROPERABLE COMMERCIAL SOFTWARE IN SUPPORT OF DESIGN OF ENERGY-EFFICIENT BUILDINGS," 1999. Accessed: Apr. 11, 2020. [Online]. Available: http://www.inive.org/members_area/medias/pdf/Inive/IBPSA/UFSC755.pdf.

[138] A. Andriamamonjy, D. Saelens, and R. Klein, "A combined scientometric and conventional literature review to grasp the entire BIM knowledge and its integration with energy simulation," *Journal of Building Engineering*, vol. 22. Elsevier Ltd, pp. 513–527, Mar. 01, 2019, doi: 10.1016/j.jobe.2018.12.021.

[139] D. B. Crawley *et al.*, "EnergyPlus: Creating a new-generation building energy simulation program," *Energy Build.*, vol. 33, no. 4, pp. 319–331, 2001, doi: 10.1016/S0378-7788(00)00114-6.

[140] J. Hirsch, "DOE-2 building energy use and cost analysis tool," 1998. http://doe2.com/ (accessed Apr. 11, 2020).

[141] DOE, "EnergyPlus." 2021.

[142] DOE, "Simergy | Energy-Models.com." 2013.

[143] L. Bottaccioli *et al.*, "Building Energy Modelling and Monitoring by Integration of IoT Devices and Building Information Models," *2017 IEEE 41st Annu. Comput. Softw. Appl. Conf.*, pp. 914–922, 2017, doi: 10.1109/COMPSAC.2017.75.

[144] D. A. Shafiq, N. Z. Jhanjhi, A. Abdullah, and M. A. Alzain, "A Load Balancing Algorithm for the Data Centres to Optimize Cloud Computing Applications," *IEEE Access*, vol. 9, pp. 41731–41744, 2021, doi: 10.1109/ACCESS.2021.3065308.

[145] S. Oniani, G. Marques, S. Barnovi, I. M. Pires, and A. K. Bhoi, "Artificial Intelligence for Internet of Things and Enhanced Medical Systems," *Stud. Comput. Intell.*, vol. 903, pp. 43–59, 2021, doi: 10.1007/978-981-15-5495-7_3.

[146] A. Hodorog, A. H. S. Alhamami, I. Petri, Y. Rezgui, S. Kubicki, and A. Guerriro, "Social media mining for BIM skills and roles for energy efficiency," Jun. 2019, doi: 10.1109/ICE.2019.8792571.

[147] L. Sathish Kumar, M. Ramanan, J. A. Alzubi, P. Jayarajan, and S. Thenmozhi, "Smart Metering Using IoT and ICT for Sustainable Seller Consumer in Smart City," *EAI/Springer Innov. Commun. Comput.*, pp. 75–89, 2021, doi: 10.1007/978-3-030-70183-3_4.

[148] L. Ruddock, "ICT in the construction sector: Computing the economic benefits," *Int. J. Strateg. Prop. Manag.*, vol. 10, no. 1, pp. 39–50, Jan. 2006, doi: 10.1080/1648715X.2006.9637543.

[149] International Data Corporation, "IDC - Global ICT Spending - Forecast 2020 – 2023," 2020.

[150] N. Sanders, "A Possible First Use of CAM / CAD," 2017.

[151] Y. Rezgui, S. Boddy, M. Wetherill, and G. Cooper, "Past, present and future of information and knowledge sharing in the construction industry: Towards semantic service-based e-construction?," *Comput. Des.*, vol. 43, no. 5, pp. 502–515, May 2011, doi: 10.1016/J.CAD.2009.06.005.

[152] B.-C. Björk, "Basic structure of a proposed building product model," *Comput. Des.*, vol. 21, no. 2, pp. 71–78, Mar. 1989, doi: 10.1016/0010-4485(89)90141-3.

[153] C. M. Eastman and A. Siabiris, "A generic building product model incorporating building type information," *Autom. Constr.*, vol. 3, no. 4, pp. 283–304, Jan. 1995, doi: 10.1016/0926-5805(94)00028-L.

[154] S. E. Mattsson, M. Andersson, and K. J. Åström, "Object-Oriented Modeling and Simulation," in *CAD for Control Systems*, CRC Press, 2020, pp. 31–69.

[155] Y. Rezgui, "Exploring virtual team-working effectiveness in the construction sector," *Interact. Comput.*, vol. 19, no. 1, pp. 96–112, Jan. 2007, doi: 10.1016/j.intcom.2006.07.002.

[156] Y. Rezgui, G. Cooper, and P. Brandon, "Information Management in a Collaborative Multiactor Environment: The COMMIT Approach," *J. Comput. Civ. Eng.*, vol. 12, no. 3, pp. 136–144, Jul. 1998, doi: 10.1061/(ASCE)0887-3801(1998)12:3(136).

[157] Y. Rezgui, G. Cooper, and P. Brandon, “Information Management in a Collaborative Multiactor Environment: The COMMIT Approach,” *J. Comput. Civ. Eng.*, vol. 12, no. 3, pp. 136–144, Jul. 1998, doi: 10.1061/(ASCE)0887-3801(1998)12:3(136).

[158] “Product modeling using STEP,” *Comput. Des.*, vol. 27, no. 3, pp. 163–179, 1995.

[159] A. Coulibaly, B. Mutel, and D. Ait-Kadi, “Product modeling framework for behavioral performance evaluation at design stage,” *Comput. Ind.*, vol. 58, no. 6, pp. 567–577, Aug. 2007, doi: 10.1016/J.COMPIND.2006.12.005.

[160] A. Z. Sampaio, “BIM as a Computer-Aided Design Methodology in Civil Engineering,” *J. Softw. Eng. Appl.*, vol. 10, no. 2, pp. 194–210, Feb. 2017, doi: 10.4236/JSEA.2017.102012.

[161] WSP-PB, “What is BIM?,” 2013. http://www.wsp-pb.com/en/Who-we-are/In-the-media/News/2013/What-is-BIM/ (accessed Jul. 20, 2018).

[162] M. Yakami, V. Singh, and S. Suwal, “What Do Students and Professionals Think of BIM Competence?,” in *Product Lifecycle Management and the Industry of the Future*, 2017.

[163] S. Yarmohammadi and B. Ashuri, “Exploring the approaches in the implementation of BIM-based MEP coordination in the USA,” *J. Inf. Technol. Constr.*, vol. 20, pp. 347–363, Sep. 2015.

[164] S. Mohd and A. Latiffi, “Building Information Modeling (BIM) application in construction planning,” 2013.

[165] A. Dainty, D. Moore, and M. Murray, *Communication in construction: Theory and practice*, 1st Editio. Taylor & Francis Taylor & Francis Group, 2005.

[166] I. Petri, Y. Rezgui, T. Beach, H. Li, M. Arnesano, and G. M. Revel, “A semantic service-oriented platform for energy efficient buildings,” *Clean Technol. Environ. Policy*, vol. 17, no. 3, pp. 721–734, Mar. 2015, doi: 10.1007/s10098-014-0828-2.

[167] U. Isikdag, J. Underwood, and M. Kuruoglu, “Building Information Modelling,” in *Construction Innovation and Process Improvement*, Wiley-Blackwell, 2012, pp. 385–407.

[168] B. Succar, W. Sher, and A. Williams, “An integrated approach to BIM competency assessment, acquisition and application,” *Autom. Constr.*, vol. 35, pp. 174–189, Nov.

2013, doi: 10.1016/J.AUTCON.2013.05.016.

[169] P. Caratti and G. Locascio, "Sustainable Development Policies in Europe," *SSRN Electron. J.*, 2006, doi: 10.2139/ssrn.952936.

[170] K. Davies, D. McMeel, and S. Wilkinson, "Soft skill requirements in a BIM project team," in *the 32nd International Conference of CIB*, 2015, pp. 108–117.

[171] M. B. Barison and E. T. Santos, "The Competencies of BIM Specialists: a Comparative Analysis of the Literature Review and Job Ad Descriptions," 2011, Accessed: Jul. 20, 2018. [Online]. Available: http://www.ascelib.

[172] C. S. Dossick, N. Lee, and S. Foleyk, "Building Information Modeling in Graduate Construction Engineering and Management Education," in *Computing in Civil and Building Engineering (2014)*, Jun. 2014, pp. 2176–2183, doi: 10.1061/9780784413616.270.

[173] W. Wu and R. R. A. Issa, "Key Issues in Workforce Planning and Adaptation Strategies for BIM Implementation in Construction Industry," in *Construction Research Congress 2014*, May 2014, pp. 847–856, doi: 10.1061/9780784413517.087.

[174] M. Taiebat and K. Ku, "Industry's Expectations of Construction School Graduates' BIM Skills," *ASC Annu. Int. Conf.*, 2009, Accessed: Jul. 20, 2018. [Online]. Available: http://ascpro.ascweb.org/chair/paper/CEUE217002010.pdf.

[175] R. A. Rahman, S. Alsafouri, and S. K. Ayer, "Comparing Building Information Modeling Skills of Project Managers and BIM Managers Based on Social Media Analysis," *Procedia Eng.*, vol. 145, pp. 812–819, Jan. 2016, doi: 10.1016/J.PROENG.2016.04.106.

[176] R. Murphy and S. Walsh, "Employment Opportunities and Skills Requirements for Construction and Property Surveying," *Reports Sch. Surv. Constr. Manag.*, 2014, Accessed: Jul. 20, 2018. [Online]. Available: http://arrow.dit.ie/beschrecrep.

[177] R. Bush and M. Robinson, "Developing a BIM Competency Framework: Research and Key Principle," *Scottish Futur. Trust*, no. July, pp. 1–43, 2018.

[178] M. Yakami *et al.*, "What Do Students and Professionals Think of BIM Competence ?," 2018.

[179] S. Fan, M. Skibniewski, T. H.-J. of A. Science, and undefined 2014, "Effects of building

information modeling during construction," *J. Appl. Sci.*, 2014, doi: 10.6180/jase.2014.17.2.06.

[180] M. Kassem, N. Iqbal, G. Kelly, S. Lockley, and N. Dawood, "Building information modelling: Protocols for collaborative design processes," *J. Inf. Technol. Constr.*, vol. 19, no. July, pp. 126–149, 2014.

[181] M. Kassem, G. Kelly, N. Dawood, M. Serginson, and S. Lockley, "BIM in facilities management applications: A case study of a large university complex," *Built Environ. Proj. Asset Manag.*, vol. 5, no. 3, pp. 261–277, Jul. 2015, doi: 10.1108/BEPAM-02-2014-0011.

[182] T. Beach, T. Kasim, and H. LI, *RegBIM - BIM for Smart Engineering*. 2014.

[183] BRE Group, "BREEAM - Sustainability Assessment Method," 2012. .

[184] J. Parker, "The value of BREEAM : a BSRIA report," 2012.

[185] W. Wu and R. Issa, "INTEGRATED PROCESS MAPPING FOR BIM IMPLEMENATION IN GREEN BUILDING PROJECT DELIVERY 1," pp. 30–31, 2013, Accessed: Mar. 06, 2018. [Online]. Available: http://itc.scix.net/data/works/att/convr-2013-3.pdf.

[186] A. Fazeli, F. Jalaei, M. Khanzadi, and S. Banihashemi, "BIM-integrated TOPSIS-Fuzzy framework to optimize selection of sustainable building components," *https://doi.org/10.1080/15623599.2019.1686836*, 2019, doi: 10.1080/15623599.2019.1686836.

[187] M. Gujral and A. P. Dash, "Technology and the Changing Communications Environment," pp. 261–292, 2021, doi: 10.1007/978-3-030-81329-1_10.

[188] European Commission, "Improving the human capital basis," 2020.

[189] Manchester Business School, "BAA The T5 Project Agreement (A) ecch the case for learning," *Univ. Manchester*, vol. 44, no. 308, 2008.

[190] R. Russell, M. Ormerod, and R. Newton, "The Development of a Design and Construction Process Protocol to Support the Home Modification Process Delivered by Occupational Therapists," *J. Aging Res.*, 2018, doi: 10.1155/2018/4904379.

[191] Ministry of Defence, "Appropriation accounts 1997-98.," Stationery Office, 1998.

[192] M. Potter, *Planning to build? : a practical introduction to the construction process*.

Construction Industry Research and Information Association, 1995.

[193] The British Standards Institution, “BS7000 : Part 4 : 1996 Design management systems Part 4 : Guide to managing design in construction,” no. 1, pp. 4–7, 2014.

[194] V. Hubka and W. E. (Wolfgang E. Eder, *Principles of engineering design*. 1982.

[195] G. Pahl and W. Beitz, “Engineering Design: A Systematic Approach,” p. 212, 2007, Accessed: Mar. 08, 2018. [Online]. Available: https://books.google.co.uk/books?hl=ar&lr=&id=4uvSBwAAQBAJ&oi=fnd&pg=PR12&dq=Engineering+Design:+A+Systematic+Approach.+Pahl,+G.+%26+Beitz,+W.&ots=plofsdqeSr&sig=6-CsSPkhMixZE-lR4oXgWrVGAU0#v=onepage&q=Engineering%2520Design%253A%2520A%2520Systematic%2520.

[196] VDI-Richtlinie 2222, “Konstruktionsmethodik, Konzipieren technischer Produkte,” 1973.

[197] M. J. French, *Conceptual Design for Engineers*. Berlin, Heidelberg: Springer Berlin Heidelberg, 1971.

[198] P. Holden, *Construction : a practical guide to RIBA Plan of work 2013 stages 4, 5 and 6*. Royal Institute of British Architects, 2019.

[199] S. Macmillan, J. Steele, S. Austin, R. Spence, and P. Kirby, “MAPPING THE EARLY STAGES OF THE DESIGN PROCESS -A COMPARISON BETWEEN ENGINEERING AND CONSTRUCTION,” 1999, Accessed: Mar. 07, 2018. [Online]. Available: http://www.eclipseresearch.co.uk/download/design_innovation_and_value/mapping_early_stages.pdf.

[200] I. Davies, “The RIBA Plan of Work 2013: Overview,” *Contract Adm.*, pp. 10–11, 2020, doi: 10.4324/9780429347177-2.

[201] RIBA, “RIBA President reacts to new UK Government,” 2021. .

[202] D. Sinclair, S. Beck, and A. Tait, “RIBA Plan of Work 2013 Overview,” *R. Inst. Br. Archit.*, p. 40, 2013, doi: ISBN 978 1 85946 519 6.

[203] D. Sinclair, *Guide to Using the Riba Plan of Work 2013.* 2019.

[204] A. Travaglini, M. Radujkovic, and M. Mancini, “Building Information Modelling (BIM)

and Project Management: a Stakeholders Perspective," *Organ. Technol. Manag. Constr. An Int. J.*, vol. 6, no. 2, 2014, doi: 10.5592/otmcj.2014.2.8.

[205] J. Karlshoj, "A BIM Mandate Lesson from Denmark.," 2016.

[206] Dobrindt, "Road Map for Digital Design and Construction: Introduction of modern, IT-based processes and technologies for the design, construction and operation of assets in the built environment," 2016.

[207] GOV.UK, "Government Construction Strategy GCS 2016-2020," no. March, p. 16, 2016.

[208] Ministère de la Transition écologique, "Building and digital," 2019. .

[209] Irish Green Building Council, "Green Building Network - BIM and Sustainability ," 2018. .

[210] Spanish Labour Foundation for Construction, "Barcelona training centre," 2020. .

[211] B. R. Norton and W. C. McElligott, "Value Management in Construction," *Value Manag. Constr.*, 2014, doi: 10.1007/978-1-349-13350-5.

[212] H. Cherkaoui, "BIM Loket: The Dutch BIM Gateway," 2017.

[213] L. Berg, "Digital'Construction'in'Lithuania," no. 20130051, 2015.

[214] European Commission, "European Construction Sector Observatory: Country profile Czech Republic," pp. 1–38, 2018.

[215] J. Patacas, N. Dawood, V. Vukovic, and M. Kassem, "BIM for facilities management: evaluating BIM standards in asset register creation and service life planning," *ITcon Vol. 20, pg. 313-331, http//www.itcon.org/2015/20*, vol. 20, no. January, pp. 313–331, 2015.

[216] ABBL, "House of Training," 2021. .

[217] C. Vidalakis, F. H. Abanda, and A. H. Oti, "BIM adoption and implementation: focusing on SMEs," *Constr. Innov.*, vol. 20, no. 1, pp. 128–147, Jan. 2020, doi: 10.1108/CI-09-2018-0076/FULL/XML.

[218] E. Bakogiannis, K. Papadaki, C. Kyriakidis, and C. Potsiou, "How to Adopt BIM in the Building Construction Sector across Greece?," *Appl. Sci. 2020, Vol. 10, Page 1371*, vol. 10, no. 4, p. 1371, Feb. 2020, doi: 10.3390/APP10041371.

[219] A. Guerriero *et al.*, “BIM4VET, Towards BIM Training Recommendation for AEC Professionals,” *Adv. Informatics Comput. Civ. Constr. Eng.*, pp. 833–840, 2019, doi: 10.1007/978-3-030-00220-6_100.

[220] E. Hochscheid and G. Halin, “BIM Implementationin Architecture Firms Interviews,case studies and action research used to build a method that facilitates implementation of BIM processes and tools,” Sep. 2018.

[221] INES, “Our trainings INES - Institut National de l’Énergie Solaire,” 2021. .

[222] EQUA, “Building Performance - Simulation Software,” 2021. .

[223] I. Musonda, “The Strategic Application of Building Information Modelling (BIM) to the Role of Construction Project Management,” pp. 470–479, 2019, doi: 10.3311/ccc2019-065.

[224] G. Burgess, M. Jones, and K. Muir, “BIM in the UK house building industry: opportunities and barriers to adoption,” *Cambridge Univ. Cambridge*, no. March, pp. 1–8, 2018.

[225] K. A. Awwad, A. Shibani, and M. Ghostin, “Exploring the critical success factors influencing BIM level 2 implementation in the UK construction industry: the case of SMEs,” *Int. J. Constr. Manag.*, 2020, doi: 10.1080/15623599.2020.1744213.

[226] M. C. Georgiadou, “An overview of benefits and challenges of building information modelling (BIM) adoption in UK residential projects,” *Constr. Innov.*, vol. 19, no. 3, pp. 298–320, Jul. 2019, doi: 10.1108/CI-04-2017-0030.

[227] A. Kraak, “Sector skills councils in international perspective : in search of best practice,” no. September, 2015, doi: 10.13140/RG.2.1.1090.9927.

[228] H. M. I. for E. Estyn and and T. in Wales, “A report on CITB-ConstructionSkills,” 2011.

[229] Energy & Utility Skills, “Energy & Utility Skills brings industry leaders together to identify and address the skills challenges our sector faces.,” 2017. .

[230] The Sector Skills Council for Building Services Engineering, “SummitSkills,” 2011.

[231] BSI, “PAS 1192-3:2014 Specification for information management for the operational phase of assets using building information modelling ,” 2014.

[232] C. Wales, “Low carbon skills requirements for the regeneration and built environment professional services sector in Wales2011 ”,.

[233] S. Lester, "The European Qualifications Framework: a technical critique," *http://dx.doi.org/10.1080/13596748.2015.1030251*, vol. 20, no. 2, pp. 159–172, Apr. 2015, doi: 10.1080/13596748.2015.1030251.

[234] R. Metraglia, G. Baronio, and V. Villa, "Learning levels in technical drawing education: Proposal for an assessment grid based on the european qualifications framework (EQF)," *ICED 11 - 18th Int. Conf. Eng. Des. - Impacting Soc. Through Eng. Des.*, vol. 8, no. August, pp. 161–172, 2011.

[235] IEA, "Saudi Arabia - Countries & Regions," 2021. https://www.iea.org/countries/saudi-arabia (accessed May 10, 2021).

[236] U.S. Energy Information Administration, "Saudi Arabia used less crude oil for power generation in 2018 - Today in Energy - U.S. Energy Information Administration (EIA)," 2018. https://www.eia.gov/todayinenergy/detail.php?id=39693 (accessed May 10, 2021).

[237] M. Alhashmi, S. M. Asce, H. Haider, K. Hewage, and R. Sadiq, "Energy Efficiency and Global Warming Potential in the Residential Sector: Comparative Evaluation of Canada and Saudi Arabia," *ascelibrary.org*, vol. 23, no. 3, p. 04017009, Sep. 2017, doi: 10.1061/(ASCE)AE.1943-5568.0000253.

[238] H. M. Abd-ur-Rehman, F. A. Al-Sulaiman, A. Mehmood, S. Shakir, and M. Umer, "The potential of energy savings and the prospects of cleaner energy production by solar energy integration in the residential buildings of Saudi Arabia," *J. Clean. Prod.*, vol. 183, pp. 1122–1130, May 2018, doi: 10.1016/j.jclepro.2018.02.187.

[239] N. W. . Young Jr., S. A. Jones, H. M. Bernstein, and J. E. Gudgel, "SmartMarket Report: the business value of BIM," 2009. [Online]. Available: http://bim.construction.com/research/pdfs/2009_BIM_SmartMarket_Report.pdf.

[240] R. Awwad and M. Ammoury, "Surveying BIM in the lebanese construction industry," in *ISARC 2013 - 30th International Symposium on Automation and Robotics in Construction and Mining, Held in Conjunction with the 23rd World Mining Congress*, 2013, pp. 963–971, doi: 10.22260/isarc2013/0105.

[241] W. Jung and G. Lee, "The Status of BIM Adoption on Six Continents," *ournal Civ. Environ. Eng.*, 2015.

[242] M. Sodangi, A. F. Salman, and M. Saleem, “Building Information Modeling: Awareness Across the Subcontracting Sector of Saudi Arabian Construction Industry,” *Arab. J. Sci. Eng.*, vol. 43, no. 4, pp. 1807–1816, 2018, doi: 10.1007/s13369-017-2756-z.

[243] I. Petri, T. Beach, Y. Rezgui, I. E. Wilson, and H. Li, “Engaging construction stakeholders with sustainability through a knowledge harvesting platform,” *Comput. Ind.*, vol. 65, no. 3, pp. 449–469, Apr. 2014, doi: 10.1016/J.COMPIND.2014.01.008.

[244] Y. Rezgui, T. Beach, and O. Rana, “A governance approach for BIM management across lifecycle and supply chains using mixed-modes of information delivery,” *J. Civ. Eng. Manag.*, vol. 19, no. 2, pp. 239–258, Apr. 2013, doi: 10.3846/13923730.2012.760480.

[245] Pauline Traetto, “The step change needed in construction skills,” 2018. https://www.bre.ac/ (accessed Mar. 02, 2019).

[246] A. Alhamami, I. Petri, Y. Rezgui, and S. Kubicki, “Promoting Energy Efficiency in the Built Environment through Adapted BIM Training and Education,” *Energies*, vol. 13, no. 9, p. 2308, May 2020, doi: 10.3390/en13092308.

[247] I. Petri, A. Alhamami, Y. Rezgui, and S. Kubicki, “A Virtual Collaborative Platform to Support Building Information Modeling Implementation for Energy Efficiency,” in *IFIP Advances in Information and Communication Technology*, 2018, vol. 534, pp. 539–550, doi: 10.1007/978-3-319-99127-6_46.

[248] D. Zhao, A. P. McCoy, T. Bulbul, C. Fiori, and P. Nikkhoo, “Building Collaborative Construction Skills through BIM-integrated Learning Environment,” *Int. J. Constr. Educ. Res.*, vol. 11, no. 2, pp. 97–120, Apr. 2015, doi: 10.1080/15578771.2014.986251.

[249] B. Oates, *Researching information systems and computing*. 2005.

[250] D. Muijs, *Doing quantitative research in education with SPSS*. 2010.

[251] A. Bowling, *Research methods in health: investigating health and health services*. 2014.

[252] A. Bryman, *Social research methods*. 2016.

[253] M. Saks and J. Allsop, *Researching health: Qualitative, quantitative and mixed methods*. 2012.

[254] P. R. Giacobbi, A. Poczwardowski, and P. Hager, “A Pragmatic Research Philosophy for Sport and Exercise Psychology,” *Sport Psychol.*, vol. 19, no. 1, pp. 18–31, Mar. 2005, doi:

10.1123/TSP.19.1.18.

[255] M. Saunders, P. Lewis, A. Thornhill, and P. Hall, *Research Methods for Business Students* , Fourth Edition. 2009.

[256] M. N. K. Saunders and P. C. Tosey, “The layers of research design rapport,” 2012.

[257] M. D. Myers, “Critical Ethnography in Information Systems,” *Inf. Syst. Qual. Res.*, pp. 276–300, 1997, doi: 10.1007/978-0-387-35309-8_15.

[258] R. Yin, *Applications of case study research*. 2011.

[259] R. Fellows and A. Liu, *Research Methods for Construction*, Fourth Edition. 2015.

[260] E. Bell, A. Bryman, and B. Harley, *Business Research Methods*, Fifth. 2018.

[261] G. Peng, F. A.-I. systems research and, and undefined 2013, “Experiences in applying mixed-methods approach in information systems research,” *igi-global.com*, Accessed: May 23, 2021. [Online]. Available: https://www.igi-global.com/chapter/content/70720.

[262] J. F. Molina-Azorin, R. Cameron, and J. Molina Azorín, “The Application of Mixed Methods in Organisational Research: A Literature Review,” *Electron. J. Bus. Res. Methods*, vol. 8, pp. 95–105, 2010, Accessed: May 23, 2021. [Online]. Available: www.ejbrm.com.

[263] T. C. Lethbridge, S. E. Sim, and J. Singer, “Studying software engineers: Data collection techniques for software field studies,” *Empir. Softw. Eng.*, vol. 10, no. 3, pp. 311–341, Sep. 2005, doi: 10.1007/s10664-005-1290-x.

[264] J. Creswell and J. Creswell, *Research Design (Qualitative, Quantitative and Mixed Methods Approaches)*. 2017.

[265] R. B. Johnson and A. J. Onwuegbuzie, “Mixed Methods Research: A Research Paradigm Whose Time Has Come,” *Educ. Res.*, vol. 33, no. 7, pp. 14–26, 2004, doi: 10.3102/0013189X033007014.

[266] R. B. Johnson, A. J. Onwuegbuzie, and L. A. Turner, “Toward a Definition of Mixed Methods Research,” *journals.sagepub.com*, vol. 1, no. 2, pp. 112–133, 2007, doi: 10.1177/1558689806298224.

[267] A. Tashakkori and C. Teddie, *Handbook on mixed methods in the behavioral and social*.

2003.

[268] D. Niemeijer and R. S. de Groot, “A conceptual framework for selecting environmental indicator sets,” *Ecol. Indic.*, vol. 8, no. 1, pp. 14–25, 2008, doi: 10.1016/j.ecolind.2006.11.012.

[269] D. Simpson, M. K.-U. of Louisville, and undefined 2006, “Indicator issues and proposed framework for a disaster preparedness index (DPi),” *beta.fritzinstitute.org*, 2006.

[270] B. BLUMBERG, D. COOPER, and P. SCHINDLER, *Quantitative and qualitative research*. 2008.

[271] S. Becker, A. Bryman, and H. Ferguson, *Understanding research for social policy and social work 2E: themes, methods and approaches*. 2012.

[272] K. Popper, “The Logic of Scientific Discovery,” 2005. Accessed: May 23, 2021. [Online]. Available: https://books.google.co.uk/books?hl=en&lr=&id=LWSBAgAAQBAJ&oi=fnd&pg=PP1&dq=POPPER,+K.+2005.+The+logic+of+scientific+discovery.&ots=pAEe1Z-LeN&sig=vDXtq9nvAgKHuTr1EQKoMfFwjNk.

[273] F. Khosrowshahi and Y. Arayici, “Roadmap for implementation of BIM in the UK construction industry,” *Engineering, Construction and Architectural Management*, vol. 19, no. 6. pp. 610–635, 2012, doi: 10.1108/09699981211277531.

[274] C. Carpino, D. Mora, and M. De Simone, “On the use of questionnaire in residential buildings. A review of collected data, methodologies and objectives,” *Energy and Buildings*, vol. 186. Elsevier Ltd, pp. 297–318, Mar. 01, 2019, doi: 10.1016/j.enbuild.2018.12.021.

[275] A. Oppenheim, *Questionnaire design, interviewing and attitude measurement*. 2000.

[276] D. Remenyi, B. Williams, A. Money, and E. Swartz, *Doing research in business and management: an introduction to process and method.* 1998.

[277] P. Brewerton and L. Millward, *Organizational research methods: A guide for students and researchers*2001 ·.

[278] Z. Zainal, “Case study as a research method,” 2007. Accessed: May 23, 2021. [Online]. Available:

https://jurnalkemanusiaan.utm.my/index.php/kemanusiaan/article/view/165.

[279] E. M. Carr, G. D. Zhang, J. (Hung) Y. Ming, and Z. S. Siddiqui, "Qualitative research: An overview of emerging approaches for data collection," *Australas. Psychiatry*, vol. 27, no. 3, pp. 307–309, 2019, doi: 10.1177/1039856219828164.

[280] J. A. Greene, N. K. Choudhry, E. Kilabuk, and W. H. Shrank, "Online Social Networking by Patients with Diabetes: A Qualitative Evaluation of Communication with Facebook," *J. Gen. Intern. Med. 2010 263*, vol. 26, no. 3, pp. 287–292, Oct. 2010, doi: 10.1007/S11606-010-1526-3.

[281] B. Hemsley, S. Dann, S. Palmer, M. Allan, and S. Balandin, "'We definitely need an audience': experiences of Twitter, Twitter networks and tweet content in adults with severe communication disabilities who use augmentative and alternative communication (AAC)," *https://doi.org/10.3109/09638288.2015.1045990*, vol. 37, no. 17, pp. 1531–1542, Aug. 2015, doi: 10.3109/09638288.2015.1045990.

[282] D. Velliaris and D. Coleman, *Handbook of Research on Study Abroad Programs and Outbound Mobility*. 2016.

[283] A. Kumar and B. Bahadur, "Computer Application in Ethnobotany," in *Ethnobotany of India, Volume 1*, 2016.

[284] S. Suwal *et al.*, "Building Energy-Efficiency delivered with the Help of Improved Building Information Modelling Skills Collective activity modeling and visualisation View project Roles of industry associations in macro-BIM adoption in Quebec and Luxembourg View project Building Energy-Efficiency delivered with the Help of Improved Building Information Modelling Skills," 2018, Accessed: May 20, 2020. [Online]. Available: https://www.researchgate.net/publication/326836100.

[285] A. Alhamami, I. Petri, and Y. Rezgui, "Use-case analysis for assessing the role of Building Information Modeling in energy efficiency*2018* ",, Accessed: Jan. 18, 2020. [Online]. Available: http://orca.cf.ac.uk/id/eprint/121056.

[286] M. E. Falagas, E. I. Pitsouni, G. A. Malietzis, and G. Pappas, "Comparison of PubMed, Scopus, Web of Science, and Google Scholar: Strengths and weaknesses," *FASEB J.*, vol. 22, no. 2, pp. 338–342, Feb. 2008, doi: 10.1096/fj.07-9492LSF.

[287] J. F. Burnham, "Scopus database: A review," *Biomedical Digital Libraries*, vol. 3. Mar.

08, 2006, doi: 10.1186/1742-5581-3-1.

[288] T. Bartol, G. Budimir, D. Dekleva-Smrekar, M. Pusnik, and P. Juznic, “Assessment of research fields in Scopus and Web of Science in the view of national research evaluation in Slovenia,” *Scientometrics*, vol. 98, no. 2, pp. 1491–1504, 2014, doi: 10.1007/s11192-013-1148-8.

[289] R. Sebastian, “Changing roles of the clients, architects and contractors through BIM,” *Eng. Constr. Archit. Manag.*, vol. 18, no. 2, pp. 176–187, 2011, doi: 10.1108/09699981111111148.

[290] V. Singh, “BIM and systemic ICT innovation in AEC: Perceived needs and actor’s degrees of freedom,” *Construction Innovation*, vol. 14, no. 3. Emerald Group Publishing Ltd., pp. 292–306, Jul. 01, 2014, doi: 10.1108/CI-02-2013-0006.

[291] A. Braun and A. Borrmann, “Combining inverse photogrammetry and BIM for automated labeling of construction site images for machine learning,” *Autom. Constr.*, vol. 106, Oct. 2019, doi: 10.1016/j.autcon.2019.102879.

[292] F. Shadram and J. Mukkavaara, “An integrated BIM-based framework for the optimization of the trade-off between embodied and operational energy,” *Energy Build.*, vol. 158, pp. 1189–1205, Jan. 2018, doi: 10.1016/j.enbuild.2017.11.017.

[293] M. Bew, “Briefing: Level 2 building information modelling and the institution of civil engineers’ action groups,” in *Proceedings of Institution of Civil Engineers: Management, Procurement and Law*, Jun. 2014, vol. 167, no. 3, pp. 112–113, doi: 10.1680/mpal.14.00010.

[294] G. Costa, Á. Sicilia, X. Oregi, J. Pedrero, and L. Mabe, “A catalogue of energy conservation measures (ECM) and a tool for their application in energy simulation models,” *Journal of Building Engineering*, vol. 29. Elsevier Ltd, May 01, 2020, doi: 10.1016/j.jobe.2019.101102.

[295] S. Habibi, “The promise of BIM for improving building performance,” *Energy Build.*, vol. 153, pp. 525–548, Oct. 2017, doi: 10.1016/j.enbuild.2017.08.009.

[296] R. Davies and C. Harty, “Implementing ‘site BIM’: A case study of ICT innovation on a large hospital project,” *Autom. Constr.*, vol. 30, pp. 15–24, 2013, doi: 10.1016/j.autcon.2012.11.024.

[297] T. K. Gustavsson, “Liminal roles in construction project practice: exploring change through the roles of partnering manager, building logistic specialist and BIM coordinator,” *Constr. Manag. Econ.*, vol. 36, no. 11, pp. 599–610, Nov. 2018, doi: 10.1080/01446193.2018.1464197.

[298] P. M. Bosch-Sijtsema, P. Gluch, and A. A. Sezer, “Professional development of the BIM actor role,” *Autom. Constr.*, vol. 97, pp. 44–51, Jan. 2019, doi: 10.1016/j.autcon.2018.10.024.

[299] C. Zanchetta, P. Borin, C. Cecchini, and G. Xausa, “Computational design e sistemi di classificazione per la verifica predittiva delle prestazioni di sistema degli organismi edilizi,” *TECHNE*, vol. 13, pp. 329–336, 2017, doi: 10.13128/Techne-19759.

[300] J. Daller, M. Žibert, C. Exinger, and M. Lah, “Implementation of BIM in the tunnel design – Engineering consultant’s aspect,” *Geomech. und Tunnelbau*, vol. 9, no. 6, pp. 674–683, Dec. 2016, doi: 10.1002/geot.201600054.

[301] D. Ladenhauf *et al.*, “Computational geometry in the context of building information modeling,” *Energy Build.*, vol. 115, pp. 78–84, Mar. 2016, doi: 10.1016/j.enbuild.2015.02.056.

[302] F. Zamora-Polo, M. M. Sánchez-Cortés, A. M. Reyes-Rodríguez, and J. G. Sanz-Calcedo, “Developing project managers’ transversal competences using building information modeling,” *Appl. Sci.*, vol. 9, no. 19, Oct. 2019, doi: 10.3390/app9194006.

[303] A. Osello and E. Macii, “A BIM interoperable process for energy efficiency control in existing buildings,” *Int. J. Des. Sci. Technol.*, vol. 19, no. 1, pp. 27–44, 2012.

[304] A. Costa, M. M. Keane, J. I. Torrens, and E. Corry, “Building operation and energy performance: Monitoring, analysis and optimisation toolkit,” *Appl. Energy*, vol. 101, pp. 310–316, 2013, doi: 10.1016/j.apenergy.2011.10.037.

[305] R. Eadie, M. Browne, H. Odeyinka, C. McKeown, and S. McNiff, “BIM implementation throughout the UK construction project lifecycle: An analysis,” *Autom. Constr.*, vol. 36, pp. 145–151, 2013, doi: 10.1016/j.autcon.2013.09.001.

[306] E. Alreshidi, M. Mourshed, and Y. Rezgui, “Factors for effective BIM governance,” *J. Build. Eng.*, vol. 10, pp. 89–101, Mar. 2017, doi: 10.1016/j.jobe.2017.02.006.

[307] M. A. Zanni, R. Soetanto, and K. Ruikar, “Towards a BIM-enabled sustainable building design process: roles, responsibilities, and requirements,” *Archit. Eng. Des. Manag.*, vol. 13, no. 2, pp. 101–129, Mar. 2017, doi: 10.1080/17452007.2016.1213153.

[308] L. Ustinovichius, V. Popov, J. Cepurnaite, T. Vilutienė, M. Samofalov, and C. Miedziałowski, “BIM-based process management model for building design and refurbishment,” *Arch. Civ. Mech. Eng.*, vol. 18, no. 4, pp. 1136–1149, Sep. 2018, doi: 10.1016/j.acme.2018.02.004.

[309] F. Svalestuen, V. Knotten, O. Lædre, F. Drevland, and J. Lohne, “USING BUILDING INFORMATION MODEL (BIM) DEVICES TO IMPROVE INFORMATION FLOW AND COLLABORATION ON CONSTRUCTION SITES,” *J. Inf. Technol. Constr.*, vol. 22, pp. 204–219, Oct. 2017.

[310] H. Kreiner, A. Passer, and H. Wallbaum, “A new systemic approach to improve the sustainability performance of office buildings in the early design stage,” *Energy Build.*, vol. 109, pp. 385–396, 2015, doi: 10.1016/j.enbuild.2015.09.040.

[311] S. Van Nederveen and W. Gielingh, “Modelling the life-cycle of sustainable, living buildings,” *Electron. J. Inf. Technol. Constr.*, vol. 14, pp. 674–691, Oct. 2009.

[312] A. Schlueter and P. Geyer, “Linking BIM and Design of Experiments to balance architectural and technical design factors for energy performance,” *Autom. Constr.*, vol. 86, pp. 33–43, Feb. 2018, doi: 10.1016/j.autcon.2017.10.021.

[313] A. Sánchez, C. Gonzalez-Gaya, P. Zulueta, Z. Sampaio, and B. Torre, “Academic proposal for heritage intervention in a BIM environment for a 19th century flour factory,” *Appl. Sci.*, vol. 9, no. 19, Oct. 2019, doi: 10.3390/app9194134.

[314] R. Miettinen and S. Paavola, “Beyond the BIM utopia: Approaches to the development and implementation of building information modeling,” *Autom. Constr.*, vol. 43, pp. 84–91, 2014, doi: 10.1016/j.autcon.2014.03.009.

[315] T. K. Gustavsson, O. Samuelson, and Ö. Wikforss, “Organizing IT in construction: Present state and future challenges in Sweden,” *Electron. J. Inf. Technol. Constr.*, vol. 17, pp. 520–534, Sep. 2012.

[316] C. Koch and S. Beemsterboer, “Making an engine: performativities of building information standards,” *Build. Res. Inf.*, vol. 45, no. 6, pp. 596–609, Aug. 2017, doi:

10.1080/09613218.2017.1301745.

[317] Y. Arayici, T. Fernando, V. Munoz, and M. Bassanino, “Interoperability specification development for integrated BIM use in performance based design,” *Autom. Constr.*, vol. 85, pp. 167–181, Jan. 2018, doi: 10.1016/j.autcon.2017.10.018.

[318] B. Duguid, H. Pullan, and J. Hyde, “Innovative digital design delivery for the Ordsall Chord in Manchester, UK,” *Proc. Inst. Civ. Eng. Bridg. Eng.*, vol. 171, no. 2, pp. 91–105, Jun. 2018, doi: 10.1680/jbren.16.00012.

[319] Z. Liu, L. Jiang, M. Osmani, and P. Demian, “Building information management (BIM) and blockchain (BC) for sustainable building design information management framework,” *Electron.*, vol. 8, no. 7, Jul. 2019, doi: 10.3390/electronics8070724.

[320] C. Boton, D. Forgues, and G. Halin, “A framework for building information modeling implementation in engineering education,” *Can. J. Civ. Eng.*, vol. 45, no. 10, pp. 866–877, 2018, doi: 10.1139/cjce-2018-0047.

[321] F. J. Chaves, P. Tzortzopoulos, C. T. Formoso, and C. N. Biotto, “Building information modelling to cut disruption in housing retrofit,” in *Proceedings of the Institution of Civil Engineers: Engineering Sustainability*, Jun. 2017, vol. 170, no. 6, pp. 322–333, doi: 10.1680/jensu.16.00063.

[322] M. Al Ahbabi and M. Alshawi, “BIM for client organisations: A continuous improvement approach,” *Constr. Innov.*, vol. 15, no. 4, pp. 402–408, Oct. 2015, doi: 10.1108/CI-04-2015-0023.

[323] A. Knopp-Trendafilova, J. Suomi, and M. Tauriainen, “Link between a structural model of buildings and classification systems in construction,” in *VTT Symposium (Valtion Teknillinen Tutkimuskeskus)*, 2009, no. 259, pp. 285–301.

[324] M. Mathews, “BIM collaboration in student architectural technologist learning,” *J. Eng. Des. Technol.*, vol. 11, no. 2, pp. 190–206, 2013, doi: 10.1108/JEDT-10-2011-0067.

[325] A. Sánchez, C. Gonzalez-Gaya, P. Zulueta, and Z. Sampaio, “Introduction of building information modeling in industrial engineering education: Students’ perception,” *Appl. Sci.*, vol. 9, no. 16, Aug. 2019, doi: 10.3390/app9163287.

[326] S. Badi and D. Diamantidou, “A social network perspective of building information

modelling in Greek construction projects," *Archit. Eng. Des. Manag.*, vol. 13, no. 6, pp. 406–422, Nov. 2017, doi: 10.1080/17452007.2017.1307167.

[327] P. Pauwels, S. Zhang, and Y. C. Lee, "Semantic web technologies in AEC industry: A literature overview," *Automation in Construction*, vol. 73. Elsevier B.V., pp. 145–165, Jan. 01, 2017, doi: 10.1016/j.autcon.2016.10.003.

[328] U. Isikdag and J. Underwood, "Two design patterns for facilitating Building Information Model-based synchronous collaboration," *Autom. Constr.*, vol. 19, no. 5, pp. 544–553, 2010, doi: 10.1016/j.autcon.2009.11.006.

[329] E. Hjelseth, "Exchange of relevant information in BIM objects defined by the role-and life-cycle information model," *Archit. Eng. Des. Manag.*, vol. 6, no. SPECIAL ISSUE, pp. 279–287, 2010, doi: 10.3763/aedm.2010.IDDS5.

[330] R. Jin *et al.*, "Project-based pedagogy in interdisciplinary building design adopting BIM," *Eng. Constr. Archit. Manag.*, vol. 25, no. 10, pp. 1376–1397, Nov. 2018, doi: 10.1108/ECAM-07-2017-0119.

[331] H. Gao, C. Koch, and Y. Wu, "Building information modelling based building energy modelling: A review," *Applied Energy*, vol. 238. Elsevier Ltd, pp. 320–343, Mar. 15, 2019, doi: 10.1016/j.apenergy.2019.01.032.

[332] S. Suwal and V. Singh, "Assessing students' sentiments towards the use of a Building Information Modelling (BIM) learning platform in a construction project management course," *Eur. J. Eng. Educ.*, vol. 43, no. 4, pp. 492–506, Jul. 2018, doi: 10.1080/03043797.2017.1287667.

[333] M. E. Murphy and M. M. Nahod, "Stakeholder competency in evaluating the environmental impacts of infrastructure projects using BIM," *Eng. Constr. Archit. Manag.*, vol. 24, no. 5, pp. 718–735, 2017, doi: 10.1108/ECAM-07-2015-0106.

[334] L. Szönyi, "Building Information Modelling in the decision process of retrofitting the envelope of public buildings - a case Study," *Period. Polytech. Civ. Eng.*, vol. 54, no. 2, pp. 143–154, 2010, doi: 10.3311/pp.ci.2010-2.10.

[335] Ž. Turk, "Ten questions concerning building information modelling," *Build. Environ.*, vol. 107, pp. 274–284, Oct. 2016, doi: 10.1016/j.buildenv.2016.08.001.

[336] Ó. LóPez-Zaldívar, A. Verdú-VáZquez, T. Gil-López, and R. V. Lozano-Diez, "The implementation of building information modeling technology in university teaching: The case of the polytechnic university of madrid," *International Journal of Engineering Education*, vol. 33, no. 2. Tempus Publications, pp. 712–722, 2017.

[337] G. Stegnar and T. Cerovšek, "Information needs for progressive BIM methodology supporting the holistic energy renovation of office buildings," *Energy*, vol. 173, pp. 317–331, Apr. 2019, doi: 10.1016/j.energy.2019.02.087.

[338] R. Santos, A. A. Costa, J. D. Silvestre, and L. Pyl, "Informetric analysis and review of literature on the role of BIM in sustainable construction," *Automation in Construction*, vol. 103. Elsevier B.V., pp. 221–234, Jul. 01, 2019, doi: 10.1016/j.autcon.2019.02.022.

[339] M. E. Murphy, "Implementing innovation: A stakeholder competency-based approach for BIM," *Constr. Innov.*, vol. 14, no. 4, pp. 433–452, Sep. 2014, doi: 10.1108/CI-01-2014-0011.

[340] T. El-Diraby, T. Krijnen, and M. Papagelis, "BIM-based collaborative design and socio-technical analytics of green buildings," *Autom. Constr.*, vol. 82, pp. 59–74, Oct. 2017, doi: 10.1016/j.autcon.2017.06.004.

[341] S. O. Ajayi, L. O. Oyedele, B. Ceranic, M. Gallanagh, and K. O. Kadiri, "Life cycle environmental performance of material specification: a BIM-enhanced comparative assessment," *Int. J. Sustain. Build. Technol. Urban Dev.*, vol. 6, no. 1, pp. 14–24, Jan. 2015, doi: 10.1080/2093761X.2015.1006708.

[342] S. Chardon, B. Brangeon, E. Bozonnet, and C. Inard, "Construction cost and energy performance of single family houses: From integrated design to automated optimization," *Autom. Constr.*, vol. 70, pp. 1–13, Oct. 2016, doi: 10.1016/j.autcon.2016.06.011.

[343] M. Jacobsson and C. Merschbrock, "BIM coordinators: a review," *Engineering, Construction and Architectural Management*, vol. 25, no. 8. Emerald Group Publishing Ltd., pp. 989–1008, Sep. 17, 2018, doi: 10.1108/ECAM-03-2017-0050.

[344] E. A. Pärn, D. J. Edwards, and M. C. P. Sing, "The building information modelling trajectory in facilities management: A review," *Automation in Construction*, vol. 75. Elsevier B.V., pp. 45–55, Mar. 01, 2017, doi: 10.1016/j.autcon.2016.12.003.

[345] M. R. Hosseini, I. Martek, E. Papadonikolaki, M. Sheikhkhoshkar, S. Banihashemi, and M. Arashpour, “Viability of the BIM Manager Enduring as a Distinct Role: Association Rule Mining of Job Advertisements,” *J. Constr. Eng. Manag.*, vol. 144, no. 9, 2018, doi: 10.1061/(ASCE)CO.1943-7862.0001542.

[346] C. A. Balaras, S. Kontoyiannidis, E. G. Dascalaki, and K. G. Droutsa, “Intelligent Services for Building Information Modeling - Assessing Variable Input Weather Data for Building Simulations,” *Open Constr. Build. Technol. J.*, vol. 7, no. 1, pp. 138–145, Nov. 2013, doi: 10.2174/1874836820131022005.

[347] R. Jin, Y. Zou, K. Gidado, P. Ashton, and N. Painting, “Scientometric analysis of BIM-based research in construction engineering and management,” *Engineering, Construction and Architectural Management*, vol. 26, no. 8. Emerald Group Publishing Ltd., pp. 1750–1776, Sep. 16, 2019, doi: 10.1108/ECAM-08-2018-0350.

[348] M. M. Singh, A. Sawhney, and V. Sharma, “Utilising building component data from BIM for formwork planning,” *Constr. Econ. Build.*, vol. 17, no. 4, pp. 20–36, Dec. 2017, doi: 10.5130/AJCEB.v17i4.5546.

[349] K. McGlinn, B. Yuce, H. Wicaksono, S. Howell, and Y. Rezgui, “Usability evaluation of a web-based tool for supporting holistic building energy management,” *Autom. Constr.*, vol. 84, pp. 154–165, Dec. 2017, doi: 10.1016/j.autcon.2017.08.033.

[350] E. Alreshidi, M. Mourshed, and Y. Rezgui, “Cloud-based BIM governance platform requirements and specifications: Software engineering approach using BPMN and UML,” *J. Comput. Civ. Eng.*, vol. 30, no. 4, Jul. 2016, doi: 10.1061/(ASCE)CP.1943-5487.0000539.

[351] I. Petri, S. Kubicki, Y. Rezgui, A. Guerriero, and H. Li, “Optimizing energy efficiency in operating built environment assets through building information modeling: A case study,” *Energies*, vol. 10, no. 8, Aug. 2017, doi: 10.3390/en10081167.

[352] M. B. Miles, • A Michael Huberman, and J. Saldaña, “Qualitative Data Analysis A Methods Sourcebook Edition.”

[353] S. Suwal *et al.*, “Building Energy-Efficiency delivered with the Help of Improved Building Information Modelling Skills ,” 2018. Accessed: Jan. 21, 2020. [Online]. Available: https://www.researchgate.net/publication/326836100.

[354] I. Petri, A. Alhamami, Y. Rezgui, and S. Kubicki, "A Virtual Collaborative Platform to Support Building Information Modeling Implementation for Energy Efficiency," in *PRO-VE 2018, IFIP Advances in Information and Communication Technology, Springer, Cham*, Sep. 2018, vol. 534, pp. 539–550, doi: 10.1007/978-3-319-99127-6_46.

[355] D. B. Thomson and R. G. Miner, "Building Information Modeling -BIM: Contractual Risks are Changing with Technology," 2010, Accessed: Jan. 25, 2018. [Online]. Available: https://s3.amazonaws.com/academia.edu.documents/7562887/ge - 2006_09 - building information modeling.pdf?AWSAccessKeyId=AKIAIWOWYYGZ2Y53UL3A&Expires=1516926400&Signature=tiOvYHsY3b4Ncpj4qZiqyRsgwCU%3D&response-content-disposition=inline%3B f.

[356] S. Eleftheriadis, D. Mumovic, and P. Greening, "Life cycle energy efficiency in building structures: A review of current developments and future outlooks based on BIM capabilities," *Renew. Sustain. Energy Rev.*, vol. 67, pp. 811–825, Jan. 2017, doi: 10.1016/J.RSER.2016.09.028.

[357] Z. Alwan, A. Nawarathna, R. Ayman, M. Zhu, and Y. ElGhazi, "Framework for parametric assessment of operational and embodied energy impacts utilising BIM," *J. Build. Eng.*, vol. 42, p. 102768, Oct. 2021, doi: 10.1016/J.JOBE.2021.102768.

[358] D. Zangani, "PROJECT FINAL REPORT Grant Agreement number: 260124 Project acronym: SPORTE 2 Project title: Intelligent Management System to Integrate and control energy generation, consumption and exchange for European Sport and Recreation Buildings," 2014. Accessed: Nov. 10, 2019. [Online]. Available: http://europa.eu/abc/symbols/emblem/index_en.htmlogoofthe7thFP:http://ec.europa.eu/research/fp7/index_en.cfm?pg=logos.

[359] Skanska, "Case studies | www.skanska.co.uk," 2014. https://www.skanska.co.uk/about-skanska/sustainability/health-and-safety/case-studies/ (accessed Apr. 25, 2018).

[360] European Commission, "KnoholEM," 2014. https://www.smart-homes.nl/en/project/knoholem/ (accessed Nov. 10, 2019).

[361] EU, "Resilient project - Virtual Casino," 2018. http://www.resilient-project.eu/

(accessed Nov. 10, 2019).

[362] Europe Commission, “Sporte 2,” 2018. http://webcache.googleusercontent.com/search?q=cache:https://www.sporte2.eu/ (accessed Nov. 10, 2019).

[363] EU, “FASUDIR | Friendly and Affordable Sustainable Urban Districts Retrofitting,” 2019. http://fasudir.eu/ (accessed Nov. 10, 2019).

[364] FP7, “PERFORMER Project,” 2017. http://performerproject.eu/ (accessed Nov. 10, 2019).

[365] Hugh Dutton Associes (HDA), “Climate ribbon - Miami,” Miami, 2018. [Online]. Available: https://www.hda-paris.com/project/climate-ribbon-tm-miami-usa/.

[366] EU, “BaaS Project: Building as a Service (Ecosystem) | Build Up,” 2013. https://www.buildup.eu/en/explore/links/baas-project-building-service-ecosystem (accessed Feb. 27, 2020).

[367] Walton Centre NHS Foundation Trust, “Delivering outstanding environments at the Walton Centre,” *2014*. https://www.interserve.com/latest-insight/2014/delivering-outstanding-environments-at-the-walton-centre (accessed Feb. 27, 2020).

[368] Renor Oy property investment company and Ilmarinen Mutual Pension Insurance Company, “BIMEET - BIM for energy efficiency, training, education, expertise and best practice,” 2017. https://www.energy-bim.com/login (accessed Feb. 27, 2020).

[369] E. O. and F. YIT, “Tripla is the new heart of Helsinki | Tripla by YIT,” 2016. https://tripla.yit.fi/en (accessed Feb. 27, 2020).

[370] HM Government, “Industrial Strategy: government and industry in partnership (Construction 2025),” 2013. Accessed: Sep. 15, 2019. [Online]. Available: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/210099/bis-13-955-construction-2025-industrial-strategy.pdf.

[371] BIS, “ILR standard file specifications and reference data - GOV.UK,” 2016. https://www.gov.uk/government/publications/sfa-ilr-standard-file-specifications-and-reference-data (accessed Sep. 15, 2019).

[372] D. for Buisness Innovation & Skills, “UK Construction: An economic analysis of the

sector," 2013.

[373] HM Government, "Construction 2025. Industrial Strategy: Government and industry in partnership," 2013. doi: HM Government.

[374] D. Pearce, "Is the construction sector sustainable?: definitions and reflections," *https://doi.org/10.1080/09613210600589910*, vol. 34, no. 3, pp. 201–207, May 2007, doi: 10.1080/09613210600589910.

[375] P. Fletcher and H. Satchwell, *A Practical Guide to the RIBA Plan of Work 2013 Stages 7, 0 and 1*, 1st Editio., vol. 160. London: RIBA Publishing, 2019.

[376] M. Young, "Towards a European qualifications framework: some cautionary observations," *J. Eur. Ind. Train.*, vol. 32, no. 2–3, pp. 128–137, 2008, doi: 10.1108/03090590810861677.

Appendices (A-E)

Appendix A

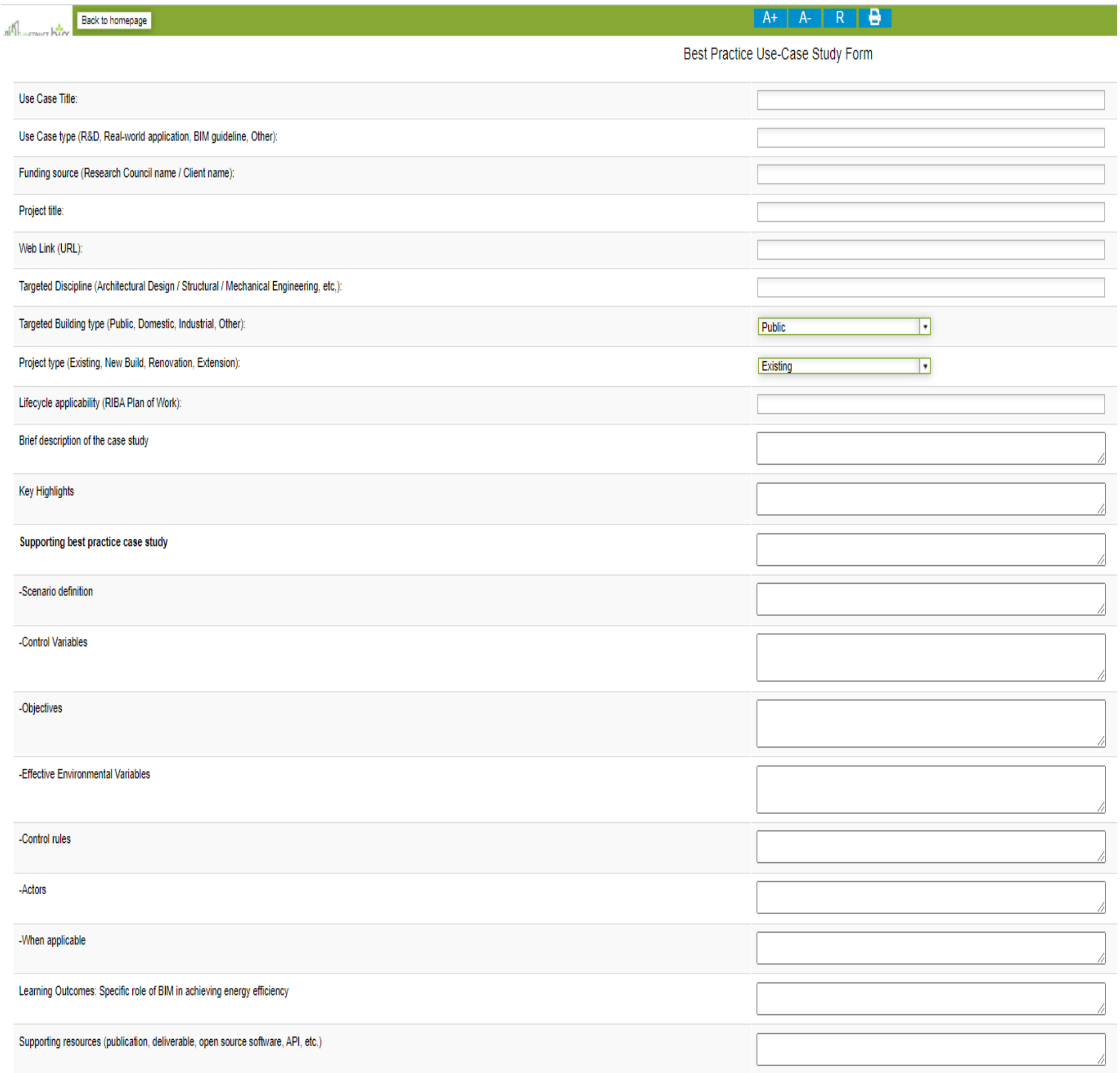
Repository of best practice use-cases form

1- Use Cases Manual Form

<table>
<tr><td>Use Cases Title</td><td></td></tr>
<tr><td>Use Case type</td><td></td></tr>
<tr><td>Funding source</td><td></td></tr>
<tr><td>Project Title</td><td></td></tr>
<tr><td>Web Link (URL)</td><td></td></tr>
<tr><td>Targeted Discipline</td><td></td></tr>
<tr><td>Targeted Building type</td><td></td></tr>
<tr><td>Project type</td><td></td></tr>
<tr><td>Lifecycle applicability</td><td></td></tr>
<tr><td>Brief description of the case study</td><td></td></tr>
<tr><td rowspan="4">Key Highlights</td><td></td></tr>
<tr><td></td></tr>
<tr><td></td></tr>
<tr><td></td></tr>
<tr><td>Supporting best practice case study</td><td>
<table>
<tr><th>Scenario Definitions</th><th>Holistic Solution</th></tr>
<tr><td>Scenario Definition</td><td></td></tr>
<tr><td>Control Variables</td><td></td></tr>
<tr><td>Objectives</td><td></td></tr>
</table>
</td></tr>
</table>

	Effective Environmental Variables	
	Control Rules	
	Actors	
	When Applicable	
Learning Outcomes:		
Supporting resources		

2- Use Cases Electronic Form


Back to homepage

A+ A- R

Best Practice Use-Case Study Form

Use Case Title:	
Use Case type (R&D, Real-world application, BIM guideline, Other):	
Funding source (Research Council name / Client name):	
Project title:	
Web Link (URL):	
Targeted Discipline (Architectural Design / Structural / Mechanical Engineering, etc.):	
Targeted Building type (Public, Domestic, Industrial, Other):	Public
Project type (Existing, New Build, Renovation, Extension):	Existing
Lifecycle applicability (RIBA Plan of Work):	
Brief description of the case study	
Key Highlights	
Supporting best practice case study	
-Scenario definition	
-Control Variables	
-Objectives	
-Effective Environmental Variables	
-Control rules	
-Actors	
-When applicable	
Learning Outcomes: Specific role of BIM in achieving energy efficiency	
Supporting resources (publication, deliverable, open source software, API, etc.)	

3- More of use cases has been illustrated in BIMEET platform (www.energy-bim.com) in the below link:

https://www.energy-bim.com/view/bim?optRes=Y&doctitle=List%20of%20use-cases&q=&token=425633c1bf034bd6a9f04d5889db7530

Appendix B

Repository of Interview Questions for EU Experts

“Interview on BIM as a toolset to optimize energy in the industry field”

The Study

BIM-based EU-wide Standardized Qualification Framework for achieving Energy Efficiency Training.

Building Information Modelling (BIM) is paving the way to more effective multi-disciplinary collaborations with a total lifecycle and supply chain integration perspective. BIM is helping the sustainability agenda as the digitalisation of product and process information provides a unique opportunity to optimise energy efficiency related decisions across the entire lifecycle and supply chain.

The research aims to broaden the BIM training agenda to support the European Union building energy efficiency agenda. This requires broad awareness and expertise in BIM practice across different asset types and across different roles in the industry.

In that respect, the study will endeavour to enhance the skills, qualifications and capabilities of construction practitioners (from high professionals to blue collar workers), thus increasing market penetration and adoption of key technological development in BIM, given the timeliness of the need for training in combined green and functional performance engineering.

More information can be found here: http://energy-bim.com/

Aim of the interview

My interview focuses on understanding and utilizing BIM as a toolset to optimize energy in the industry field during the lifecycle of the activity. We focus on demonstrating the benefits of building information modelling in maximizing energy efficiency and sustainable outcomes.

Thank you for your participation and we assure you that any personally identifiable information will remain confidential.

*** Obligator**

By checking the box below, I accept that the data collected in this survey will be treated by the researcher *

Personally identifiable information will remain confidential.

☐ I accept

☐ I refuse (and close this questionnaire)

Demographic information

* 2. What is your age?

☐ Under 18 ☐ 18-24 ☐ 25-34 ☐ 35-44 ☐ 45-54 ☐ 55-64 ☐ 65+

* 3. What is your gender?

☐ Male ☐ Female ☐ Other

* 4. Years of professional experience?

☐ 0-2 years ☐ 3-5 years ☐ 6-10 years ☐ 10+ years ☐ Not applicable

* 5. What is your field of expertise?

(Please choose as many boxes as you think is appropriate)

☐ Briefing ☐ Architectural Design ☐ Architectural Engineering

☐ Structural / Civil Engineering ☐ Mechanical Engineering ☐ Electrical Engineering

☐ Fire Engineering ☐ Acoustics ☐ Quantity Surveying

☐ Project Management ☐ Contractor / Subcontractor ☐ Facility Management

☐ Other (please specify: ....)

1- What is your field of expertise?

2- Could you please give a brief of your historic experience of using BIM?

3- What aspects of BIM are (were) used in the activity and how is the activity related to energy?

4- What is (was) your role discipline in construction projects?

5- Is there any use case that you have been used BIM for Energy Efficiency?

☐ Yes, please fill this template in below

☐ No. skip the template

Best Practice Use-Case Study Template

Use Cases Title	
Use Case type (R&D, Real-world application, BIM guideline, Other)	
Funding source (Research Council name / Client name)	
Project Title	
Web Link *(URL)*	
Targeted Discipline (Architectural Design / Structural / Mechanical Engineering, etc,)	
Targeted Building type (Public, Domestic, Industrial, Other)	
Project type (Existing, New Build, Renovation, Extension)	
Lifecycle applicability *(RIBA Plan of Work)*	
Brief description of the case study	
Key Highlights	

<table>
<tr><td>Supporting best practice case study</td><td>
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<tr><th>Scenario Definitions</th><th>Holistic Solution</th></tr>
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<tr><td>Actors</td><td></td></tr>
<tr><td>When Applicable</td><td></td></tr>
</table>
</td></tr>
<tr><td>Learning Outcomes: Specific role of BIM in achieving energy efficiency</td><td></td></tr>
<tr><td>Supporting resources (publication, deliverable, open</td><td></td></tr>
</table>

source software, API, etc.)	

6- Considering your experience within a given use case, could you please identify for each discipline involved (designers, contractors, ranging from site superintendent to blue collar workers) the skills they require to handle BIM data for the purpose of energy efficiency?

> Authoring BIM models, Coordinating BIM modelling within organizations, Managing BIM and Information delivery at project level, Accessing BIM data from the field…

7- Based on experience, what skills are lacking at the moment for using BIM for Energy Efficiency in the construction field?

8- What are or could be the particular ways to enhance the stakeholders' skills for using the BIM for Energy Efficiency in the project? **According to:**

> I. Blue collar workers: workers, technicians:
> II. Designers/Engineers
> III. Contractors
> IV. Facility management teams

9- [illegible] project?

> Programming phase, Design, Construction, Operation,

10- What are the common barriers to use BIM for Energy Efficiency in the industry?

11- What are your recommendations to enhance using the BIM for Energy Efficiency in the construction industry?

12- Is your organisation support the training BIM for Energy Efficiency?

☐ If yes, please explain a brief description about the training followed or given by your employees/collaborators?

☐ NO, why?

Thank you very much for your participation.

Soe examples of the interviews as follows:

Interview (1):

1- What is your field of expertise?

> BAUPHYSIK Physics of building

2- Could you please give a brief of your historic experience of using BIM?

> Since 4 years, use of Revit until APD. Issues in coordination.
>
> Centre commercial cloche d'or, BIM until call for tenders, incl. coordination. Then Bauteam.
>
> Example on sudspital (hospital) (APD>Design Development)
>
> - structure et matériaux, isolation thermique, phonique, raumacoustics
> - partie structure en BIM
> - Conseil à l'architecte, sur isolation. Mais pas de BIM.

3- What aspects of BIM are (were) used in the activity and how is the activity related to energy?

> Chateau d'eau Ban de Gasperich (Jim Clemes > Schroeder). Incl water technics.

4- What is (was) your role discipline in construction projects?

> Structure
>
> Sometimes technics, 3D scan
>
> CHEM Sudspital: openBIM. Wiemer (arch) coordination, Felgen
>
> Schroeder own building: AU21 (arch), Goblet, Schroeder, BIM Consult. APD BIM, execution drawings derived from BIM. Goblet is doing simulations, but don't know how?
>
> Advice sustainable development (materials etc.), bank of material & LCA

5- Is there any use case that you have been used BIM for Energy Efficiency?

☐ Yes, please fill this template in below

☒ No. skip the template

6- Considering your experience within a given use case, could you please identify for each discipline involved (designers, contractors, ranging from site superintendent to blue collar workers) the skills they require to handle BIM data for the purpose of energy efficiency?

Authoring BIM models, Coordinating BIM modelling within organizations, Managing BIM and Information delivery at project level, Accessing BIM data from the field…

Thermal bridges. 3D Simulation tool because it's building physics.

Should be based on BIM structural model, insulation following limits/advice of technics (HVAC engineer) (energiepass)

7- Based on experience, what skills are lacking at the moment for using BIM for Energy Efficiency in the construction field?

N/A

8- What are or could be the particular ways to enhance the stakeholders' skills for using the BIM for Energy Efficiency in the project? **According to:**

V. Blue collar workers: workers, technicians:

VI. Designers/Engineers

Need for improving internal organization in the BIM authoring and delivery. At their level of maturity, BIM skills are either basic authoring (ex-drawers) or strategic management. But there is not enough activity (number of BIM projects) to really develop the role of BIM coordinator on projects (and their associated skills).

VII. Contractors

VIII. Facility management teams

9- What are the benefits of using BIM for Energy Efficiency during the lifecycle of the project?

Programming phase, Design, Construction, Operation,

No direct relationship with structural studies. But it would be very usefule for developing their activities in relationship with sustainability advice (materials, circular eceonomy). This would require managing Banks of materials, analysis of material sustainability.

10- What are the common barriers to use BIM for Energy Efficiency in the industry?

Changement, pas de retour sur investissement pour le moment

Construction drawings rapidly extracted

11- What are your recommendations to enhance using the BIM for Energy Efficiency in the construction industry?

N/A

12- Is your organisation support the training BIM for Energy Efficiency?

☒ If yes, please explain a brief description about the training followed or given by your employees/collaborators?

A BIM manager has been recruited and trained: Mensch un Maschine (DE), TASE (B), online training

Issue with standardization of workflow: It's continuous learning

Skills of BIM Coordinators vs BIM Manager not clearly defined

Modelers: internal training. Technicians, not trained in technical drawing, should be trained BIM modeler

Complicated to find training sessions, because they have very specific process, libraries of objects.

(BIM Modeler Lux bien alignée

BIM Coordinator formés sur des projets par le BIM Manager du bureau)

☐ NO, why?

Interviewer(s) comments.

Best practice(s) identified

Use of BIM for thermal bridges detection and resolution.

Description: Structural model, combined with arch. Model and energy performance requirements, can allow design teams to control the design, coordinate the structure and insulation objects, and calculate related thermal bridges.

Related BIM uses: BIM Coordination, Energy simulation

Related BIM models required: Structural BIM, Architectural BIM, Energy BIM (or energy requirements)

Thank you very much for your participation.

Interview (2):

1- What is your field of expertise?

Trainings of

- energy efficiency and durability of constructions
- Tools for calculations of points above (PHPP, energy performance,..)

2- Could you please give a brief of your historic experience of using BIM?

We have knowledge of BIM Ideas.

3- What aspects of BIM are (were) used in the activity and how is the activity related to energy and sustainable construction?

- List of material
- Use of the sun (optimisation of windows-proportion, orientations of buildings and photovoltaic)
- Dimensioning of isolation
- Less printed plans

4- What is (was) your role discipline in construction projects?

- Planning and consulting of energy efficient buildings
- Trainings for architects, trade persons and blue collar workers about the themes listed above

5- Is there any use case that you have been used BIM for Energy Efficiency?

☐ Yes, please fill this template in below

☒ No. skip the template

6- Considering your experience within a given use case, could you please identify for each discipline involved (designers, contractors, ranging from site superintendent to blue collar workers) the skills they require to handle BIM data for the purpose of energy efficiency?

Authoring BIM models, Coordinating BIM modelling within organizations, Managing BIM and Information delivery at project level, Accessing BIM data from the field…

- Planning/Designer:
  - Capability to use CAD-programs
  - Knowledge about the principles of energy efficiency and sustainability
- Contractor:
  - Skills to separate the information needed
- Tradespersons /blue collar workers:
  - Knowledge of reading the plans and separate the information needed

7- Based on experience, what skills are lacking at the moment for using BIM for Energy Efficiency in the construction field?

Links between the different software-tools:

For example: PHPP + BIM or LuxEeB + BIM

8- What are or could be the particular ways to enhance the stakeholders' skills for using the BIM for Energy Efficiency in the project? **According to:**

IX. *Blue collar workers: workers, technicians:*

Trainings and field-meetings to explain the specific plans like for example airtightness or thermal bridges (details)

X. *Designers/Engineers*

Trainings to explain the programme and positive aspects of BIM

Starting a project by inputting the first layers together in the construction-team

XI. *Contractors*

Contract a consultant of energy for the project and give him the authority in the team above (II)

XII. *Facility management teams*

As result of BIM for people working in the facility management, a guiding handbook would be useful. It should contain all aspects necessary of building construction and technics.

9- What are the benefits of using BIM for Energy Efficiency during the lifecycle of the project?

Programming phase, Design, Construction, Operation,

- Easy generation of a material list
- Possibility of recycling
- Simulation of orientation of the building, so: optimisation of isolation or positioning of the windows
- All participants work on the same version

10- What are the common barriers to use BIM for Energy Efficiency in the industry?

- Different software-tools in the involved offices
- Security of internet
- Potential and speed of internet connection

11- What are your recommendations to enhance using the BIM for Energy Efficiency in the construction industry?

- Implantation of the different software tools (named above) in the BIM
- Implantation of the different verification of consumption in the BIM

12- Is your organisation support the training BIM for Energy Efficiency?

☐ If yes, please explain a brief description about the training followed or given by your employees/collaborators?

☒ NO, why?

Not yet, we are currently working on the integration of BIM-Trainings in our Training-

Thank you very much for your participation.

Interview (3):

1- Could you please give a brief of your historic experience of using BIM?

The Real Estate Centre of Porvoo Town has constructed a new central kitchen where BIM was used both in design and building phase, but aim is also to maintain whole facility through its life-cycle with help of as-built BIM model. Also a gaming environment of the facility has been produced based on BIM, which has been used for showcasing the project. Aim that was set was that it will work as useful instrument, not toy.

2- What aspects of BIM are used in the activity and how is the activity related to energy?

The central kitchen as a facility has very energy intensive manufacturing processes, it is difficult to describe it as an actual energy efficiency project. The building forms a carefully optimized core/envelope for sufficient manufacturing process. So that the manufacturing process and controlled material flows has been the starting point of the design process. As also the maximal utilizing of heat from the production processes.

3- What is your role discipline in construction projects?

Orderer

4- Is there any use case that you have been used BIM for Energy Efficiency?

☒ Yes

Name of the project: Porvoo Central Kitchen

Contact person: BIM-coordinator Jarkko Räsänen (FCG), Project Manager Marjo Puolakka, Rakennuttajatoimisto Valvontakonsultit Oy

5- Considering your experience within a given use case, could you please identify for each discipline involved (designers, contractors, ranging from site superintendent to blue collar workers) the skills they require to handle BIM data for the purpose of energy efficiency?

Target must be ambitious in all levels, meaning commitment for using of BIM is disciplinary obligated (starting from the constructor and the design). When contractors see that model is valid, it is also used at construction phase. (Examples of off-handed BIM models has been reached, and have been not of use).

As-build-models unfortunately at the moment have rather poor connectivity to service manuals/property management programs. For the Central Kitchen the as-built model will be maintained separately (Town of Porvoo has Visma Fivaldi –Real Estate Maintenace program in use).

6- Based on experience, what skills are lacking at the moment for using BIM for Energy Efficiency in the construction field?

Targets are not set enough high and BIM is not taken part of the program at early enough stage. Challenges also exists coupling property management programs to the as-built-models.

7- What are or could be the particular ways to enhance the stakeholders' skills for using the BIM for Energy Efficiency in the project?

All is in the attitude! The added value gained from use of BIM should be made visible.

8- What are the benefits of using BIM for Energy Efficiency during the lifecycle of the project?

Up-to-date and maintained as-built-model, working as a base of all changes made during the life-cycle of the building.

9- What are the common barriers to use BIM for Energy Efficiency in the industry?

Achieving BIM model that is good in quality and well maintained.

10- What are your recommendations to enhance using the BIM for Energy Efficiency in the construction industry?

Committing for BIM from the start from the project – use of professional BIM-coordinator. Attitude of constructor matters!

11- Is your organisation support the training BIM for Energy Efficiency?

☐ If yes, please explain a brief description about the training followed or given by your employees/collaborators

☒ NO, why?

The Central Kitchen project for Porvoo was both new and unique project but we will educate personnel in charge and continue co-operation with BIM-coordinators. Aim is that good experiences from the design and construction phases will extend through the life-cycle of the building. (Project was handed over on 30th December 2017 and commissioning is now going on.)

Thank you very much for your participation.

Interview (4):

1- Could you please give a brief of your historic experience of using BIM?

I have worked 7 years in development of modelling aiming to a) increase designers and constructors understanding of the benefits of BIM during construction and maintenance b) execute extensive initialization of BIM into building maintenance

2- What aspects of BIM are used in the activity and how is the activity related to energy?

Energy simulations are done during the design phase, but when buildings are in use then comparisons remain mainly. At the moment BIM is only used in design.

3- What is your role discipline in construction projects?

Real estate maintenance data management consultant

4- Is there any use case that you have been used BIM for Energy Efficiency?

☒ Yes

5- Considering your experience within a given use case, could you please identify for each discipline involved (designers, contractors, ranging from site superintendent to blue collar workers) the skills they require to handle BIM data for the purpose of energy efficiency?

Constructors should have more understanding of how BIM can be utilized. Process must be developed so that connection in between building project and maintenance does not get cut. Maintenance companies should have more understanding of simulations and know-how to adapt the results in actual buildings.

6- Based on experience, what skills are lacking at the moment for using BIM for Energy Efficiency in the construction field?

In the maintenance point of view BIM typically does not include enough information. If the model had enough data, would maintenance staff already be using the BIM in their work. Using of model is learned if found useful. My opinion is that people should not be educated utilizing BIM as they are now, but primarily the skills of how such BIM is created that it is sound and practical for maintenance purposes.

7- What are or could be the particular ways to enhance the stakeholders' skills for using the BIM for Energy Efficiency in the project?

Educating designers to make such models that include the information what maintenance and users need. Educating constructors to understand the needs the maintenance have and to realize that a building project is not an end it self but buildings are made to be used. Educating maintenance staff to understand the essence of simulations and to apply the results in practice.

8- What are the benefits of using BIM for Energy Efficiency during the lifecycle of the project?

Not much use can be made of BIM as how they currently are (in maintenance?). Only reasonable way to use them is creating a 3D-view of the building, on which different kind of outlooks can be generated for the use of the maintenance of technical devices and indoor climate. Not until the model is completely in order, starts BIM profiting back euros that have been put in it.

9-

10- What are the common barriers to use BIM for Energy Efficiency in the industry?

Lack of know-how of constructors and models lacking of needed content.

11- What are your recommendations to enhance using the BIM for Energy Efficiency in the construction industry?

Proper design of BIM, require also energy-simulations during operation. Don’t accept excuses but instead demand investigation why energy targets are not actualized. BIM is used only when client/buyer starts demanding it. Building sector will not come up new things to do by itself, someone has to lead the progress and pay for it.

12- Is your organisation support the training BIM for Energy Efficiency?

☐ If yes, please explain a brief description about the training followed or given by your employees/collaborators

☒ NO, why?

Have not been available. Also it seems that energy efficiency has got cuffs on the ear from indoor air quality issues. Nowadays biggest weight seems to be on the health of users of the building and level of their productivity. Spending energy is ok when improving aforesaid things. Indoor climate is sexy, energy is not.

Thank you very much for your participation.

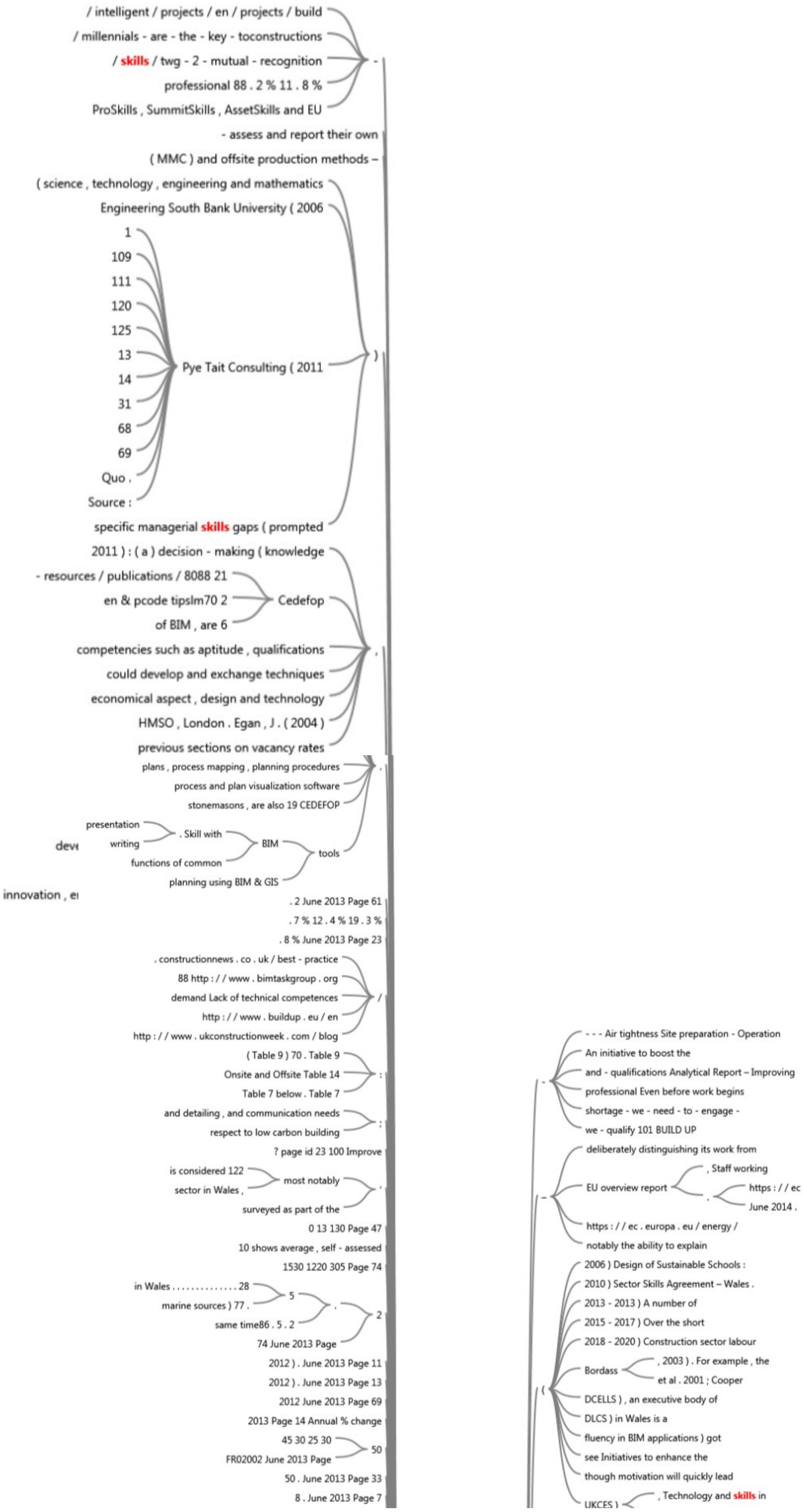
Appendix C

Repository of NVivo Word Tree from Different Sources

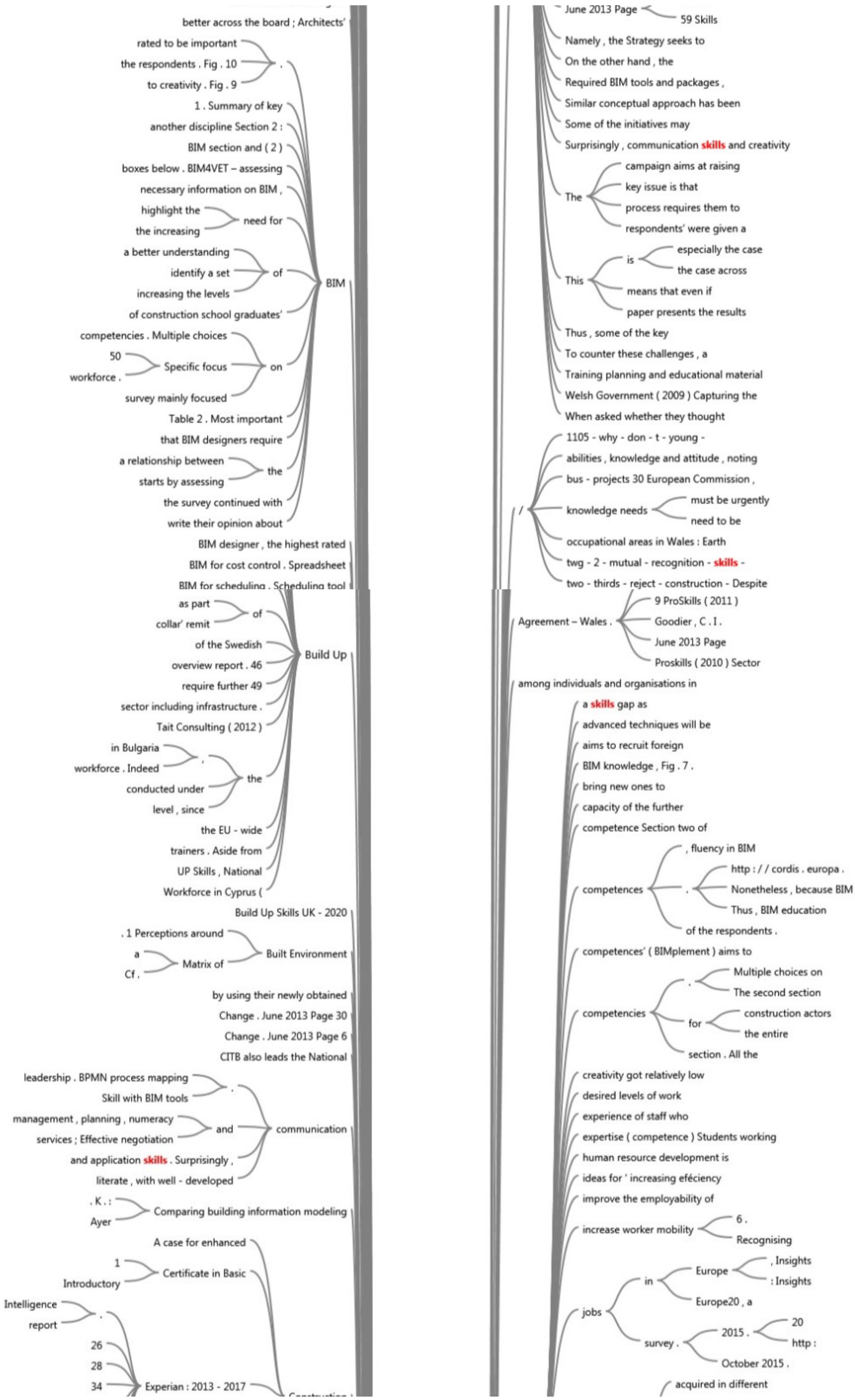
1- Use-cases and Interviews

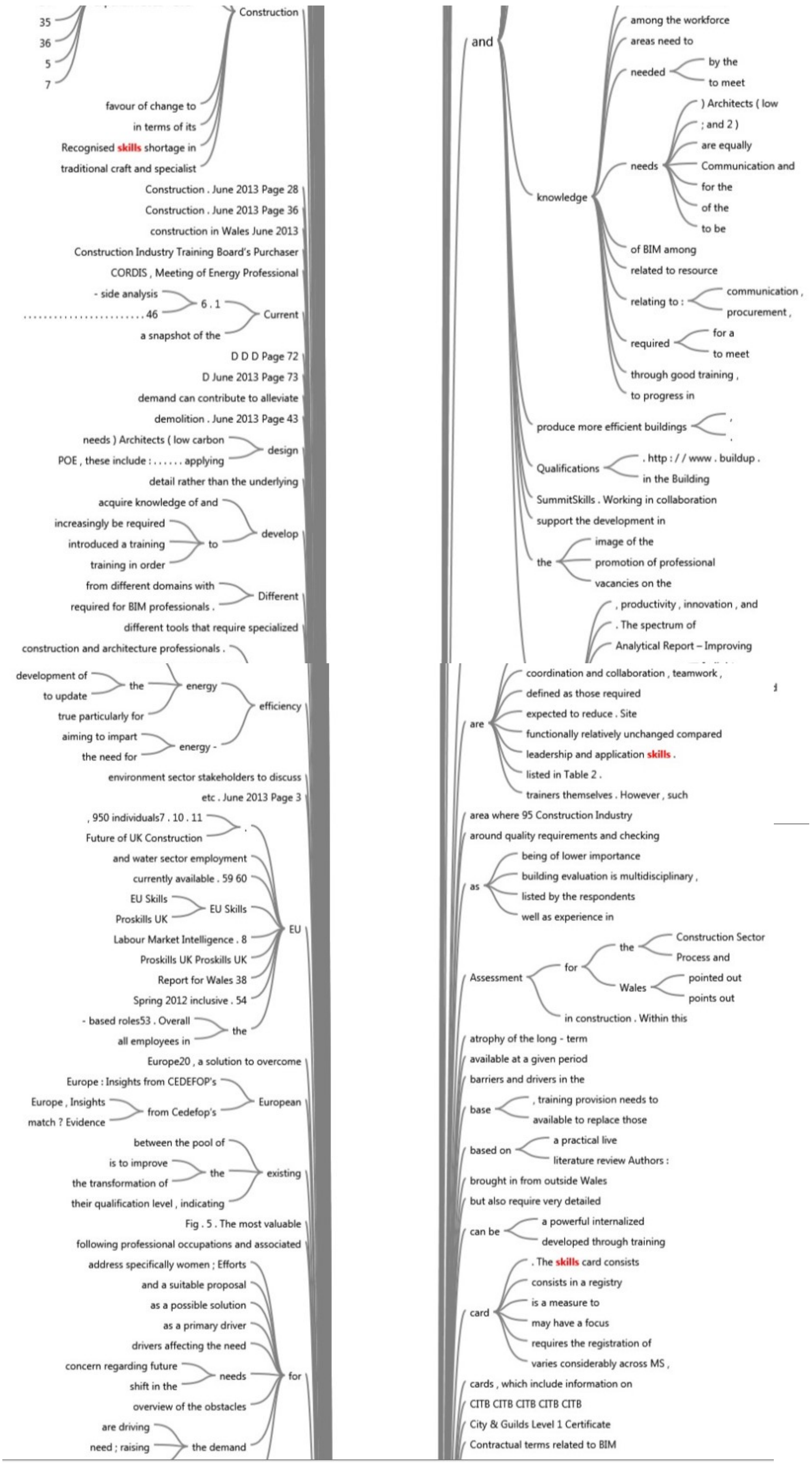

training
industrial buildings Instructor in Building Information Modeling implementation
your role discipline in construction projects ? BIM instructor
Assessment performance in the construction sector 2017 - 2016
According to : Blue collar workers : workers , technicians
methodology / software training & Energy training / experience Contractors
According to : People need to do more
and delivery of public sector assets . Developing
energy consultants / engineers / architects Facility management teams
solutions / cost predictions for the projects . Energy &
BIM
BIM practice) Lack of engineers / architects / owners / contractors
conception et integrated management for professionals Continues vocational
construction industry ? I think we need a massive
employees / collaborators ? I would look forward to further
for Energy Efficiency in the construction industry ? Basic
do more BIM training . They need many
the construction industry ? More integration , less costly ,
more
need to be fully aware and provide extensive
on the integration of BIM - Trainings in our
other hand , hands - on experience is the best
should be trained BIM modeler Complicated to find
data from the field ... Designers : BIM methodology /
services 2016 - 2015 Instructor in BIM Revit
software
software interoperability solutions Assessment performance evaluation and appropriate
/ consultant , teaching Revit (Basic , Advanced) Autodesk software
from early design
from the outset
in simulation programs
into this phase (?)
our energy engineers
pay for it
Zero Carbon Hub
for energy efficiency
in the BIM
in the industry
of constructor matters !
on these programmes
the construction industry ?
Is your organisation support
the
yes , please explain a brief description about
the field ... Designers : BIM methodology / software training & Energy
trained : Mensch un Maschine (DE) , TASE (B) , online
vs BIM Manager not clearly defined Modelers : internal
workflow , energy tools BIM consulting , BIM and Revit
workflows) for a PHD study Autodesk Building Performance
- offer .
&
Energy training / experience Contractors : BIM training , ability to
site meetings for the comprehension of BIM data
ability to implement BIM construction with energy specs
consulting
, software tools Sustainable design , building energy performance
Architect / Project leader , design development and construction
data management Contractors Work with Energy and BIM
organizing seminars , Architects Association Thessaloniki What aspects of
seminars , Building Information Modeling with Revit workflow , energy
Technicians , not trained in technical drawing , should be
They need many more training about procedures and
Work with BIM managers & energy consultants to understand
/ experience Contractors : BIM training , ability to implement BIM
about
energy modelling to a few specialists on
procedures and modelling skills . What are the
and
certificate , Energy analysis with Revit Autodesk tools
certification as a BIM professional from BRE ,
BIM for Energy Efficiency ?
If yes , please explain
NO , why ?
Because , in
BIM already
Have not
Learning the
Not yet ,
The Central
University , not
courses Auditing organizations against the BRE Global scheme
followed or given by your employees / collaborators ?
- Internal
A
I
Master
Yes ,
for
our energy engineers . Is your organisation support
professionals not for their employees working at
in this area . I think there is still
includes the creation of the Energy Model and
Issue with standardization of workflow : It's continuous learning
mechanisms in the industry Is your organisation support
on
how BIM could support building performance Lack
these programmes Is your organisation support the
sessions , because they have very specific process , libraries
showing their interface based on collaboration with energy

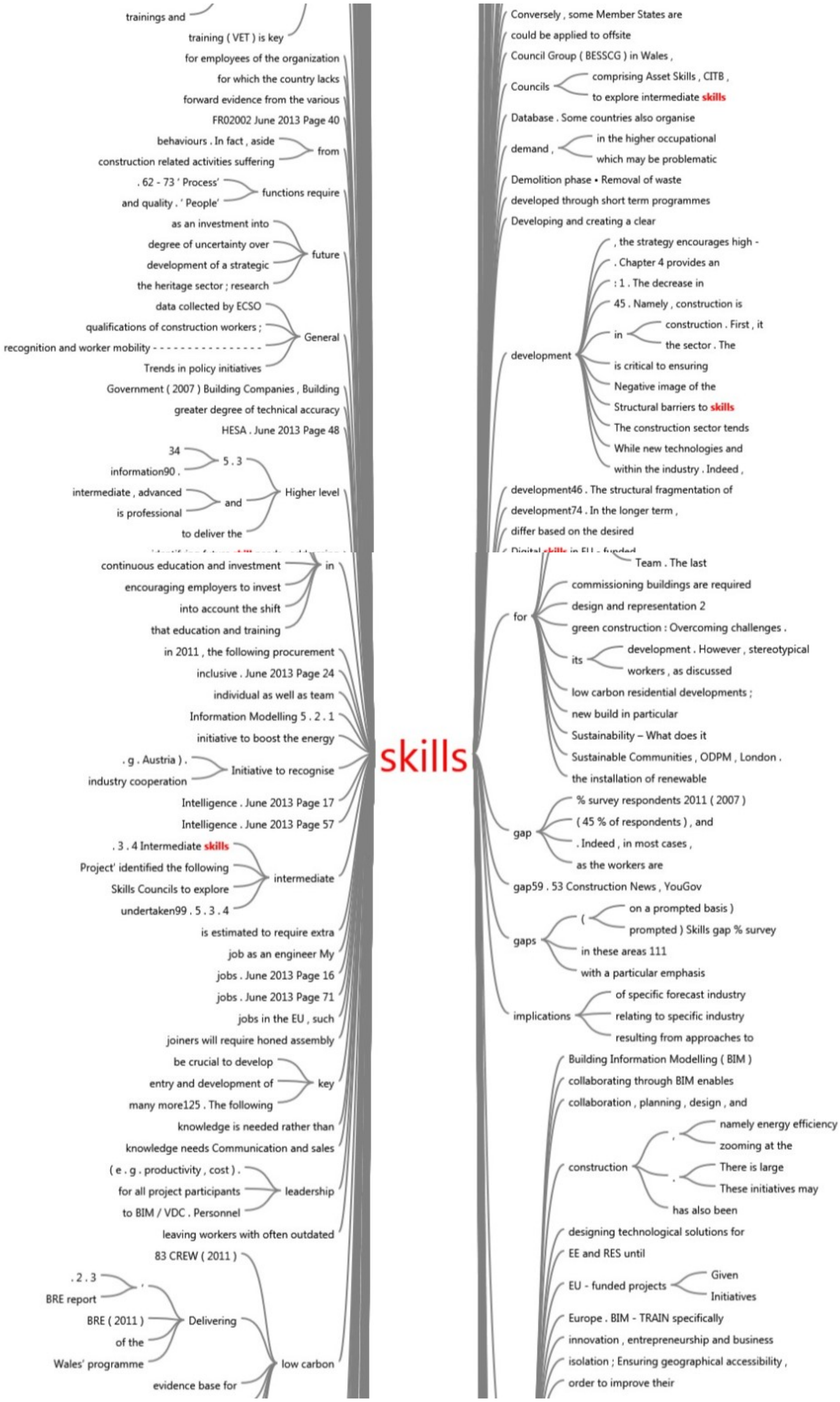
2- Scientific Publication and Standard Reports

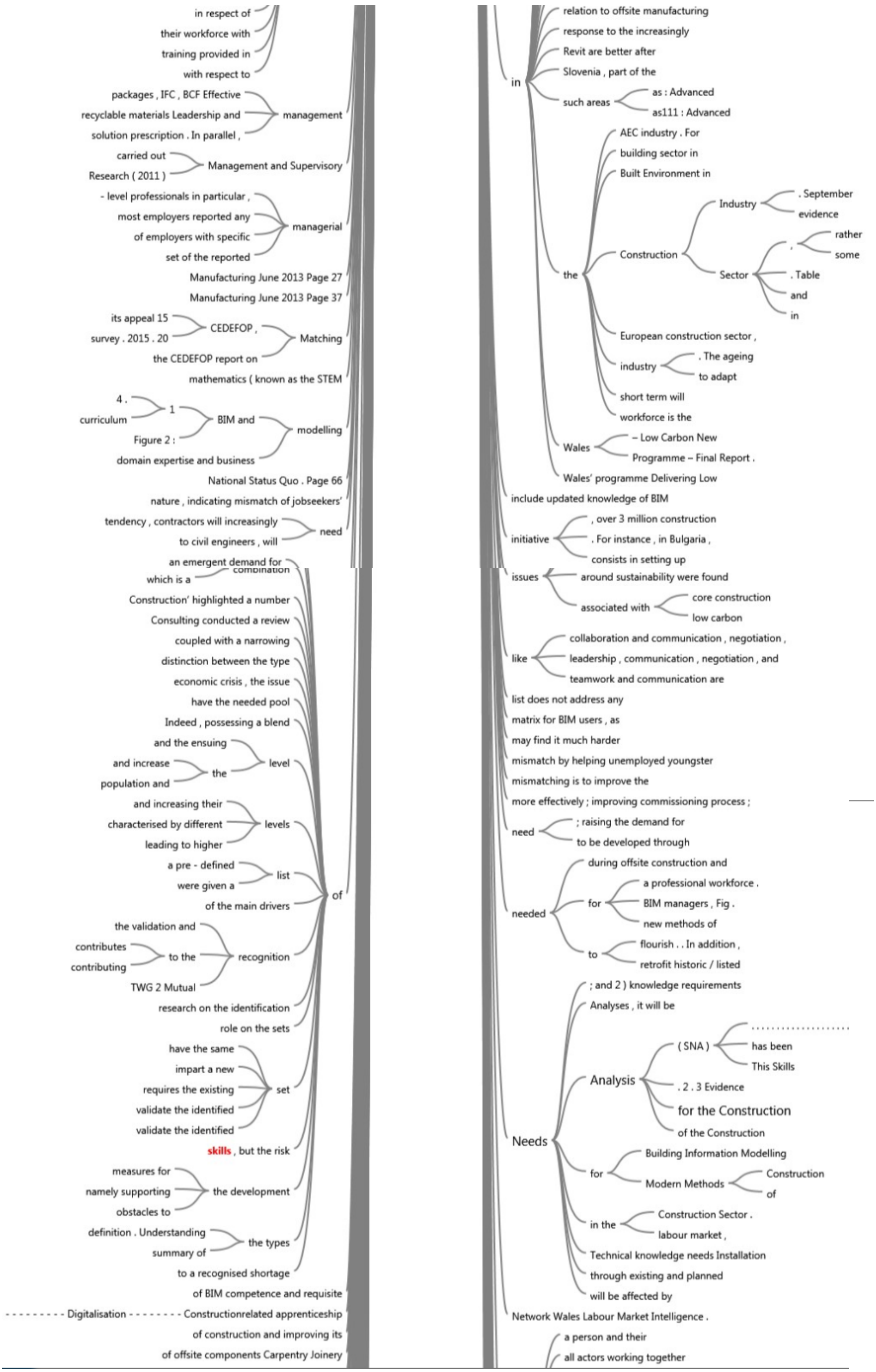


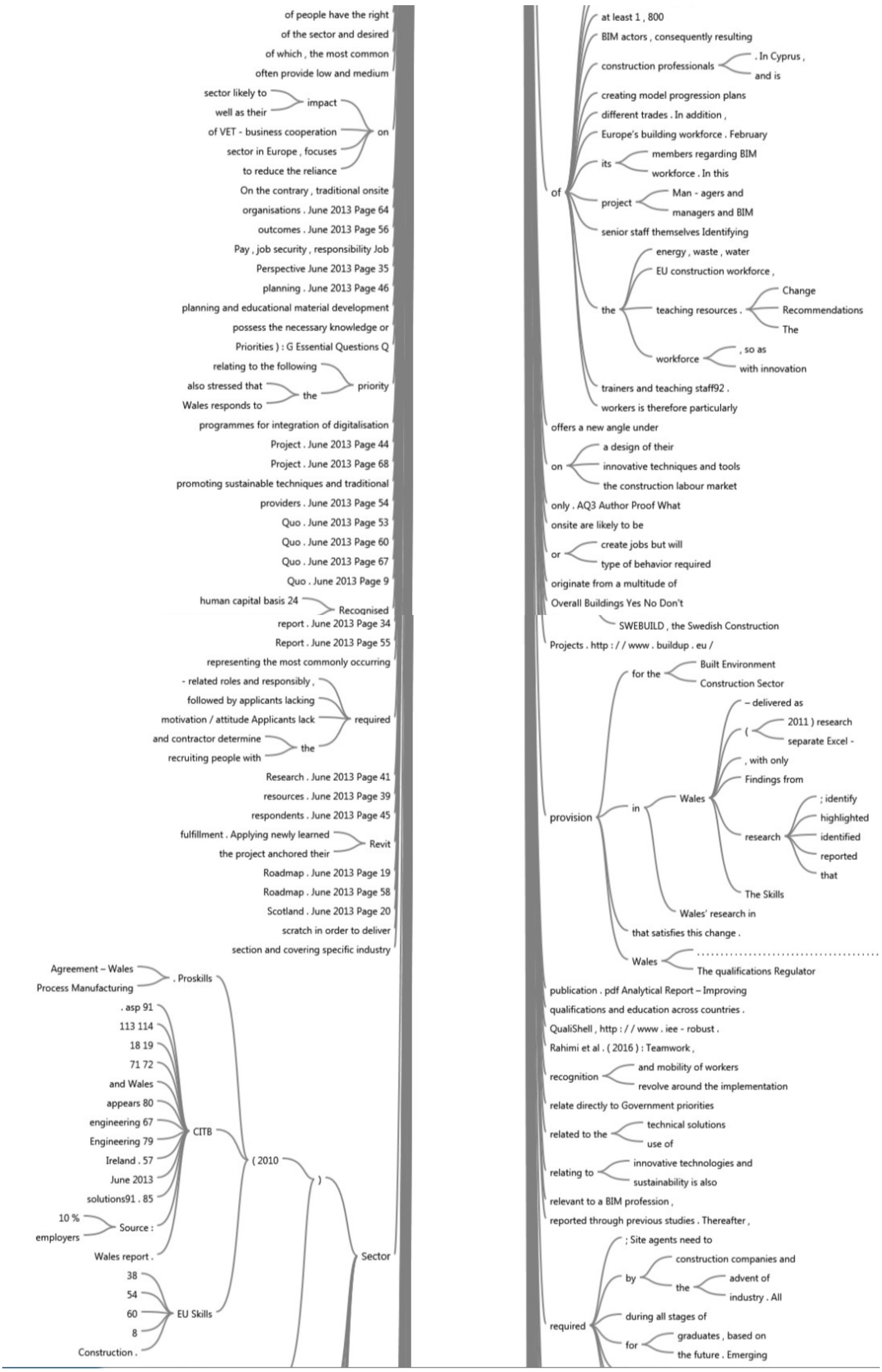

9 . The most commonly reported
for new skills and
project aims to devise
sector is indeed experiencing
which may have created
a
a potential means of tackling
a shortterm approach to human
a specialised approach to address
a well - informed and cohesive
importance Question 13 asked
Question 9 asked respondents
about
it easy to get
it is likely that
additional
address the specific challenges affecting
aerospace or automotive , since transferrable
an example , the Building Green
and reliable indicators
defending professional integrity
, time
aimed at supporting upskilling
Children , Education , Lifelong Learning
CITB (2012) Workforce Mobility
construction sector . Improving
buildings ?
technical and practical
terms of
to increase
the
the following current
The need for
to apply their
moisture movement Understanding of
Moreover , energy efficiency awareness
on strengthening the competences
review Authors : BIM Competencies
Technological Institute , Future Qualification
and Skills (UKCES) ,
data / file / 305024 /
Technology
to increase the understanding
scheme to support
to investment in
training
and increase worker mobility Recognising
annex) . June 2013 Page 52
coordination and collaboration , teamwork
knowledge of BIM development
,
Process understanding LOD concept
skills are leadership and
than those with BIM
application
Application skills Time management Negotiation
home energy advice) . There
products is essential , as
are
are likely to be severe
are the key to construction's
of common challenges , such
States . The activities identified
as
as valuable schemes for meeting
Sector Skills Councils comprising
the following Joint Sponsors :
Wales , which consists of
Asset
attitude , motivation , specific and linguistic
be given to addressing identified
be registered in the ID06
be requested to have coordination
below . June 2013 Page 8
points out that the
)
. As described in the CEDEFOP
; Prefabrication , timber framing and pods ;
' Train the trainers' initiatives are
2006 , pp . 12 – 19) . 3Ventilation
although it is becoming increasingly
and
assess respondents' perception of
BIM education . The survey
especially process management , will
knowledge of BIM standards .
SummitSkills . DLCS is a
Working conditions in some
applying theoretical knowledge and eventually
are considered relevant to this
as
the base for better
well as
achieving improved
ICT , digital ,
based on the responses , Fig .
but
also relevant knowledge and
the risk of skills
CITB , Energy & Utility Skills and
Constructing Excellence Wales , CITB , the
ConstructionSkills , Energy and Utility Skills ,
motivations and judgments) , (b) individual
National BUILD UP Skills Projects .
only a limited number of
providing practical and modern tools
qualifications and jobs in the
Rapid technological change , Mobility , and
requiring the construction workforce of
team building , leadership , conflict management ,
their profiles could be very
TWG 2 Mutual recognition of
.
Multiple methods The authors have
101 Defined by the Royal
2
. 3 Data Collection and
PRESENTATION OF THE BIM
4D tools and procedures Knowledge
5D tools and procedures Project
74 UKCES (2012) Sector Skills
Aligning the competences of the
Although construction is one of
Appendix B contains the proposed
As part of their evaluation
Because these skills relate directly
BPMN process mapping , developing justification
Demand for , and value of ,
Designing a BIM - based portal
Enhancing the BIM qualifications and
Exchanging service life information and
Fig . 5 . Skill sets as
For higher - level professionals in
Furthermore , the fragmentation of the
http : / / cordis . europa . eu / project /
In
: 2010 Proceedings of ASC
essence , the emergence of
Italy , Formedil , the national
order to overcome the
Innovation in the sector and
It will therefore be important
5 Skills


better across the board ; Architects'
rated to be important
the respondents . Fig . 10
to creativity . Fig . 9
1 . Summary of key
another discipline Section 2 :
BIM section and (2)
boxes below . BIM4VET – assessing
necessary information on BIM ,
highlight the
the increasing
need for
a better understanding
identify a set
increasing the levels
of
of construction school graduates'
BIM
competencies . Multiple choices
50
workforce .
Specific focus
on
survey mainly focused
Table 2 . Most important
that BIM designers require
a relationship between
starts by assessing
the
the survey continued with
write their opinion about
BIM designer , the highest rated
BIM for cost control . Spreadsheet
BIM for scheduling . Scheduling tool
as part
collar' remit
of
of the Swedish
overview report . 46
require further 49
Build Up
sector including infrastructure .
Tait Consulting (2012)
in Bulgaria
workforce . Indeed
conducted under
level , since
the
the EU - wide
trainers . Aside from
UP Skills , National
Workforce in Cyprus (
Build Up Skills UK - 2020
. 1 Perceptions around
a
Cf .
Matrix of
Built Environment
by using their newly obtained
Change . June 2013 Page 30
Change . June 2013 Page 6
CITB also leads the National
leadership . BPMN process mapping
Skill with BIM tools
management , planning , numeracy
services ; Effective negotiation
and
communication
and application skills . Surprisingly ,
literate , with well - developed
. K . :
Ayer
Comparing building information modeling
A case for enhanced
1
Introductory
Certificate in Basic
Intelligence
report
26
28
34
Experian : 2013 - 2017
June 2013 Page
59 Skills
Namely , the Strategy seeks to
On the other hand , the
Required BIM tools and packages ,
Similar conceptual approach has been
Some of the initiatives may
Surprisingly , communication skills and creativity
The
campaign aims at raising
key issue is that
process requires them to
respondents' were given a
This
is
especially the case
the case across
means that even if
paper presents the results
Thus , some of the key
To counter these challenges , a
Training planning and educational material
Welsh Government (2009) Capturing the
When asked whether they thought
/
1105 - why - don - t - young -
abilities , knowledge and attitude , noting
bus - projects 30 European Commission ,
knowledge needs
must be urgently
need to be
occupational areas in Wales : Earth
twg - 2 - mutual - recognition - skills -
two - thirds - reject - construction - Despite
Agreement – Wales .
9 ProSkills (2011)
Goodier , C . I .
June 2013 Page
Proskills (2010) Sector
among individuals and organisations in
a skills gap as
advanced techniques will be
aims to recruit foreign
BIM knowledge , Fig . 7 .
bring new ones to
capacity of the further
competence Section two of
competences
, fluency in BIM
http : / / cordis . europa .
Nonetheless , because BIM
Thus , BIM education
of the respondents .
competences' (BIMplement) aims to
competencies
Multiple choices on
The second section
for
construction actors
the entire
section . All the
creativity got relatively low
desired levels of work
experience of staff who
expertise (competence) Students working
human resource development is
ideas for ' increasing eféciency
improve the employability of
increase worker mobility
6 .
Recognising
jobs
in
Europe
, Insights
: Insights
Europe20 , a
survey .
2015 .
20
http :
October 2015 .
acquired in different


35
36
5
7
Construction
favour of change to
in terms of its
Recognised skills shortage in
traditional craft and specialist
Construction . June 2013 Page 28
Construction . June 2013 Page 36
construction in Wales June 2013
Construction Industry Training Board's Purchaser
CORDIS , Meeting of Energy Professional
- side analysis
........................46
6 . 1
Current
a snapshot of the
D D D Page 72
D June 2013 Page 73
demand can contribute to alleviate
demolition . June 2013 Page 43
needs) Architects (low carbon
POE , these include : . . . . . . applying
design
detail rather than the underlying
acquire knowledge of and
increasingly be required
introduced a training
training in order
to
develop
from different domains with
required for BIM professionals .
Different
different tools that require specialized
construction and architecture professionals .
and
among the workforce
areas need to
needed
by the
to meet
) Architects (low
; and 2)
are equally
needs
Communication and
for the
of the
to be
knowledge
of BIM among
related to resource
relating to :
communication ,
procurement ,
required
for a
to meet
through good training ,
to progress in
produce more efficient buildings
Qualifications
. http : / / www . buildup .
in the Building
SummitSkills . Working in collaboration
support the development in
the
image of the
promotion of professional
vacancies on the
, productivity , innovation , and
. The spectrum of
Analytical Report – Improving
development of
to update
the
energy
efficiency
true particularly for
aiming to impart
the need for
energy -
environment sector stakeholders to discuss
etc . June 2013 Page 3
, 950 individuals7 . 10 . 11
Future of UK Construction
.
and water sector employment
currently available . 59 60
EU Skills
Proskills UK
EU Skills
EU
Labour Market Intelligence . 8
Proskills UK Proskills UK
Report for Wales 38
Spring 2012 inclusive . 54
- based roles53 . Overall
all employees in
the
Europe20 , a solution to overcome
Europe : Insights from CEDEFOP's
Europe , Insights
match ? Evidence
from Cedefop's
European
between the pool of
is to improve
the transformation of
their qualification level , indicating
the
existing
Fig . 5 . The most valuable
following professional occupations and associated
address specifically women ; Efforts
and a suitable proposal
as a possible solution
as a primary driver
drivers affecting the need
concern regarding future
shift in the
needs
for
overview of the obstacles
are driving
need ; raising
the demand
are
coordination and collaboration , teamwork ,
defined as those required
expected to reduce . Site
functionally relatively unchanged compared
leadership and application skills .
listed in Table 2 .
trainers themselves . However , such
area where 95 Construction Industry
around quality requirements and checking
as
being of lower importance
building evaluation is multidisciplinary ,
listed by the respondents
well as experience in
Assessment
for
the
Construction Sector
Process and
Wales
pointed out
points out
in construction . Within this
atrophy of the long - term
available at a given period
barriers and drivers in the
base
, training provision needs to
available to replace those
based on
a practical live
literature review Authors :
brought in from outside Wales
but also require very detailed
can be
a powerful internalized
developed through training
card
. The skills card consists
consists in a registry
is a measure to
may have a focus
requires the registration of
varies considerably across MS ,
cards , which include information on
CITB CITB CITB CITB CITB
City & Guilds Level 1 Certificate
Contractual terms related to BIM

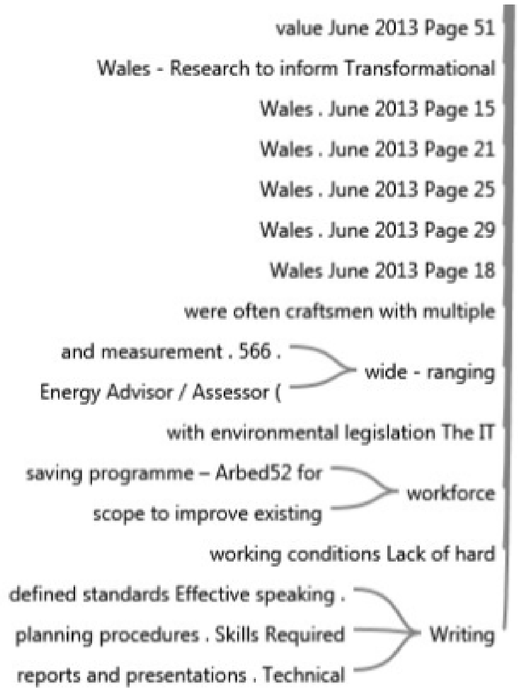

trainings and
training (VET) is key
for employees of the organization
for which the country lacks
forward evidence from the various
FR02002 June 2013 Page 40
behaviours . In fact , aside
construction related activities suffering
from
. 62 - 73 ' Process'
and quality . ' People'
functions require
as an investment into
degree of uncertainty over
development of a strategic
the heritage sector ; research
future
data collected by ECSO
qualifications of construction workers ;
recognition and worker mobility - - - - - - - - - - - - - - -
Trends in policy initiatives
General
Government (2007) Building Companies , Building
greater degree of technical accuracy
HESA . June 2013 Page 48
34
information90 .
5 . 3
intermediate , advanced
is professional
and
to deliver the
Higher level
continuous education and investment
encouraging employers to invest
into account the shift
that education and training
in
in 2011 , the following procurement
inclusive . June 2013 Page 24
individual as well as team
Information Modelling 5 . 2 . 1
initiative to boost the energy
. g . Austria) .
industry cooperation
Initiative to recognise
Intelligence . June 2013 Page 17
Intelligence . June 2013 Page 57
. 3 . 4 Intermediate skills
Project' identified the following
Skills Councils to explore
undertaken99 . 5 . 3 . 4
intermediate
is estimated to require extra
job as an engineer My
jobs . June 2013 Page 16
jobs . June 2013 Page 71
jobs in the EU , such
joiners will require honed assembly
be crucial to develop
entry and development of
many more125 . The following
key
knowledge is needed rather than
knowledge needs Communication and sales
(e . g . productivity , cost) .
for all project participants
to BIM / VDC . Personnel
leadership
leaving workers with often outdated
83 CREW (2011)
. 2 . 3
BRE report
,
BRE (2011)
of the
Wales' programme
Delivering
evidence base for
low carbon
skills
Conversely , some Member States are
could be applied to offsite
Council Group (BESSCG) in Wales ,
Councils
comprising Asset Skills , CITB ,
to explore intermediate skills
Database . Some countries also organise
demand ,
in the higher occupational
which may be problematic
Demolition phase • Removal of waste
developed through short term programmes
Developing and creating a clear
development
, the strategy encourages high -
. Chapter 4 provides an
: 1 . The decrease in
45 . Namely , construction is
in
construction . First , it
the sector . The
is critical to ensuring
Negative image of the
Structural barriers to skills
The construction sector tends
While new technologies and
within the industry . Indeed ,
development46 . The structural fragmentation of
development74 . In the longer term ,
differ based on the desired
for
Team . The last
commissioning buildings are required
design and representation 2
green construction : Overcoming challenges .
its
development . However , stereotypical
workers , as discussed
low carbon residential developments ;
new build in particular
Sustainability – What does it
Sustainable Communities , ODPM , London .
the installation of renewable
gap
% survey respondents 2011 (2007)
(45 % of respondents) , and
. Indeed , in most cases ,
as the workers are
gap59 . 53 Construction News , YouGov
gaps
(
on a prompted basis)
prompted) Skills gap % survey
in these areas 111
with a particular emphasis
implications
of specific forecast industry
relating to specific industry
resulting from approaches to
Building Information Modelling (BIM)
collaborating through BIM enables
collaboration , planning , design , and
construction
,
namely energy efficiency
zooming at the
.
There is large
These initiatives may
has also been
designing technological solutions for
EE and RES until
EU - funded projects
Given
Initiatives
Europe . BIM - TRAIN specifically
innovation , entrepreneurship and business
isolation ; Ensuring geographical accessibility ,
order to improve their

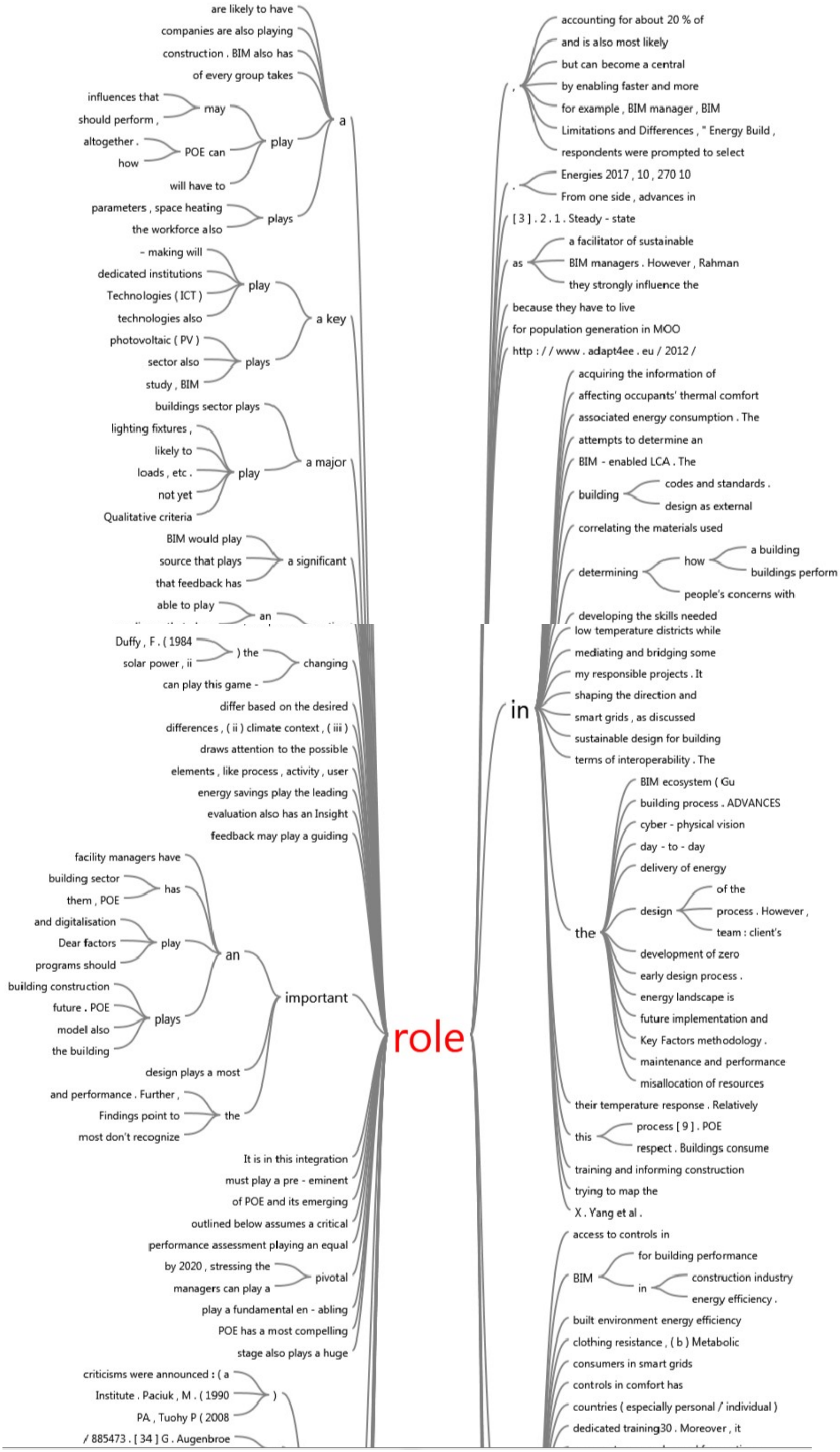

in respect of
their workforce with
training provided in
with respect to
packages , IFC , BCF Effective
recyclable materials Leadership and
solution prescription . In parallel ,
management
carried out
Research (2011)
Management and Supervisory
- level professionals in particular ,
most employers reported any
of employers with specific
set of the reported
managerial
Manufacturing June 2013 Page 27
Manufacturing June 2013 Page 37
its appeal 15
survey . 2015 . 20
CEDEFOP ,
the CEDEFOP report on
Matching
mathematics (known as the STEM
4 .
curriculum
1
Figure 2 :
BIM and
domain expertise and business
modelling
National Status Quo . Page 66
nature , indicating mismatch of jobseekers'
tendency , contractors will increasingly
to civil engineers , will
need
an emergent demand for
which is a
combination
Construction' highlighted a number
Consulting conducted a review
coupled with a narrowing
distinction between the type
economic crisis , the issue
have the needed pool
Indeed , possessing a blend
and the ensuing
and increase
population and
the
level
and increasing their
characterised by different
leading to higher
levels
a pre - defined
were given a
list
of the main drivers
of
the validation and
contributes
contributing
to the
TWG 2 Mutual
recognition
research on the identification
role on the sets
have the same
impart a new
requires the existing
validate the identified
validate the identified
set
skills , but the risk
measures for
namely supporting
obstacles to
the development
definition . Understanding
summary of
the types
to a recognised shortage
of BIM competence and requisite
- - - - - - - - Digitalisation - - - - - - - - Constructionrelated apprenticeship
of construction and improving its
of offsite components Carpentry Joinery
in
relation to offsite manufacturing
response to the increasingly
Revit are better after
Slovenia , part of the
such areas
as : Advanced
as111 : Advanced
the
AEC industry . For
building sector in
Built Environment in
Construction
Industry
. September
evidence
Sector
,
rather
some
. Table
and
in
European construction sector ,
industry
. The ageing
to adapt
short term will
workforce is the
Wales
– Low Carbon New
Programme – Final Report .
Wales' programme Delivering Low
include updated knowledge of BIM
initiative
, over 3 million construction
. For instance , in Bulgaria ,
consists in setting up
issues
around sustainability were found
associated with
core construction
low carbon
like
collaboration and communication , negotiation ,
leadership , communication , negotiation , and
teamwork and communication are
list does not address any
matrix for BIM users , as
may find it much harder
mismatch by helping unemployed youngster
mismatching is to improve the
more effectively ; improving commissioning process ;
need
; raising the demand for
to be developed through
needed
during offsite construction and
for
a professional workforce .
BIM managers , Fig .
new methods of
to
flourish . . In addition ,
retrofit historic / listed
Needs
; and 2) knowledge requirements
Analyses , it will be
Analysis
(SNA)
has been
This Skills
. 2 . 3 Evidence
for the Construction
of the Construction
for
Building Information Modelling
Modern Methods
Construction
of
in the
Construction Sector .
labour market ,
Technical knowledge needs Installation
through existing and planned
will be affected by
Network Wales Labour Market Intelligence .
a person and their
all actors working together


of people have the right
of the sector and desired
of which , the most common
often provide low and medium
sector likely to
impact
well as their
of VET - business cooperation
on
sector in Europe , focuses
to reduce the reliance
On the contrary , traditional onsite
organisations . June 2013 Page 64
outcomes . June 2013 Page 56
Pay , job security , responsibility Job
Perspective June 2013 Page 35
planning . June 2013 Page 46
planning and educational material development
possess the necessary knowledge or
Priorities) : G Essential Questions Q
relating to the following
also stressed that
the
priority
Wales responds to
programmes for integration of digitalisation
Project . June 2013 Page 44
Project . June 2013 Page 68
promoting sustainable techniques and traditional
providers . June 2013 Page 54
Quo . June 2013 Page 53
Quo . June 2013 Page 60
Quo . June 2013 Page 67
Quo . June 2013 Page 9
human capital basis 24
Recognised
report . June 2013 Page 34
Report . June 2013 Page 55
representing the most commonly occurring
- related roles and responsibly ,
followed by applicants lacking
motivation / attitude Applicants lack
required
and contractor determine
the
recruiting people with
Research . June 2013 Page 41
resources . June 2013 Page 39
respondents . June 2013 Page 45
fulfillment . Applying newly learned
Revit
the project anchored their
Roadmap . June 2013 Page 19
Roadmap . June 2013 Page 58
Scotland . June 2013 Page 20
scratch in order to deliver
section and covering specific industry
Agreement – Wales
. Proskills
Process Manufacturing
. asp 91
113 114
18 19
71 72
and Wales
appears 80
engineering 67
CITB
Engineering 79
Ireland . 57
(2010
June 2013
)
solutions91 . 85
10 %
Source :
employers
Wales report .
Sector
38
54
60
EU Skills
8
Construction .
at least 1 , 800
BIM actors , consequently resulting
construction professionals
. In Cyprus ,
and is
creating model progression plans
different trades . In addition ,
Europe's building workforce . February
its
members regarding BIM
workforce . In this
of
project
Man - agers and
managers and BIM
senior staff themselves Identifying
energy , waste , water
EU construction workforce ,
the
teaching resources .
Change
Recommendations
The
workforce
, so as
with innovation
trainers and teaching staff92 .
workers is therefore particularly
offers a new angle under
on
a design of their
innovative techniques and tools
the construction labour market
only . AQ3 Author Proof What
onsite are likely to be
or
create jobs but will
type of behavior required
originate from a multitude of
Overall Buildings Yes No Don't
SWEBUILD , the Swedish Construction
Projects . http : / / www . buildup . eu /
for the
Built Environment
Construction Sector
– delivered as
(
2011) research
separate Excel -
, with only
Findings from
provision
in
Wales
; identify
highlighted
research
identified
reported
that
The Skills
Wales' research in
that satisfies this change .
Wales
The qualifications Regulator
publication . pdf Analytical Report – Improving
qualifications and education across countries .
QualiShell , http : / / www . iee - robust .
Rahimi et al . (2016) : Teamwork ,
recognition
and mobility of workers
revolve around the implementation
relate directly to Government priorities
related to the
technical solutions
use of
relating to
innovative technologies and
sustainability is also
relevant to a BIM profession ,
reported through previous studies . Thereafter ,
; Site agents need to
by
construction companies and
the
advent of
industry . All
required
during all stages of
for
graduates , based on
the future . Emerging

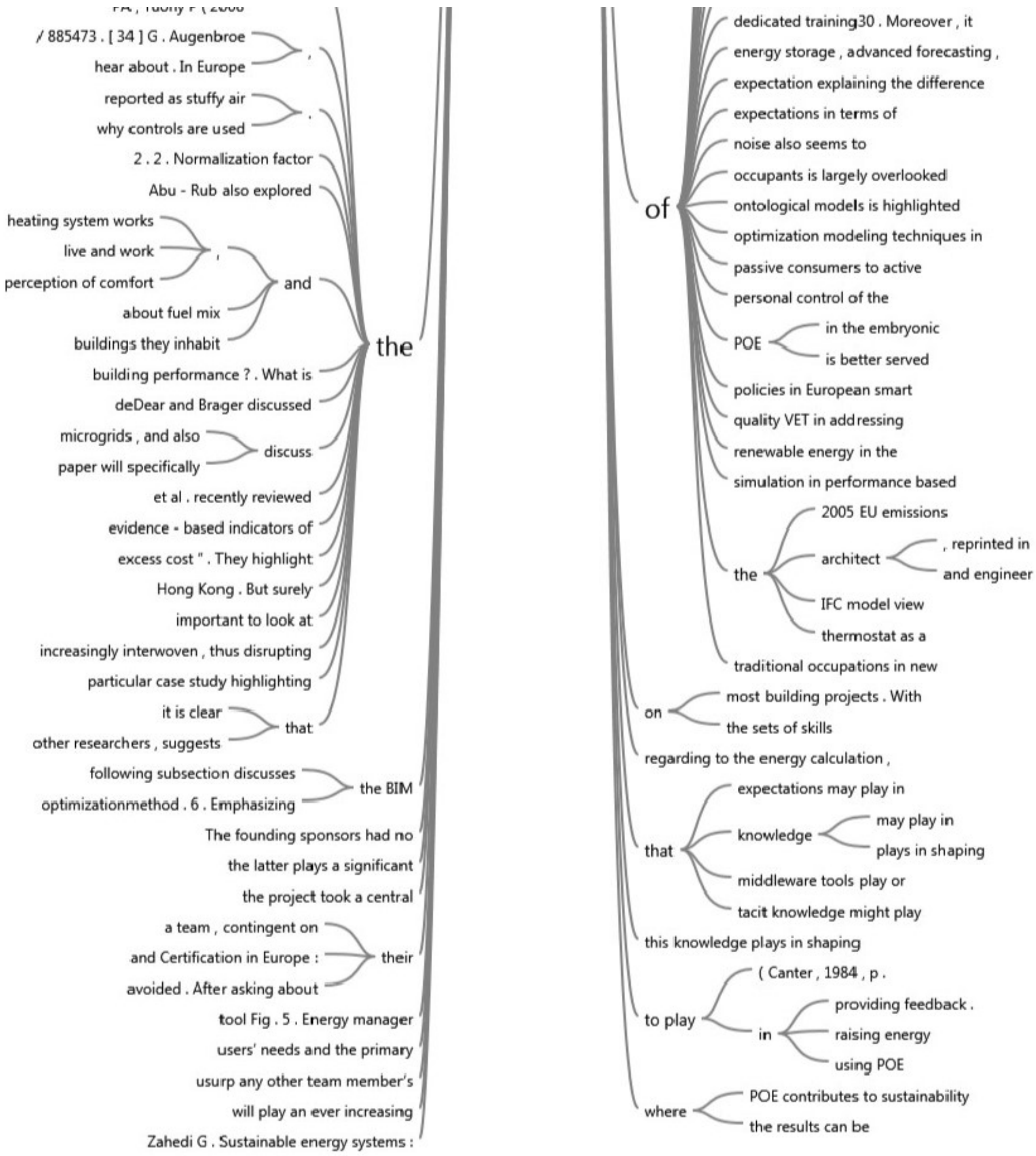

Skills . 74
the professional
UKCES (2012
an alliance of UK
by the Built Environment
Having said that ,
sized enterprises (SMEs) .
the sustainability agenda –
CITB's
distinguishes between 1) pan -
Environment in Wales ConstructionSkills'
Project' included interviews with
Sector – Wales report . Page 42
sector . June 2013 Page 63
simultaneously teaching sought - after practical
Skill with spreadsheets . Cost estimation
Skills . June 2013 Page 5
Skills . June 2013 Page 59
also focus on the
also in terms of
combination of technical and
women in strengthening their
soft
a need for different ,
affect the need for
specialised
- skilling
upskilling
at all levels
at all levels . 16
low carbon , sustainable buildings
space required) ; Heritage (including
Specialist
construction38 . With regard to
and that needs
need and demand
for
to design for that .
Specific
specific technical and manage - ment
Spring 2012 inclusive . Page 4
Short
for , and value of ,
skills 5 . 3 . 1
employees of the organization
tools , energy analysis tools
and educational material development
to fulfil BxP requirements
Teaching
document : distinguishes between 1
onsite and offsite construction
)
general therefore , managerial
in BIM applications ,
Maintenance phase •
of core
Soft
and
have been outsourcing their
i . e . not just
impart better and
to developing completely
new
of technical and non -
technical
technical , methodological , procedural and organizational
cautious acceptance by employers
The authors also highlight
the authors had expected
that
- Brandenburg aims at reducing
[2] . In many ways
capital basis 58 measure
qualifications and training . Generally
a socalled skills card
on the opportunities . 25
also asked to rate
and green issues was
and measures to build
deemed in - scope
stakeholders with responsibilities
for
Wales108
Wales119
Wales12
, substantiates evidence
Gap analysis
in Wales
Findings
from
and industry stakeholders
in a BIM team .
to be a competent
Writing skills , developing justification
requirement to help the planning
requirements for the regeneration and
Research
99 BRE (2011) Delivering
Despite green issues and
June 2013 Page 41
McCarney , M . and Gibb ,
on behalf of CITB .
Road -
14 Pye Tait Consulting
map3 to ensure that
Roadmap and Action Plan .
17
4
Pye
scheme (BeställarKompetens) , which aims to
sector workforce
are male ; the
has the same
shortage
, we need to engage
. Figure 8 below provides
and
surplus occupations in
the main reasons
in
Construction
activities at
Skills shortage
the
construction sector
EU . However ,
include : Modernising and strengthening
problem includes foreseeing investment
shortage47 . Indeed , the lack of
42 McKinsey Global Institute ,
Moreover , different requirements across
and
gaps could remain
mismatches4 . The tightness
shortages21 indicates that sectors with
situation in the construction sector
Skill with
BIM tools Using
spreadsheets . Cost estimation
sought by employers . In essence ,
Source : Ofqual A total of
Standardised Vocational Education and Training
STEM (science , technology , engineering and
such as drainage and foundation
supply and demand , technological change ,
Surveying skills were found by
that
are
currently lacking in
required for BIM
BIM education should deliver ?
can potentially influence the
demands a life cycle
through BIM promotion
Analytical Report
Most Member
Time management Negotiation skills Project
to
achieve such priorities should
assemble framed buildings to
be able to sustainably
carry out sustainable construction
choose from , and self -
construct and maintain buildings ;
construction workers to meet
develop a professional and
diagnose and help businesses
ensure that new buildings
enter professions and trades
fill their open vacancies
fully benefit from the
improve their employability66 . 63http :
meet the
115 In
requirements of
model their own design .
oversee increasingly collaborative design
rate as per their
the practical needs of

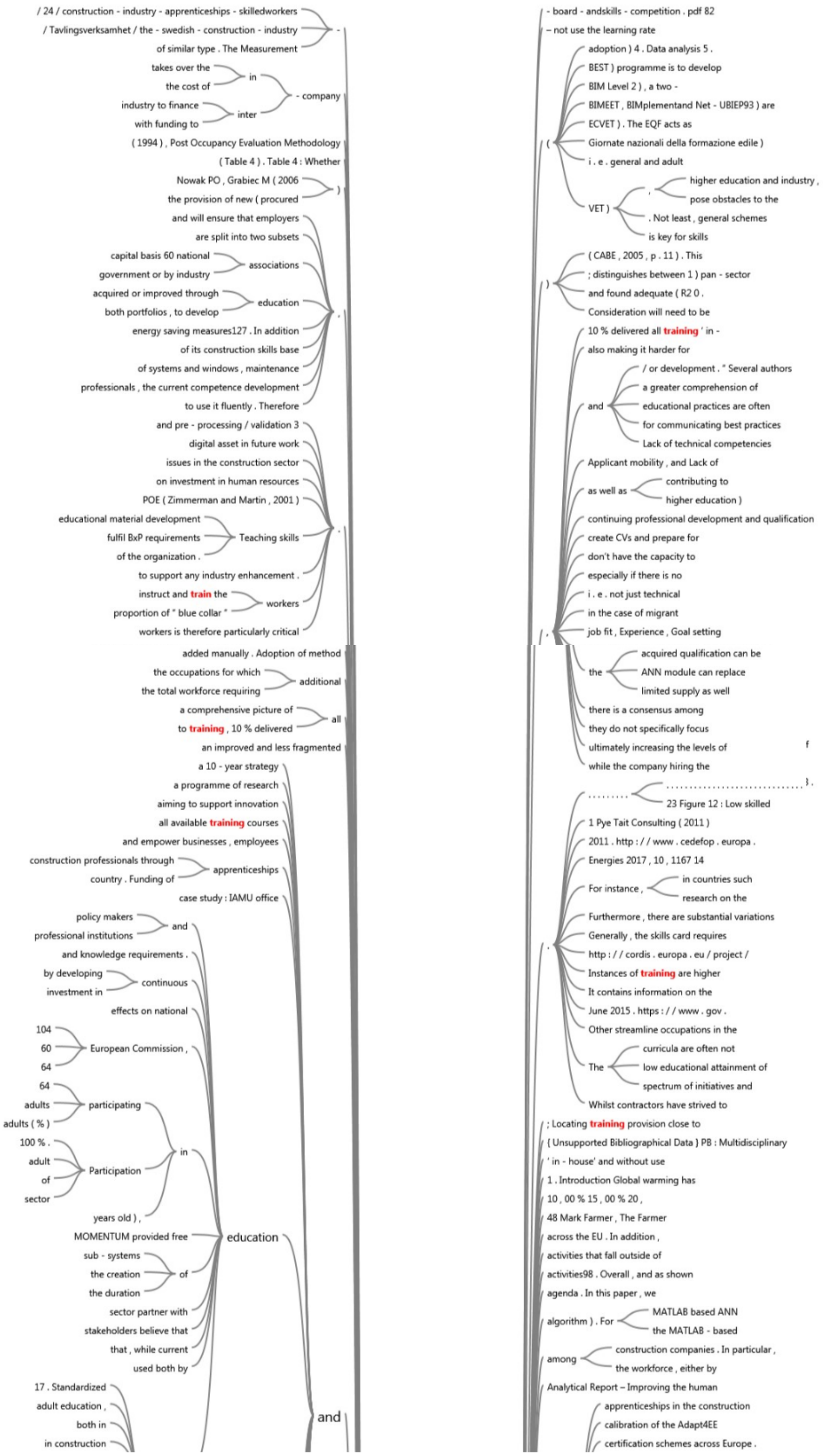
and private sector
have
be required to
key role in developing
the
key role in limiting
leading to mismatch between
main policy responses to
allow the assessment
bring a transformation
technologies . Thus , some
of
around
the implementation
Nevertheless ,
through an upgrade
of seminars to enhance
of training Including understanding
on the need aligned
operational processes . Consequently , tackling
people throughout the organization
pieces of equipment , requiring
quality VET in addressing
relevant criteria . Key takeaways
skills provision in Wales
Status Quo (2012) identified
Wales – Onsite and Offsite
and rail links –
an outcome
the 2011
of
as part
the challenge of promoting BIMrelated
the development of a socalled
able to choose
the essential
the risk of a diminishing
the workforce to develop suitable
are encouraged to develop
in order to
most appropriate jobs
improve
their
revisit their designs ,
of staff , and developing
will need to increase
in the labour force
the EU 2020 targets
at ways to add
different , specialised skills . Because
these
in the study rated
the main reason explaining
to increased demand for
was some disappointment that
2 . 2 Scope of
this
Skills Needs Analysis (SNA)
competence in each of
those
own competence levels in
clear information on access
construction sector . With respect
implemented specific initiatives related
35 % 42 . 4 .
to
scaling – offsite construction
Obstacles
the chapter on
35 the
Structural barriers
skills development
to concerns about the potential
to June 2013 Page 70
to note that these particular
to translate technical jargon Administrative
tools supporting COBie . Problem - solving
total construction employment , and hence
trained to increase their specific
Trainer programmes and the increased
up by the technology41 . Appropriate
Asset Skills , CITB , Energy &
Utility
Skills , ConstructionSkills , Energy and
their curriculum [3] . In
training programmes , educational courses , etc .
translate into the capacity of
2020 Skills Roadmap and
Analysis of the National
UK
, an alliance of UK
. Having said that , BEST
research supported the finding
under the Thematic Objective 2
Understanding of occupational remits / impacts
upgrading and behaviour ; commitment from
VET reform - - - recognition and worker
Low Carbon New Build
100
Wales –
Project .
94
Retrofit Learning
CADW
Project' included
was steady at about 13 %
WE
- QUALIFY) . https : / / ec . europa .
asked the students what
deemed by respondents to
found by the BRE
were
listed by the respondents ,
not awarded grades . The
where possible , to make the
crucial , including management ,
increasingly needed at
be
partially essential for
will
required to plan ,
little or no experience ,
rendering , visualization , graphics and
respect to low carbon
use of BIM for


value June 2013 Page 51
Wales - Research to inform Transformational
Wales . June 2013 Page 15
Wales . June 2013 Page 21
Wales . June 2013 Page 25
Wales . June 2013 Page 29
Wales June 2013 Page 18
were often craftsmen with multiple
and measurement . 566 .
Energy Advisor / Assessor (
wide - ranging
with environmental legislation The IT
saving programme – Arbed52 for
scope to improve existing
workforce
working conditions Lack of hard
defined standards Effective speaking .
planning procedures . Skills Required
reports and presentations . Technical
Writing



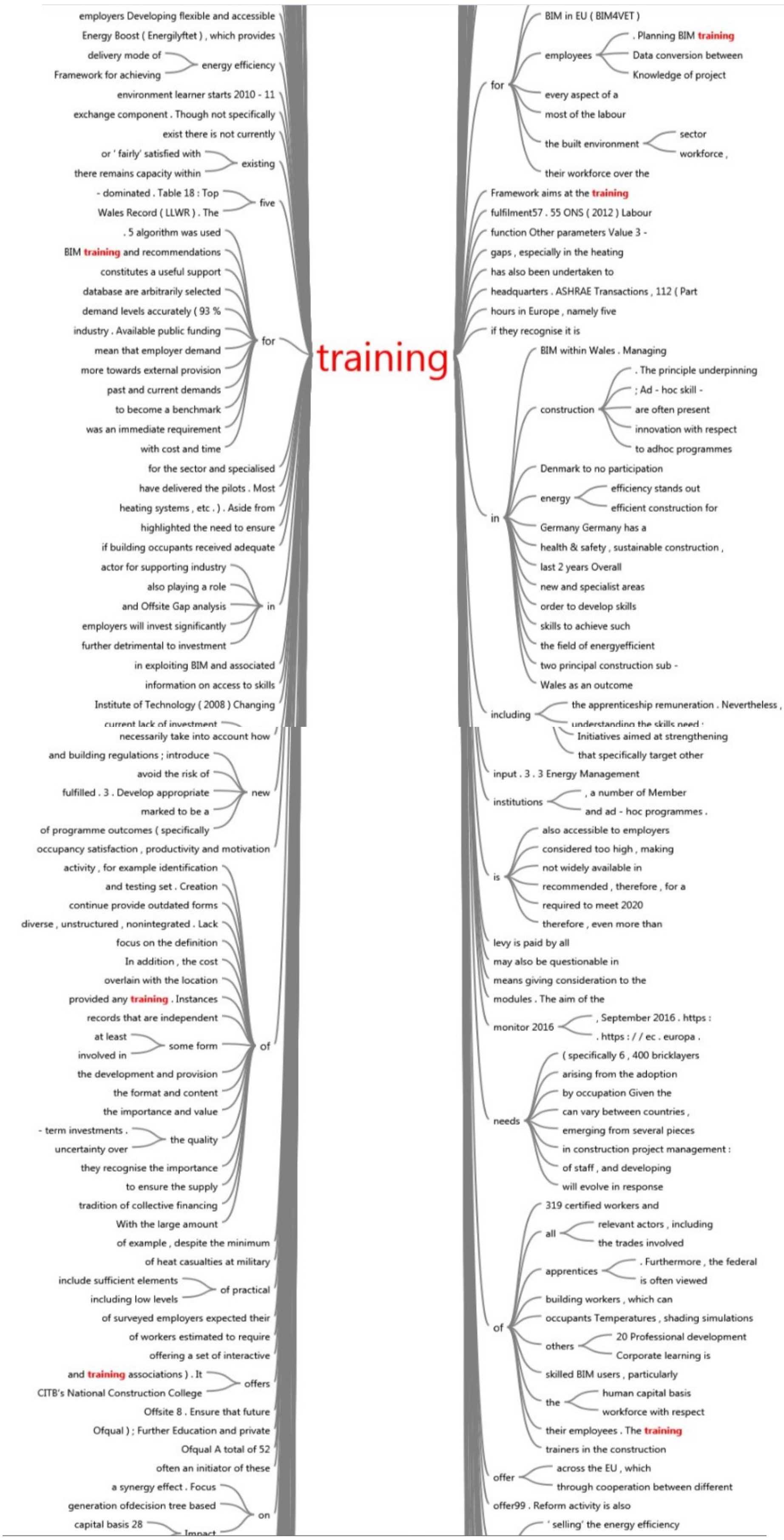
are likely to have
companies are also playing
construction . BIM also has
of every group takes
influences that
should perform ,
may
altogether .
how
POE can
play
a
will have to
parameters , space heating
the workforce also
plays
- making will
dedicated institutions
Technologies (ICT)
technologies also
play
a key
photovoltaic (PV)
sector also
study , BIM
plays
buildings sector plays
lighting fixtures ,
likely to
loads , etc .
not yet
Qualitative criteria
play
a major
BIM would play
source that plays
that feedback has
a significant
able to play
an
Duffy , F . (1984
solar power , ii
) the
can play this game -
changing
differ based on the desired
differences , (ii) climate context , (iii)
draws attention to the possible
elements , like process , activity , user
energy savings play the leading
evaluation also has an Insight
feedback may play a guiding
facility managers have
building sector
them , POE
has
and digitalisation
Dear factors
programs should
play
an
building construction
future . POE
model also
the building
plays
important
design plays a most
and performance . Further ,
Findings point to
most don't recognize
the
It is in this integration
must play a pre - eminent
of POE and its emerging
outlined below assumes a critical
performance assessment playing an equal
by 2020 , stressing the
managers can play a
pivotal
play a fundamental en - abling
POE has a most compelling
stage also plays a huge
criticisms were announced : (a
Institute . Paciuk , M . (1990
PA , Tuohy P (2008
/ 885473 . [34] G . Augenbroe
)
role
,
accounting for about 20 % of
and is also most likely
but can become a central
by enabling faster and more
for example , BIM manager , BIM
Limitations and Differences , " Energy Build ,
respondents were prompted to select
.
Energies 2017 , 10 , 270 10
From one side , advances in
[3] . 2 . 1 . Steady - state
as
a facilitator of sustainable
BIM managers . However , Rahman
they strongly influence the
because they have to live
for population generation in MOO
http : / / www . adapt4ee . eu / 2012 /
acquiring the information of
affecting occupants' thermal comfort
associated energy consumption . The
attempts to determine an
BIM - enabled LCA . The
building
codes and standards .
design as external
correlating the materials used
determining
how
a building
buildings perform
people's concerns with
developing the skills needed
low temperature districts while
mediating and bridging some
my responsible projects . It
in
shaping the direction and
smart grids , as discussed
sustainable design for building
terms of interoperability . The
the
BIM ecosystem (Gu
building process . ADVANCES
cyber - physical vision
day - to - day
delivery of energy
design
of the
process . However ,
team : client's
development of zero
early design process .
energy landscape is
future implementation and
Key Factors methodology .
maintenance and performance
misallocation of resources
their temperature response . Relatively
this
process [9] . POE
respect . Buildings consume
training and informing construction
trying to map the
X . Yang et al .
access to controls in
BIM
for building performance
in
construction industry
energy efficiency .
built environment energy efficiency
clothing resistance , (b) Metabolic
consumers in smart grids
controls in comfort has
countries (especially personal / individual)
dedicated training30 . Moreover , it

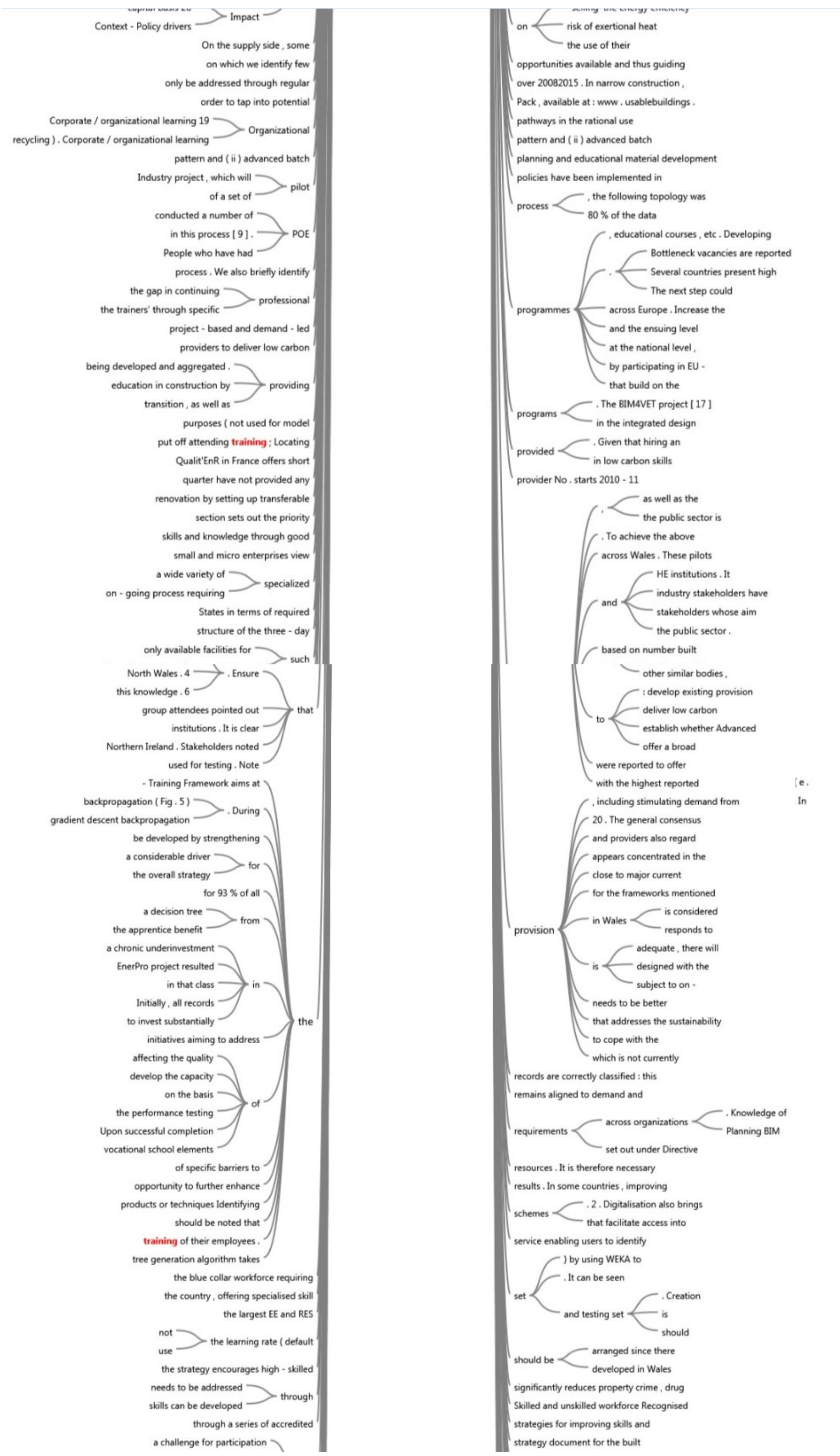

/ 885473 . [34] G . Augenbroe
hear about . In Europe
reported as stuffy air
why controls are used
2 . 2 . Normalization factor
Abu - Rub also explored
heating system works
live and work
perception of comfort
and
about fuel mix
buildings they inhabit
the
building performance ? . What is
deDear and Brager discussed
microgrids , and also
paper will specifically
discuss
et al . recently reviewed
evidence - based indicators of
excess cost " . They highlight
Hong Kong . But surely
important to look at
increasingly interwoven , thus disrupting
particular case study highlighting
it is clear
other researchers , suggests
that
following subsection discusses
optimizationmethod . 6 . Emphasizing
the BIM
The founding sponsors had no
the latter plays a significant
the project took a central
a team , contingent on
and Certification in Europe :
avoided . After asking about
their
tool Fig . 5 . Energy manager
users' needs and the primary
usurp any other team member's
will play an ever increasing
Zahedi G . Sustainable energy systems :
of
dedicated training30 . Moreover , it
energy storage , advanced forecasting ,
expectation explaining the difference
expectations in terms of
noise also seems to
occupants is largely overlooked
ontological models is highlighted
optimization modeling techniques in
passive consumers to active
personal control of the
POE
in the embryonic
is better served
policies in European smart
quality VET in addressing
renewable energy in the
simulation in performance based
the
2005 EU emissions
architect
, reprinted in
and engineer
IFC model view
thermostat as a
traditional occupations in new
on
most building projects . With
the sets of skills
regarding to the energy calculation ,
that
expectations may play in
knowledge
may play in
plays in shaping
middleware tools play or
tacit knowledge might play
this knowledge plays in shaping
to play
(Canter , 1984 , p .
in
providing feedback .
raising energy
using POE
where
POE contributes to sustainability
the results can be



/ 24 / construction - industry - apprenticeships - skilledworkers
/ Tavlingsverksamhet / the - swedish - construction - industry
of similar type . The Measurement
takes over the
the cost of
in
- company
industry to finance
with funding to
inter
(1994) , Post Occupancy Evaluation Methodology
(Table 4) . Table 4 : Whether
Nowak PO , Grabiec M (2006
the provision of new (procured
and will ensure that employers
are split into two subsets
capital basis 60 national
government or by industry
associations
acquired or improved through
both portfolios , to develop
education
energy saving measures127 . In addition
of its construction skills base
of systems and windows , maintenance
professionals , the current competence development
to use it fluently . Therefore
and pre - processing / validation 3
digital asset in future work
issues in the construction sector
on investment in human resources
POE (Zimmerman and Martin , 2001)
educational material development
fulfil BxP requirements
of the organization .
Teaching skills
to support any industry enhancement .
instruct and train the
proportion of " blue collar "
workers
workers is therefore particularly critical
added manually . Adoption of method
the occupations for which
the total workforce requiring
additional
a comprehensive picture of
to training , 10 % delivered
all
an improved and less fragmented
a 10 - year strategy
a programme of research
aiming to support innovation
all available training courses
and empower businesses , employees
construction professionals through
country . Funding of
apprenticeships
case study : IAMU office
policy makers
professional institutions
and
and knowledge requirements .
by developing
investment in
continuous
effects on national
104
60
64
European Commission ,
64
adults
adults (%)
participating
100 % .
adult
of
sector
Participation
in
years old) ,
MOMENTUM provided free
education
sub - systems
the creation
the duration
of
sector partner with
stakeholders believe that
that , while current
used both by
17 . Standardized
adult education ,
both in
in construction
and
- board - andskills - competition . pdf 82
– not use the learning rate
adoption) 4 . Data analysis 5 .
BEST) programme is to develop
BIM Level 2) , a two -
BIMEET , BIMplementand Net - UBIEP93) are
ECVET) . The EQF acts as
Giornate nazionali della formazione edile)
i . e . general and adult
(
higher education and industry ,
pose obstacles to the
VET)
. Not least , general schemes
is key for skills
(CABE , 2005 , p . 11) . This
; distinguishes between 1) pan - sector
and found adequate (R2 0 .
Consideration will need to be
)
10 % delivered all training ' in -
also making it harder for
/ or development . " Several authors
a greater comprehension of
and
educational practices are often
for communicating best practices
Lack of technical competencies
Applicant mobility , and Lack of
as well as
contributing to
higher education)
continuing professional development and qualification
create CVs and prepare for
don't have the capacity to
especially if there is no
i . e . not just technical
in the case of migrant
job fit , Experience , Goal setting
acquired qualification can be
the
ANN module can replace
limited supply as well
there is a consensus among
they do not specifically focus
ultimately increasing the levels of
while the company hiring the
23 Figure 12 : Low skilled
1 Pye Tait Consulting (2011)
2011 . http : / / www . cedefop . europa .
Energies 2017 , 10 , 1167 14
For instance ,
in countries such
research on the
Furthermore , there are substantial variations
Generally , the skills card requires
http : / / cordis . europa . eu / project /
Instances of training are higher
It contains information on the
June 2015 . https : / / www . gov .
Other streamline occupations in the
The
curricula are often not
low educational attainment of
spectrum of initiatives and
Whilst contractors have strived to
; Locating training provision close to
{ Unsupported Bibliographical Data } PB : Multidisciplinary
' in - house' and without use
1 . Introduction Global warming has
10 , 00 % 15 , 00 % 20 ,
48 Mark Farmer , The Farmer
across the EU . In addition ,
activities that fall outside of
activities98 . Overall , and as shown
agenda . In this paper , we
algorithm) . For
MATLAB based ANN
the MATLAB - based
among
construction companies . In particular ,
the workforce , either by
Analytical Report – Improving the human
apprenticeships in the construction
calibration of the Adapt4EE
certification schemes across Europe .

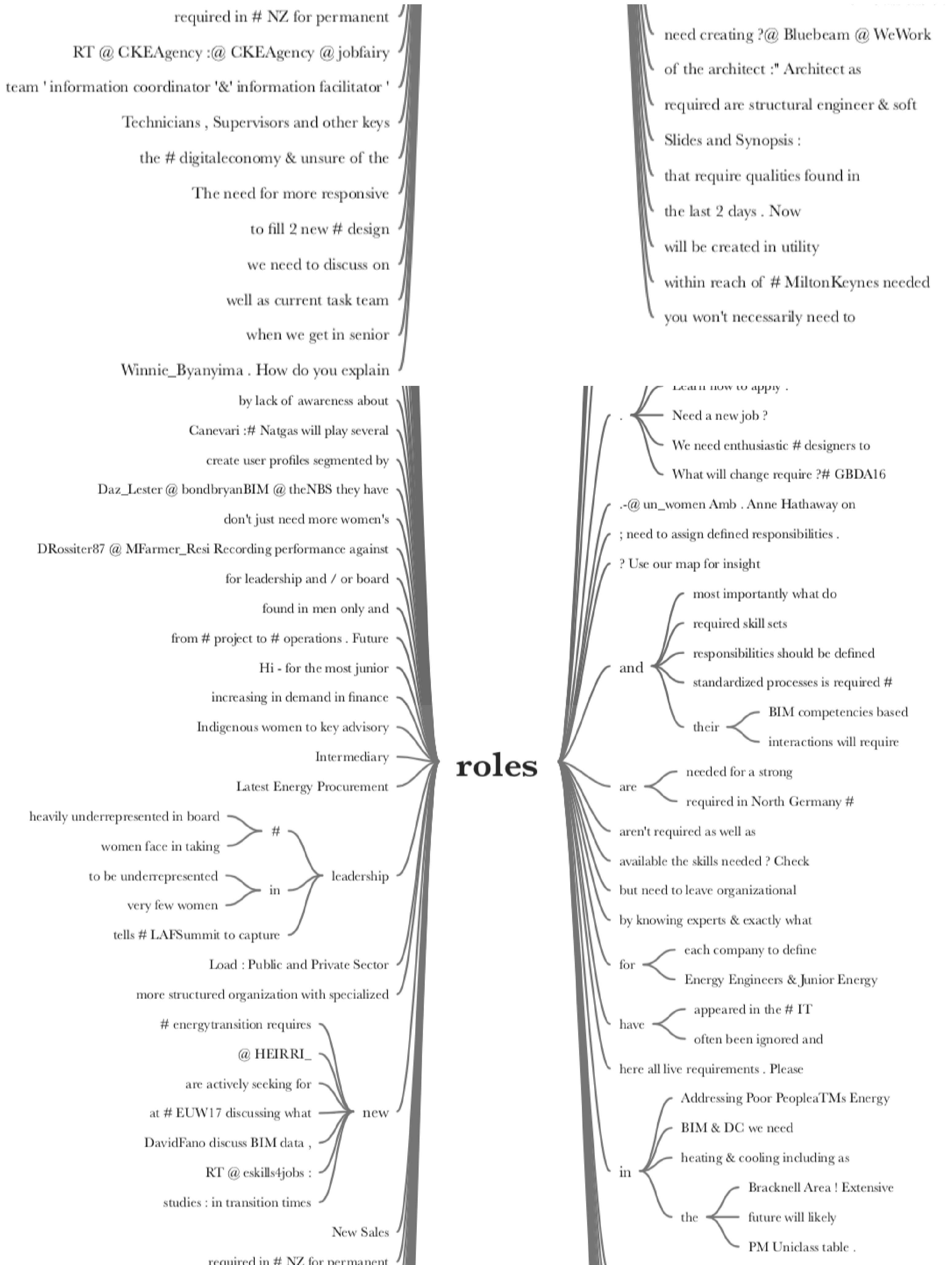
in delivering
benefits
of
quality
skills Standardised
system for
to postsecondary
vocational
Housing and various construction
in its use . Promotions
in respect of jobs
Events include both
provisions regarding the
sources . It recognises
information
MESTA . net offers career
need for BIM skilling
of manufacturing methods . Work
developing multi - country
focusing on BIM
qualification
self - motivation , aptitude , experience
- informed and cohesive
by ECSO
construction workers ;
policy initiatives
General
worker mobility - - - - - - - - - - - - - - -
skills
has the necessary
initiatives related to
outcomes for sustainability
to impact on
. 4M from the
pledged from project
Sponsors
technical , legal , regulatory , organisational
track of professional qualifications
Understanding Sustainable Energy Efficiency
with industry specialists , colleges
continuous professional development , including
development
, which will be
in these skill
qualifications to ensure
does not necessarily take
education
.
Table 6 below
There is a
schemes . The most
enable professional networking . – Bi -
facilitating apprenticeships81 . Austria has
and
information needs to be
informing construction professionals about
qualifications
) once funding arrangements
/ units that have
are developed at
recommendations for training modules .
research programmes , and to
skill needs
brought about
in the
skills
development46 . The structural
in construction . These
technical studies , Benefits trap ,
the remained data records
validation refers to [12]
ANN
model Running building simulation
modelwith simulation results WHILE
are
also in line with
higher among the professional
primarily social designers or
some distance from Welsh
as
a loss work hours
well as support the
associations) . It offers training courses
are not put off
pose a difficulty for
attending
four - hour interactive web -
need for additional knowledge
based
be essential that built environment
behaviours – information to educate consumers
and improvement of existing
and resulted in a
Developing software update protocols
education approaches and opportunities .
to subject matter
training for employees
.
Planning
requirements across organizations
providing a repository of
BIM
by low enrolment in relevant
million . Aside from
Some of the
classroom - style
companies in providing in - house
Construcción) opened up the Badalona
organised mostly
typically offered
by national
centre of excellence for
national body for professional
the National Days of
construction
- 20141 . pdf 80
instance , the UK's
registered with the
. uk / 81
include
Sweden ,
the
Swedish
Construction Industry
construction sector , with actions including '
construction workforce through 6 - month
Council offers the BIM International
may be offered through
Offering knowledge units and
CPD
currently facing fragmentation and inadequate
including overall construction strategies ,
the subsequent creation of
dedicated
develop harmonised vocational and education
double the amount of continuous
due to the uncertainty over
effective BIM - based Europe - wide
effects of continuous hot weather
bodies . The identified barriers led
budgets to remain the same
by 2020 to reach the
can provide several advantages across
centers . AMA Archives of Industrial
centre , aiming to become a
centres
. Similarly , in some cases ,
with the opportunity to
challenges based on the construction
concept , where the client and
counselling in addition to providing
courses
, other types of initiatives
and training providers in
at level 2 , 3 ,
based on an understanding
becoming quickly outdated following
for construction professionals
. In
to
funded through BEST . Cardiff
on
health and safety ,
the thermal renovation
or learning resources to
to be attended based
which were commissioned and ,
courses86 . Furthermore , the portal 79
data
and
92 % for test
the evaluation of
are grouped together into
as input and outputs
from the Adapt4EE pilot
is explained as follows .
set
(55 records were
of 55 data
delivered by BEST is
responsive
sufficiently
delivery roadmap . That roadmap will
demand from the supply chain ;
directions with regards to BIM ,
directory endorsed by partners and
DK EU28 AT LU UK
efforts should be increased to
facilities as well as reimbursements
architects ranges from a

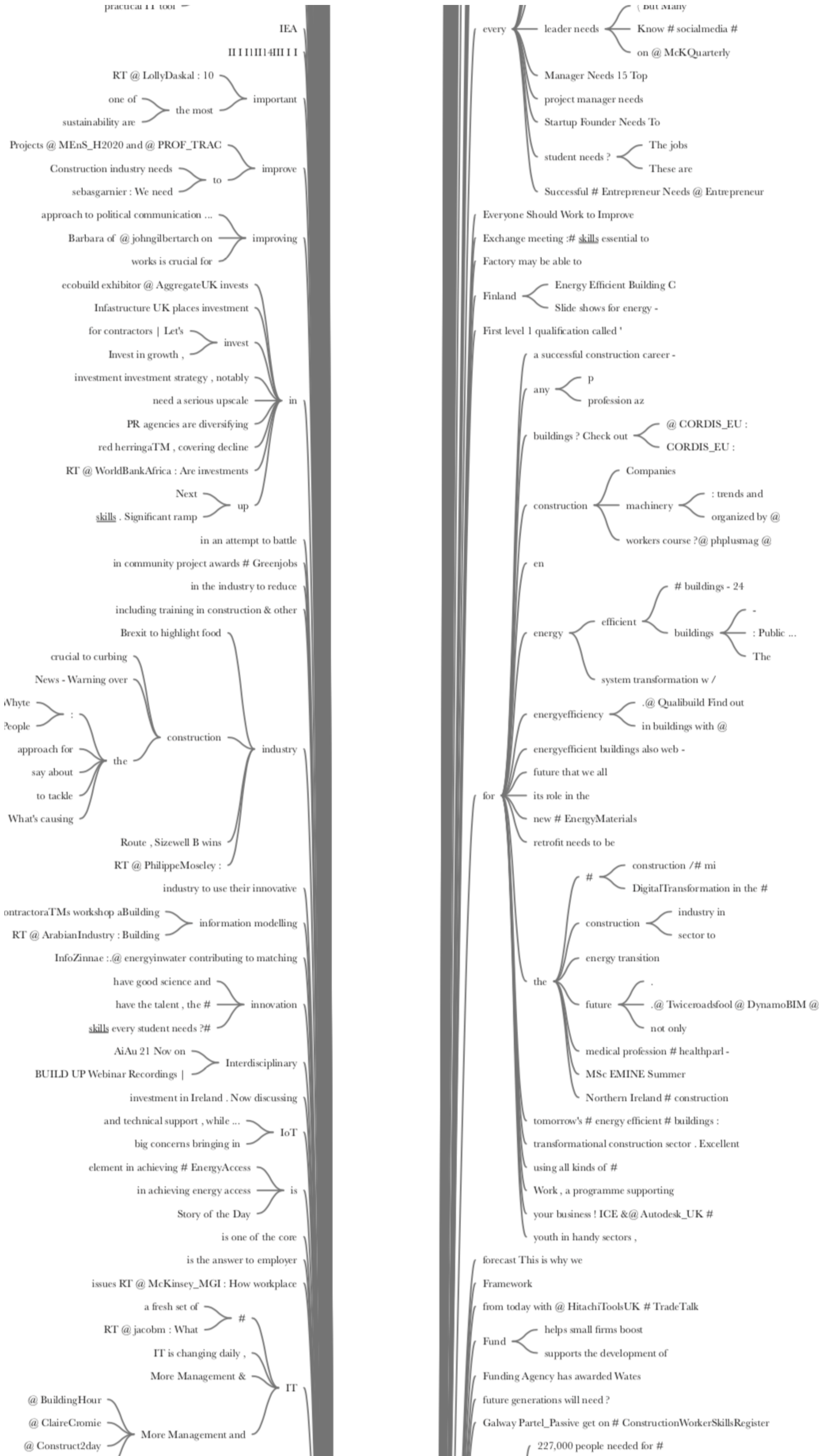

training
employers Developing flexible and accessible
Energy Boost (Energilyftet) , which provides
delivery mode of
Framework for achieving
energy efficiency
environment learner starts 2010 - 11
exchange component . Though not specifically
exist there is not currently
or ' fairly' satisfied with
there remains capacity within
existing
- dominated . Table 18 : Top
Wales Record (LLWR) . The
five
. 5 algorithm was used
BIM training and recommendations
constitutes a useful support
database are arbitrarily selected
demand levels accurately (93 %
industry . Available public funding
mean that employer demand
more towards external provision
past and current demands
to become a benchmark
was an immediate requirement
with cost and time
for
for the sector and specialised
have delivered the pilots . Most
heating systems , etc .) . Aside from
highlighted the need to ensure
if building occupants received adequate
actor for supporting industry
also playing a role
and Offsite Gap analysis
employers will invest significantly
further detrimental to investment
in
in exploiting BIM and associated
information on access to skills
Institute of Technology (2008) Changing
necessarily take into account how
and building regulations ; introduce
avoid the risk of
fulfilled . 3 . Develop appropriate
marked to be a
of programme outcomes (specifically
new
occupancy satisfaction , productivity and motivation
activity , for example identification
and testing set . Creation
continue provide outdated forms
diverse , unstructured , nonintegrated . Lack
focus on the definition
In addition , the cost
overlain with the location
provided any training . Instances
records that are independent
at least
involved in
some form
the development and provision
the format and content
the importance and value
- term investments .
uncertainty over
the quality
they recognise the importance
to ensure the supply
tradition of collective financing
With the large amount
of
of example , despite the minimum
of heat casualties at military
include sufficient elements
including low levels
of practical
of surveyed employers expected their
of workers estimated to require
offering a set of interactive
and training associations) . It
CITB's National Construction College
offers
Offsite 8 . Ensure that future
Ofqual) ; Further Education and private
Ofqual A total of 52
often an initiator of these
a synergy effect . Focus
generation ofdecision tree based
capital basis 28
on
BIM in EU (BIM4VET)
. Planning BIM training
Data conversion between
Knowledge of project
employees
every aspect of a
most of the labour
sector
workforce ,
the built environment
their workforce over the
for
Framework aims at the training
fulfilment57 . 55 ONS (2012) Labour
function Other parameters Value 3 -
gaps , especially in the heating
has also been undertaken to
headquarters . ASHRAE Transactions , 112 (Part
hours in Europe , namely five
if they recognise it is
BIM within Wales . Managing
. The principle underpinning
; Ad - hoc skill -
are often present
innovation with respect
to adhoc programmes
construction
Denmark to no participation
efficiency stands out
efficient construction for
energy
Germany Germany has a
health & safety , sustainable construction ,
last 2 years Overall
new and specialist areas
order to develop skills
skills to achieve such
the field of energyefficient
two principal construction sub -
Wales as an outcome
in
the apprenticeship remuneration . Nevertheless ,
Initiatives aimed at strengthening
that specifically target other
including
input . 3 . 3 Energy Management
, a number of Member
and ad - hoc programmes .
institutions
also accessible to employers
considered too high , making
not widely available in
recommended , therefore , for a
required to meet 2020
therefore , even more than
is
levy is paid by all
may also be questionable in
means giving consideration to the
modules . The aim of the
, September 2016 . https :
. https : / / ec . europa .
monitor 2016
(specifically 6 , 400 bricklayers
arising from the adoption
by occupation Given the
can vary between countries ,
emerging from several pieces
in construction project management :
of staff , and developing
will evolve in response
needs
319 certified workers and
relevant actors , including
the trades involved
all
. Furthermore , the federal
is often viewed
apprentices
building workers , which can
occupants Temperatures , shading simulations
20 Professional development
Corporate learning is
others
skilled BIM users , particularly
human capital basis
workforce with respect
the
their employees . The training
trainers in the construction
of
across the EU , which
through cooperation between different
offer
offer99 . Reform activity is also
' selling' the energy efficiency


Impact
Context - Policy drivers
On the supply side , some
on which we identify few
only be addressed through regular
order to tap into potential
Corporate / organizational learning 19
recycling) . Corporate / organizational learning
Organizational
pattern and (ii) advanced batch
Industry project , which will
of a set of
pilot
conducted a number of
in this process [9] .
People who have had
POE
process . We also briefly identify
the gap in continuing
the trainers' through specific
professional
project - based and demand - led
providers to deliver low carbon
being developed and aggregated .
education in construction by
transition , as well as
providing
purposes (not used for model
put off attending training ; Locating
Qualit'EnR in France offers short
quarter have not provided any
renovation by setting up transferable
section sets out the priority
skills and knowledge through good
small and micro enterprises view
a wide variety of
on - going process requiring
specialized
States in terms of required
structure of the three - day
only available facilities for
such
North Wales . 4
this knowledge . 6
. Ensure
group attendees pointed out
institutions . It is clear
Northern Ireland . Stakeholders noted
used for testing . Note
that
- Training Framework aims at
backpropagation (Fig . 5)
gradient descent backpropagation
. During
be developed by strengthening
a considerable driver
the overall strategy
for
for 93 % of all
a decision tree
the apprentice benefit
from
a chronic underinvestment
EnerPro project resulted
in that class
Initially , all records
to invest substantially
in
the
initiatives aiming to address
affecting the quality
develop the capacity
on the basis
the performance testing
Upon successful completion
vocational school elements
of
of specific barriers to
opportunity to further enhance
products or techniques Identifying
should be noted that
training of their employees .
tree generation algorithm takes
the blue collar workforce requiring
the country , offering specialised skill
the largest EE and RES
not
use
the learning rate (default
the strategy encourages high - skilled
needs to be addressed
skills can be developed
through
through a series of accredited
a challenge for participation
on
risk of exertional heat
the use of their
opportunities available and thus guiding
over 20082015 . In narrow construction ,
Pack , available at : www . usablebuildings .
pathways in the rational use
pattern and (ii) advanced batch
planning and educational material development
policies have been implemented in
process
, the following topology was
80 % of the data
programmes
, educational courses , etc . Developing
Bottleneck vacancies are reported
Several countries present high
The next step could
across Europe . Increase the
and the ensuing level
at the national level ,
by participating in EU -
that build on the
programs
. The BIM4VET project [17]
in the integrated design
provided
. Given that hiring an
in low carbon skills
provider No . starts 2010 - 11
as well as the
the public sector is
. To achieve the above
across Wales . These pilots
and
HE institutions . It
industry stakeholders have
stakeholders whose aim
the public sector .
based on number built
other similar bodies ,
to
: develop existing provision
deliver low carbon
establish whether Advanced
offer a broad
were reported to offer
with the highest reported
provision
, including stimulating demand from
20 . The general consensus
and providers also regard
appears concentrated in the
close to major current
for the frameworks mentioned
in Wales
is considered
responds to
is
adequate , there will
designed with the
subject to on -
needs to be better
that addresses the sustainability
to cope with the
which is not currently
records are correctly classified : this
remains aligned to demand and
requirements
across organizations
. Knowledge of
Planning BIM
set out under Directive
resources . It is therefore necessary
results . In some countries , improving
schemes
. 2 . Digitalisation also brings
that facilitate access into
service enabling users to identify
set
) by using WEKA to
. It can be seen
and testing set
. Creation
is
should
should be
arranged since there
developed in Wales
significantly reduces property crime , drug
Skilled and unskilled workforce Recognised
strategies for improving skills and
strategy document for the built

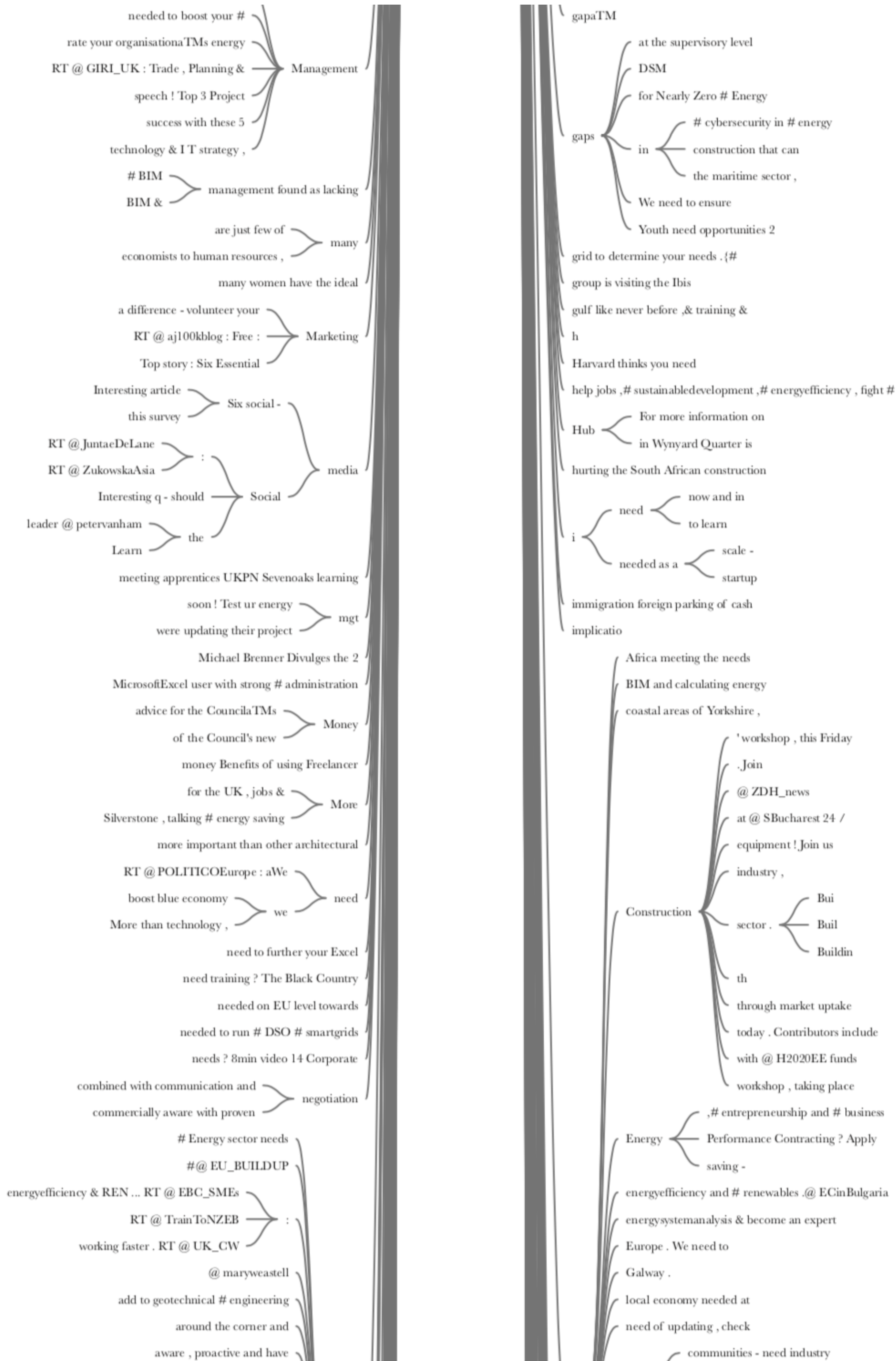

as improvements or enhancements
construction sector ; Institutions dedicated
lack of public support
least , general schemes related
numbers of participants on
3 : Whether
employers who
provided access
sub - sectors ; gives consideration
to
to BIM and energy efficiency
to boost apprenticeships and transform
to develop and pilot strategic
from sectoral enterprises
sort of scheme
to support
Training target mean squared error
Transfer of Building Information Modelling
update the unknown parameters . After
users , as well as standardising
needed , allowing to prioritise
participation and quality of
VET
aims to specifically promote
candidates , Low interest in
capital basis 57 company
European Business Forum on
introduced a Support for
longstanding institutions dedicated to
for the funding
in the offer
labour , Decreasing uptake
of
of educational programmes and
that provide least continuous
vocational
weights are updated after each
well as on all available
will be on - going safety
with domain experts . 4) While
within the design profession . Extensive
workforce , either by explicitly setting
support and communication tools : as
systems also vary greatly across
target mean squared error Training
targets in their national strategies ,
that
responds to the increasing
will be attractive to
The
AHU model , as it
construction workforce therefore becomes
model with onemonth worth
present section investigates the
trainers . As previously discussed ,
trainers' through specific professional
workforce and improving skills
throughout the industry , which is
time for ANN modeling is
to
apprentices105 . Other schemes are
approximately 13 , 000 long -
bid for and win
civil engineers dedicated to
develop skills on innovative
entrepreneurs (Steun voor opleding
meet the requirements of
support individuals working in
young people and adults82 .
Tool
for Increasing Competence of
to be used both
Understand the roles of all
were set out by the
which seeks to enhance the
will
be applied , whenever a
cost time and money ,
within in this area (Table
without any theory or collaborative
workshops
– how to learn about
for institutional and corporate
is as follows : • Day

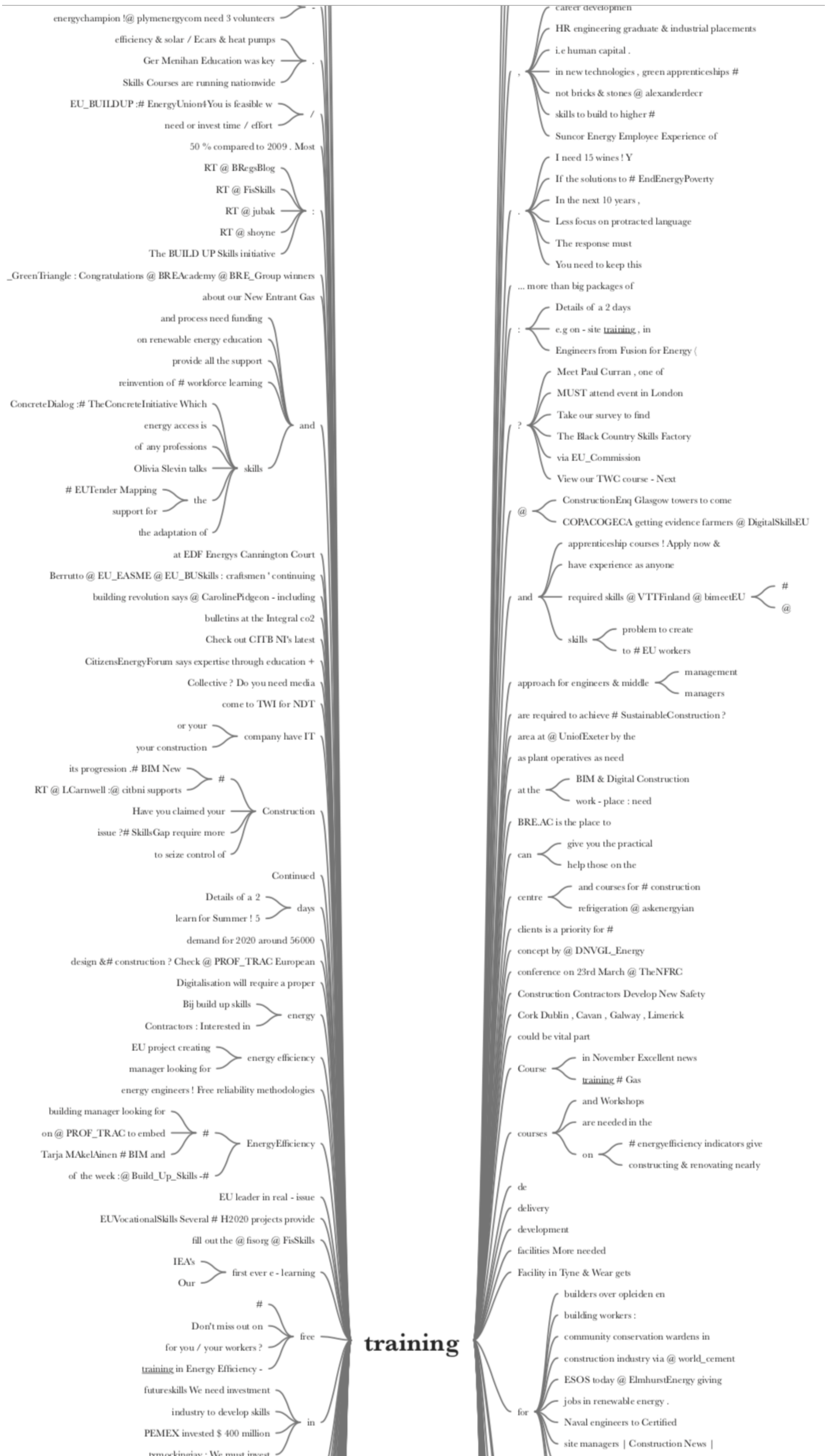
3- Scalable heuristic social media analysis


required in # NZ for permanent
RT @ CKEAgency :@ CKEAgency @ jobfairy
team ' information coordinator '&' information facilitator '
Technicians , Supervisors and other keys
the # digitaleconomy & unsure of the
The need for more responsive
to fill 2 new # design
we need to discuss on
well as current task team
when we get in senior
Winnie_Byanyima . How do you explain
need creating ?@ Bluebeam @ WeWork
of the architect :" Architect as
required are structural engineer & soft
Slides and Synopsis :
that require qualities found in
the last 2 days . Now
will be created in utility
within reach of # MiltonKeynes needed
you won't necessarily need to
by lack of awareness about
Canevari :# Natgas will play several
create user profiles segmented by
Daz_Lester @ bondbryanBIM @ theNBS they have
don't just need more women's
DRossiter87 @ MFarmer_Resi Recording performance against
for leadership and / or board
found in men only and
from # project to # operations . Future
Hi - for the most junior
increasing in demand in finance
Indigenous women to key advisory
Intermediary
Latest Energy Procurement
heavily underrepresented in board
women face in taking
#
to be underrepresented
very few women
in
leadership
tells # LAFSummit to capture
Load : Public and Private Sector
more structured organization with specialized
energytransition requires
@ HEIRRI_
are actively seeking for
at # EUW17 discussing what
DavidFano discuss BIM data ,
RT @ eskills4jobs :
studies : in transition times
new
New Sales
required in # NZ for permanent
roles
Learn how to apply .
.
Need a new job ?
We need enthusiastic # designers to
What will change require ?# GBDA16
.-@ un_women Amb . Anne Hathaway on
; need to assign defined responsibilities .
? Use our map for insight
and
most importantly what do
required skill sets
responsibilities should be defined
standardized processes is required #
their
BIM competencies based
interactions will require
are
needed for a strong
required in North Germany #
aren't required as well as
available the skills needed ? Check
but need to leave organizational
by knowing experts & exactly what
for
each company to define
Energy Engineers & Junior Energy
have
appeared in the # IT
often been ignored and
here all live requirements . Please
in
Addressing Poor PeopleaTMs Energy
BIM & DC we need
heating & cooling including as
the
Bracknell Area ! Extensive
future will likely
PM Uniclass table .



practical IT tool
IEA
II I I1II14III I I
RT @ LollyDaskal : 10
one of
sustainability are
the most
important
Projects @ MEnS_H2020 and @ PROF_TRAC
Construction industry needs
sebasgarnier : We need
to
improve
approach to political communication ...
Barbara of @ johngilbertarch on
works is crucial for
improving
ecobuild exhibitor @ AggregateUK invests
Infastructure UK places investment
for contractors | Let's
Invest in growth ,
invest
investment investment strategy , notably
need a serious upscale
PR agencies are diversifying
red herringaTM , covering decline
RT @ WorldBankAfrica : Are investments
in
Next
skills . Significant ramp
up
in an attempt to battle
in community project awards # Greenjobs
in the industry to reduce
including training in construction & other
Brexit to highlight food
crucial to curbing
News - Warning over
Whyte
People
:
approach for
say about
to tackle
What's causing
the
construction
industry
Route , Sizewell B wins
RT @ PhilippeMoseley :
industry to use their innovative
ontractoraTMs workshop aBuilding
RT @ ArabianIndustry : Building
information modelling
InfoZinnae :.@ energyinwater contributing to matching
have good science and
have the talent , the #
skills every student needs ?#
innovation
AiAu 21 Nov on
BUILD UP Webinar Recordings |
Interdisciplinary
investment in Ireland . Now discussing
and technical support , while ...
big concerns bringing in
IoT
element in achieving # EnergyAccess
in achieving energy access
Story of the Day
is
is one of the core
is the answer to employer
issues RT @ McKinsey_MGI : How workplace
a fresh set of
RT @ jacobm : What
#
IT is changing daily ,
More Management &
IT
@ BuildingHour
@ ClaireCromie
@ Construct2day
More Management and
every
leader needs
But Many
Know # socialmedia #
on @ McKQuarterly
Manager Needs 15 Top
project manager needs
Startup Founder Needs To
student needs ?
The jobs
These are
Successful # Entrepreneur Needs @ Entrepreneur
Everyone Should Work to Improve
Exchange meeting :# skills essential to
Factory may be able to
Finland
Energy Efficient Building C
Slide shows for energy -
First level 1 qualification called '
a successful construction career -
any
p
profession az
buildings ? Check out
@ CORDIS_EU :
CORDIS_EU :
construction
Companies
machinery
: trends and
organized by @
workers course ?@ phplusmag @
en
energy
efficient
buildings - 24
buildings
-
: Public ...
The
system transformation w /
energyefficiency
.@ Qualibuild Find out
in buildings with @
energyefficient buildings also web -
future that we all
for
its role in the
new # EnergyMaterials
retrofit needs to be
the
#
construction /# mi
DigitalTransformation in the #
construction
industry in
sector to
energy transition
future
.
.@ Twiceroadsfool @ DynamoBIM @
not only
medical profession # healthparl -
MSc EMINE Summer
Northern Ireland # construction
tomorrow's # energy efficient # buildings :
transformational construction sector . Excellent
using all kinds of #
Work , a programme supporting
your business ! ICE &@ Autodesk_UK #
youth in handy sectors ,
forecast This is why we
Framework
from today with @ HitachiToolsUK # TradeTalk
Fund
helps small firms boost
supports the development of
Funding Agency has awarded Wates
future generations will need ?
Galway Partel_Passive get on # ConstructionWorkerSkillsRegister
227,000 people needed for #


needed to boost your #
rate your organisationaTMs energy
RT @ GIRI_UK : Trade , Planning &
speech ! Top 3 Project
success with these 5
technology & I T strategy ,
Management
BIM
BIM &
management found as lacking
are just few of
economists to human resources ,
many
many women have the ideal
a difference - volunteer your
RT @ aj100kblog : Free :
Top story : Six Essential
Marketing
Interesting article
this survey
Six social -
RT @ JuntaeDeLane
RT @ ZukowskaAsia
:
Interesting q - should
Social
leader @ petervanham
Learn
the
media
meeting apprentices UKPN Sevenoaks learning
soon ! Test ur energy
were updating their project
mgt
Michael Brenner Divulges the 2
MicrosoftExcel user with strong # administration
advice for the CouncilaTMs
of the Council's new
Money
money Benefits of using Freelancer
for the UK , jobs &
Silverstone , talking # energy saving
More
more important than other architectural
RT @ POLITICOEurope : aWe
boost blue economy
More than technology ,
we
need
need to further your Excel
need training ? The Black Country
needed on EU level towards
needed to run # DSO # smartgrids
needs ? 8min video 14 Corporate
combined with communication and
commercially aware with proven
negotiation
Energy sector needs
#@ EU_BUILDUP
energyefficiency & REN ... RT @ EBC_SMEs
RT @ TrainToNZEB
working faster . RT @ UK_CW
:
@ maryweastell
add to geotechnical # engineering
around the corner and
aware , proactive and have
gapaTM
at the supervisory level
DSM
for Nearly Zero # Energy
gaps
in
cybersecurity in # energy
construction that can
the maritime sector ,
We need to ensure
Youth need opportunities 2
grid to determine your needs .{#
group is visiting the Ibis
gulf like never before ,& training &
h
Harvard thinks you need
help jobs ,# sustainabledevelopment ,# energyefficiency , fight #
Hub
For more information on
in Wynyard Quarter is
hurting the South African construction
i
need
now and in
to learn
needed as a
scale -
startup
immigration foreign parking of cash
implicatio
Africa meeting the needs
BIM and calculating energy
coastal areas of Yorkshire ,
Construction
' workshop , this Friday
. Join
@ ZDH_news
at @ SBucharest 24 /
equipment ! Join us
industry ,
sector .
Bui
Buil
Buildin
th
through market uptake
today . Contributors include
with @ H2020EE funds
workshop , taking place
Energy
,# entrepreneurship and # business
Performance Contracting ? Apply
saving -
energyefficiency and # renewables .@ ECinBulgaria
energysystemanalysis & become an expert
Europe . We need to
Galway .
local economy needed at
need of updating , check
communities - need industry


training
energychampion !@ plymenergycom need 3 volunteers
efficiency & solar / Ecars & heat pumps
Ger Menihan Education was key
Skills Courses are running nationwide
EU_BUILDUP :# EnergyUnion4You is feasible w
need or invest time / effort
50 % compared to 2009 . Most
RT @ BRegsBlog
RT @ FisSkills
RT @ jubak
RT @ shoyne
The BUILD UP Skills initiative
_GreenTriangle : Congratulations @ BREAcademy @ BRE_Group winners
about our New Entrant Gas
and process need funding
on renewable energy education
provide all the support
reinvention of # workforce learning
ConcreteDialog :# TheConcreteInitiative Which
energy access is
of any professions
Olivia Slevin talks
EUTender Mapping
support for
the
skills
and
the adaptation of
at EDF Energys Cannington Court
Berrutto @ EU_EASME @ EU_BUSkills : craftsmen ' continuing
building revolution says @ CarolinePidgeon - including
bulletins at the Integral co2
Check out CITB NI's latest
CitizensEnergyForum says expertise through education +
Collective ? Do you need media
come to TWI for NDT
or your
your construction
company have IT
its progression .# BIM New
RT @ LCarnwell :@ citbni supports
#
Have you claimed your
issue ?# SkillsGap require more
to seize control of
Construction
Continued
Details of a 2
learn for Summer ! 5
days
demand for 2020 around 56000
design &# construction ? Check @ PROF_TRAC European
Digitalisation will require a proper
Bij build up skills
Contractors : Interested in
energy
EU project creating
manager looking for
energy efficiency
energy engineers ! Free reliability methodologies
building manager looking for
on @ PROF_TRAC to embed
Tarja MAkelAinen # BIM and
#
of the week :@ Build_Up_Skills -#
EnergyEfficiency
EU leader in real - issue
EUVocationalSkills Several # H2020 projects provide
fill out the @ fisorg @ FisSkills
IEA's
Our
first ever e - learning
#
Don't miss out on
for you / your workers ?
training in Energy Efficiency -
free
futureskills We need investment
industry to develop skills
PEMEX invested $ 400 million
txmockingjay : We must invest
in
career developmen
HR engineering graduate & industrial placements
i.e human capital .
in new technologies , green apprenticeships #
not bricks & stones @ alexanderdecr
skills to build to higher #
Suncor Energy Employee Experience of
,
I need 15 wines ! Y
If the solutions to # EndEnergyPoverty
In the next 10 years ,
Less focus on protracted language
The response must
You need to keep this
.
... more than big packages of
Details of a 2 days
e.g on - site training , in
Engineers from Fusion for Energy (
:
Meet Paul Curran , one of
MUST attend event in London
Take our survey to find
The Black Country Skills Factory
via EU_Commission
View our TWC course - Next
?
ConstructionEnq Glasgow towers to come
COPACOGECA getting evidence farmers @ DigitalSkillsEU
@
apprenticeship courses ! Apply now &
have experience as anyone
required skills @ VTTFinland @ bimeetEU
#
@
problem to create
to # EU workers
skills
and
approach for engineers & middle
management
managers
are required to achieve # SustainableConstruction ?
area at @ UniofExeter by the
as plant operatives as need
BIM & Digital Construction
work - place : need
at the
BRE.AC is the place to
give you the practical
help those on the
can
and courses for # construction
refrigeration @ askenergyian
centre
clients is a priority for #
concept by @ DNVGL_Energy
conference on 23rd March @ TheNFRC
Construction Contractors Develop New Safety
Cork Dublin , Cavan , Galway , Limerick
could be vital part
in November Excellent news
training # Gas
Course
and Workshops
are needed in the
energyefficiency indicators give
constructing & renovating nearly
on
courses
de
delivery
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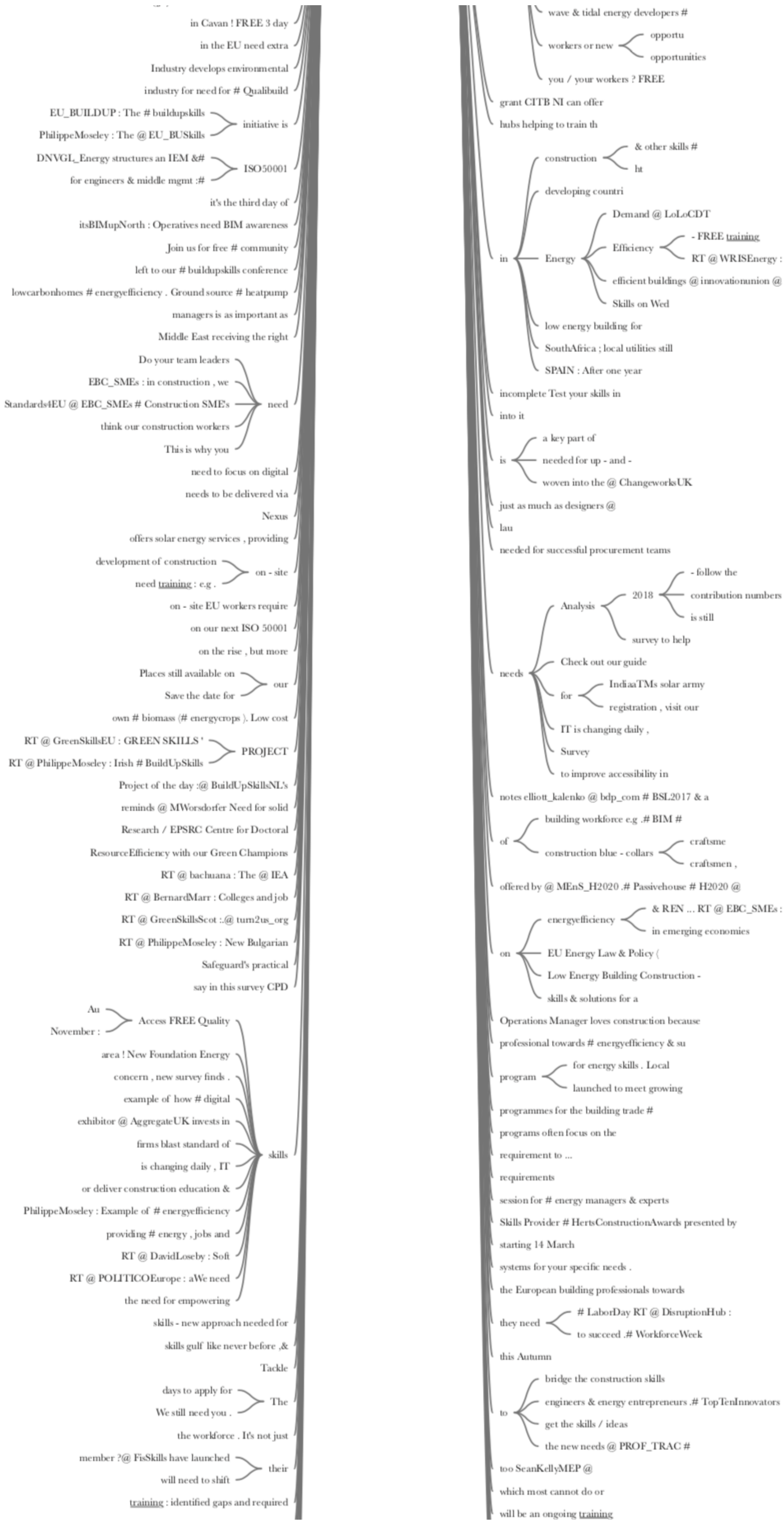
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RT @ bachuana : The @ IEA
RT @ BernardMarr : Colleges and job
RT @ GreenSkillsScot :.@ turn2us_org
RT @ PhilippeMoseley : New Bulgarian
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IndiaaTMs solar army
registration , visit our
IT is changing daily ,
Survey
to improve accessibility in
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construction blue - collars
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launched to meet growing
programmes for the building trade #
programs often focus on the
requirement to ...
requirements
session for # energy managers & experts
Skills Provider # HertsConstructionAwards presented by
starting 14 March
systems for your specific needs .
the European building professionals towards
they need
LaborDay RT @ DisruptionHub :
to succeed .# WorkforceWeek
this Autumn
to
bridge the construction skills
engineers & energy entrepreneurs .# TopTenInnovators
get the skills / ideas
the new needs @ PROF_TRAC #
too SeanKellyMEP @
which most cannot do or
will be an ongoing training

Appendix D

Repository of Questionnaire of the Framework

European skills of BIM and Energy Efficiency Trainings - Enquiry form

Dear participant,

We would like to thank you in advance for your contribution and time.

We have developed a framework for BIM and energy efficiency skills recommended for different stakeholders involved in the construction sector (professionals to blue-collar workers) to enhance the energy efficiency in the construction sector through adapted training and addressing the lack of a Continuing Professional Development (CPD) strategy. For each stakeholder discipline, a group of skills has been identified by the expert panel, and the level of each skill was assigned according to The European Qualifications Framework (EQF).

We would like to ask you to validate the proposed framework by reviewing the matrix of skills and their EQF levels for each stakeholder group listed in **Tables 2.1 to 2.5.** Please check box if you disagree with the mentioned skills. If you check a box, i.e. disagree with the proposed skill, please explain the reason on the comment's column.

Please send the completed document to alhamamia@cardiff.ac.uk at your earliest convenience, ideally by the by 15th Jul 2021.

Name: Mr Ali Alhamami

Institution: Cardiff University

Country: UK

Consent Form

This questionnaire is used solely for research purposes as part of the PhD study. All data are collected anonymously and will be handled in a confidential manner.

Please read carefully:

The procedure involves filling an online survey that will take approximately 15 minutes. Your responses will be confidential and we do not collect identifying information such as your name, email address or IP address. To help protect your confidentiality, the surveys will not contain information that will personally identify you. The results of this study will be used for scholarly purposes only. **If you wish to participate in the research study, please also make sure that by clicking "yes, I consent" you agree to the below:**

I declare that:

1. I have been informed about the PhD research project. I have been given the opportunity to ask questions and have had them answered.
2. I understand that my participation is voluntary and that I am free to withdraw at any time without giving a reason immediately without consequences.
3. I have been given the information about the expected duration of my participation and that no personal data will be gathered.
4. I consent to the processing of my personal information for research done in the study.
5. I agree that the study had been explained to me to my satisfaction and I consent voluntarily to be a participant in this study.
6. I understand that the information I have submitted will be published, as a report, scientific publication or other dissemination and communication outputs. Confidentiality and anonymity will be maintained, and it will not be possible to identify me from any publications.
7. I agree that my non-personal research data may be used by others for future research. I am assured that the confidentiality of my personal data will be upheld through the removal of identifiers.
8. I understand that such information will be treated as strictly confidential and handled in accordance with the provisions of the EU General Data Protection Regulation.

* 1. By checking the box below, I consent to the use and processing of the data provided in this questionnaire by the researchers. If you do not wish to participate in the research study, please decline participation by clicking on the "no, I do not consent" button.

☒ Yes, I consent ☐ No, I do not consent

Demographic information

* 2. What is your age?

☐ Under 18 ☐ 18-24 ☐ 25-34 ☒ 35-44 ☐ 45-54 ☐ 55-64 ☐ 65+

* 3. What is your gender?

☒ Male ☐ Female ☐ Other

* 4. Years of professional experience?

☐ 0-2 years ☐ 3-5 years ☐ 6-10 years ☒ 10+ years ☐ Not applicable

* 5. What is your field of expertise?

(Please choose as many boxes as you think is appropriate)

☐ Briefing ☒ Architectural Design ☐ Architectural Engineering

☐ Structural / Civil Engineering ☐ Mechanical Engineering ☐ Electrical Engineering

☐ Fire Engineering ☐ Acoustics ☐ Quantity Surveying

☐ Project Management ☐ Contractor / Subcontractor ☐ Facility Management

☒ Other (please specify: …………………………………………..)

Overview:

European Qualification Framework

The European Qualifications Framework (EQF) is a European-wide qualifications framework promoted by the European Union. The EQF levels are rated from **1 to 8** and are defined in terms of knowledge, **skills** and competencies, and Responsibility and Autonomy, encompassing all levels of qualifications as illustrated in **Table 1**.

Table 1: EQF levels definition

EQF	Knowledge	Skills	Responsibility and autonomy
Level 1	Basic general knowledge	Basic skills required to carry out simple tasks	Work or study under direct supervision in a structured context
Level 2	Basic factual knowledge of a field of work or study	Basic cognitive and practical skills required to use relevant information in order to carry out tasks and to solve routine problems using simple rules and tools	Work or study under supervision with some autonomy
Level 3	Knowledge of facts, principles, processes and general concepts, in a field of work or study	A range of cognitive and practical skills required to accomplish tasks and solve problems by selecting and applying basic methods, tools, materials and information	Take responsibility for completion of tasks in work or study; adapt own behaviour to circumstances in solving problems
Level 4	Factual and theoretical knowledge in broad contexts within a field of work or study	A range of cognitive and practical skills required to generate solutions to specific problems in a field of work or study	Exercise self-management within the guidelines of work or study contexts that are usually predictable, but are subject to change; supervise the routine work of others, taking some responsibility for the evaluation and improvement of work or study activities

Level 5	Comprehensive, specialised, factual and theoretical knowledge within a field of work or study and an awareness of the boundaries of that knowledge	A comprehensive range of cognitive and practical skills required to develop creative solutions to abstract problems	Exercise management and supervision in contexts of work or study activities where there is unpredictable change; review and develop performance of self and others
Level 6	Advanced knowledge of a field of work or study, involving a critical understanding of theories and principles	Advanced skills, demonstrating mastery and innovation, required to solve complex and unpredictable problems in a specialised field of work or study	Manage complex technical or professional activities or projects, taking responsibility for decision-making in unpredictable work or study contexts; take responsibility for managing professional development of individuals and groups
Level 7	Highly specialised knowledge, some of which is at the forefront of knowledge in a field of work or study, as the basis for original thinking and/or research Critical awareness of knowledge issues in a field and at the interface between different fields	Specialised problem-solving skills required in research and/or innovation in order to develop new knowledge and procedures and to integrate knowledge from different fields	Manage and transform work or study contexts that are complex, unpredictable and require new strategic approaches; take responsibility for contributing to professional knowledge and practice and/or for reviewing the strategic performance of teams
Level 8	Knowledge at the most advanced frontier of a field of work or study and at the interface between fields	The most advanced and specialised skills and techniques, including synthesis and evaluation, required to solve critical problems in research and/or innovation and to extend and redefine existing knowledge or professional practice	Demonstrate substantial authority, innovation, autonomy, scholarly and professional integrity and sustained commitment to the development of new ideas

			or processes at the forefront of work or study contexts including research[3]

Note: Please tick the check box if you disagree with the proposed skills in the following tables. If you check the box, please explain the reason in the comment's column.

Please note	
Levels (1-8)	The number indicates the skill level recommended for the stakeholder group's role based on EQF levels
-	Not relevant to the stakeholder group's role

* Table 2.1: EQF levels for BIM skills for Energy Efficiency recommended for the project client group, i.e. Clients, Project Managers and BIM Managers.

Label	Skills	EQF level			Experts	
	Client & Client advisors Client (C), Project manager (PM), BIM manager (BM)	C	PM	BM	Mark if disagree	Comments if any
EX.	Understanding BIM workflow and standards	-	3	3	☒	BIM manager should have high level (5) of this skill because ….. (if any)
S1	Understanding BIM workflow and standards	-	3	5	☐	

S2	Recognising engineering graphical information (architecture, structure, etc.)	1	3	4	☐	
S3	Understanding energy efficiency principle & sustainable construction	1	4	4	☐	
S4	Implementing building regulations and development awareness	1	5	2	☐	
S5	Understanding energy policies, market, and tariffs structures	1	5	3	☐	
S7	Creativity and analytical thinking	2	4	4	☐	
S9	Defining opportunities for energy efficiency improvement	-	4	2	☐	
S11	Understanding construction supply chain standards	-	4	1	☐	
S12	Communication (speaking and Presentation)	2	4	2	☐	
S13	Technical writing	3	4	3	☐	
S18	Achieving BIM and energy efficiency certifications (LEED, BREEM, etc)	-	4	-	☐	
S19	Reviewing BIM models and performing automatic model checks	-	2	6	☐	
S21	BIM and energy models management	-	3	5	☐	
S22	Reviewing design and coordination	1	3	1	☐	
S24	Extracting measures and data from plans	-	3	3	☐	
S29	Using BIM tools and applications (Revit, etc)	-	3	6	☐	

S31	Using CAD programs	-	3	6	☐	
S35	Using BIM tools for energy efficiency	-	2	5	☐	
S40	Optimal decision making	3	5	3	☐	
S42	Teamwork and collaboration	2	6	2	☐	
S43	Establishing on-site/off-site meetings to comprehend BIM data and energy efficiency features	-	3	4	☐	
S44	Handling communications and interactions between project managers (client, designer and constructor)	-	6	1	☐	
S45	Exchanging and extracting model information with designers	-	4	3	☐	
S46	Facilitating information exchange to meet stakeholders' business needs in BIM execution	-	4	1	☐	
S47	Understanding life cycle assessment (LCA) and life cycle costing (LCC) applications	1	3	2	☐	
S48	Leadership	-	4	2	☐	
S49	Strategy and policy management	1	4	1	☐	
S51	Demonstrating concrete proposals for improvements	-	4	4	☐	
S52	Risk management	1	5	2	☐	
S53	Manging transmission and distribution processes	-	4	1	☐	
S54	Applying knowledge to complete tasks and solve problems	2	5	3	☐	

S55	Ensuring construction/renovation projects meet stringent energy efficiency requirements	1	6	3	☐	
S56	Energy costs operation	2	5	3	☐	
S57	Energy demand operation	1	5	3	☐	
S58	QA specifically in relation to energy efficiency	-	4	2	☐	
S59	Energy efficiency implementations marketing	1	4	2	☐	

*Table 2.2: EQF levels for BIM skills for Energy Efficiency recommended for the project engineering group, i.e. Architecture, Structure and (Mechanical, Electrical & Plumbing).

Label	Skills	EQF level			Experts	
	Design & Engineering Architectural (ARCH), Structural (SE), Mechanical, Electrical & Plumbing (MEP)	ARCH	SE	MEP	Mark if disagree	Comments if any
EX.	Understanding BIM workflow and standards	4	5	5	☒	Architect should have high level (6) of this skill because ….. (if any)
S1	Understanding BIM workflow and standards	6	5	5	☐	
S3	Understanding energy efficiency principle & sustainable construction	6	6	5	☐	
S4	Implementing building regulations and development awareness	2	2	2	☐	
S6	Recognising low carbon materials through the supply chain and the project lifecycle	3	4	4	☐	
S7	Creativity and analytical thinking	6	5	4	☐	
S8	Observing and separating the information needed	6	6	6	☐	
S9	Defining opportunities for energy efficiency improvement	6	4	6	☐	
S10	Knowing physical principles related to energy (thermal, electrical, thermodynamics, heat transfer, fluid mechanics, etc.)	5	4	7	☐	

S12	Communication (speaking and Presentation)	3	2	2	☐	
S13	Technical writing	2	3	3	☐	
S14	Developing collaborative ICT platform	1	1	2	☐	
S15	Adapting to environmental conditions changes	4	2	4	☐	
S16	Energy performance measuring, monitoring and optimisation	3	2	5	☐	
S17	Establishing energy models	3	1	6	☐	
S18	Achieving BIM and energy efficiency certifications (LEED, BREEM, etc)	3	3	3	☐	
S19	Reviewing BIM models and preforming automatic model checks	4	4	4	☐	
S21	BIM and energy models management	5	4	4	☐	
S22	Reviewing design and coordination	6	4	4	☐	
S25	Understanding BIM technologies with respect to sustainability	4	4	4	☐	
S26	Energy harvesting and production (renewable energy sources implementations)	3	2	6	☐	
S27	Energy saving technologies, NZEB and low-zero energy building designing	4	3	4	☐	
S28	Information and communication technology (ICT)	2	2	4	☐	
S29	Using BIM tools and applications (Revit, etc)	6	4	6	☐	
S30	Linking between different software	5	2	4	☐	

S31	Using CAD programs	6	6	6	☐	
S32	Applying energy simulation programs	4	2	6	☐	
S33	3D software usage and coordination	5	3	4	☐	
S34	4D software usage and coordination	2	3	3	☐	
S35	Using BIM tools for energy efficiency	4	3	5	☐	
S36	Computer programming (Python, MatLab, etc.)	2	2	4	☐	
S37	Virtual reality operation	1	1	3	☐	
S40	Optimal decision making	3	3	3	☐	
S42	Teamwork and collaboration	4	4	4	☐	
S43	Establishing on-site/off-site meetings to comprehend BIM data and energy efficiency features	2	2	2	☐	
S51	Demonstrating concrete proposals for improvements	5	4	5	☐	
S54	Applying knowledge to complete tasks and solve problems	4	4	4	☐	
S55	Ensuring construction/renovation projects meet stringent energy efficiency requirements	3	4	4	☐	

* Table 2.3: EQF levels for BIM skills for Energy Efficiency recommended for the project construction group, i.e. Site manger and Construction engineer.

Label	Skills	EQF level		Experts	
	Contractor Site manager (SM), Construction engineer (CE)	SM	CE	Mark if disagree	Comments if any
EX.	Understanding BIM workflow and standards	2	1	☒	Site manager should have higher level (4) of this skill because ….. (if any), construction engineer should have higher level (3) of this skill because ….. (if any)
S1	Understanding BIM workflow and standards	4	3	☐	
S2	Recognising engineering graphical information (architecture, structure, etc.)	5	6	☐	
S3	Understanding energy efficiency principle & sustainable construction	4	3	☐	
S6	Recognising low carbon materials through the supply chain and the project lifecycle	4	3	☐	
S8	Observing and separating the information needed	4	5	☐	
S10	Knowing physical principles related to energy (thermal, electrical, thermodynamics, heat transfer, fluid mechanics, etc.)	3	4	☐	
S11	Understanding construction supply chain standards	4	3	☐	
S12	Communication (speaking and Presentation)	4	2	☐	

S13	Technical writing	4	3	☐	
S16	Energy performance measuring, monitoring and optimisation	3	2	☐	
S19	Reviewing BIM models and preforming automatic model checks	4	2	☐	
S21	BIM and energy models management	4	2	☐	
S24	Extracting measures and data from plans	4	5	☐	
S28	Information and communication technology (ICT)	2	-	☐	
S29	Using BIM tools and applications (Revit, etc)	4	3	☐	
S30	Linking between different software	1	-	☐	
S31	Using CAD programs	4	2	☐	
S33	3D software usage and coordination	2	-	☐	
S34	4D software usage and coordination	1	-	☐	
S35	Using BIM tools for energy efficiency	4	2	☐	
S38	Implementing energy efficiency applications in construction and renovation projects (materials, system, etc)	2	3	☐	
S39	Installing renewable energy systems (Solar panels, heat pump, etc)	2	3	☐	
S40	Optimal decision making	5	2	☐	
S41	Integrating information and data management framework	4	1	☐	

S42	Teamwork and collaboration	4	2	☐	
S43	Establishing on-site/off-site meetings to comprehend BIM data and energy efficiency features	4	3	☐	
S45	Exchanging and extracting model information with designers	4	1	☐	
S47	Understanding life cycle assessment (LCA) and life cycle costing (LCC) applications	2	-	☐	
S48	Leadership	3	3	☐	
S51	Demonstrating concrete proposals for improvements	4	3	☐	
S52	Risk management	5	2	☐	
S53	Manging transmission and distribution processes	4	1	☐	
S55	Ensuring construction/renovation projects meet stringent energy efficiency requirements	4	3	☐	
S56	Energy costs operation	2	1	☐	
S57	Energy demand operation	1	-	☐	
S58	QA specifically in relation to energy efficiency	2	1	☐	

*Table 2.4: EQF levels for BIM skills for Energy Efficiency recommended for the project management group, i.e. Facility manager and Maintenance operator.

Label	Skills	EQF level		Experts	
	Management & operation Facility manager (FM), Maintenance operator (MO)	FM	MO	Mark if disagree	Comments if any
EX.	Understanding BIM workflow and standards	2	1	☒	Facility manager should have higher level (4) of this skill because ….. (if any), Maintenance operator should have higher level (3) of this skill because ….. (if any)
S1	Understanding BIM workflow and standards	4	3	☐	
S2	Recognising engineering graphical information (architecture, structure, etc.)	4	3	☐	
S3	Understanding energy efficiency principle & sustainable construction	3	1	☐	
S4	Implementing building regulations and development awareness	3	-	☐	
S5	Understanding energy policies, market, and tariffs structures	4	1	☐	
S6	Recognising low carbon materials through the supply chain and the project lifecycle	3	1	☐	
S7	Creativity and analytical thinking	3	1	☐	
S8	Observing and separating the information needed	4	3	☐	

S9	Defining opportunities for energy efficiency improvement	4	1	☐	
S10	Knowing physical principles related to energy (thermal, electrical, thermodynamics, heat transfer, fluid mechanics, etc.)	4	2	☐	
S12	Communication (speaking and Presentation)	3	2	☐	
S13	Technical writing	3	1	☐	
S14	Developing collaborative ICT platform	4	3	☐	
S15	Adapting to environmental conditions changes	4	4	☐	
S16	Energy performance measuring, monitoring and optimisation	4	4	☐	
S19	Reviewing BIM models and preforming automatic model checks	5	3	☐	
S21	BIM and energy models management	5	2	☐	
S22	Reviewing design and coordination	3	-	☐	
S23	Energy auditing	4	3	☐	
S24	Extracting measures and data from plans	4	3	☐	
S26	Energy harvesting and production (renewable energy sources implementations)	4	1	☐	
S27	Energy saving technologies, NZEB and low-zero energy building designing	3	1	☐	
S28	Information and communication technology (ICT)	4	2	☐	

S29	Using BIM tools and applications (Revit, etc)	3	1	☐	
S30	Linking between different software	3	-	☐	
S31	Using CAD programs	2	2	☐	
S32	Applying energy simulation programs	4	1	☐	
S33	3D software usage and coordination	1	-	☐	
S35	Using BIM tools for energy efficiency	3	1	☐	
S37	Virtual reality operation	2	-	☐	
S39	Installing renewable energy systems (Solar panels, heat pump, etc)	3	4	☐	
S40	Optimal decision making	4	1	☐	
S41	Integrating information and data management framework	4	1	☐	
S42	Teamwork and collaboration	3	1	☐	
S43	Establishing on-site/off-site meetings to comprehend BIM data and energy efficiency features	4	-	☐	
S45	Exchanging and extracting model information with designers	3	-	☐	
S46	Facilitating information exchange to meet stakeholders' business needs in BIM execution	3	-	☐	
S47	Understanding life cycle assessment (LCA) and life cycle costing (LCC) applications	4	2	☐	
S48	Leadership	3	-	☐	

S49	Strategy and policy management	3	-	☐	
S50	Planning, administration and organisational management	4	-	☐	
S51	Demonstrating concrete proposals for improvements	3	1	☐	
S52	Risk management	4	1	☐	
S53	Manging transmission and distribution processes	4	1	☐	
S54	Applying knowledge to complete tasks and solve problems	3	1	☐	
S55	Ensuring construction/renovation projects meet stringent energy efficiency requirements	3	1	☐	
S56	Energy costs operation	5	3	☐	
S57	Energy demand operation	5	3	☐	
S58	QA specifically in relation to energy efficiency	5	3	☐	
S59	Energy efficiency implementations marketing	3	-	☐	

*Table 2.5: EQF levels for BIM skills for Energy Efficiency recommended for the project blue-collar group, i.e. Construction worker.

Label	Skills	EQF level	Experts	
	Blue-collar Construction worker (CW)	CW	Mark if disagree	Comments if any

EX.	Understanding energy efficiency principle & sustainable construction	2	☒	Workers should have lower level (1) of this skill because ..... (if any)
S3	Understanding energy efficiency principle & sustainable construction	1	☐	
S8	Observing and separating the information needed	1	☐	
S12	Communication (speaking and Presentation)	1	☐	
S20	Math and estimation	1	☐	
S24	Extracting measures and data from plans	1	☐	
S38	Implementing energy efficiency applications in construction and renovation projects (materials, system, etc)	1	☐	
S39	Installing renewable energy systems (Solar panels, heat pump, etc)	1	☐	
S42	Teamwork and collaboration	2	☐	
S43	Establishing on-site/off-site meetings to comprehend BIM data and energy efficiency features	1	☐	

Appendix E

Repository of Interview Questions for Saudi Experts

“Interview on BIM as a toolset to optimize energy in the industry field”

Overview:

I would like to introduce myself as Ali H. Alhamami; PhD candidate in the subject building information modelling (BIM) for energy efficiency in the industry field, Cardiff school of Engineering, Cardiff University-United Kingdom.

Building Information Modelling (BIM) is paving the way to more effective multi-disciplinary collaborations with a total lifecycle and supply chain integration perspective. BIM is helping the sustainability agenda as the digitalisation of product and process information provides a unique opportunity to optimise energy efficiency related decisions across the entire lifecycle and supply chain.

My study aims to broaden the BIM training agenda to support Saudi Arabia building energy efficiency agenda. This requires broad awareness and expertise in BIM practice across different asset types and across different roles in the industry.

In that respect, my study will endeavour to enhance the skills, qualifications and capabilities of construction practitioners (from high professionals to blue collar workers), thus increasing market penetration and adoption of key technological development in BIM, given the timeliness of the need for training in combined green and functional performance engineering.

Aim of the interview

My interview focuses on understanding and utilizing BIM as a toolset to optimize energy in the industry field during the lifecycle of the activity. I focus on demonstrating the benefits of building information modelling in maximizing energy efficiency and sustainable outcomes.

Thank you for your participation and we assure you that any personally identifiable information will remain confidential.

* Obligator

By checking the box below, I accept that the data collected in this survey will be treated for my study*

Personally identifiable information will remain confidential.

☐ I accept

☐ I refuse (and close this questionnaire)

Demographic information

* 2. What is your age?

☐ Under 18 ☐ 18-24 ☐ 25-34 ☐ 35-44 ☐ 45-54 ☐ 55-64 ☐ 65+

* 3. What is your gender?

☐ Male ☐ Female ☐ Other

* 4. Years of professional experience?

☐ 0-2 years ☐ 3-5 years ☐ 6-10 years ☐ 10+ years ☐ Not applicable

* 5. What is your field of expertise?

(Please choose as many boxes as you think is appropriate)

☐ Briefing ☐ Architectural Design ☐ Architectural Engineering

☐ Structural / Civil Engineering ☐ Mechanical Engineering ☐ Electrical Engineering

☐ Fire Engineering ☐ Acoustics ☐ Quantity Surveying

☐ Project Management ☐ Contractor / Subcontractor ☐ Facility Management

☐ Other (please specify: …………………………………………..)

6- What is your field of expertise?

7- Could you please give a brief of your historic experience of using BIM?

8- What aspects of BIM are (were) used in the activity and how is the activity related to energy?

9- What is (was) your role discipline in construction projects?

10- Is there any use case that you have been used BIM for Energy Efficiency?

☐ Yes, please fill this template in below ☐ No. skip the template

Best Practice Use-Case Study Template

Use Cases Title	
Use Case type (R&D, Real-world application, BIM guideline, Other)	
Funding source (Research Council name / Client name)	
Project Title	
Web Link *(URL)*	
Targeted Discipline (Architectural Design / Structural / Mechanical Engineering, etc,)	
Targeted Building type (Public, Domestic, Industrial, Other)	
Project type (Existing, New Build, Renovation, Extension)	
Lifecycle applicability *(RIBA Plan of Work)*	
Brief description of the case study	
Key Highlights	

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(publication, deliverable, open source software, API, etc.)	

11- Considering your experience within a given use case, could you please identify for each discipline involved (designers, contractors, ranging from site superintendent to blue collar workers) the skills they require to handle BIM data for the purpose of energy efficiency?

Authoring BIM models, Coordinating BIM modelling within organizations, Managing BIM and Information delivery at project level, Accessing BIM data from the field…

12- Based on experience, what skills are lacking at the moment for using BIM for Energy Efficiency in the construction field?

13- What are or could be the particular ways to enhance the stakeholders' skills for using the BIM for Energy Efficiency in the project? **According to:**

XIII. Blue collar workers: workers, technicians: XIV. Designers/Engineers XV. Contractors XVI. Facility management teams

14- What are the benefits of using BIM for Energy Efficiency during the lifecycle of the project?

Programming phase, Design, Construction, Operation,

15- What are the common barriers to use BIM for Energy Efficiency in the industry?

16- What are your recommendations to enhance using the BIM for Energy Efficiency in the construction industry?

17- Is your organisation support the training BIM for Energy Efficiency?

☐ If yes, please explain a brief description about the training followed or given by your employees/collaborators?

☐ NO, why?

Thank you very much for your participation.