Managing BIM based Sustainable Domestic Buildings Adoption in Saudi Arabia

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Abstract

Implementing sustainable construction is a difficult prospect in Saudi Arabia, with the energy consumption in buildings being one of the major problems. The environmental conditions in Saudi Arabia cause increasing energy demand primarily through the significant need for cooling systems.

One of the most important factors that governs Saudi Arabia's building design is the culture of general public in Saudi Arabia. Furthermore, there is a distinct lack of skills and knowledge within the construction sector professional's community related to sustainability. This presents significant barriers to achieving sustainability in Saudi Arabia.

This research has identified that there is (a) lack of sustainability adoption, (b) lack of technology to help with sustainable building design, (c) lack of utilisation of Building Information Modelling (BIM), and (d) cultural factors that hinder widespread sustainable design adoption.

This research will develop a framework of measures of sustainable design for houses with consideration of specific factors relevant to Saudi Arabia. The Saudi Housing Sustainability Framework (SHSF) will; (a) provide a list of sustainable design interventions in Saudi Arabia, (b) provide a list of requirements to deliver an increasing level of adoption of sustainable design in Saudi Arabia depending on criteria such as building requirements, cultural factors, economic factors, climate requirements, sustainability impact, and data requirements, (c) remove unsuitable combinations by showing the positive impact of installing the interventions and list unstable combination between the interventions, and (d) formalizing the data and interactions needed to conceptualise sustainable design. SHSF has been validated by experts within Saudi Arabia.

The SHSF framework, developed in this thesis, will guide building designers in Saudi Arabia to improve the sustainability of non-domestic buildings. The SHSF will also consider the use of BIM data thus, enabling the bridging of the data gap to achieve wider adoption of sustainable design in Saudi Arabia and providing a level of automation not before possible.

List Of Publications

Alghamdi, M.S., Beach, T.H. and Rezgui, Y., 2022. Reviewing the effects of deploying building information modelling (BIM) on the adoption of sustainable design in Gulf countries: a case study in Saudi Arabia. City, Territory and Architecture, 9(1), pp.1-17.

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Chapter 1: Introduction

In recent years, it has become evident that buildings play a significant role in rising environmental issues such as carbon emission (Mohsin, Beach, & Kwan, 2023). Around the world, buildings are responsible for 30% of energy consumption and 27% of total carbon emissions (Al Mughairi, Beach, & Rezgui, 2023). Therefore, the built environment is one of the critical fields where work can be undertaken to decrease impacts on the environment and reduce the demands of traditional energy generation (Mohsin et al., 2023).

The focus of sustainability is on reducing negative impacts while improving the environment to ensure a better quality of living for future generations (Langston & Mackley, 1998). This requires using renewable natural resources in a way which does not diminish nor destroy them and using non-renewable natural resources at a rate slow enough to ensure a clear societal shift to new alternatives (Langston & Mackley, 1998).

However, buildings consume about 30% of energy globally and produce 27% of total energy emissions (Al Mughairi et al., 2023), there is a need to reduce the energy demands of existing buildings and to harness, store, and distribute alternative energy sources. In addition, cities worldwide are the main engines of economic prosperity and are considered the primary source of approximately 70% of greenhouse gas emissions. That is because of the extreme use of energy consumption and weaknesses in management (Mohsin et al., 2023). In Saudi Arabia, the household sector consumes above than 50% of all electrical energy which means it is important to decrease CO_2 emissions and energy consumption (Aldossary, Rezgui, & Kwan, 2017).

Furthermore, the housing sector is expanding quickly in Saudi Arabia because of increasing population growth and urbanization. From 1981 to 2019, the total population of Saudi Arabia has increased from 10 million to 34 million, and by 2030 the population is expected to reach 41 million (Rahman et al., 2022) this is despite many barriers in relation to government regulations and building codes, one of which is the application of sustainable systems to housing construction (M. Al Surf, Susilawati, & Trigunarsyah, 2014; Karam, 2010). Furthermore, Saudi Arabia electricity generation is entirely reliant on the unsustainable practice of burning fossil fuels, which has significant environmental consequences for the climate, air, land, and water (Kamal, 2014; H. Taleb, 2009; H. M. Taleb & Sharples, 2011). Moreover, many researchers have claimed that one of the most important and cost-effective methods to enforce the usage of sustainable practices is to set a clear standards and codes, especially concerning reducing buildings’ energy and water consumption (M. Al Surf et al., 2014; Raji Banani, Vahdati, Shahrestani, & Clements-Croome, 2016; Chwieduk, 2003; Karam, 2010; H. M. Taleb & Sharples, 2011).

1.1. Scope and Motivation

Saudi Arabia's residential sector has high rates of CO2 emissions and energy consumption (Aldossary et al., 2017). Since the domestic sector consumes more than 50% of all electrical energy, it is important to lower CO2 emissions and energy consumption (Aldossary et al., 2017). This is important because natural resources, such as wind and solar power, are abundant in Saudi Arabia (Aldossary et al., 2017).

Many studies have shown that, there is a huge impact of resident's culture on buildings which cause some delay of achieving sustainable design in Saudi Arabia. However, Saudi Arabia is a country relating to Islam which needs a special understanding of the culture (Abu-Gaueh, 1995; Alrashed & Asif, 2015). Also, previous studies have shown that, there is a lack of analysis of the different viewpoints on sustainability within and between professionals involved in sustainable design and the members of public this means the designer should consider both the professionals and public opinion about the designing process (Alhumayn, Chinyio, & Ndekugri, 2017; Cardenas, 2016).

But there is a lack of adopting of any framework of comprehensive measures for evaluating, rating, and certifying the sustainable design of buildings such as BREEAM in the United Kingdom or LEED in the United State with a full consideration to a specific factor. Specifically, this means Saudi Arabia needs to consider specific factors such as culture of residents and the different climate for each region in the country to achieve more sustainable design in Saudi Arabia especially, with the growth of the housing sector in Saudi Arabia (Alhumayn et al., 2017).

However, the scope of the interventions proposed by this thesis does not extend to attempting to change the culture of residents in Saudi Arabia. The scope of this work is to enable the best sustainable design for domestic buildings based on the existing cultural values.

1.2. Aims of the research and research questions

The main aim of this research is to understand how Saudi Arabian construction professionals can achieve a more sustainable design in their domestic building projects by overcoming issues such as the lack of sustainability knowledge for both public and experts within the fast growth of housing sector in Saudi Arabia.

More specifically, this research aims to:

1. To develop an understanding of the impact and extent of the cultural issues that must be considered to achieve adoption sustainable design in Saudi Arabia.
2. To determine the current level of use of BIM technologies in general, and specifically for sustainability analysis in Saudi Arabia.
3. To analyse the differing viewpoints on sustainability between professionals involved in sustainable design and members of the general public.
4. To develop a framework of comprehensive measures for evaluating, rating, and certifying the sustainable design of buildings with consideration to locality specific factors in Saudi Arabia.
5. To develop a methodology, supported by BIM, for both government projects and private houses to enable Saudi Arabia's construction industry to improve its decision-making regarding sustainability for both refurbishment and new build.

The hypothesis of this research is:

That the wider adoption of BIM based tools that facilitate the consideration of both climate and cultural contexts have the potential to achieve an increased level of sustainable construction in Saudi Arabia.

Based on the hypothesis, five research questions have been derived:

- **Research Question One (RQ1):** What is the current level of BIM adoption in Saudi Arabia?
- **Research Question Two (RQ2):** What is the current awareness level of the general public in Saudi Arabia and sustainable building design?
- **Research Question Three (RQ3):** What are the suitable requirements for achieving sustainable domestic building design of housing in Saudi Arabia and how could privacy factors impinge on their adoption?
- **Research Question Four (RQ4):** How can the experts in the sustainability field understand the resident requirements considering the achievement of sustainability in Saudi Arabia?
- **Research Question Five (RQ5):** How can the construction/refurbishment processes of existing traditional Saudi Arabian buildings be changed and improved to achieve a more sustainable design?

1.3. Thesis Summary

This Section will be summarised the thesis as listed below.

Chapter 1 (*Introduction*): This Chapter is the starting point of this research. This Chapter presents an overview of the research area, offering a statement of the problem in the case study location (Saudi Arabia) and explaining how other countries are dealing with this problem. Additionally, this Chapter presents the aims and objectives, research questions, and hypothesis.

Chapter 2 (*Background and related work*): This Chapter will present a literature review in sustainable building design and the impact of cultural issues, focusing on the case of Saudi Arabia. Moreover, this Chapter will analyse related literature in sustainable building design and the influence of cultural issues, focusing on the case of Saudi Arabia. Furthermore, this Chapter will identify the lack of the use of technology to support design in Saudi Arabia, the lack of sustainability in Saudi Arabia, cultural issues that effect on design in Saudi Arabia, and the limited adoption of Building Information Modelling (BIM) in Saudi Arabia for both public and private project.

Chapter 3 (*Methodology*): This Chapter will discuss the research methodology and methods that will be adopted in this study. This will refer to Saunders research onion to outline the methodology process of this thesis. This Chapter will present a background of the research nature and theory, also will defines the research philosophy and design selected for this thesis. Additionally, this Chapter will describe the research questions and the research objectives. Finally, this Chapter presents the research strategy of this research and will describe data collection and analysis.

Chapter 4 (*Studying BIM adoption level in Saudi Arabia*): This Chapter will present the results of the first research question of this thesis (**RQ1:** *What is the current level of BIM adoption in Saudi Arabia*). To do this, the Chapter will examine the level of experts understanding of BIM level adoption in Saudi Arabia through a survey of experts. Finally, this Chapter will focus on the problem of BIM level adoption in Saudi Arabia and examine the main factors that causing the delay of adopting BIM in Saudi Arabia.

Chapter 5 (*Saudi Arabian Awareness of Sustainable Construction*): This Chapter will present the results of the second research question of this thesis (**RQ2:** *What is the current awareness level of experts and the general public in Saudi Arabia of sustainable building design*). It will focus on the implementation of sustainable design principles in Saudi Arabia, through surveys of experts and the general public. In addition, this Chapter will address the problem of the lack of implementation of sustainable design in Saudi Arabia and will illustrate the main factors that causing the delay of implementing sustainability standards.

Chapter 6 (*Understanding the impact of privacy on achieving sustainable design in Saudi Arabia*): This Chapter will answer the third research question (**RQ3:** *What are the suitable* *requirements for achieving sustainable domestic building design of housing in Saudi Arabia and how could privacy factors impinge on their adoption*) through a systemic literature review. The literature review will focus on identifying the important requirements for achieving sustainable building design in Saudi Arabia. Also, this Chapter will focus on the impact of culture on sustainable design and general, and then, in more detail, understand the impact of culture on the adoption of sustainable design in Saudi Arabian buildings. Furthermore, this Chapter will identify the requirements for achieving more sustainable designs with more consideration of the resident's culture in Saudi Arabia.

Chapter 7 (*The Saudi Housing Sustainability Framework (SHSF) to improve the construction processes for buildings to become more sustainable design*): This Chapter will answer the fourth research question (**RQ4:** *How can the experts in the sustainability field understand the resident requirements considering the achievement of sustainability in Saudi Arabia*) by developing a framework through to meet the requirements of the Saudi Arabian construction industry. This will be performed through a systematic literature review. The SHSF will; (a) provide a list of sustainable design interventions in Saudi Arabia, (b) provide a list of requirements to achieve the sustainable design in Saudi Arabia depending on a criteria such as building requirements, cultural factors, economic factors, climate requirements, sustainability impact, and data requirements, (c) remove unstable combinations by showing the positive impact of installing the interventions and list unstable combination between the interventions, and (d) formalizing the data and interactions needed to conceptualise sustainable design.

Chapter 8 (*Validation of the Saudi Housing Sustainability Framework (SHSF*)): This Chapter will answer the fifth research question (**RQ5:** *How can the construction/refurbishment processes of existing traditional Saudi Arabian buildings be changed and improved to achieve a more sustainable design*). This will be answered through, the verification and validation of the framework.

Chapter 9 (*Conclusion*): This Chapter will conclude the thesis by documenting the research findings well as answers to the research questions. Furthermore, this Chapter will share the conclusions reached during the research process and illustrate the results. Finally, this Chapter will offer recommendations for the Saudi construction sector and further recommendations for future researchers working in this area. It will also present future work in this area.

Chapter 2: Background and related work

This Chapter aims to present a literature review in the area of sustainable building design and the impact of cultural issues, focusing on the case of Saudi Arabia. Moreover, this Chapter has analysed related literature in the area of sustainable building design and the influence of cultural issues, focusing on the case of Saudi Arabia. Furthermore, this Chapter has identified the lack of using technology to support design in Saudi Arabia, the lack of achieving sustainability in Saudi Arabia, cultural issues that effect on design in Saudi Arabia, and the lack of using Building Information Modelling (BIM) in Saudi Arabia for both public and private project. These issues have led to the research gaps that have the potential to improve the adoption of sustainable design in Saudi Arabia by using Building Information Modelling (BIM). These gaps were identified as a result of many studies which were analysed critically and categorised in this literature review into three areas: Sustainable design, Building Information Modelling (BIM), and Cultural around the world and focusing on Saudi Arabia case.

2.1. Sustainability

Sustainable design was defined by the United Nations World Commission on Environment and Development (WCED) as “development which meets the needs of the present generations without compromising the ability of the future generations to meet their own needs” (Brundtland, 1987). This definition implies the need to achieve a balance between, on the one hand, required economic activity, and development, and on the other, natural resource conservation and social balance (Langston & Mackley, 1998). Sustainability is consequently concerned with reducing negative influences while improving the environment to guarantee a better quality of living for future generations. This requires using renewable natural resources in a way which does not diminish nor destroy them and using non-renewable natural resources at a rate slow enough to guarantee a clear societal shift to new alternatives (Langston & Mackley, 1998). Furthermore, Sustainable construction refers to the practice of creating structures and using processes that are environmentally responsible and resource-efficient throughout a building’s life cycle, from siting to design, construction, operation, maintenance, renovation, re-purposing, and deconstruction (Kibert, 2016). The sustainable construction change is now global in scope, with nearly 70 national green building councils introducing ambitious performance targets for the built environment in their countries (Kibert, 2016). To develop green building, countries improve and conduct building assessment systems that produce ratings for buildings based on an evaluation of their performance against a wide range of environmental, economic, and social requirements (Kibert, 2016). Moreover, existing buildings around the world account for almost one third of global energy requirements and the availability of fossil fuels declining, there is an urgent need to guarantee that this energy need can be efficiently met and controlled using renewable energy (Kaewunruen, Rungskunroch, & Welsh, 2018).

Many past research papers have mentioned the need to decrease the energy demands of existing buildings and to find alternative energy sources to fossil fuels. A European Union report stated that, in the EU, 40% of total energy consumption comes from buildings, meanwhile, in the United States buildings consume 41% of total energy (Union, 2010). The new United Nations Sustainable Development Goals (SDG) that seek to end poverty, protect the planet, and ensure prosperity for all, require transformative and solution-oriented research to offer the knowledge required to support changes towards sustainable development (Leal Filho et al., 2018). In this regard, Future Earth has been designed as a global research platform, seeking to provide the knowledge needed to help transformation geared towards sustainability and to contribute to reaching goals on global sustainable development (Leal Filho et al., 2018). In addition, the global extraction of non-metallic minerals such as stone, sand, clay, and limestone, reached a large number which was about 35 billion tons in 2010. Sand and stone included the main share of global extraction of non-metallic minerals in 2010 (40.8% stone and 31.1% sand) (Ghaffar, Burman, & Braimah, 2020). Infrastructure developments and construction projects are one of the biggest reasons for this consumption. The change towards a better circular economy where output flows could be reintegrated as secondary help give a good solution for the construction industry. Materials in buildings that should support their value where buildings should work as banks of valuable materials and products (Ghaffar et al., 2020). This procedure can be done using smart design and circular construction, which is critical for a sector to facilitate both waste and the number of resources used. Consequently, new business models replace the ‘end-of-life’ perception with decreasing, recycling, reusing, and recovering materials in production and consumption methods (Ghaffar et al., 2020). Also, many studies are supporting adopting a tough goal of net-zero CO2 emissions by the year 2050 to supercharge a powerful new step to avoid pervasive climate damage (Deutch, 2020). The path to net zero in the U.S. needs a change to an essentially all-electric economy. Such a change begins with deep decarbonization of the electricity system by leveraging the massive penetration of renewable electricity generation notably wind and solar (Deutch, 2020).

2.1.1. Sustainable design state of the art

According to Cho and colleagues (2012), construction experts now need to pay attention to sustainability and the energy performance of new buildings (Cho, Chen, & Woo, 2012). Notably, society is increasingly conscious of the environmental and energy implications of special building designs. Consequently, researchers must explore the assets that designer and architects can leverage, to design energy efficient buildings (Kensek, 2014). In addition, architects and those involved in the design process need to engage in preliminary brainstorming sessions before approving a particular construction plan to provide an appropriate design. It is regularly documented that nearly 40% of global energy usage is linked to operational energy consumption of buildings (Berardi, GhaffarianHoseini, & GhaffarianHoseini, 2014). Buildings are also responsible for 33% of greenhouse gas emission around the world. Due to the high rate of energy consumption different sustainable strategies and environmentally responsible energy-efficient technologies have been recommended and implemented to obtain low-energy buildings. These include energy-efficient systems, advanced eco-technologies, and renewable energy sources (Berardi et al., 2014).

The consumption of fossil fuels has led to environmental problems such as global warming, ozone layer depletion, acid rain, and air pollution (Sudhakar, Winderl, & Priya, 2019). Furthermore, the conversion efficiency of energy from primary energy to electricity is low and 60–70% of the energy is lost in terms of waste heat, so waste heat recovery is needed to increase the overall energy conversion efficiency (Sudhakar et al., 2019). The Organic Rankins Cycle (ORC) is a promising technology for recovering low-grade heat from loss (Sudhakar et al., 2019). The construction industry plays a top role in improving the quality of the built environment, but its actions also affect the wider environment in several ways. As the rate of construction is set to grow, there is a critical need to decrease waste at all phases of construction by considering the long-term effects of design (Osmani, Glass, & Price, 2008). However, the construction industry's culture and resistance to change are important challenges. Moreover, the architect has a strong role to play in supporting the reduction of waste in construction at all levels by concentrating on designing. In order to maximise their impact, architects need to understand the problems, constraints and opportunities linked to the practical means by which improvements can be achieved. By enhancing design practices, architects could realistically and successfully accelerate the rate of change (Osmani et al., 2008).

2.1.2. Sustainability assessment

Sustainability assessment can be easily explained as a process that directs decision-making towards sustainability (Bond, Morrison-Saunders, & Pope, 2012). It has been named the third generation of impact assessment, following strategic environmental assessment (SEA) and environmental impact assessment (EIA) (Sadler, 1999). Additionally, it is true that it has developed simultaneously from other areas such as natural resource management and planning (Kemp, Parto, & Gibson, 2005). Arguably, the point has not been reached yet at which there is a universal agreement as to what sustainability assessment is, nor how it should be implemented. The international practice differs considerably depending on the legal and governance structures in place and the form of decision-making, also the conceptualization of sustainability that is included in the process (Bond et al., 2012).

Environmental Impact Assessment (EIA) has expanded around the world and currently, it has been followed in at least 191 countries (Morgan, 2012). Moreover, the US Environmental Protection Agency is regarding the adoption of sustainability assessment and management process. That would support the classic steps in the actual impact assessment method, for instance, scoping, screening, stakeholder involvement, analysis, and approval decision-making. However, according to the National Research Council of the National Academies, there are three key features which are Comprehensive and systems-based, Intergenerational, and Stakeholder involvement and collaboration (N. R. Council, 2012). That could propose a new phase of assessment, designed especially to help to achieve sustainable improvement as explained in original documents and events which have taken place since NEPA was set in 1970 (Bond et al., 2012). Moreover, many factors can affect the criteria used in sustainability assessment tools, such as cultural issues, social, economic, and environmental factors. Therefore, standard international methods for estimating the sustainability of construction projects in all countries do not yet exist, in light of the differences in some of these areas (R Banani, Vahdati, & Elmualim, 2013).

2.1.3. Sustainability in Saudi Arabia

The extreme environmental conditions in Saudi Arabia increase the demand for water and energy; as such, it is one of the countries spending the most money on water desalination globally, despite its limited non-saltwater assets (Alsulaihi, 2017). The Saudi government has reserved approximately $53 billion for various water projects to be completed by 2022, and throughout the following decade, approximately $79.9 billion was reserved for energy projects

(Alsulaihi, 2017). In addition, there is a basic need to receive manageability in numerous sectors in Saudi Arabia, including the development sector, which is a significant purchaser of non-renewable assets. Moreover, it is responsible for a significant proportion of waste generation and CO2 emissions (Bakhoum & Brown, 2012). Globally, the operational energy of buildings in developed nations expends approximately 30% of total used energy and is responsible for 40% of carbon emissions (Change, 2007). For instance, in the USA, buildings are responsible for 40% of the national energy utilization, 39% of carbon emissions, and 13% of water utilization (U. G. B. Council & Council, 2016).

In recent years, Saudi Arabia has experienced significant economic growth due to high oil prices and continuing improvements in the country (Al-Yami & Price, 2006). This has been driven by significant government construction projects and the development of infrastructure and building projects, including accommodation, private construction, hospitals, and schools, as well as the rapidly growing tourism sector (Al-Yami & Price, 2006). At the same time, the Saudi government has paid important attention to protecting the environment, preserving biodiversity, natural resources, and ensuring a better quality of life (Al-Yami & Price, 2006). The government has contributed significantly to sustainable development through the initiation of several policies, regulations, and reports by relevant agencies, which are playing an important role in realizing principles of sustainability in the Kingdom (Al-Yami & Price, 2006).

According to Al-Yami and Price (2006), the Saudi government played an effective role in realizing sustainable development during the Seventh Five-Year Development Plan (2000–2004) (Al-Yami & Price, 2006). Agenda 21 issued at the 1992 Earth Summit in Rio, as the international blueprint for sustainable development, was supported by the Saudi government in December 1994. Many environmental objectives were achieved, such as decreasing the level of and controlling desertification, reducing pollution, adopting a coastal management plan, designing an environmental data network, and protecting national wildlife (Al-Yami & Price, 2006). In addition, the General Environmental Regulations were established in 2001, and the official by-law in 2003, which began with the appointment of the Presidency of Meteorology and Environment, the principal agency responsible for the implementation of the environmental regulations in coordination with other relevant agencies (Al-Yami & Price, 2006). Furthermore, Saudi Arabia entered the following international environmental organizations during the Seventh Five-Year Development Plan: The United Nations Framework Convention on Climate Change (UNFCCC); the supplement to the Kyoto Protocol, which was approved in 2005; the United Nations Desertification Control; and the United Nations Bio-Diversity Convention (Al-Yami & Price, 2006).

These impacts are increasing the need to create maintainability estimates that will guarantee the construction of practical and green buildings to limit the negative environmental influence (Abdallah, El-Rayes, & Liu, 2013). More than 600 rating frameworks for appraising the sustainability of buildings are used around the world (T. Saunders, 2008). These rating frameworks are used to assess the sustainability of buildings in accordance with green building criteria (Asif, 2016). The differences in natural environments from one nation to another have led to various sustainability measures/criteria and diverse significance loads for these measures.

Based on the Saudi Vision 2030, achieving sustainability in all aspects of life is important, especially in residential buildings. The “Mostadam” rating system for the evaluation of existing as well as new residential buildings was recently suggested by the government (Balabel & Alwetaishi, 2021). Mostadam is a standard that contains three green building rating systems dependent on the type of built asset being examined: (a) residential buildings, (b) neighbourhoods and residents, and (c) commercial buildings.

However, emerging technologies and methodologies are transforming how people work and live. The Fourth Industrial Revolution, also known as Industry 4.0, is having an immediate impact on how people communicate and interact with each other (Bolpagni, Gavina, Ribeiro, & Arnal, 2022). This change affects all industries, including the built environment, which is transitioning to the “Construction 4.0” era. Climate change and global health emergencies have accelerated the digitization and automation of the construction sector, demonstrating the importance of having reliable real-time data to support decision-making processes. Construction 4.0 is creating new job opportunities and necessitates the addition of new knowledge and skills (Bolpagni et al., 2022). It is necessary for every nation to develop a sustainability rating framework that fits with its environmental conditions.

In conclusion, sustainability encompasses a mix of economic, environmental, and social responsibilities (H. M. Taleb & Sharples, 2011). Given new and emerging environmental and energy concerns, there has been significant interest in Saudi Arabia in recent years concerning the concept of sustainable design (H. M. Taleb & Sharples, 2011). The main drivers behind supporting sustainable design are environmental and energy considerations, as well as additional factors such as the desire to improve residents’ quality of life and address health-related concerns in the KSA. In principle, sustainable buildings are related to the idea of climate-responsive design (Richard Hyde, 2013). This indicates the need for natural energy sources and systems to deliver building comfort through interactions between the dynamic conditions of the building’s environment. For instance, the placing of a window in a sustainable building is of vital importance as it could provide useful natural light, comfortable ventilation, and cooling (Richard Hyde, 2013).

However, firstly, previous studies have shown that applying some sustainability measures to Islamic houses without considering residents' privacy could affect the residents' privacy, which means that Islamic countries need a unique understanding of the culture. Secondly, there is a lack of analysis of the different perspectives on sustainability between specialists involved in sustainable design and members of the public in Saudi Arabia. That means the designer must consider both professional and public opinion during the design process of any project. Finally, there is no formalised framework of comprehensive standards for evaluating, rating, and certifying the sustainable design of buildings, such as BREEAM in the UK or LEED in the US, with consideration for locality-specific factors. This means Saudi Arabia, in particular, requires considering specific factors in order to reach more sustainable design in the country.

2.2. Building Information Modelling (BIM)

BIM can be described as a process of data sharing, exchange, and information management, which delivers a building design from the early stage of design to finish the project (Vanlande, Nicolle, & Cruz, 2008). This confirms that BIM is a process rather than being a tool (Eadie, Browne, Odeyinka, McKeown, & McNiff, 2013). It is important to note that some observers believe the acronym BIM should be modified to Building Information Management, while others use the expression BIM(M) to point to Building Information Modelling and Management (Eadie et al., 2013). BIM functions are possible in several applications, such as Ecotect, Tekla structure, Autodesk Revit, and Energy Plus. Available BIM functions can also be utilized using the Revit API (Application Programming Interface), which is a valuable tool for including external applications into Revit products, such as transferring data to other applications or linking with an external database (Wu, 2010).

In the present condition of globalized business, examining the construction sector likely remains the ideal method for investigating financial conditions in the economy in general (Alhumayn et al., 2017). Construction industry projects remain fundamental to the arrangement of the framework and to employment creation throughout the world. In terms of business promotion, the construction industry is a driving force (Zhou, Goh, & Li, 2015).

Numerous nations globally are highly dependent on construction employment, and this sector has consistently been the single largest source of employment in Saudi Arabia (Asif, 2016). Abubakar et al. (2014) stress that, regardless of the undeniable importance of the construction business to the national economy of most nations, the industry worldwide has faced numerous criticisms for its wastefulness and low efficiency (Abubakar, Ibrahim, Kado, & Bala, 2014). These criticisms have generally been based on the complex process of supply chain management in the construction sector. Confirming this, Hassan (2012) likewise recognized that the construction business is commonly seen as poorly managed (Hassan, 2012).

2.2.1. The state of the art for BIM

BIM is a building industry improvement that reflects a shift from electronic planning to a model-based procedure (Alhumayn et al., 2017). BIM is used to make a model that is not just a geometrical portrayal, but also contains information and properties that can be utilized by project members at any time and place (Brundtland, 1987). The BIM model can be made 4D by associating model components with timetables, as typically 5D models involve coordinating cost estimations with model components (Alhumayn et al., 2017). Furthermore, 6D is defined as the representation of the As-Built model, an extension of the BIM model for Facilities Management that incorporates specific data required for the Operation and Maintenance stage using information embodied in the rich Project Information Model (Charef, Alaka, & Emmitt, 2018). Operation and Maintenance manuals, plans, and technical support can all be embedded in the 6D BIM. This is an "As-Built" model that must be updated throughout the asset lifecycle. The 6D is also defined by the National Building Specification (NBS) as a dimension that includes information to support facility management and operation actions (Charef et al., 2018).

Developed nations in Asia, Europe, and North America are presently seeing the benefits of applying BIM which developed many projects in these countries. In an investigation directed by Gerges and colleagues (2017) to determine the present status of BIM in the Middle East by investigating the degree of BIM execution among partners in the construction industry, it was found that BIM reception in the Middle East has been unfavourable (Gerges et al., 2017). The authors further identified that just 20% of construction companies that are using BIM or are engaged with the BIM adoption process in some way, while the remaining 80% are neither applying it nor associated with it in a limited capacity.

Another study by Sun and colleagues (2017) shows the important information on the construction market in relation to BIM and to identify the relevant skills, proficiencies, and barriers to BIM usage. The study did not clearly plot the nations surveyed and the nations the respondents originated from. The respondents to the study were generally ventured proprietors, temporary workers, venture designers, specialists, and providers (C. Sun, Jiang, Skibniewski, Man, & Shen, 2017). The findings of the study showed that over half of the respondents did not utilize BIM, and approximately 20% did not have enough experience with BIM, which suggests a low awareness level. Furthermore, the review uncovered that accessibility of skilled staff, cost of programming, and cost of usage were the highest-ranking barriers to BIM appropriation in the area (C. Sun et al., 2017).

From the findings of the literature review discussed previously, BIM usage status is associated with awareness level, difficulties in execution, and barriers in selected Saudi regions.

Within BIM, a significant proportion of the information required for supporting a task's execution can be captured readily through planning (Salgueiro & Ferries, 2015). By utilizing a structured data model, designers can dissect how a structure will perform in the early stages of planning and based on this, can rapidly survey structure choices to decide on the best option to repeat on a greener structure (Salgueiro & Ferries, 2015). The majority of BIM tools have different benefits for assessing energy and material utilization investigation and an electrical and mechanical component of the structure with the aim that it would quickly generate data for reducing the wastage of energy and resources (Salgueiro & Ferries, 2015). Part of the BIM programming, for example, Autodesk Ecotect and Revit, give some normal devices that process data to clarify the environmental benefits of the project. This further empowers designers and planners to manage utilization of energy and material assets effectively (Nugraha Bahar, Pere, Landrieu, & Nicolle, 2013). Giving examination on the sun-oriented way, building direction, concealing plan and warming, and cooling assurance, such programming can incorporate information to accomplish a greener structure (Nugraha Bahar et al., 2013).

2.2.2. Building Information Modelling (BIM) and Sustainability

One of the principal contributions of BIM to sustainable development, which additionally is one of its general uses, is its immediate role in financial management. Evaluating the costs of a project and the required resources can be broken down into phases to predict and calculate the costs of each stage (Banawi, 2017). In addition, to reducing the cost of a project, and aside from the 3D models of BIM portrayals, project administrators can utilize 4D models to determine the risks of the project more accurately and efficiently (Alhumayn et al., 2017). Despite the fact that this procedure can help the project to be dynamic and practical, it would not be considered a sustainable methodology unless it incorporated environmental benefit and individual and societal needs (Alhumayn et al., 2017). In addition, the use of BIM in different parts of the project can contribute significantly to cost efficiency (Alhumayn et al., 2017). For example, predicting the future requires coordinated efforts and communication among colleagues reducing wastage, saving time, improving the structure of the board, and lowering project costs (Alhumayn et al., 2017).

The Western Australia Council of Social Services (WACOSS) characterizes the event of social sustainability as "when the formal and casual procedures, frameworks, structures, and connections effectively bolster the limit of present and future ages to make sound and decent networks" (Ghahramanpouri, Lamit, & Sedaghatnia, 2013). Usually, the advantages of sustainability from a social perspective are considered inside enhancement for different aspects of sustainability, which result in advancing human prosperity, happiness, and wellbeing (Alhumayn et al., 2017). In regard to sustainability, social responsibility tends to incorporate a wide range of ideas and definitions, which can be separated into two groups relative to their association with BIM: reliant and free benefits (Alhumayn et al., 2017). However, most of the definitions and ideas recommended as socially sustainable plans are independent from different factors, which are primarily subjective (Sassi, 2006). There are various different ways in which a sustainable building structure can improve personal satisfaction for the general public, leading to a better-quality environment, neighbourhood reclamation, and reducing threats to wellbeing from toxins related to building energy use (Asif, 2016).

2.2.3. Building Information Modelling (BIM) in Saudi Arabia

Although BIM is utilized in Saudi Arabia, it remains in the early phases of adoption, and BIM usage in the Saudi Arabian construction industry remains generally limited and has not been used for many projects (Alhumayn et al., 2017). This is because some business owners began to recognize the various advantages related to BIM usage, such as enabling different structure choices, the capacity to carry out numerous tests on a model, and its capacity to accommodate early identification of planned errors to reduce expensive rebuilds. BIM is an improvement and utilization of a PC programming model to simulate the development and activity of an office (Alhumayn et al., 2017; Bank, McCarthy, Thompson, & Menassa, 2010). According to study by Sodangi (2019), the usage of BIM in construction in Saudi Arabia is, for the most part, carried out by a small number of large organizations; the subcontracting sector is relatively under developed (Mahmoud Sodangi, 2019). The author further observed that in the few large construction organizations that utilize BIM in their key activities improved the quality of the buildings design (Mahmoud Sodangi, 2019).

Considering that BIM usage in Saudi Arabia is limited to the few largest organizations, and the subcontracting sector comprises mainly small and medium-size construction companies it is yet to appropriate BIM, making it is necessary relevant to develop systems that would guarantee the adoption of BIM by the industry (Mahmoud Sodangi, 2019).

Furthermore, some studies show that the use of BIM in some construction projects in Saudi Arabia, which, there are no available sources to determine the genuine status of BIM usage in the whole Saudi region. The key findings of a study conducted by Alhumayn et al (2017), was the evidence collected of a low usage rate of BIM in construction projects in the Saudi construction sector. The study also found the absence of BIM awareness and the reluctance of partners to accept changes to the current working practices (Alhumayn et al., 2017). In a related study by Ahmed and colleagues (2014) titled "Barriers to BIM/4D implementation in Qatar", the aim was to assess the awareness and experience levels of 4D planning and BIM in the construction industry in Qatar, and to distinguish the potential barriers to the general usage of BIM (S. M. Ahmed, Emam, & Farrell, 2014). The assessment was based on an industry-wide overview limited to related professionals in Qatar (S. M. Ahmed et al., 2014). The findings of the study showed that the level of BIM adoption is still low and in the research phase. Moreover, the study has recommended that the level of BIM adoption should increase. The use of BIM should move from research only to its practical deployment in the industry. Also, the paper suggested level of BIM knowledge for managers and those who are involved in the designing process should be improved (S. M. Ahmed et al., 2014). Again, in the Middle East, Hamada and colleagues (2017) carried out a similar study in titled "Challenges and obstacles of adoption BIM technology in the construction industry in Iraq" on the use of BIM innovation to identify the key benefits and barriers that point of confinement BIM appropriation in the Iraqi construction industry (Hamada, Haron, Zakaria, & Humada, 2016). The findings of the study suggested low BIM adoption among construction experts in Iraq. Additionally, the findings also showed that the cost factor is one of the main reasons for a lack of BIM adoption (Hamada et al., 2016). The study however, only summarised that BIM adoption is low in Iraq without providing any specific quantification of this finding.

Considering the significance of the Saudi Arabian economy, which is one of the largest in the Middle East, and the volume of construction projects being initiated in Saudi Arabia, a similar study needs to be conducted to provide further insight into this subject (Alhumayn et al., 2017). However, there is no evidence of any such examination carried out in the context of the Saudi Arabian construction industry (Alhumayn et al., 2017). In this context, the author is the first to examine the degree of subcontractors' awareness of and readiness for BIM usage in construction projects in the Saudi Arabian construction industry. It is predicted that the findings of this paper would be important to management in the Saudi Arabian construction industry, identifying rules and strategies to improve the general level of BIM awareness, preparedness, adoption, and to generally increase the skills of the subcontractor sector of the local construction industry (Alhumayn et al., 2017).

One of the benefits that can be considered is the openings in vernacular design and their advantages in inactive energy (significance and size) (Alhumayn et al., 2017). Installing large openings in a house (such as windows and doors) could negatively affect the resident's satisfaction with the dwelling because of the cultural requirement for privacy is key in any Islamic household. This issue should be considered during the design stage of any domestic building intended for an Islamic family (Alhumayn et al., 2017).

If a new region is to be built, moving away from the present predominately cement neighbourhoods, investigating the utilization of latent cooling and conventional ventilation procedures could be helpful (Alhumayn et al., 2017). One of the current issues is the materials used for roads and structures, which add significantly to the warmth island impact made in existing urban communities. Conventions are significant, but not the only necessity for structures.

In conclusion, BIM is important in this study because it allows for a better design interpretation; better evaluation of design options; and better analysis, early detection, and resolution of conflicts between building components. BIM makes Mechanical Electrical Plumbing (MEP) and Fire Protection (FP) work better, which is not optional in any project.

The Mostadam rating system for the evaluation of existing as well as new residential buildings was recently suggested by the government in Saudi Arabia (Balabel & Alwetaishi, 2021) (as mentioned in Section 2.1.3). This means Saudi Arabia, in particular, requires considering specific factors in order to reach more sustainable design in the country. Furthermore, the current level of utilization of BIM technologies in general in Saudi Arabia, specifically for sustainability analysis is uncertain. In Saudi Arabia, the adoption of BIM is still developing and needs to be more incorporated in the construction sector, for example, by implementing some software such as Nevada software, and ACCA software. Moreover, there is a lack of a methodology, that can be supported by BIM, for both government projects and private houses which can improve the Saudi Arabian construction sector. Specifically, Saudi Arabia needs to adopt BIM in the domestic construction sector to enable it to improve its decision-making regarding sustainability for both refurbishment and new buildings. These advantages have been seen in the UK and Netherlands' and evidenced from their experience of applying BIM to domestic construction which can improve its decision-making regarding sustainability for both refurbishment and new buildings (Aibinu, 2015; Georgiadou, 2019; Sebastian, Haak, & Vos, 2009).

2.3. Cultural factors affecting sustainable design

In academic literature, the home environment is conceptualized in many ways. Some designers consider a home in terms of the rich interdependent psychological meaning for the residents (Stafford, 2011). Different designers advise that a home represents a typical social communication that describes an interpersonal creative expression and style, also, describes the social network and social class of its homeowner (Zulkeplee Othman, Aird, & Buys, 2015). The 2030 Agenda for Sustainable Development, which was adopted by all United Nations Member States in 2015, aims to coordinate efforts to improve sustainable growth. The 12th Sustainable Development Goal promotes sustainable consumption and production patterns; one of its goals encourages people to educate and interest in sustainable consumption and lifestyles. However, different results are observed across countries, these countries' differences highlight the importance of the influence of the complex cultural and geographical contexts where studies were carried out (Zulkeplee Othman et al., 2015). Individuals with a similar religious affiliation/belief in the same religion are thought to share a common cognitive system of beliefs, values, and aspirations and are expected to behave accordingly. However, this theory ignores the contextual influences that may explain why those sharing a religious affiliation behave differently in many countries. Moreover, cross-cultural studies have shown that religion cannot be studied in isolation from all contextual influences (Zulkeplee Othman et al., 2015). In a study conducted in the United States and Canada, researchers discovered that not only religious affiliation and religiosity but also the nation and the relationships between the two significantly predicted sustainable behaviour (Zulkeplee Othman et al., 2015). Another cross-country study in the United States and Germany discovered striking differences between people of the same religion in these two countries: among United State respondents, a positive greater correlation between religious attendance and ethical consumption was found, whereas, among Germans, the relationship was negative and not substantial (Zulkeplee Othman et al., 2015). The religion factor is vital for this study senses it represents the influence of the religion to achieve the sustainable design across the world.

According to a study by Heathcote (2012), the interior decoration or the design of the furniture in the home shows the lifestyle and goals, as well as the personal life journey of the homeowner (Heathcote, 2012). Furthermore, the same study identified some architectural elements for example windows, doors, and bedrooms as features that are functional and useful but also exert much impact on human domestic behaviours and actions inside the house environment. Despite the size, the number of rooms, style, or real estate value, each house provides its residents or owners with objects that help both their social and personal needs (Heathcote, 2012). Furthermore, the architectural styles and materials utilised in houses created in the Middle East change from houses in her predominantly Muslim countries, for instance, Malaysia, because of climate factors and the locally available materials in the country. Despite these factors, some houses in predominantly Muslim countries tend to share a "humility in design" approach, such that houses are built with more sustainable and economical materials that additionally give thermal comfort inside the building (Zulkeplee Othman et al., 2015). With the significant development of projects in the gulf countries and specifically in Saudi Arabia, culture is different which may effect on the design of houses, construction industry, and energy consumption in these countries (Zulkeplee Othman et al., 2015).

2.3.1. Cultural factors affecting sustainable design in Saudi Arabia

Saudi culture has been described as the most preservationist culture in the world (Burkhart & Goodman, 1998). The religion of Islam is followed by most of the Saudi population, Islam governs all aspects of Saudi life (Burkhart & Goodman, 1998). The Qur'an and the Hadith of Prophet Mohammed (PBUH) are followed and applied in regular activities (Sulandari, Wijayanti, & Sari, 2017). Islam is reflected in the structure of a Saudi or Muslim house on account of the requirement for separation between male and female members of the family (Sulandari et al., 2017). In some circumstances, Muslim women must wear unobtrusive garments that cover their entire bodies, and a Hijab that covers their heads (Nordin, 2019). Muslim women must not uncover herself in front of any man, except for her family relative (of blood connection) and grandfather. This requirement has significantly affected the structure of the Muslim house, requiring separate sections: one for men and the other for women. Gender separation in Saudi houses is commonplace and required to follow the Islamic way of life (Nordin, 2019). This is the reality in Saudi Arabia, where separation between male and female areas in a house is typical and required to adhere to the Islamic way of life (M. Al Surf, Susilawati, & Trigunarsyah, 2012). As it is clear that separation between men and women is compulsory, building designers should consider this reality and incorporate secluded areas for both genders so privacy can be achieved for all inhabitants of any Saudi house (M. Al Surf et al., 2012).

The Saudi culture is characterized by the teachings of Islam, represented by the Hadith and the Qur'an. Islam, as indicated by Al Surf and colleagues (2012), is an extensive lifestyle where every human action – for example, education, business, social connections, and science is driven and administered by God (M. Al Surf et al., 2012). For a significant period, the provision of housing to Saudi inhabitants has used a traditional methodology, since interest in housing in the Middle East developed because of fluctuations in population growth and income levels. In addition, the social and strict foundations of Saudi society determine how far people live from a mosque, further influencing the structure of a Saudi house from various perspectives. Since a Muslim must pray five times a day, living near to a mosque is a necessity in the Saudi culture (M. Al Surf et al., 2012). Traditional neighbourhoods were based on a large focal Masjid (mosque), which was commonly surrounded by the town. Traditionally, one large Masjid would serve the entire town, which had various implications of interest (Nordin, 2019). One of the many disadvantages of having such a large number of Masjids in a single neighbourhood is that individuals do not collaborate as they used to previously (M. Al Surf et al., 2012).

2.3.2. Privacy

In the last years, many Muslims have established new houses in many different locations around the world. Islam has strong religious traditions that are directly applicable to the construction and organization of life within the home and its environment (Zulkeplee Othman et al., 2015). The design of traditional Muslim houses is subjected to guidelines from principles outlined in Islamic Sharia Law, which is obtained from the Quran as well as hadiths and sunnah (Zulkeplee Othman et al., 2015). Following three main principles have developed from these guidelines: privacy, hospitality, and modesty. In order, these three principles form the primary considerations of those who aim to build a traditional Muslim house. However, the migration of Muslims around the world also exposes them to the traditions and cultures of their host nations (Zulkeplee Othman et al., 2015).

Privacy in the traditional Islamic house contains four central layers: (a) privacy between gender (male and female), (b) privacy between neighbours, (c) privacy between family members inside the house, and (d) personal privacy. Such privacy conditions are usually met by a very careful design by making sure that the safety of the family and separating the private life from public associations (Memarian & Ranjbar-Kermani, 2011). Several studies have focused on how Muslims can achieve privacy and increase hospitality within their houses while still implementing sustainable design principles (Aman, Abbas, Mahmood, Nurunnabi, & Bano, 2019). However, about the importance of domestic spaces for performing religious ceremonies and the practice of humility in the context of house design (Zulkeplee Othman et al., 2015).

Furthermore, a typical Saudi Arabian home is intended to be as far away from others' view as possible. Privacy is central to the design of any Saudi Arabian house, and all individuals associated with development projects in Saudi Arabia for example, urban originators, draftsmen, scene planners, and social researchers–should consider this critical aspect of the building (Abu-Gaueh, 1995). Furthermore, privacy is fundamental to the building of housing for tenants in accordance with Muslim culture (Mahmud, 2009).

2.3.3. Privacy violation in Saudi Arabia

Violation of privacy is the primary issue faced by inhabitants of Riyadh today (Ukuhor & Abdulwahab, 2018). This is the result of the lack of appropriate building regulations preventing the development of elevated structures in proximity to low-level private homes (Cardenas, 2016). This has meant that the inhabitants of homes have suffered violations of their privacy, something that is considered to a greater extent in the MENA district as a result of the requirements of the religion and culture of the region (Nordin, 2019). There is now a potentially hazardous mix of single workers that would prefer to live in densely populated high rises, living in or close to separated single-family residential zones (Nordin, 2019). This has prompted numerous privacy issues across the city of Riyadh, and throughout the KSA (Ukuhor & Abdulwahab, 2018). According to a study carried out by Hanan and Sharples which focused on typical Saudi residential buildings (i.e., apartment complex), such buildings must achieve energy and water efficiency, and certain design and operational changes could have a major influence on the sustainability performance of the building (H. M. Taleb & Sharples, 2011). The energy-saving measures considered were increasing thermal insulation of the roofs and external walls, fitting external shading devices, efficient glazing, and fitting energy-efficient fluorescent lighting (H. M. Taleb & Sharples, 2011).

2.4. Current deployment of sustainable design and future recommendations

The sustainable performance of buildings is currently a huge concern among Architecture, Construction, and Engineering experts due to measures such as building codes which consider different factors such as building legislation in addition to national and regional targets (Zanni, Soetanto, & Ruikar, 2017). The overall aim is to decrease the influence of buildings on the environment while improving human comfort and health. Many countries and international organisations such as the UK and the USA have started rating systems to assess sustainable construction. Currently, these assessment methods are utilised as frameworks for environmental design by building experts, although they do not guide the design process (Zanni et al., 2017). Furthermore, the design of high-performance buildings is a complex, nonlinear, iterative, and interactive process that needs active collaboration between the multidisciplinary teams from the early stages to reach sustainability results (Zanni et al., 2017).

In the UK, BIM adoption has risen in recent years, there is limited evidence that sustainability has been systematically considered as an essential part of the BIM collaborative process. Some BIM related frameworks are based on the international assessment rating systems such as BREEAM and LEED, while others have generated tools that are combined into BIM design software to automate performance-based decision making (Zanni et al., 2017). This is a compliance measure that has been successfully used to reach sustainable improvement in countries around the world such as the UK, where the BREEAM rating scale is a successful tool. BREEAM in the UK, and different certification systems in other countries, are of high importance at the global level and play a key role in the entire construction of sustainability (Hamedani & Huber, 2012). Furthermore, more clients in the USA are requesting LEED or other third-party certification of their projects (Brahme, Mahdavi, Lam, & Gupta, 2001). To maximize the actual sustainability advantages of LEED certification, designers are required to understand which combination of credits gives the optimal design variables to raise the building's sustainability while keeping within budgetary limitations (Brahme et al., 2001). Moreover, there are more sustainability standards around the world such as, Minergie from Switzerland, Passivhaus from Austria, and Deutsche Gesellschaft für Nachhaltiges Bauen (DGNB) from Germany.

The main drivers promoting sustainable design are environmental and energy considerations, as well as several other factors such as health-related concerns and the desire to improve citizens' quality of life (Richard Hyde, 2013). In principle, sustainable buildings relate to the notion of climate-responsive design, which highlights the importance of natural energy sources with the aim of achieving building comfort through interactions between the dynamic conditions of the building's environment (Richard Hyde, 2013). For example, the position of a window in a sustainable building is of the greatest importance as it could provide natural light, a source of air cooling, and ventilation (Richard Hyde, 2013).

Specifically, in gulf countries (including the KSA), as a result of badly designed buildings, approximately 80% of electricity in the home is used for air conditioning and cooling purposes (Akbari, Morsy, & Al-Baharna, 1996). In addition, in Saudi Arabia, as a result of fast population growth and increased urbanization, the residential sector booming and accounts for more than half of the country's energy demand (Al-Shehri, 2008). The design of new houses in Saudi Arabia is no longer based on the principles of vernacular architecture, which tends to involve the utilization of local building resources, as well as the use of passive and low-energy strategies that could begin to decrease the need for both air conditioning and lighting requirements (Al-Ismaily & Probert, 1997). Furthermore, electricity generation in Saudi Arabia is entirely dependent on the unsustainable practice of using fossil fuels, which has major environmental impacts on the climate, air, land, and water (Alnatheer, 2006).

Following the energy crises of the 1970s, building codes have been established in developed nations, and more recently in the developing countries of China, Argentina, and Taiwan; the sustainable building laws in some of the countries of the European Union are among the most stringent (Chwieduk, 2003). The role that can be played by BIM in meeting sustainability requirements should thus be investigated. In addition, Saudi Arabia construction industry is not growing well in achieving effective management and reaching great organisational performance. This was proved by the number of projects suffering delay, which increased from 700 projects in 2009 to 3000 projects in 2013 (Alhumayn et al., 2017). Also, the Saudi Arabia construction industry is characterized by inefficiency, due to a range of factors such as rising demands from the clients and the use of traditional methods (Alhumayn et al., 2017). Furthermore, it has been stated that most of the construction companies in Saudi Arabia have a lack of knowledge, experience, and management across the lifecycle of the project which makes it difficult for these companies to compete with more technologically advanced international companies. This inefficiency makes delays, time overruns, and increases construction project costs (Alhumayn et al., 2017).

Based on Saudi Arabia's Vision 2030 for achieving sustainability in all aspects of life, particularly in residential buildings, the "Mostadam" rating system for the evaluation of existing as well as new residential buildings was recently suggested by the government

(Balabel & Alwetaishi, 2021). Mostadam is a standard that contains three green building rating systems dependent on the type of built asset being examined: (a) residential buildings, (b) neighbourhoods and residents, and (c) commercial buildings. Each rating system has two parts: (a) design and construction, and (b) operation.

However, there are challenges which have resulted in a low number of projects and buildings in Saudi Arabia for instance, international sustainable building rating systems do not consider regional differences and different climates (Balabel & Alwetaishi, 2021). As a result, it is important to adopt local rating systems such as Mostadam for each city in Saudi Arabia depending on the climate of each region. Additionally, it is essential to investigate the lack of development in the Saudi building industry by considering modern building materials and techniques (Balabel & Alwetaishi, 2021). Therefore, Balabel and colleagues (2021) suggest that it is highly enhance the local building industry to overcome this problem and improve the implementation of the Mostadam rating system throughout the country. However, Mostadam rating system is still not been used in the country and is still a recommendation (Balabel & Alwetaishi, 2021).

2.5. Current uses of BIM for sustainable design

Several studies have shown that Saudi Arabia is considering cultural issues and how these are having an effect on the design of houses, especially given the large area of the country and the differences of culture between regions (H. M. Taleb & Sharples, 2011).

The years 1990–2010 saw dramatic growth in the urbanization of Saudi Arabia as compared with the other developing countries of the Arabian Gulf. Moreover, the Saudi housing typology and citizen behaviours and preferences have greatly changed over the past three decades. In developing countries such as Saudi Arabia, the experience of a rapid rate and ratio of urbanization and infrastructure expansion, especially with respect to residential buildings, is large (Karam, 2010). However, comparing this significant growth with other countries is clear that the issue of energy efficiency is not given serious consideration in Saudi building designs (Karam, 2010).

Consequently, a few studies have been conducted in the areas of development advancement and basic leadership, prompting the improvement of various enhancement models utilizing an assortment of methodologies. The establishment of a rating framework for green building is proposed to fit the unique natural conditions in Saudi Arabia. This rating framework is called the Saudi Arabia Green Building Rating System (SAGRS). The SAGRS would be coordinated as a system committed to selecting the most ideal appropriate building materials highlighting the potential benefits of BIM innovation (M. Ahmed, Abul Hasan, & Mallick, 2016). The system will consider the cultural issues and Life Cycle Cost (LCC) to complete its functionality. Saudi Arabia is one of the Middle East developing countries that consider cultural issues as a key criterion for green building assessments which restrict the architect during the design process (M. Ahmed et al., 2016). BIM is not a solution to sustainability in itself; however, it can be a key enabling tool in the process of achieving sustainability. It can; (a) help designers to understand current structure and characteristics performance of a building, (b) can provide a base for creation of simulation models to measure building performance and (c) the modelling of future interventions. Thus, the use of BIM supports sustainability through measurement planning, explicit building data, and enabling simulations (Alhumayn et al., 2017). The using of BIM for sustainable design has many benefits as follows below.

2.5.1. Benefits of utilizing BIM for sustainable design

The Saudi locale is suffering, arguably more so than in many parts of the world, from difficulties with regard to sustainability in the housing sector (Asif, 2016). Not only is the region well known for its harsh dry conditions, but it also additionally shows evidence of an exceptionally high use of energy and water per capita compared with other densely populated territories globally (Asif, 2016). Thus, it is essential to provide some insight into the unique difficulties, which include financial, environmental, and socio-cultural issues, facing Saudi Arabia (Asif, 2016). BIM can offer and set out multi-disciplinary information within one model. This enables sustainability to be measured through planning and conveying expectations (Alhumayn et al., 2017). BIM has become an essential piece of sustainability examination and recreation and assumes a significant role in reducing industry waste and environmental damage (Alhumayn et al., 2017). In this way, the interest in BIM-based investigations in the field of sustainability is increasing significantly (Alhumayn et al., 2017).

BIM innovation, alongside its general uses, can add to sustainable development in different phases of a building project, from making significant decisions in the early stages to destruction, to increase the efficiency and execution of the project. Concerning practical development, the commitment of BIM to building procedure can be contrasted, and the three fundamental elements of sustainability: environmental, financial, and social (Alhumayn et al., 2017). Integration of a BIM model with a decision-making tool and sustainability metrics could address the challenges of making decisions earlier in the design process and allow for specific sustainability cost–benefit analyses to be conducted, based on the exact building state and characteristics (Bank et al., 2010). BIM is intended to improve the way information is used in a building throughout its life cycle, and to reduce the influence of design, operations, maintenance, and occupant behaviour modification decisions made to improve the building's contribution to sustainable infrastructure (Bank et al., 2010).

According to a study by Zanni and colleagues (2017), using BIM to achieve a sustainable building in the UK has an important impact on the sustainable outcome of buildings. The development of a structured process can help in sustainable design practice with building professionals (Zanni et al., 2017). Learning from implemented projects, using BIM methods, facilitates the scope of this process creation and advises future projects to prevent crashes. Process mapping is necessary to streamline the process, support key project processes and assist the design team to manage their responsibilities (Zanni et al., 2017).

2.6. Conclusion

The lack of measures and not having extensive understanding of Building Information Modelling (BIM) adoption, and the related expenses and benefits, are among the fundamental difficulties facing BIM execution in the Saudi Arabia construction industry. This literature review has shown that BIM is now used in Dubai, but only for particular kinds of projects. Although BIM is beginning to be adopted in Saudi Arabia, there is a lack of authoritative sources about BIM (Alhumayn et al., 2017). There are a few programming organizations that provide some component of the BIM procedure, but they do not regard the procedure as one entirety. Thus, there is a need to institutionalize the BIM procedure strategically in the Saudi Arabia construction industry (Asif, 2016). To advance BIM adoption, businesses and organizations must learn about its affordances (Alhumayn et al., 2017).

Businesses should develop procedures and approaches to advance BIM adoption to diminish current risks within the construction sector. BIM came as a solution which can be used during the project life cycle, which can help the quality of the design from the early stage of design until the demolition of the building. BIM is at the start of moving the construction industry into the digital age and will help to achieve the sustainable design in Saudi Arabia. Although building associations are demonstrating enthusiasm for BIM, their interest is communicated as belief in things to come and not as a present-day reality.

This Chapter has analysed relevant literature in the area of sustainable building design and the impact of cultural issues, focusing on the case of Saudi Arabia. This review has identified the lack of using technology to support designs in Saudi Arabia, lack of achieving sustainability in Saudi Arabia, culture issues effect on designing in Saudi Arabia, and lack of using BIM in Saudi Arabia for both public and private project. These issues have led to the research gap that have the potential to improve the adoption of sustainable design in Saudi Arabia by using Building Information Modelling (BIM). Through this analysis of the research described in this Section the following research gaps have been identified:

1. There is a lack of understanding of the extent and impact of cultural issues on achieving sustainable design. In Saudi Arabia specifically this means Saudi is a country relating to Islam which needs a special understanding of the culture (Abu-Gaueh, 1995; Alrashed & Asif, 2015). (As discussed in Section 2.1 and Section 2.3).
2. Lack of analysis of the different viewpoints on sustainability within and between professionals involved in sustainable design and members of the public in Saudi Arabia. This means the designer should consider both construction industry professionals and public opinion about the designing process (Alhumayn et al., 2017; Cardenas, 2016). (As discussed in Section 2.1).
3. Lack of any formalised framework of comprehensive measures for evaluating, rating, and certifying the sustainable design of buildings such as BREEAM in the UK or LEED in the USA with consideration to locality specific factors. Specifically this means Saudi Arabia needs to consider specific factors to achieve more sustainable design in the country (Alhumayn et al., 2017; H. M. Taleb & Sharples, 2011). (As discussed in Section 2.1 and Section 2.2).
4. Uncertainty as to the current level of utilization of BIM technologies in general in Saudi Arabia, and specifically for sustainability analysis. In Saudi Arabia the current level of BIM is still developing and need to be more incorporate in the construction sector. Moreover, implement some software's such as, Nevada software, ACCA software (Alhumayn et al., 2017; Asif, 2016; M Sodangi, Salman, & Shaawat, 2016). (As discussed in Section 2.2).
5. Lack of a methodology for implementing sustainable design that can be supported by BIM, for domestic properties. Specifically, Saudi Arabia needs to adopt BIM in the domestic construction sector to improve its decision-making regarding sustainability for both refurbishment and new buildings. To do this Saudi Arabia

needs to take advantage of the UK, France, and Netherlands' experience of applying BIM (Aibinu, 2015; Georgiadou, 2019; Hamada et al., 2016; Sebastian et al., 2009; C. Sun et al., 2017) . (As discussed in Section 2.2).

These gaps were identified through many studies as shown in Table 1 and came up with keywords which were analysed critically and classified in this literature review into three areas: (1) Sustainable design, (2) BIM, and (3) Cultural around the world and focusing on Saudi Arabia. These keywords were selected since it was commonly used in the available research in this area.

No	Keyword	Number of studies
1	BIM	15
2	BIM in Saudi Arabia	12
3	Cultural factors	1
4	Cultural factor in Saudi Arabia	9
5	Sustainable design	40
6	Sustainable design in Saudi Arabia	31

Table 1: Keywords and number of studies

Saudi Arabia specifically has been chosen as a case study in this thesis for many reasons such as, construction industry, the impact of culture especially privacy on houses, general public awareness of sustainable design, and energy consumption in the country.

Chapter 3: Methodology

This Chapter describes the methodology employed within the thesis. In this Chapter, the first Section 3.1 presents a background of the research nature and theory. Section 3.2 defines the research philosophy and design selection for this work. Section 3.3 will describe the research questions and the research objectives. Section 3.4 presents the research strategy of this research. Section 3.5 will describe data collection and analysis. Section 3.6 will present a summary for this Chapter.

3.1. Background of research nature and theory

Researchers debate the definitions and characteristics of research. The term 'research' has been misused in many ways: to describe collecting data without a clear objective, to describe an activity irrelevant to people's daily lives, to describe the reordering of information collected facts without understanding, and to use this concept to obtain respect (Walliman, 2010). Moreover, research should have a stated goal and a specific objective to solve a problem(s), manage the data systematically, and analyse the data systematically (MNK Saunders, Lewis, & Thornhill, 2019).

This dissertation will use the research onion to describe the methodology process. The research onion model can be applied to almost any research methodology or situation in which researchers are conducting research to answer a question (MNK Saunders et al., 2019).

3.1.1. Research philosophy and approaches/design

A research philosophy is a set of ideas and beliefs about the development of knowledge. It expresses how the researcher contributes to the expansion of knowledge in a specific research field (MNK Saunders et al., 2019).

The 'research onion' stages are:

1. The research philosophy, in which a starting point is selected to shape the research.
2. The methodological choice, which highlights the research options while designing the study.
3. The choice of research strategies, where one or more strategy is chosen to design how to answer or address the research questions.
4. The time horizon, which highlights both where and when the study is being undertaken.
5. The choice of techniques associated with the methods of collecting and analysing the research data.

3.1.2. Research paradigm

The definition of the research paradigm is a collection of related beliefs about the social world that serves as a philosophical and abstract framework for the systematic study of that environment (Filstead, 1979). Selecting the paradigm is an important step in the research process because it allows the researcher to select the tools, instruments, participants, and methods which will be used in the study (Denzin & Lincoln, 2008). According to Saunders and colleagues (2019) in the revised edition of the 'research onion' model, the philosophy of the paradigm consists of positivism, critical realism, interpretivism, postmodernism and pragmatism (MNK Saunders et al., 2019). Table 2 will summarise the research paradigms.

No	Research Paradigms	Summary
1	**Pragmatism**	This is achieved by analysing many theories, concepts, hypotheses, and research findings not abstractly, but in terms of their functions as a tool of thought and their functional importance in particular cases (Brierley, 2017; Muhaise, Ejiri, Muwanga-Zake, & Kareyo, 2020; MNK Saunders et al., 2019).
2	**Postmodernism**	Postmodernism highlights the importance of language and power connections, seeking to question established methods of thought and give voice to marginalised viewpoints (Muhaise et al., 2020; MNK Saunders et al., 2019).
3	**Interpretivism**	Interpretivism emphasises the difference between humans and physical phenomena in that they generate meaning and investigate these performances (Muhaise et al., 2020; MNK Saunders et al., 2019).
4	**Critical realism**	Critical realism is a meta-theoretical paradigm that describes what we see and experience in terms of the underlying facts structures that control visible phenomena (Muhaise et al., 2020; MNK Saunders et al., 2019).
5	**Positivism**	Positivism is the philosophical perspective of natural scientists that needs them to work with observable social facts to generate law-like generalisations that ensure specific knowledge (Muhaise et al., 2020; MNK Saunders et al., 2019).

Table 2: Research philosophy key component

3.1.3. Research Methods

A research methodology is a method of investigation that explains how the research will be carried out (Wiles, Bengry-Howell, Crow, & Nind, 2013). Furthermore, Saunders and colleagues (2019) determined three common methodological choices of research methods that often use (MNK Saunders et al., 2019).

3.1.3.1. Quantitative approach

Quantitative research is defined as research that is based on methodological positivism and neo-positivist principles and adheres to the strict criteria of a pre-research design in order to study relationships between facts and determine how facts and relationships correspond with theories and previous research results (Adams, Khan, & Raeside, 2014; Fellows & Liu, 2015). It is used for quantitative measurement, which requires the use of statistical analysis.

3.1.3.2. Qualitative approach

The qualitative approach examines people's beliefs and perspectives to produce an understanding of individuals' and communities' perceptions around the world. Based on theoretical principles, the qualitative approach uses a combination of methodological strategies (phenomenology, hermeneutics, and social interactionism) (Adams et al., 2014; Fellows & Liu, 2015). It is using non-quantitative data collection and analysing methods, investigating social relationships, and describing facts as perceived by respondents (Adams et al., 2014; Fellows & Liu, 2015).

3.1.3.3. Mixed-Methods approach

It is the process of conducting research by the researcher that combines elements of qualitative and quantitative research approaches for the general purpose of increasing the breadth and depth of knowledge and corroboration (Curry & Nunez-Smith, 2014; Johnson, Onwuegbuzie, & Turner, 2007). According to study by Saunders and colleagues (2019), the researchers use these integrated quantitative and qualitative methods in data collection techniques and analytical methods in the same research project when they have a pluralist view of the research methodology (MNK Saunders et al., 2019). Therefore, both qualitative and quantitative analysis are affected to some extent by the researchers' characteristics and disciplinary approach (Gale, Heath, Cameron, Rashid, & Redwood, 2013).

3.1.4. The theoretical approach

Following research philosophy and paradigm selection, the debate over research methodology moves to the next step. As a result, the research approach that best corresponds to the research theory will be chosen (Greener, 2008; Malalgoda, Amaratunga, & Haigh, 2018). There are three key methods to research theory development (MNK Saunders et al., 2019) as shown below:

1- **Deductive**: Inferences (quantitative) are described as a linear process in which one step follows another, with a logical sequence involved in the development of a theory when it is tested by the research design.

2- **Inductive**: Inferences (qualitative) entail gathering data to better understand the nature of a problem in order to develop a theory.

3- **Abductive:** Inferences (similar to inductive data) are used to investigate a phenomenon, explain patterns, and find themes in order to build or change a current hypothesis, which is then tested, often with additional data collection.

Because the selected research paradigm (positivism paradigm), has been made based on the research philosophy and design, the deductive approach is the most suitable approach to serve this research.

In conclusion, this research investigates the importance of BIM in achieving more sustainable construction in Saudi Arabia. The research methodology builds on Saunders' research onion, applying an objectivist research philosophy, integrated with a deductive approach. Combining these two aspects ensures a suitable foundation for planning sustainability in Saudi Arabia by using BIM and considering the cultural factor of the general public people. To take benefit of the available sample group, the study implements a survey approach to address gaps affecting alternative research techniques, such as the grounded theory approach.

3.2. Research hypothesis and the research questions

The overall hypothesis of this work is:

The wider adoption of BIM based tools that facilitate the consideration of both climate and cultural contexts have the potential to achieve an increased level of sustainable construction in Saudi Arabia.

To answer hypothesis, a number of research questions have been established as a basis upon which to design the research methodology. This research questions are:

1. What is the current level of BIM adoption in Saudi Arabia?

2. What is the current awareness level of the general public in Saudi Arabia and sustainable building design?
3. What are the suitable requirements for achieving sustainable domestic building design of housing in Saudi Arabia and how could privacy factors impinge on their adoption?
4. How can the experts in the sustainability field understand the resident requirements considering the achievement of sustainability in Saudi Arabia?
5. How can the construction/refurbishment processes of existing traditional Saudi Arabian buildings be changed and improved to achieve a more sustainable design?

3.3. Research philosophy and design selection

Selecting important philosophical assumptions assists the researcher in providing good answers to research questions by clarifying the research design, especially in terms of the required type of evidence and how it is to be gathered and analysed. Additionally, it assists researchers in identifying the various limitations of research approaches, allowing the researcher to choose and implement the most appropriate research design for the study (Easterby-Smith, Thorpe, & Lowe, 2002). Figure 1 depicts the research philosophy design chosen for the study.

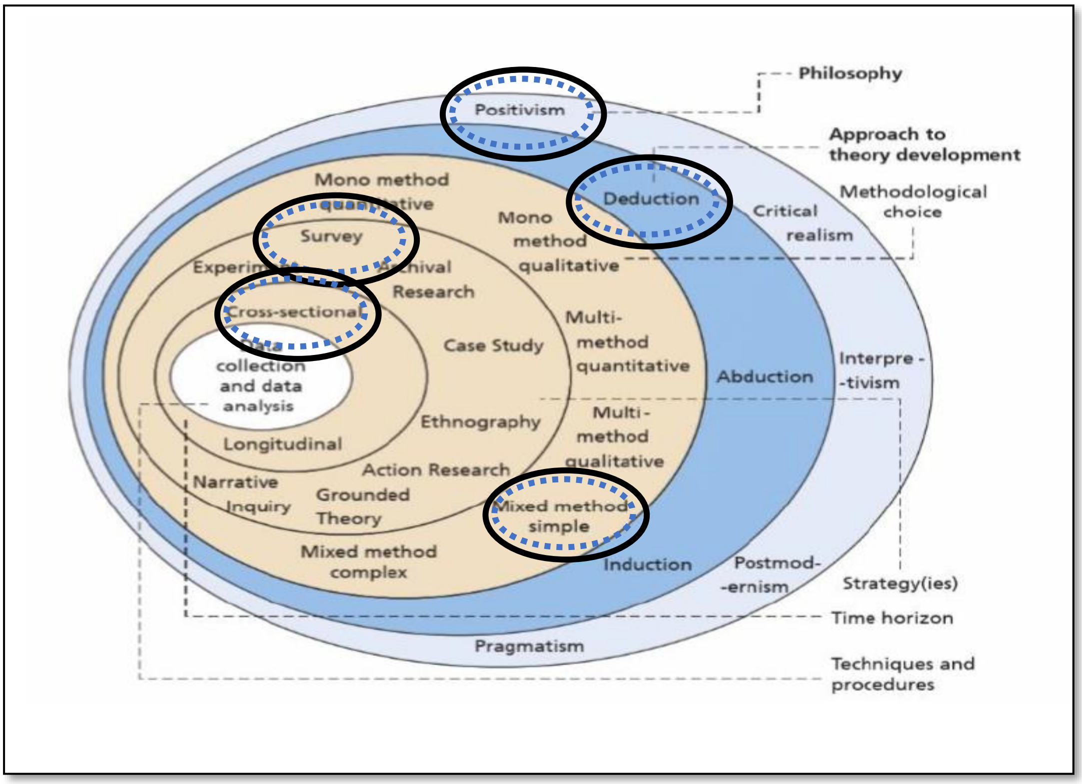


Figure 1: The selected research philosophy design (Saunders et al., 2019).

Research Philosophy: Positivism has been selected as the overarching research paradigm in this research. This selection has been made, because the research questions necessitate measurement or assessment methods which align with the positivism philosophy. Also, positivism is frequently used as a worldview or lens in research that focuses on the measurement or assessing an observation, occurrence, or reality (Easterby-Smith et al., 2002).

Research Approach: The deductive approach has been chosen for this research. This is because it is the most compatible with the research hypothesis and the research questions. This is because both quantitative and qualitative methods will be used in this research (Johnson et al., 2007; Sutrisna, 2009; Walliman, 2010). Additionally, the data collected in this study needs statistical analysis, repeatability, and comparisons to determine and characterise the relationships between variables and constructs (Denscombe, 2009; Jonker & Pennink, 2010). This is confirmed by a study by Draper (2004) who found the deductive approach is a suitable approach for evaluating behaviours and perspectives (Draper, 2004). That means this approach is suitable for this research with specific communities i.e., experts and especially for research with the general public.

Research Methodology: A mixed method methodology has been chosen for this research. This is because using mixed methods can sometimes give the researcher a better chance of achieving the research objectives (Johnson & Onwuegbuzie, 2004). Particularly qualitative data could complete the use of quantitative data when it comes to evaluating behaviours and perspectives (Draper, 2004). The choice of research methods depends on the research aim and objectives, the resources, and the time and skills available (Punch, 2013). Furthermore, subjectivity exists when analysing both types of data. It is found not only in the selection and interpretation of the data to be analysed but also in the design of the data collection methods (Rabiee, 2004). Given that mixed methods are typically developed from the positivist paradigm, which is the paradigm used in this research, the mixed methods strategy logically presents a primary survey approach for this research.

Research Strategy: This research will utilise both survey and systemic literature review to answer the research questions. Questionnaires will be used answer research questions 1, 2, and 5 while, systemic literature review will answer research questions 3 and 4. Both will now be discussed.

Research surveys: Are made to gather information, create a quantitative description of the population being studied, they can be analysed to investigate the correlations between different variables (Pinsonneault and Kraemer 1993). Surveys appear to be the logical choice when trying to understand people's values and opinions. It can aid in the "conceptualization of culture as beliefs and attitudes" (Della Porta & Keating, 2008). Surveys enable the collection of similar information from a large group of people via predefined and structured questions, which leads to quantitative data analysis (Pinsonneault & Kraemer, 1993). Operates on statistical sampling and is commonly used in deductive, experimental, and descriptive research. It is typically carried out using highly structured questionnaires or unstructured interviews, involves qualitative or quantitative data collected with two or more variables, and investigates the relationship between variables (MNK Saunders et al., 2019).

Systematic literature reviews: Systematic literature reviews and evidence syntheses are essential research strategies that help researchers reach science incrementally, by building on previous studies' outcomes. Compared to classic literature overviews, systemic literature reviews treat the literature review procedure as a scientific process and use ideas of practical research to create the review process more evident and replicable, also to decrease the possibility of discrimination (Lame, 2019). The systematic literature review strategy can be used to describe the methodology and the outcome of any research (MNK Saunders et al., 2019). It is frequently used in inductive and qualitative research and is more concerned with theory formulation than hypothesis testing of a research process (MNK Saunders et al., 2019). Additionally, another key use of systemic literature reviews is to provide in depth knowledge of a given area/domain. However, there is no widely accepted singular method to conduct a systemic literature review. Further, the approach is not part of the traditional design research onion, however given its common use across research domains and its use in this thesis it is described here for completeness.

Research Time Horizon: This research project is cross-sectional. Cross-sectional studies focus on the study of a particular phenomenon at a particular time. In this research, people's attitudes and beliefs about the cultural issues that affect achieving sustainable design in Saudi Arabia are studied along with the current, understanding the current level of BIM in Saudi Arabia.

The two key research instruments; systemic literature review and survey will now be described in more detail:

3.3.1. Questionnaires

The questionnaire survey method, or data collection strategy, is frequently associated with the deductive approach. This strategy has been used in many fields of knowledge, as well as in experimental and descriptive research, all over the world (MNK Saunders et al., 2019). Many authors in various fields have stated that the questionnaire is the most popular tool among survey instruments for collecting the necessary data in much scientific research. Moreover, the questionnaire technique is very general because it allows the collection of a great amount of data from different interests and is easy to compare (MNK Saunders et al., 2019). As with any other tool used in the survey process, questionnaires furthermore have both advantages and disadvantages. Table 3 summarises some of these.

Advantages	Disadvantages
1. Questionnaires deliver savings of material, time, and money. 2. Anonymity is useful when dealing with sensitive subjects for example ethics, and politics. 3. Questionnaires are easy to help and respond to. 4. Questionnaire methods help the investigator to cover a wide geographical area at a lower cost. 5. Standardised answers are delivered.	1. The researcher has no control over the interpretation or respondents of the questions. 2. A lower response rate, compared to the interviews method. 3. No possibility extends for additional answers. 4. No additional data will be added once the questionnaire is collected. 5. This tool is not suitable for some respondents if there are language difficulties.

Table 3: Summarising some of the questionnaire advantages and disadvantages

Kumar (2018) defines a questionnaire as a list of written questions that will be answered by respondents who receive the questions, solve them, and then write down the answers (Kumar, 2018). According to Saunders and colleagues (2019), the technique of answering a questionnaire depends on whether the questionnaire will be completed by the respondents themselves (self-completed) or the other way which is by the researcher (face-to-face questionnaires), which means the researcher meets the respondents, and how the questionnaire will be distributed (MNK Saunders et al., 2019).

The questions in a questionnaire are mainly divided into two types: open and closed questions. An open-question (Open-ended) questionnaire allows respondents to provide a complete answer or provide an answer in their way. In a closed-question (closed-ended) questionnaire, the researcher selects a set of answers and presents respondents with alternatives.

Accordingly, this research adopted the method of self-completed questionnaire to collect the needed data. It used an internet (online) questionnaire method since this way is fastest and easiest way to get to the respondents. Additionally, the open question (open-ended) technique has been implemented in this questionnaire survey to get more accurate answers and to hear from the experts about some useful information. Moreover, one of the reasons of the questionnaire was to give the respondents (experts) the chance to add any additional approaches and recommendations that were relevant to the Saudi Arabian context that was not already covered.

3.3.2. Systematic literature review

A systemic literature review is a method of synthesising scientific evidence to answer a particular research question in a way that is reproducible while aiming to include all published studies on the topic and appraising the quality of these studies (Lame, 2019). The main goal of the systemic literature review method is to decrease the risk of discrimination and to improve clarity at all the stages of the review process by depending on explicit, systematic methods to decrease bias in the choice and inclusion of studies, to appraise the quality of the included studies, and to summarise the studies objectively (Lame, 2019; Liberati et al., 2009). In addition, by providing a structured methods, the systemic literature review can help to determine and synthesise case studies, summarise conclusions, and identify blind spots in the investigation (Lame, 2019). Furthermore, an important aspect is systematic literature review is the process of analysing the results of the literature search. This analysis can evaluate research impact and identify further papers through citations that are related to the same area of the investigator's research.

However, there are some challenges of doing systemic literature review such as locating studies, appraising studies, synthesising results, and the general process of the systematic literature review can be time consuming (Lame, 2019). Despite this systemic literature review method can reduce discrimination and improve clarity in a review process by depending on explicit, systematic methods to reduce bias in the chosen studies, to appraise the quality of the included studies, and to summarise the studies objectively (Lame, 2019; Liberati et al., 2009).

3.4. Research strategy

The research strategy is the approach taken to achieve the research objectives (Oates, 2005). It is defined as "a plan of action to achieve a goal" (Mark Saunders, Lewis, & Thornhill, 2009). A research process can employ a variety of research strategies (Oates, 2005; Mark Saunders et al., 2009). The selecting research strategies should be guided by the research objectives, research philosophy, approach, and purposes, but also by the available knowledge, resources, and time (Mark Saunders et al., 2009).

Figure 2 shows the flowchart of this research, which describes all the steps that have been taken to achieve the purpose of the research. Beginning from academic literature review to identifying the research gap. Then, find out both the aims and objectives and the research questions of this research. After the research questions step, both the surveys and systemic

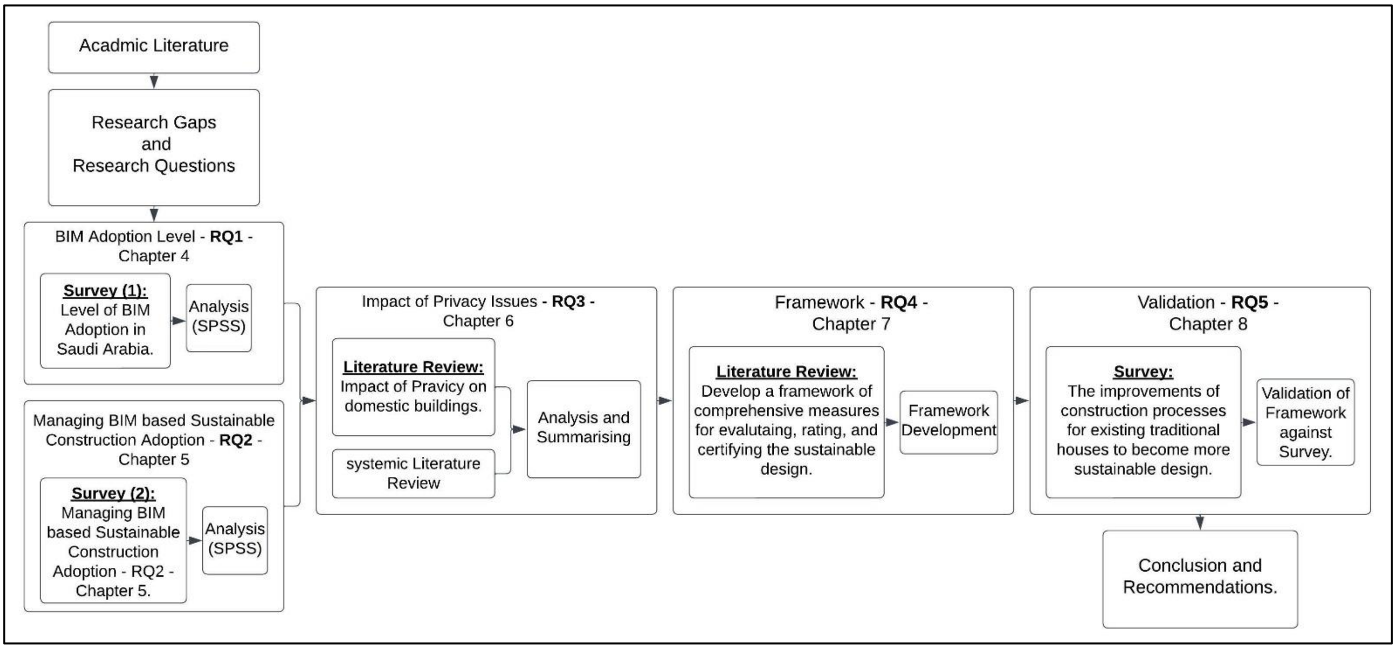


Figure 2: Thesis flowchart

literature review were the best way to answer all the questions. Finally, all the collected data have been analysed in order to introduce the conclusion and a valuable recommendation.

Each of these steps will utilise a variety of research strategies. The research strategy is a methodological link between data collection and analysis and the research philosophy. It is defined as the researcher's approach to answering the research questions (Denzin & Lincoln, 2011). Fellows and Liu (2015) also stated that steps in the research design link data collection and analysis to produce results, and the conclusion with the main research questions are a critical consideration in selecting the most suitable approach (methodology and methods) to use (Fellows & Liu, 2015). The goal is to increase the chance of achieving the research's objectives. As a result, the research design must take into account the research questions, identify the necessary data, and decide how the data will be collected and then analysed (Fellows & Liu, 2015).

Saunders and colleagues (2019) proposed several research strategies that related to research methodologies (quantitative, qualitative, and mixed method). They also stated that maintaining a reasonable level of coherence throughout the research design in order to answer the research questions and meet the research objectives (MNK Saunders et al., 2019). As a result, the research strategy should be guided by the research questions and objectives, realistic concerns, research coherence, research approach and purpose, and the availability of potential participants and other data resources. The following research strategies are suggested by Saunders and colleagues (2019): experiment, survey, archival and documentary research, case study, ethnography, action research, grounded theory, and narrative inquiry. Additionally, multiple authors have described different strategies or techniques such as Experiment, Survey, Archival Research, Case Study, Ethnography, Action Research, Grounded Theory, and Narrative Inquiry (MNK Saunders et al., 2019).

The remainder of this Chapter will describe each item in Figure 2 in more detail.

3.5. Studying BIM adoption level in Saudi Arabia (RQ 1)

This research question will be answered using the survey (questionnaire) research strategy. A questionnaire will be developed to examine the views of Saudi Arabian experts into the level of BIM adoption in Saudi Arabia. These questions will be distributed to Saudi Arabian experts together with questions concerning the cultural issues that form part of RQ2. Moreover, since experts are currently working in the construction industry in Saudi Arabia their views are required because they are embedded in the industry and understand the reality of the construction sector.

The questionnaire will be designed based on a literature review of existing studies in related fields including other studies of BIM adoption globally. Previous questionnaire on this subject (from a variety of other countries), will also be used to help develop the questionnaire.

The questionnaire will first be tested by conducting a pilot study (with 5 volunteer participants) before the final release to check for questions clarity and any technical issues. Five pilot experts were chosen because it allows a variety of viewpoints on the survey structure, but also such a small number will enable a rapid iteration of the survey content. The initial set of 5 experts were chosen based on their experience and knowledge in design, construction, maintenance, and operation, as well as their availability and willingness to provide feedback on the survey.

The questionnaire will then be distributed and sent to experts via the Internet (Email and social media: will be used including platforms such as: LinkedIn, Twitter, and Facebook). This distribution technique will be used as it is much faster and less costly than the printed survey (Stanton, 1998; Weible & Wallace, 1998). To reach participants across the country the survey will be made using Microsoft forms. The survey will also be sent directly to contacts acquired through previous work. Then, the snowball approach will be used by suggesting to the set of 20 experts that were originally sent the survey that they forward it to their colleagues. Snowball sampling, an established technique, will be used enable the survey to achieve larger scale distribution (Etikan, Alkassim, & Abubakar, 2016).

The data collected will then be coded and cleaned in preparation for final analysis. Survey results will be analysed in the Statistical Package for the Social Sciences (SPSS) software. This will be used performing statistical analysis, which will help to further understand the results of the survey (Hinton & McMurray, 2017). SPSS will also be used to present useful tables, offers a variety of languages, and is useful for both quantitative and qualitative data. Moreover, SPSS is one of the most commonly software package used for data analysis (Hinton & McMurray, 2017). Finally, any free text submitted as part of the questionnaire will be analysed manually.

3.6. Saudi Arabian Awareness of Sustainable Construction (RQ 2)

This research question will be answered with the survey (questionnaire) research strategy. Two sets of survey questions will be prepared some, which will form part of the expert survey described in the previous Section and some fill form part of a new survey that will be developed to examine the current level of understanding among the public of sustainable building design in Saudi Arabia.

The questionnaire will be designed based on a literature review of existing studies in similar fields. Additionally, questions asked in previous questionnaires on this subject (from a variety of other countries), will be used to help develop the questionnaire.

The questionnaire will first be tested by conducting a pilot study (with 5 participants) before the final release to check for questions clarity and any technical issues. The questionnaire will first be tested by conducting a pilot study as described previously. This questionnaire will be distributed in the same manner as the one described in Section 3.5.

The data collected will then be coded and cleaned in preparation for final analysis. Survey results will be analysed in the Statistical Package for the Social Sciences (SPSS) software. This will be used to perform statistical analysis, which will help to further understand the results of the survey (Hinton & McMurray, 2017). SPSS will also be used to present useful tables, offers a variety of languages, and is useful for both quantitative and qualitative data. Moreover, SPSS is one of the most commonly used software package for data analysis (Hinton & McMurray, 2017). Finally, any free text submitted as part of the questionnaire will be analysed manually.

3.7. Understanding the impact of privacy on achieving sustainable design in Saudi Arabia (RQ 3)

This research question will be answered through both a systematic literature review and a survey.

Systematic Literature Review: This literature review element will cover the following aspects:

(a) The past impact of culture on buildings in Saudi Arabia.
(b) The importance of sustainable design to human comfort and energy consumption.
(c) Important requirements for achieving a sustainable building design.
(d) Possible culture factors that could impinge upon sustainable design.

Publications will be identified using a keywork search, relevant publications will then be through analysis of both the title, keywords and abstract.

Survey: Additionally, questions will be added to both surveys described in the previous Sections (targeted at experts and the general-public). These questions will assess the level of understanding of the target groups of the effect of cultural issues on building design in Saudi Arabia. This will be used to supplement the data collected from the systematic literature review. Combining the results of both phases will identify the impacts of Saudi culture on its adoption of sustainable design, both through authoritative literature and through the opinions of those designing and living in Saudi Arabian buildings. This will enable an understanding of the key cultural factors that will impinge on the adoption of sustainable design.

3.8. Develop a framework of comprehensive measures for evaluating, rating, and certifying the sustainable design (RQ 4)

This research question will be answered in two phases: (1) a systematic literature review and (2) the development of a framework for evaluating, rating, and certifying sustainable design.

Systematic Literature Review: A literature review will first be conducted to derive:

(a) A list of sustainability interventions which can have a clear impact on the Saudi buildings in both the private and public sectors. These interventions will primarily be summarised from BREEAM, LEED, Energy Stars, NAHB rating systems and other literature sources.

(b) The possible results that can be achieved using these sustainability interventions.

(c) The building centric requirements of the deployment of the interventions i.e., what is required in a given building for them to be successfully deployed.

Based on the results of this literature review, as well as answers to previous research questions, a framework will be developed in the following stages:

Stage 1: Will identify a set of practical sustainability interventions (drawn from the previous literature survey) that are feasible for deployment in Saudi Arabia. Furthermore, the anticipated impacts of these sustainability interventions will also be documented. This step is needed to provide an indicative set of template interventions that can be applied. This will act as guidance for construction industry professionals that are not adequately aware of sustainable interventions.

Stage 2: A list of the data needed to understand; (a) if these interventions can be deployed in each property, and (b) what is their performance potential. This will also include factors needed to decide the cultural acceptability of these interventions. This will be drawn from the literature review conducted as well as data from the questionnaires from RQ2 and RQ3. This step is important to collect the needed to ensure that these interventions can be measured, analysed, and differentiated to enable the selection of the best interventions for a given building.

Stage 3: The results from previous stages will then be arranged into a step-by-step methodology to help buildings designers to determine what sustainability design interventions are suitable for a given building and its occupants, based on the cultural views. This can be reached by utilising BIM data which can then reduce and provide structure to data gathering. This step is required to provide a formalized approach to; (a) provide a structure to collect data about the building by BIM and the occupants by a survey and (b) to provide structures decision making to enable designers and occupants to make the best decisions regarding sustainability interventions based on their applicability and impacts.

Stage 4: Has been added documentation the verification of the framework on a sample building.

All of these stages come together as a framework work of measures and a methodology that enables experts in the sustainability field to gather and understand the resident requirements considering and then appropriately select sustainability measures, leading to the increased achievement of sustainability in Saudi Arabia.

3.9. The improvements of construction processes for existing traditional buildings to become more sustainable design (RQ 5)

A questionnaire will be developed to examine the views of Saudi Arabian experts on the framework itself with the aim of validating it. This will enable the determine if the framework is a valid way to alter the construction/refurbishment processes of existing traditional Saudi Arabian buildings to achieve a more sustainable design.

Thus, this questionnaire will firstly present the framework and then ask a variety of questions designed to collecting the views of experts about the framework, this will include its validity, applicability, and information about possible improvements in construction/refurbishment processes to enable existing traditional Saudi Arabian buildings to become more sustainable. In addition, to judge the level of understanding/current industry positions of the respondents the questionnaire will ask the experts about if they have used BIM before and if BIM is useful for design process to create more sustainable buildings. This will enable the responses to be fully analysed given the understanding of how BIM aware the respondent is.

The questionnaire will first be tested by conducting a pilot study (with 5 participants) before distribution. The questionnaire will then be distributed to the experts that responded to the survey in RQ1. The data collected will then be coded and cleaned in preparation for final analysis. It will be analysed in the Statistical Package for the Social Sciences (SPSS) software.

The results of this analysis will provide quantitative data on expert's views of the framework from the (RQ4). Finally, any free text submitted as part of the questionnaire will be analysed manually. The feedback from the experts will be used the validate the contents and applicability of the framework as well as understanding future steps in its development and deployment.

3.10. Conclusion

This Chapter has presented the research design and the adopted methodology for this research, starting from the research philosophy to the data collection and analysis methods. Additionally, this Chapter has provided a discussion about the concept of research in general and what research characteristics should be considered.

The research philosophical foundation is based on the positivism paradigm and uses the deductive approach to investigate the understanding of BIM level for the experts in engineering field in Saudi Arabia. Moreover, to understand the awareness level of sustainability for the general public in Saudi Arabia considering the cultural issues. The mixed method was adopted in this research, and this Chapter explains the reasons for using such a methodology and the consequences of this adoption. To answer the five research questions quantitative methods such as Surveys, Questionnaires and Systemic literature review will be used. Each one of the research questions will now be considered in turn in the remaining Chapters, RQ1 will be answered in Chapter 4, RQ2 will be answered in Chapter 5, RQ3 will be answered in Chapter 6, RQ4 will be answered in Chapter 7, and RQ5 will be answered in Chapter 8.

Chapter 4: Studying BIM adoption level in Saudi Arabia

4.1. Introduction

This Chapter will present the results, based on the methodology outlined in Chapter 3 of the first research question of this thesis (**RQ1:** *What is the current level of BIM adoption in Saudi Arabia*). To do this, this Chapter will examine the level of experts understanding of BIM level adoption in Saudi Arabia.

To address the problem of BIM level adoption in Saudi Arabia, it is very important to examine the main factors causing the delay of adopting BIM in Saudi Arabia.

The questionnaire focused on the current and future situation of BIM in Saudi Arabia, the type of projects that have used BIM on projects, BIM courses in Saudi universities, the significant barriers of BIM adoption in Saudi Arabia.

In this Chapter, Section 4.2 presents questionnaire design and development. Section 4.3 will describe the methods of analysis in Chapter. Section 4.4 presents the results and analysis of the research. Finally, Section 4.5 will conclude the Chapter.

4.2. Questionnaire design and development

Since this research is using mixed method, this research question will use a survey to collect the needed data. The questionnaire includes several questions that have been pre-formulated and designed to extract the data from the experts in the engineering field to answer this research question to understand the level of BIM adoption in Saudi Arabia. Both English and Arabic languages were used in the questionnaire which provides a better understanding of the questions for Saudi Arabian residents and for non-Arabic speakers to drive more responses. Table 4 shows the experts questionnaire.

No	Question	Question type
1	How best would you describe your profession?	Open and closed
2	Please provide your area of business?	Open and closed
3	How many years of experience do you have in your field?	Closed
4	Please provide the size of your organisation (Number of employees)	Closed
5	Approximately what is the percentage of projects have you used BIM for in the last 5 years?	Closed

6	On which type of projects type has your organization used BIM on in Saudi Arabia?	Closed
7	How would you like to describe your organization's current and future use of BIM?	Closed
8	Thinking of the projects you were working into over the last 12 months, did you ever	Closed
9	In your opinion, BIM can help to achieve	Closed
10	In your opinion, what is the benefit of using BIM now and in the near future?	Closed
11	What BIM software tools have you used?	Open and closed
12	While studying at university has BIM been taught in any of your courses?	Closed
13	In which country did you study?	Closed
14	In your view, how significant are the following barriers for your organization in adopting BIM?	Closed

Table 4: Experts questionnaire

In this study, the online questionnaire distribution technique is utilised as it is much faster and less costly than the printed survey (Stanton, 1998; Weible & Wallace, 1998). To reach participants across the country the survey was made using Microsoft forms. The questionnaire was distributed, and responses received from 42 experts in Saudi Arabia via the Internet (Email and social media such as LinkedIn, Twitter, and Facebook). This distribution technique will be used as it is faster and less costly than the printed survey (Stanton, 1998; Weible & Wallace, 1998). To reach participants across the country the survey will be made using Microsoft forms in Arabic and English. However, there is the possibility that the survey distribution approach could miss some experts who are not currently using e-mail technology. This may mean the results could be unnecessarily biased towards indicating a higher level of technology adoption. However, this is deemed to be of low risk due to the current high level of adoption of basic digital skills in Saudi Arabia (Boyer, Olson, & Jackson, 2001). Additionally, this survey was distributed during the COVID-19 pandemic, so it was the only real option for distribution.

4.2.1. Respondent Selection and Survey Distribution

The survey was distributed to a selection of experts in the engineering field, across Saudi Arabia. Responses were received from 42 experts in the engineering field such as construction, design, consultation, maintenance, and operation. This level of response is in line with what has been seen in other surveys and, thus, can provide confidence that the results have acceptable accuracy (Singh & Masuku, 2014). The criteria for choosing the experts in the survey are their construction-specific expertise. Furthermore, the participants are from different regions around Saudi Arabia which will help achieve a nationwide view within the results. To achieve this the survey was first distributed to a set of known experts from previous studies in a similar domain, and then, the snowball approach was utilised by suggesting to the experts that they send the survey to their colleagues.

The initial set of 5 experts was chosen based on their experience and knowledge. In addition, another significant factor in choosing the participants was their willingness to participate in this survey and begin the snowball approach (Bernard, 2017; Palinkas et al., 2015). The Snowball sampling was also used in this study, and it is technique that used for the large-scale distribution of the questionnaires. The technique of snowball is an academic approach used to collect data and has always been used for large-scale participants in Saudi Arabia (Biernacki & Waldorf, 1981). As stated previously, snowball was employed by encouraging the initial set of experts to forward the survey to their colleagues.

4.3. Methods of Analysis

An additional step that needs to be considered when using questionnaire data is, what are the suitable methods to analyse this data to answer the research questions.

For this work, the quantitative data collected from the surveys were exported into Excel and transferred to the Statistical Package for the Social Sciences (SPSS) Software to be analysed. This will be used to perform statistical analysis, which will help to further understand the results of the survey (Hinton & McMurray, 2017). SPSS will also be used to present useful tables, offers a variety of languages, and is useful for both quantitative and qualitative data. The selection of this tool is because SPSS is one of the most commonly used software package for data analysis (Hinton & McMurray, 2017). Then, all the data was coded and cleaned in preparation for the analysis stage. When the data was ready, it was analysed using descriptive and frequency statistics. There were different tests of the collected data such as:

1. **Chi-square test:** When the dependent variable is assessed at a nominal level, the Chi-square statistic is a non-parametric (distribution-free) technique used to analyse group differences. Like all non-parametric statistics, the Chi-square is reliable regardless of how the data are distributed. It enables the examination of numerous group studies as well as dichotomous independent variables. The calculations required to generate the Chi-square, in contrast to many other non-parametric statistics and certain parametric statistics, reveal a lot about how each of the study's groups did (McHugh, 2013). The Chi-square test is used in this research to compare between the different sectors, the experts in the engineering fields and general public people in the Saudi Arabia.

2. **Mean Ranking:** Equation 1 shows the ranking scale was created to compare the "mean" value for each factor in the provided sample and indicate the relative importance of each factor. In contrast to the term "mean," which is a more illuminating measure of the variable's central tendency, rank refers to a consecutive number assigned to a specific observation in a sample of observations sorted by their values, therefore, reflecting the observation's ordinal relationship to the other observations in the sample.

$$\sum_{n} (x \times i)^{n}$$

Equation 1

Where n = sample size and Σxi = represents the arithmetic sum of all scores assigned to each factor by respondents in the sample (Alyounes, 1999).

4.4. Results and analysis

This Section describes the results of analysing the questionnaire results related to the level of BIM adoption in Saudi Arabian construction sector. This analysis will help to determine the current situation of BIM usage, the project types that have used BIM, the current and future plans of organisations working in construction in Saudi Arabia. It will also analyse the benefit of using BIM, and how BIM can be integrated in the designing and operating process in Saudi Arabia.

The survey results are presented in this Section in the following categories: (a) Profession, area of business, experience of the participants, and organisation size, (b) The current and future situation of BIM in Saudi Arabia, (d) BIM education and courses, and (c) Barriers from the organisation to adopt BIM.

4.4.1. Profession, area of business, and experience of the participants

This Section will provide the profession for the participants in this questionnaire. This Section will describe the profession results (across the entire construction domain) for the participants in this questionnaire. Moreover, the area of business, the experience of the participants, and the size of the organisation will be provided to show the importance of that in this study. Moreover, this will help to measure the level of BIM understanding in the Saudi Arabian construction sector.

Experts in the engineering field in Saudi Arabia have accepted of sharing their experience and views in this questionnaire. As mentioned in the previous Section, the total number of the participants in this questionnaire is 42.

Table 5: How best would you describe your profession? (N= 42)

Profession	Frequency	Percentage%
Architect	18	43
Engineer (Civil - Structural)	14	33
Engineer (M - E)	5	12
Project manager	2	5
BIM manager	0	0
Others	3	7

Table 6: Please provide your area of business (N= 42)

Area of business	Frequency	Percentage%
Designing	12	28.5
Construction	7	17
Regulators	12	28.5
Operation and Maintenance	5	12
Other	6	14

Table 7: How many years of experience do you have in your field? (N= 42)

Years of Experience	Frequency	Percentage%
Less than 5 years	9	21
From 6 to 10 years	17	41
From 11 to 15 years	9	21
From 16 to 20 years	3	7
More than 20 years	4	10

Table 8: Please provide the size of organisation (Number of employees) (N= 42)

Number of employees	Frequency	Percentage%
Less than 50 employees	13	31
From 50 to 500	17	40.50
More than 500	12	28.50

In conclusion, Tables 5, 6, 7 and 8 show that there are respondents from a different range of company sizes, different levels of experience and across different disciplines. Among survey respondents, this spread of experience and the presence of respondents across organisation sizes and disciplines, shows that the survey represents the Saudi Arabian construction sector across company sizes and career stages.

The experience of the participants is important to this study because the views of more experience respondents will give this study more accurate results. This is because those who have more experience have been working in the industry for longer. Furthermore, the experts who have more experience have seen the development of the construction sector in the country and will have developed views on the impact of BIM on the Saudi Arabian construction field.

4.4.2. The current and future situation of BIM in Saudi Arabia

This Section will outline the results of the percentage of projects that have used BIM in the last 5 years. It will also show the type of projects that have used BIM. Furthermore, the results will show the participant's organization’s current and future use of BIM and the respondents perceived benefit of BIM on the construction sector in the country.

Table 9: Approximately what is the percentage of projects have you used BIM for in the last 5 years? (N= 42)

Percentage of projects using BIM	Frequency	Percentage%
Not at all	18	43
Currently considering adoption	5	12
Up to 25%	5	12
Up to 50%	5	12
Up to 75%	6	14
100%	3	7

Table 10: On which type of projects type has your organization used BIM on in Saudi Arabia? (N= 42)

Projects used BIM	Frequency	Percentage%
Education projects	8	19
Health projects	2	5
Transportation projects	3	7
Public housing projects	6	14
Private housing projects	3	7
None	20	48

Table 11: How would you like to describe your organization's current and future use of BIM? (N= 42)

Current and future use of BIM	Frequency	Percentage%
We currently using BIM	10	24
We aim to fully adopt BIM in one year	4	9.50
We aim to fully adopt BIM in the next three years	8	19
We aim to fully adopt BIM in the next five years	4	9.50
No current plans	16	38

Table 12: Thinking of the projects you were working into over the last 12 months, did you ever: (N= 42)

Activities in last 12 months	Frequency	Percentage%
Produce 2D digital drawings	8	19
Produce 3D digital drawings	7	16
Work collaboratively on design	13	31
have models with design team members outside your organization	8	20
Federate a model that did not depend on one piece of software	6	14

Table 13: In your opinion, BIM can help to achieve: (N= 42)

BIM can help to achieve	Frequency	Percentage%
Architecture designs include all the design phases	13	31
Construction field	4	10
MEP field	2	5
Operation and maintenance	1	2
Sustainability	8	19
Fully integrated	14	33

Table 14: In your opinion, what is the benefit of using BIM now and in the near future (N= 42)

Benefits of using BIM	Frequency	Percentage%
Increase the quality of work	6	14
Easy to work internationally	0	0
Increase the amount profit	0	0
Achieving accuracy in design, construction, operation, and maintenance	4	10
All the above	32	76

Table 15: What BIM software tools have you used? (N= 42)

BIM software used	Frequency	Percentage%
Revit	15	36
ArchiCAD	4	10
AutoCAD	16	38
Navisworks	1	2
AutoCAD MEP	2	4
Others	4	10

In conclusion, 19% of the participants agreed that they have used BIM in educational projects, the majority (49%) of the participants said that none of their projects have used BIM (Table 10). Furthermore, 38% of the participants said that there are no current plans of adopting BIM in their organisations (Table 11). Importantly, 33% of the participants agreed that if BIM fully integrated in the design of buildings that will help the construction sector in Saudi Arabia (Table 13). Finally, 76% of the participants agreed that if BIM integrated in the construction sector that will help to increase the quality of work, ease working internationally, increase the amount profit, and achieving accuracy in design, construction, operation, and maintenance (Table 14). It should be noted that, in the data in Tables 10 and 11, the participants were given the choice to pick multiple responses in the answer, additionally, some participants answered these questions inconsistently, so there are inconsistencies between these results.

Table 16: Comparison between organization's current and future use of BIM and participant's profession using Chi2 test (N=42)

Organization's current and future use of BIM	Participant's Profession					P
	Architect	Engineer (Civil - Structural)	Engineer (M - E)	Project manager	Others	
No current plans	8	3	2	1	2	0.581
Currently using BIM	5	3	1	0	1	
Aim to fully adopt BIM in one year	2	2	0	0	0	
Aim to fully adopt BIM in the next three years	1	5	2	0	0	
Aim to fully adopt BIM in the next five years	2	1	0	1	0	

*: Statistically significant if $p \leq 0.05$

Table 16 compares different professions and their plans for BIM usage in Saudi Arabia. The table is designed to test for an association or relationship between the participant's organization's current/future use of Building Information Modelling (BIM) and their professions. It aims to determine whether there is a significant connection between these two variables. However, the analysis found no statistically significant association between different professions and plans of BIM usage within the next five years (p= 0.581). The P value is the probability of getting a value equal to or more than the actual observation if the null hypothesis, is correct (i.e. there is no correlation between the data). Thus, with the P value being greater than 0.5 no statistical significance can be drawn from the data.

Table 17: Comparison between organization's current and future use of BIM and participant's area of business using Chi2 test (N=42)

Organization's current and future use of BIM	Participant's Area of business					P
	Designing	Regulators	Consultation	Operation and Maintenance	Other	
No current plans	5	0	3	4	4	0.187
Currently using BIM	3	3	3	0	1	
Aim to fully adopt BIM in one year	3	0	1	0	0	
Aim to fully adopt BIM in the next three years	1	2	3	1	1	
Aim to fully adopt BIM in the next five years	0	2	2	0	0	

*: Statistically significant if $p \leq 0.05$

Table 17 compares a participant's organization's current and future use of BIM and their area of business. This table tests the association between an organization's current and future use of Building Information Modelling (BIM) and the participants' areas of business. In essence, the table and associated statistical test provide insights into whether there is a meaningful relationship between an organization's adoption of BIM and the nature of the business areas of the participants involved. In this comparison, there is no significant association between different areas of business with current and future plans of BIM adoption (p= 0.187). The P value is the probability of getting a value equal to or more than the actual observation if the null hypothesis, is correct (i.e. there is no correlation between the data). Thus, with the P value being greater than 0.5 no statistical significance can be drawn from the data.

However, In Saudi Arabia, the regulatory authority is the authority that supervises designers.

Table 18: Comparison between organization's current and future use of BIM and "percentage of projects used BIM" using Chi2 test (N=42)

Organization's current and future use of BIM	percentage of projects used BIM						P
	Not at all	Currently considering adoption	Up to 25%	Up to 50%	Up to 75%	100%	
No current plans	12	0	3	1	0	0	0.002*
Currently using BIM	2	0	1	3	2	2	
Aim to fully adopt BIM in one year	0	3	0	0	1	0	
Aim to fully adopt BIM in the next three years	3	1	0	1	3	0	
Aim to fully adopt BIM in the next five years	1	1	1	0	0	1	

*: Statistically significant if $p \leq 0.05$

Table 18 compares a participant organization's current and future use of BIM and percentage of projects in which they have used BIM in Saudi Arabia. This table presents a comparison between an organization's current and future use of Building Information Modelling (BIM) and the percentage of projects in which BIM is used. In summary, this analysis helps to understand how an organization's BIM adoption plans correspond to the prevalence of BIM usage across their projects. In this comparison, there is statistically significant difference between participants in their plans of BIM usage with recent projects used BIM in the last 5 years (p=0.002). Most organizations that did not use BIM in the last five years (12 organizations) have no current plans for future usage of BIM, while most organizations that used BIM in 50 – 100 % of their previous projects are currently using BIM or have more plans to fully adopt BIM within the following one to five years. However, it should be noted the experts have responded inconsistently in Tables 9, 10, and 11.

4.4.3. BIM education and BIM courses

This Section presents the level of BIM education in Saudi Arabia. The results will show if any of the participants had BIM taught in their courses at the university. Also, the results will show in what country the participants studied for their degrees. This will give an idea if Saudi Arabian universities need to adopt BIM in the university's courses or not.

Table 19: While studying at university has BIM been taught in any of your courses? (N= 42)

BIM courses during university	Frequency	Percentage%
Has not been taught	18	43
Has been mentioned in some classes	15	36
Has been completely taught and adopted	4	9
Not known	5	12

Table 20: In which country did you study? (N= 42)

Country where studying	Frequency	Percentage%
Saudi	31	74
Egypt	6	14
UK	2	5
UK and USA	2	5
Germany	1	2

Table 21: Comparison between country where participant studied and BIM teaching in courses using Chi2 test (N=42)

Participants country of study	BIM teaching				P
	not been taught	mentioned in some classes	completely taught and adopted	Not known	
Saudi	16	11	2	2	0.014*
Egypt	1	4	0	1	
UK	1	0	0	1	
UK and USA	0	0	1	1	
Germany	0	0	1	0	

*: Statistically significant if p ≤ 0.05

Table 21 shows BIM teaching differs according to country of studying significantly (p= 0.014). Participants who studied in western countries (UK, USA, and Germany) seem to have some knowledge about BIM during their study in comparison to participants who studied in eastern countries (Saudi Arabia and Egypt).

In conclusion, from Tables 19, 20, and 21, it can be seen that 43% of the participants have never been taught BIM during their education. This is important because 74% of the participants in this survey are from Saudi Arabia. From those in Saudi Arabia, Table 17 shows that 52% of the Saudi participants have never been taught BIM, 35% of the participants from Saudi Arabia agreed that BIM has been just mentioned in some classes. However, 6.5% of the participants who studied in Saudi Arabia do not know if they have studied BIM or not.

Meanwhile, Table 19 shows that 43% of the participants have not been taught BIM and 12% of the participants did not know of the concept of BIM. It should be noted in some cases participants were confused between the concept of 3D modelling and BIM which explains the discrepancies between these responses and the experience levels documented in Table 7.

4.4.4. Barriers to adopting BIM

This Section presents the results of the questions asking about the significant barriers to adopting BIM in Saudi Arabia. Identification of these barriers will help to determine the problems currently faced in increasing BIM adoption in Saudi Arabia.

Table 22: In your view, how significant are the following barriers for your organization in adopting BIM? (N= 42)

	Extremely unsignificant	Somewhat unsignificant	Neither significant nor unsignificant	Significant	Extremely significant
1. Cost of hardware					
No.	5	12	9	13	3
Percentage	11.90	28.57	21.43	30.95	7.14
2- Cost of software					
No.	4	11	13	9	5
Percentage	9.52	26.19	30.95	21.43	11.90
3- Cost of training					
No.	7	4	8	16	7
Percentage	16.67	9.52	19.05	38.10	16.67
4- Lack of standards and protocols					
No.	2	9	10	11	10
Percentage	4.76	21.43	23.81	26.19	23.81
5- Lack of training					
No.	3	6	9	11	13
Percentage	7.14	14.29	21.43	26.19	30.95
6- Lack of house expertise					
No.	5	6	10	14	7
Percentage	11.90	14.29	23.81	33.33	16.67
7- Lack of collaboration					
No.	1	5	11	19	6
Percentage	2.38	11.90	26.19	45.24	14.29
8- Lack of university courses					
No.	2	5	9	13	13

Percentage	4.76	11.90	21.43	30.95	30.95
9- Low level of BIM understanding					
No.	2	3	11	16	10
Percentage	4.76	7.14	26.19	38.10	23.81
10- Lack of client demand					
No.	4	8	10	10	10
Percentage	9.52	19.05	23.81	23.81	23.81
11- No established contractual framework					
No.	2	4	7	19	10
Percentage	4.76	9.52	16.67	45.24	23.81
12- Differences in expertise					
No.	3	6	11	13	9
Percentage	7.14	14.29	26.19	30.95	21.43
13- Individuals do not see the benefit of using BIM					
No.	4	10	14	9	5
Percentage	9.52	23.81	33.33	21.43	11.90

Table 22 illustrates the 13 barriers to BIM adoption in Saudi Arabia as identified by the survey participants. The most important barriers (as per the respondents' responses for extremely significant barriers) are: (1) lack of training, (2) lack of university courses, (3) lack of standard protocols, (4) low level of BIM understanding, (5) lack of client demand, and (6)) non-established contractual framework.

4.5. Conclusion

In conclusion, this Chapter aimed to examine the level of experts understanding of the adopting of BIM in Saudi Arabia and to examine the main factors that causing the delay of adopting BIM in Saudi Arabia.

Tables 9, 10, and 11 show that 43% of the participants have not used BIM in the last 5 years for any project in Saudi Arabia. Moreover, 48% of the participants confirm that none of their projects has used BIM in Saudi Arabia. In addition, 38% of participants agreed that, at this time, they have no current plans to adopt BIM.

Meanwhile, 33% of the participants agreed that, in their view, adopting BIM will have a positive impact on the construction sector in the country and will help to increase the quality of work, increase the ease to work internationally, increase the amount profit, and achieving accuracy in design, construction, operation, and maintenance.

Since 74% of the participants are from Saudi Arabia, it shows that 52% of these participants have never been taught BIM at any course in university. Also, the results show 35% of the participants from Saudi Arabia agreed that BIM has been just mentioned in some classes. However, 6.5% of the participants who studied in Saudi Arabia do not know if they have studied BIM or not. Furthermore, the results show that there is a lack of training, a lack of university courses, a lack of standard protocols, a low level of BIM understanding, a lack of client demand, and a non-established contractual framework as barriers to adopting BIM in Saudi Arabia. This means the level of BIM awareness for experts in the engineering field in Saudi Arabia needs to be increased which will benefit the construction sector in the country. In addition, the results show BIM teaching level is significantly low in the country since most of the participants in this survey have studied in Saudi Arabia.

These results answered the first research question of this thesis (**RQ1:** *What is the current level of BIM adoption in Saudi Arabia*). The results show that:

1. The level of BIM adoption is low in the Saudi construction sector (as evidenced by Tables 9, 10, and 11).
2. From the expert’s views, BIM will have a positive impact and will develop the construction sector in Saudi Arabia (as evidenced by Tables 13 and 14).
3. Teaching BIM in Saudi universities is very low (as evidenced by Tables 19, 20, and 21).

In responses to these keys finding a set of recommendations can be derived to help the engineers to adopt BIM in the construction field:

1. The Saudi Arabian government should implement and update the standard and protocols to adopt BIM especially for the public and government projects.
2. Saudi Arabian universities should adopt BIM courses and demonstrated the benefit of BIM to the Saudi Arabian construction sector.
3. The barriers of adopting BIM in the country must be acknowledge by both the government and the private sector. A government backed plan must be put in place to overcome them. This should at a minimum include: (a) identification of the reasons for the delay in adopting BIM, (b) disseminate and demonstrate the benefit of BIM through the use of expert experience, especially those who studied in countries supporting BIM such as the UK and the USA and (c) encourage further adoption of BIM through the provision of funding, similar to strategies employed by the UK and other countries (Awwad, Shibani, & Ghostin, 2022; Smith, 2014).

The Saudi Arabian government has included in the 2030 vision of Saudi Arabia that both green buildings and sustainable design will be encouraged. BIM is a key enabler to help encourage and ease the adoption of sustainable design (Balabel & Alwetaishi, 2021). In the remainder of this thesis BIM will be used as a key underpinning tool to enable the achievement of more accessible sustainable design practice in Saudi Arabia.

Chapter 5: Saudi Arabian Awareness of Sustainable Construction

5.1. Introduction

This Chapter will present the results of the second research question of this thesis (**RQ2:** *What is the current awareness level of experts and the general public in Saudi Arabia of sustainable building design*). To do this, this Chapter will focus on the implementation of sustainable design principles in Saudi Arabia, through surveys of experts and the general public.

To address the problem of the implementation of sustainable design in Saudi Arabia, it is very important to examine the main factors causing the delay of achieving sustainability in Saudi Arabia. Moreover, how does the cultural issues have an impact on the design of buildings in Saudi Arabia. Thus, this Chapter, considers two questionnaires:

First questionnaire: These targeted experts and focused on the significant barriers to adoption sustainable design, the impact of government actions to increase adoption of sustainable design in Saudi Arabia, and the impact of culture on Saudi buildings.

Second questionnaire: This targeted the general public. It examined the current level of awareness of the general public of sustainable building design and their views on the impact of culture on buildings design in Saudi Arabia.

In this Chapter, Section 5.2 presents questionnaire design and development. Section 5.3 will describe results and analysis of the expert survey. Section 5.4 presents the results and analysis of the general public survey. Finally, Section 5.5 will conclude the Chapter.

5.2. Questionnaire design and development

As mentioned in Chapter 3, this study will use mixed methods for the research. For this research question a quantitative method will be utilised to design the questionnaire measures to be used in the evaluation procedure. The questionnaire contains several questions that have been pre-formulated and designed to extract data from experts in the engineering field. These responses will then be used to answer this research question. The purpose of this is to understand the level of the implementation of sustainable design principles in Saudi Arabia, as well as the main factors causing the delay in achieving sustainability in Saudi Arabia. Moreover, how do the cultural issues have an impact on the design of buildings in Saudi Arabia.

5.2.1. Experts survey questions

This questionnaire will ask the experts about their views of sustainable design. This will determine their awareness of the key principles of sustainable design and the barriers to adopting sustainable design in Saudi Arabia. Moreover, the questionnaire will ascertain expert's views on the government's role in requiring a more sustainable design of buildings in Saudi Arabia. These questions also will examine the impact of culture on the design of buildings. This is especially important as the current design priorities of houses in Saudi Arabia focus on achieving comfort features of living without paying significant consideration sustainable design (Alnaim & Noaime, 2022). For example, when Saudi Arabian houses are compared to the rest of the world, they tend to be larger with air conditioning units running continuously. The questions were extracted from previous studies and questionnaires that were relevant to this research. Thus, questions were drafted to cover all aspects that relate to the research question such as:

1- The reasons that caused the delay in adopting sustainable design (Q1).
2- The impact of government- sponsored technology (Q2).
3- The impact of culture on designing domestic buildings (Q7, Q8, Q12).
4- The awareness level of experts about the sustainable design (Q3, Q4, Q5, Q6).
5- Specific techniques which could improve the house design in Saudi Arabia (Q9, Q10, Q11).

Table 23 shows the experts survey questions.

No	Question	Question type
1	In your view, how significant are the following barriers for your organization not adopting the concept of sustainable design?	Closed
2	Have the government enacted technology to help both designers and households to reach more sustainable designs in Saudi Arabia?	Closed
3	Do you have experience of using the following sustainable design methods?	Closed
4	If you have not yet implemented any of the above, in your opinion, why have you not implemented them in the Saudi construction sector?	Closed
5	In what timescale could the specific measures from table 27 be adopted?	Closed

6	In the near future, do you think the Saudi Arabian construction sector will adopt and achieve sustainable design?	Closed
7	In your opinion does changing to an open plan design increase a home's sustainability (considering internal airflow)?	Closed
8	In your opinion is changing to an open plan design viable for increasing the sustainability of a home (considering internal airflow) in Saudi Arabia?	Closed
9	In your opinion, changing shape, and orientation of the building help to reach a sustainable design?	Closed
10	In your opinion, will changing colours, materials, and finishing of the building help improve its sustainability?	Closed
11	In your opinion, will changing the location and the size of the windows of a building help improve its sustainability?	Closed
12	In your opinion, do Saudi Arabian families prefer to homes built in comfort features more than ones built with more on consideration of sustainable design?	Closed

Table 23: Experts survey questions

5.2.2. General public survey questions

This questionnaire will ask the general public about their views of sustainable design the questionnaire will also confirm if the culture of the residents in Saudi Arabia have any impact and controlling the designing process of the buildings or not. This questionnaire will test the awareness of the Saudi Arabian General public by ascertaining their knowledge of the most prominent sustainable design technologies. This is important, because, in cases where there is a lack of public awareness of sustainable design, it will be because of people not understanding the words and the language used (Susilawati & Al Surf, 2011). The sustainable technologies studied will include green roofs, solar panels, double glazing, cross ventilation, wind catchers, thermal mass, and concrete with temperature control (using pre-installed cooling pipes). This list was elicited based on different studies in the area of sustainable design in Saudi Arabia (Al-Tamimi, 2017; Alattyih, Haider, & Boussabaine, 2019; Balabel & Alwetaishi, 2021). Table 24 shows the general public survey questions.

No	**Question**	**Question type**
1	Please provide your gender	Closed
2	Please provide your age?	Closed

3	What is your employment status?	Closed
4	What is your level of education?	Closed
5	How would you describe your house?	Open and closed
6	What is the age of your house?	Closed
7	How many people live in your house?	Closed
8	Do you have separate guest rooms for females and males?	Closed
9	How many guest rooms do you have for males in your property?	Closed
10	How many guest rooms do you have for females in your property?	Closed
11	Before this survey, have you heard about the following sustainability concepts: (Green roof, Solar panels, Double glazing, Cross ventilation, Wind catchers, Thermal mass, Concrete with quality temperature control (CCTC)).	Closed
12	If you were to move house in the future, which of these factors would be your primary consideration in choosing a new house?	Closed
13	If you were to change the windows in your house, would you considered using windows that would achieve more natural light and air circulation?	Closed
14	If you were to change your current house in your future, do you prefer to a design with internal walls or open plan?	Closed
15	If you were to change your current house in your future, do you prefer comfort features or focus more on consideration of sustainable design?	Closed
16	Would you consider buying a new house of a different size/shape/orientation to help contribute to a more sustainable environment?	Closed
17	Would you consider buying a new house with different colour/ materials/finishing to contribute to a more sustainable environment?	Closed

Table 24: General public survey questions

The online questionnaire distribution method has been used in this study (Stanton, 1998; Weible & Wallace, 1998). To reach participants across the country the survey was created using Microsoft forms.

5.2.3. Distribution and Methods of Analysis

The expert survey was distributed to a selection of experts in the engineering field, across Saudi Arabia (same sample as used in Chapter 4) the respondent selection and survey distribution for this survey is described in Section 4.2.1.

For the general public survey, this was distributed to general public from different genders, ages, and level of education across Saudi Arabia via the Internet (through social media such as LinkedIn, Twitter, and Facebook). The aim was to get between 150 to 250 responses from general public across Saudi Arabia. The actual number of the participants were 405 however, only 359 fully completed the survey. To assess the representativeness of this survey similar surveys in Saudi Arabia were analysed. There are several studies that utilised surveys with the same range of response. For example, "Environmental Sustainability Awareness in the Kingdom of Saudi Arabia" (Khan, Haque, & Khan, 2020). Other study had the same range of response "Level of Sustainability Awareness among University Students in the Eastern Province of Saudi Arabia" (Alsaati, El-Nakla, & El-Nakla, 2020). This gives us confidence that our survey is representative.

For this research question, the quantitative data collected from the surveys were exported into Excel and transferred to the Statistical Package for the Social Sciences (SPSS) Software. Later, all the data was coded and cleaned in preparation for the analysis stage. When the data was ready, it was analysed using descriptive and frequency statistics. This was especially helpful in explaining and summarising the data in a significant way, which helped the understanding of the results (Hinton & McMurray, 2017). The techniques used here are the same as those used in Chapter 4 – so are explained in more detail in Section 4.3.

5.3. Results and analysis: Expert Survey

This Section presents the results of expert's survey about the significant barriers to adopting sustainable design in Saudi Arabia. This Section will also present the government role of the sustainable design adoption, and the impact of the culture on the Saudi buildings. These will help to determine the problems and showing the impact of the culture and then try to resolve these barriers to achieve more sustainable design.

The survey results are presented in this Section in the following categories: (a) Barriers of adopting sustainable design in Saudi Arabia, (b) Government role of the sustainable design adoption, and (c) The impact of culture on Saudi buildings.

5.3.1. Barriers of adopting sustainable design in Saudi Arabia

This Section presents the results of the significant barriers to adopting and achieving sustainable design in Saudi Arabia. These barriers will help to determine the problem and then try to resolve these barriers to adopt sustainable design.

Table 25: In your view, how significant are the following barriers for your organization not adopting the concept of sustainable design? (N= 42)

	Extremely Unlikely	Somewhat Unlikely	Neither likely nor unlikely	Somewhat likely	Extremely likely
1- The quality of the design process					
No.	7	8	14	10	3
Percentage	16.67	19.05	33.33	23.81	7.14
2- Lack of university courses					
No.	1	4	9	19	9
Percentage	2.38	9.52	21.43	45.24	21.43
3- Lack of standards and protocols					
No.	1	8	11	12	10
Percentage	2.38	19.05	26.19	28.57	23.81
4-No client demands					
No.	1	10	10	13	8
Percentage	2.38	23.81	23.81	30.95	19.05
5-The background for the client					
No.	2	4	6	19	11
Percentage	4.76	9.52	14.29	45.24	26.19

Table 25 illustrates the barriers of adopting sustainable design in Saudi Arabia. The quality of the design process, lack of university courses, lack of standard and protocols, no client demands, and the background of the client are the questions that have been asked to the experts. Most of the participants seeing lack of the university courses and the background of the client are the most important barriers to achieve the sustainable design in Saudi Arabia.

5.3.2. Government role of the sustainable design adoption

This Section presents the results of questions asking about the government's role in encouraging the adoption of sustainable design in Saudi Arabia. The participants will answer if the government currently implementing and consider more sustainable design. Also, the survey will ask what have been implemented in the construction sector to achieve more sustainable design. Moreover, in case if sustainable design not implemented in the construction sector, what is the barriers for not implementing that the sustainable design. Also, this Section will present the experts expected time of adopting the sustainable design.

Table 26: Have the government implemented and considered technology to help both designers and households to reach more sustainable designs in Saudi Arabia? (N= 42)

Implement technology	Frequency	Percentage
Yes	16	38
No	9	22
Not known	17	40

Table 27: Do you have experience of using the following sustainable design methods (N= 42)

	Yes	No
1- Green Roofs		
No.	20	22
Percentage	48	52
2- Double glazing		
No.	29	13
Percentage	69	31
3- Cross ventilation		
No.	22	20
Percentage	52	48
4- Solar panels		
No.	28	14

Percentage	67	33
5- Wind catchers		
No.	12	30
Percentage	29	71
6- Thermal mass		
No.	15	27
Percentage	36	64
7- Concrete with quality temperature control (CCTC)		
No.	26	16
Percentage	62	38

Table 27 shows that experts in Saudi Arabia have answered this question with significant indication of not them not understanding some sustainable design methods. Moreover, the results show that the level of sustainable design awareness is still limited in Saudi Arabia and needs to be increased. Furthermore, the results show experts have never used these more advanced methods in the housing construction sector in Saudi Arabia.

Table 28: If you have not yet implemented any of the above, in your opinion, why have not implemented yet them in the Saudi construction sector? (N= 42)

	Yes	**No**
1- Political Blockers		
No.	16	26
Percentage	38	62
2- Technical Blockers		
No.	27	15
Percentage	64	36
3- Commercial Blockers		
No.	31	11
Percentage	74	26
4- Cultural Objections		
No.	25	17
Percentage	60	40

In Table 28 the participants were given the option to explain more details but unfortunately, no comment was received.

Table 29: In what timescale could the specific measures from table 27 be adopted? (N= 42)

Timescale	Frequency	Percentage
Less than 5 years	17	40
From 5 to 10 years	20	48
More than 20 years	5	12

Table 30: In the near future, do you think Saudi construction sector will adopt and achieve the sustainable design? (N= 42)

Adopt sustainable design	Frequency	Percentage
Yes	29	69
No	10	24
Not known	3	7

In conclusion, from the Tables, 38% of the participants think that the Saudi Arabian government has adopted and considered technology to assist both designers and homeowners in achieving more sustainable design. Other participants may not agree with this or are not certain if it is true (Table 26). Moreover, 69% of survey respondents is aware of double glazing and solar panels as a sustainable design method (Table 27). 74% of the participants considered commercial barriers are the most significant factor that have an impact to achieve a more sustainable design in the Saudi construction sector (Table 28). 48% of the participants believe that specific policies might be implemented by the Saudi government to achieve more sustainable design in the next 5 to 10 years (Table 29).

5.3.3. The impact of culture on Saudi buildings

This Section presents the results of the questions designed to understand the impact of culture on Saudi buildings. It will show if the experts prefer to change the design to an open plan considering the culture of the residents or not. Also, it will show the experts opinion if the size, shape, and orientation of the building will help to reach a sustainable design or not. Moreover, Table 29 will show the results of the expert's opinion if changing the place and the size of the window will help to reach a sustainable design or not. Finally, this Section presents if Saudi families prefer to build with comfort features more than build with a consideration of sustainability.

Moreover, people in Saudi Arabia do not value the importance of implementing sustainable design as much as the implementation of comfort features such as air conditioning systems, and heating systems without any importance being places on trying to decrease the use of these features or increasing their sustainability (Alnaim & Noaime, 2022). An example of this is that, with an open plan design, the using of air conditioning systems and heating systems will be less due to there being fewer internal boundaries, however, residents wish to keep privacy inside the home as much as possible. So, residents are reluctant to adopt it (Alnaim & Noaime, 2022).

Table 31: In your opinion does changing to an open plan design increase a home's sustainability (considering internal airflow)? (N= 42)

Design change	Frequency	Percentage
Yes	30	71
No	7	17
Not known	5	12

Table 32: In your opinion is changing to an open plan design viable for increasing the sustainability of a home (considering internal airflow) in Saudi Arabia? (N= 42)

Design change in KSA	Frequency	Percentage
Yes	26	62
No	11	26
Not known	5	12

From Table 31, it can be seen that 71% of participants believe that changing the design to open plan will help to provide internal airflow in the house, thus increasing sustainability by reducing the need for energy expenditure on heating and cooling. Secondly, the same question was asked but with the consideration of the resident's culture, it shows that the percentage has been reduced from 71% to became 62% (Table 32). This indicates that, in this particular case there is an impact of culture on the perceived suitability of this intervention by the experts.

Table 33: In your opinion, changing shape, and orientation of the building help to reach a sustainable design? (N= 42)

changing size, shape, and orientation	Frequency	Percentage
Yes	32	76
No	6	14
Not known	4	10

Table 34: In your opinion, changing colours, materials, and finishing of the building help to reach a sustainable design? (N= 42)

changing colours, materials, and finishing	Frequency	Percentage
Yes	32	76
No	6	14
Not known	4	10

Table 35: In your opinion, changing the place and the size of the window of the building help to reach a sustainable design? (N= 42)

Changing window shape and size	Frequency	Percentage
Yes	30	71
No	10	24
Not known	2	5

Table 36: In your opinion, do most of the Saudi families prefer to build with comfort features more than build with sustainability considerations? (N= 42)

Implement technology	Frequency	Percentage
Yes	26	62
No	12	28
Not known	4	10

From the Tables, according to 71% of the survey respondents, internal airflow within buildings will improve if internal boundaries are replaced with open plans (Table 31). Meanwhile, the percentage have been reduced to 62% in the same question but the cultural was considered (Table 32). Also, 62% of the participants believe that most of the Saudi families prefer to build with comfort features more than with a focus on sustainability considerations (Table 36). That means the cultural have a huge impact on the Saudi buildings. Moreover, the culture of the Kingdom of Saudi Arabia differs from that of many other countries. For example, the use of spatial boundaries is the most important design factor for residents, as these are the primary means of achieving privacy (Abu-Gaueh, 1995). Specifically, architects in Saudi Arabia create physical boundaries through the use of walls, curtains, and other forms of barriers (Abu-Gaueh, 1995).

In conclusion, this questionnaire has shown that only 38% of the experts believe that government has adopted technology to help both designers and households to achieve more sustainable design in Saudi Arabia. Furthermore, only 40% of the experts either do not believe or are not sure if implementing technologies will help both designers and households to achieve more sustainable designs in Saudi Arabia (Table 26).

It has also been found that commercial barriers are the most important factor (74%) as well as and cultural objections (60%) that prevents implementation of sustainable design in Saudi construction sector (Table 28).

In terms of cultural objections, it was found that the level of support for changing to open plan building design fell from 71% to 62% when privacy concerns were considered. (Tables 31 and 32).

Also, Tables 33 and 34 show that 76% of the participants believe that will help to reach a sustainable design in case changing size, shape, orientation, colours, materials, and finishing of the buildings in Saudi Arabia. Furthermore, 62% of the experts believe that most of the Saudi families prefer to build with comfort features as opposed to building with consideration for sustainability (Tables 36). This is important, because according to a study by Alnaim and Noaime (2022), if the residents prioritize comfort features over sustainability this will hinder the achievement of more sustainable designs. This is because many desired comfort features of a property such as shading and windows placement will restrict the house shape and size (Alnaim & Noaime, 2022).

Also, comparing Saudi Arabian houses to the rest of the world, they tend to be relatively large homes with air conditioning units running continuously. Thus, there is an urgent need to improve the efficiency of energy usage in Saudi buildings through the application of sustainable architectural principles (H. M. Taleb & Sharples, 2011).

5.4. Results and analysis: General Public Survey

This questionnaire is focused on sustainable construction adoption in Saudi Arabia. The questionnaire was sent by e-mail to members of the general population in the Saudi Arabia. 405 participants agreed to take part in this project, only 359 participants completed the whole questionnaire.

This questionnaire examines the current level of general public people awareness of sustainable building design and the impact of culture on buildings design in Saudi Arabia.

5.4.1. Baseline characteristics

Table 37: Baseline characteristics of the whole studied cohort (N= 359)

	Frequency	Percentage
Age Categories		
Do not wish to say.	4	1
From 18 to 50	298	83
From 51 to 61	47	13
More than 61	10	3
Gender		
Do not wish to say.	2	0.5
Male	279	77.5
Female	78	22
Education		
High school	62	17
Diploma	24	7
Bachelor’s degree or higher	273	76
Employment		
Employed	221	62
Self-employed	13	3
Student	61	17
Retired	35	10
Not employed	29	8

5.4.2. Participants Homes

Table 38: Home characteristics of the whole studied cohort (N= 359)

	Frequency	**Percentage**
House Description		
Flat	120	33
One-floor house	64	18
Two-floor house	119	33
Villa duplex	49	14
Others	7	2
House Age		
Less than 10 years	187	52
From 11 to 20 years	84	23
More than 20 years	65	18
Not sure	23	7
People in house		
From 1 to 3	70	19
From 4 to 7	223	62
From 8 to 11	54	15
From 12 to 15	9	3
More than 20	3	1
Presence of separate guest rooms		
Yes	306	85
No	53	15
Presence of male guest rooms		
One room	202	56
Two rooms	122	34
More than two rooms	35	10
Presence of female guest rooms		
One room	243	68
Two rooms	90	25
More than two rooms	26	7

5.4.3. Participants' knowledge about new construction techniques

Table 39: Degree of knowledge regarding new construction techniques (N= 359)

	Frequency	Percentage
Knowledge about Green Roofs		
Yes	137	38
No	222	62
Knowledge about Solar Panels		
Yes	310	86
No	49	14
Knowledge about Double Glaze windows		
Yes	180	50.1
No	179	49.8
Knowledge about Cross Ventilation		
Yes	88	24
No	271	76
Knowledge about Wind Catchers		
Yes	62	17
No	297	83
Knowledge about Thermal Mass		
Yes	81	23
No	278	77
Knowledge about Concrete with quality temperature control		
Yes	77	21
No	282	79

5.4.4. Moving House

Table 40: Comparison between participants regarding factors for moving house (N= 359)

	Frequency	Percentage
Most important factor towards choosing a house		
Privacy	99	28
Cultural Objections	29	8
Directions the building faces, location of entrance and exit, and the size of the site.	145	40
Cost of finishing	86	24
choice of building design		
Internal Walls	193	54
Open Plan	166	46
What is more important when conducting renovations		
Comfort features	197	55
Focus more on consideration of sustainable design	80	22.2
Not considering renovations	82	22.8
Considering changing colours, materials, and finishing to increase sustainability		
Yes	229	64
No	65	18
Not considering renovations	65	18
Considering changing shape, and orientation to increase sustainability		
Yes	206	57
No	78	22
Not considering renovations	75	21

Table 40 also shows that, when considering a change to their house, 193 participants (54%) would opt for a design with internal walls, while 166 participants (46%) would opt for open plan. In addition, the Table shows that, when considering a change to their house, 197 participants (55%) would prefer comfort features more than purely focusing more on consideration of sustainable design.

Importantly, the table shows that, many participants would opt to consider contributing to a more sustainable environment. Specifically, 229 participants (64%) considered moving to a property that made more use of sustainable materials, additionally 206 participants (57%) electing for shape and orientation of a home that increased the sustainability of property.

However, 38% of the participants knew about green roof technology, 86% of the participants knew about solar panels, and half of the participants 50% knew about double glazed windows. Meanwhile, 76% of participants did not know about cross ventilation, 83% of the participants did not know about wind catchers, and 77% of the participants did not know about thermal mass as new construction techniques. The conclusion of this is that the level of awareness of sustainable design is low and it must be increased for the general public. However, the participants have been given the option to select multiple answers.

5.5. Conclusion

In conclusion, this Chapter has examined the level of awareness of sustainable design for both experts and the general public in Saudi Arabia. It also examined the main factors causing the delay in achieving sustainability in Saudi Arabia and how cultural issues have an impact on the design of buildings in Saudi Arabia. It has done this via two questionnaires, one targeted at experts, one at members of the general public.

The key findings of these are that only 38% of the participants think that the Saudi Arabian government has adopted and deployed technology to assist both designers and homeowners in achieving more sustainable design. The results showed that 84% of the expert participants believe that specific policies might be implemented by the government to achieve a more sustainable design in the next 5 to 10 years.

To test the current awareness of the general public respondents about sustainable design technologies we found that only 38% know about green roofs, 24% know about cross ventilation, 17% know about wind catchers, 23% know about thermal mass, and 21% know about concrete with quality temperature control (Table 33). Furthermore, we found that only between 29% and 71% of expert respondents are aware of the use of the sustainable design techniques in Saudi Arabia. That give us an idea that these techniques are rare for the experts (Table 21).

In addition, the results also show that culture has a significant impact on building design in Saudi Arabia. Most of the expert's participants believe that Saudi Arabian families prefer to consider comfort features as opposed to sustainability. Moreover, 71% of the expert survey respondents responded internal airflow will improve within buildings if internal boundaries are replaced with open plans. However, this percentage decreased to 62% when asked to consider if this would be culturally acceptable.

Table 33 showed that the only commonly used sustainable technology that many participants know about is solar panels. This shows that the level of sustainable design awareness for the general public in Saudi Arabia is low.

The result presented in this Chapter have answered the second research question of this thesis (RQ2: What is the current awareness level of experts and the general public in Saudi Arabia of sustainable building design). To answer this question the results, show that:

1. The level of sustainable design awareness for general public in Saudi Arabia are low as shown by Table 33 where the participants have a low awareness of the techniques of sustainable design.
2. The available support from the government must increase to help designers and households as shown by Tables 26 and 28 to achieve more sustainable building design in Saudi Arabia.
3. The expert participants believe that most Saudi families choose to build with comfort features as opposed to building with consideration for sustainability.
4. The questionnaire showed that culture has a huge impact on the design of Saudi buildings.

In response to these key findings a set of recommendations can be derived to help both the engineers and the general public adopt more sustainable design in the construction field:

1. The Saudi Arabian government should consider requiring the adoption technologies such as energy simulation as part of regulatory processes to require both public and private construction sectors to reach a more sustainable design.
2. The government must encourage and provide materials to enable families to increase their level of awareness of the importance of sustainable design.
3. Saudi Arabian universities should adopt sustainability courses and demonstrate the benefit of sustainable design to the Saudi Arabian construction sector.
4. The Saudi Arabian government and industry experts should collaborate together to develop and adopt a framework for sustainability in domestic and non-domestic construction projects. This will support government, construction professionals and building owners/operators in achieve more sustainable building design, one of the key Saudi Arabia 2030 vision goals (Balabel & Alwetaishi, 2021).

In the remainder of the thesis, the key findings of this Chapter: (a) the low level of sustainable design awareness for general public in Saudi Arabia, (b) there is a support to help designers and households to achieve more sustainable building design in Saudi Arabia, (c) the culture of Saudi Arabia has a huge impact on the design of the Saudi houses and most of the Saudi families would prefer comfort features as opposed to incorporating sustainable design features. These findings, along with recommendations proposed will feed into the development of a framework to help construction industry professionals and domestic property owners increase the level of adoption of sustainable design in their buildings considering different factors such as climate, culture, and economy.

Chapter 6: Understanding the impact of privacy on achieving sustainable design in Saudi Arabia

6.1. Introduction

This Chapter will answer the third research question (**<u>RQ3:</u>** *What are the suitable requirements for achieving sustainable domestic building design of housing in Saudi Arabia and how could privacy factors impinge on their adoption*). This will be done through a systematic literature review. This literature review will focus on identifying the important requirements for achieving sustainable houses design in Saudi Arabia.

The literature review summarised many studies and came up with keywords which were analysed critically and classified in this literature review into two areas: (1) Sustainable design (30 studies), and (2) Culture around the world and focusing on Saudi Arabia (10 studies). These keywords were selected since it was commonly used in the available research in this area.

The aim of conducting a review in this area is to understand theories the impact of culture on sustainable design and general, and then, in more detail, understand the impact on culture in the adoption of sustainable design in Saudi Arabian buildings. Finally, this Chapter will identify the requirements for achieving more sustainable designs with more consideration of resident's culture in Saudi Arabia. This Chapter will examine the following topics:

1. The effect and importance of sustainable design on human comfort,
2. The effect and importance of sustainable design to energy consumption,
3. Important requirements for achieving a sustainable house design in Saudi Arabia,
4. Possible culture factors that could impinge upon sustainable design,
5. The current sustainability of Saudi Arabian buildings.

This literature review is combining the findings from studies about the above points, and it will reveal how Saudi culture has influenced the adoption of sustainable design. This will make it possible to understand the main influences that will affect the adoption of sustainable design.

In this Chapter, Section 6.2 presents the effect and importance of sustainable design on human comfort. Section 6.3 will describe the effect and importance of sustainable design to energy consumption. Section 6.4 will describe important requirements for achieving a sustainable building design. Section 6.5 presents possible culture factors that could impinge upon sustainable design. Section 6.6 will describe the current sustainability of Saudi Arabian buildings. Section 6.7 will conclude this Chapter.

6.2. The effect and importance of sustainable design on human comfort

Across the world, the industrial revolution created an uncontrolled and unsustainable environment because of the rapid and fast growth of urbanization in towns (Özer, Yardımlı, & Shahriary, 2020). Also, increasing urbanization in our countries is threatening life on Earth due to increased energy consumption and environmental pollution, both of which will increase the global warming problems (Özer et al., 2020). This unsustainable environment has increased greenhouse gas emissions, which has led to continuous climate change around the world (Özer et al., 2020). A significant source of these emissions comes from the generation and the use of energy (Özer et al., 2020).

Humans have begun to implement measures to decrease environmental pollution and energy waste using both new technologies and improved building design. Sustainability is affecting in a good way for the environment, social and communities which provide an improvement in energy conservation, human life comfort as well as the country's economic growth (Tharim & Samad, 2016). The environmental advantages include the conservation, protection and rebuilding of biodiversity and natural resources. While the economic advantages include a reduction in the cost of the construction lifecycle and an increase in profit and rental value (Tharim & Samad, 2016). Whereas in terms of social advantages, the implementation of green buildings can improve the comfort and health of the occupants and therefore improve the overall quality of life. Additional advantages of the green building include improvement of the indoor environmental quality, indoor thermal comfort, and resident’s productivity (Tharim & Samad, 2016).

One common strategy is to improve the indoor environmental quality of life with a proper choice of sustainable materials and green designs that are suitable and comfortable for residents, considering the climate (Akadiri, Chinyio, & Olomolaiye, 2012; Tharim & Samad, 2016; Zakaria, 2007). Therefore, a successful design of building an enclosure for a building, according to Tharim and Samad, might guarantee the accomplishment of a basic building enclosure for the external and internal of the building which contains the air control, acoustics, sustainable structural, heat and moisture control, and indoor environmental quality which meets the requirement of a building to be certified by sustainable rating standard as a green building (Akadiri et al., 2012; Tharim & Samad, 2016).

According to Garnys (2007), the definition of indoor environment quality is "The measurement of the key parameters affecting the comfort and well-being of occupants elements to provide an environment that is physically and psychologically healthy for its occupants"

(Garnys, 2007). The most popular and important environmental factors that determine indoor environmental quality are the quality of indoor air, thermal comfort, visual comfort, and acoustic comfort. The indoor environment was found to influence the productivity, comfort, and the health of the building residents (Akadiri et al., 2012). Few studies showed that there is a connection between indoor environment quality and residents' comfort and work performance which includes an improvement in the amount of work done, improved work performance, developed worker retention, decreased sick day and absenteeism (Tharim & Samad, 2016; Zakaria, 2007).

People in the developed world spend approximately 75-90% of their time inside buildings, this means the quality of the indoor environment is very important for people's health and happiness (Tharim & Samad, 2016). It is necessary for residents that they feel very comfortable with the indoor environment in the buildings. However, occupancy comfort is relating to the type of building activity that residents are engaged in (Akadiri et al., 2012).

The following subsection 6.6.1 describes the concept of a green building. This is considered one of the main concepts of sustainability incorporating structures and processes that help achieve more sustainable design (Awadh, 2017). Subsection 6.2.2 will then describe the building envelope and how it can affect the building.

6.2.1. The green building concepts

The Green building concept is one of the key concepts developed to advance the mitigation of the significant impacts of the building stock on society, the environment, and the economy (Zuo & Zhao, 2014). The green building is expanding, especially in Europe and the USA (Nelson, Rakau, & Dörrenberg, 2010). Buildings have a significant and continuously rising influence on the environment as it is handling a large portion of carbon emissions and use a considerable number of resources and energy (Tharim & Samad, 2016). Around the world, buildings are responsible for about 35% of global energy consumption and 38% of total CO2 emissions (Martínez-Camacho, Saavedra-Alamillas, & de los Ángeles Ortega-Martínez, 2023). Furthermore, now 55% of the world's population lives in urban areas and by 2050 this will increase to 68%. So the problem of sustainability application in the construction sector becomes a subject of the highest importance (Martínez-Camacho et al., 2023). The Green Building Movement has begun to decrease these impacts and improve the building construction process by supporting the use of more environmentally friendly and recycled materials, the appropriate material selection process, the implementation of sustainable techniques to protect natural resources and decrease waste consumption, which will provide a better indoor environmental quality of life (Tharim & Samad, 2016). Moreover, Green buildings designed to develop our design, construction, and landscaping practices, cost less, and give a healthy lifestyle. It also means protecting natural resources and improving the built environment which may help people, communities, and ecosystems to grow and live together in prosperity (Tharim & Samad, 2016).

Green construction is aiming to decrease the environmental influence, improve the safety, health, and productivity of a building resident (Gambatese, Rajendran, & Behm, 2007; Jami, Karade, & Singh, 2019). The main aims of the green construction are to create buildings that are sustainable with large attention focuses on the comfort and sustainability of the users and end-use of the green building. Hence, proper selection of sustainable materials is necessary for creating a green and sustainable building which includes the life cycle of the environmental impact, cost, energy saved, material, and waste management. Materials are a significant phase of sustainable results and to the extent, feasible should be selected based on the needs of the design. Therefore, sustainable materials must not only be concentrating on the material properties itself but also focus on the combination with the green construction technique (Tharim & Samad, 2016).

Over the past years, the standard of sustainable building for green buildings has been developed globally to improve the construction of green buildings in the industry sector. The establishment of green building certification systems one of the most prominent and systematic approaches to promoting sustainability which have many efforts in both construction and green building sector (Liang et al., 2014). The change from the traditional practices to sustainable design in the construction sector will need more action on many aspects and support from the leading organization (Hanna, 2011). Around the world, there are many building certifications tools to evaluate the environmental performance of the building such as BREEAM in the United Kingdom, LEED in the USA, and Green Star in Australia are assessments. The advantages of these tools are they can lead the improvement of the construction sector towards best practice and raising the quality of building for both occupants and tenants (Tharim & Samad, 2016).

In conclusion, The Green Building movement is improving the building construction process by supporting the usage of more environmentally friendly and recycled materials and implementing sustainable technique to protect natural resources and decrease waste consumption, which will improve the indoor environment of buildings (Tharim & Samad, 2016). Moreover, green construction is seeking to reduce the environmental impact, increase the safety, health, and productivity of a building resident (Gambatese et al., 2007).

Furthermore, around the world, there are many building certifications tools that calculate the environmental performance of the building such as BREEAM in the United Kingdom, LEED in the USA. However, changing from the traditional methods to sustainable design in the construction sector will need more action on many phases and support from the leading organization (Hanna, 2011).

6.2.2. Building envelope

Straube and Burnett (2005) have defined the building cover as a part of the building which separates between the indoor environment and the outdoor environment (Straube & Burnett, 2005). With the building envelope, there are many outdoor elements such as the external walls, the foundation of the building, the windows, doors, as well as roof systems. Therefore, between the internal of the building and the external of the building elements which serve as a thermal barrier plays a significant role to determine the amount of energy to maintain the comfort inside the building (Straube & Burnett, 2005). Therefore, every building envelope must have a high resistance to outside temperature and climate to improve the internal comfort of the building at the most satisfying level. The building envelope usually involves physical building barriers that contribute to the impact the quality of the indoor environment, including energy efficiency, comfort as well as air quality (Straube & Burnett, 2005). So, different popular names used apart from building enclosure are building façade, building skin as well as building exterior (Straube & Burnett, 2005).

The facade of the building is an environmental separator consisting of many layers between the residents of the building and the external environment in all climatic conditions, which usually consisting of two basic parts: walls and windows. Different types of facade systems are available, for example, steel and metal cladding, precast concrete panels, and the most widely utilised glass curtain walling (Tharim & Samad, 2016). The proper choice of materials can be complicated because the energy properties of the entire wall are influenced by both design and materials. The choice of design and materials will significantly influence the thermal properties of the building as the thermal mass of the building is controlled by the materials (Tharim & Samad, 2016).

Today non-residential building facade is usually highly glazed with a large area of glass for aesthetic appearance and prestige. Despite the beautiful and prestigious appearance of the façade area, a large amount of solar radiation passes through the glass façade to the inside of the building, which may cause discomfort to the resident of the building, especially in the tropical climate, where the heat is trapped inside the building (Tharim & Samad, 2016). Shu and Huang (2011) pointed out that in buildings with glazed perimeter zones, solar radiation and window performance have a significant impact on resident's thermal comfort (Shu, Huang, Wu, Dong, & Burdette, 2011). Therefore, in the tropical climate, it is more appropriate to construct an extremely insulated mechanical ventilation building (air-conditioned buildings) which is more suitable for controlling heat fluxes through the daytime with high external temperatures, as one of the key objectives of the building facade design is to reduce the building's energy consumption by managing and optimizing heat or heat loss (Tharim & Samad, 2016).

Many researchers believed that the design of the building facade, such as the orientation and shape of the building as well as the material types of the building envelope, will affect positively on buildings and reduce the energy consumption of the building. Moreover, selecting best facade which will decrease the radiation of the sun inside the building facade percentage areas coverage and will improve indoor environmental quality (Tharim & Samad, 2016).

6.3. The effect and importance of sustainable design to energy consumption

Previous researchers have recommended that the construction sector needs to change from being reactive to being more proactive and encourage sustainable practices (Babalola, Ibem, & Ezema, 2019; Bal, Bryde, Fearon, & Ochieng, 2013). The energy performance in buildings is affected by multiple factors, such as weather conditions, building structure, the operation of sub-level elements like lighting and air conditioning systems, and the behaviour of the residents (Zhao & Magoulès, 2012). This complex situation makes it very challenging to accurately implement the prediction of the energy consumption of buildings (Zhao & Magoulès, 2012). Recently, there has been significant interest regarding the degradation of the environment affected by the consumption of natural resources, global warming, air pollution, and the lack of attention to the earth's ecosystem (Al-Yami & Price, 2006). The principles of sustainable construction have consequently been generally adopted in many countries around the world.

The establishment of "Sustainable Cities and Communities" is one of the most significant themes for Sustainable Development Goals, and it has repeatedly been stated that cutting global energy consumption is essential to achieving this (Balali, Yunusa-Kaltungo, & Edwards, 2023). Regardless of where they are in the globe, people have a set of basic needs one of which is housing (Balali et al., 2023). Structures play important roles in people's lives since they serve as homes for the present and future populations (Balali et al., 2023). Important structures include residential, educational, commercial, industrial, medical, military, and religious structures. Despite the vital responsibilities that buildings play, countries have long struggled with how much energy these buildings consume(Balali et al., 2023).

In recent years, Saudi Arabia has experienced essential economic growth due to strong oil prices and continuing improvements in the country. This also has been impelled by significant government construction projects and improvement of infrastructure and building projects including hospitals, schools, private construction, accommodation, as well as rapidly growing tourism sectors (Al-Yami & Price, 2006).

However, the energy problem is a major feature of a certain sustainable building (Alrashed & Asif, 2014). If the desired targets for global greenhouse gas (GHG) emissions reduction achieved, emissions from the building sector require to be tackled with much greater importance than the past efforts by developing sustainable-energy building practices. The sustainable energy buildings can be performed within three main principles including renewable energy technologies, energy-efficiency measures, and sustainable design solutions (Alrashed & Asif, 2014). The Saudi construction sector is one of the largest and fastest-growing markets in Arabic countries and the largest one in the Gulf Cooperation Council (GCC) countries (Alrashed & Asif, 2014). Figure 3 shows that buildings account of approximately half the amount of the Saudi construction industry. This sector has excellent potential for an increase as the demand for residential, commercial, and industrial buildings continue to grow (Alrashed & Asif, 2014).

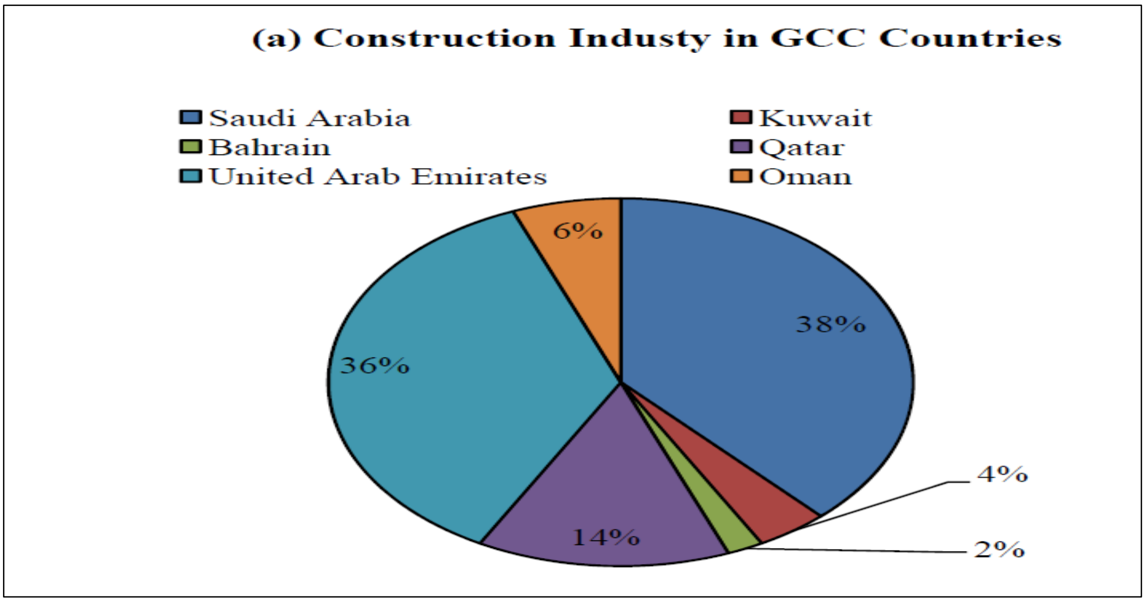


Figure 3: Construction (Alrashed and Asif 2014)

However, the traditional buildings in Saudi Arabia are constructed from natural materials that were prepared locally such as stone, limestone, wood, and coral (Alrashed & Asif, 2014). Usually, buildings in Saudi Arabia have thicker walls and roofs for better thermal insulation. Many vernacular architecture techniques such as wind catchers, mashrabiyas, and fountains were used for cooling and daylighting the building. The vernacular architecture leads to an emphasis on the utilisation of local building resources, and the use of passive and low-energy strategies that could begin to minimise the need for air-conditioning and lighting requirements (Alrashed & Asif, 2014).

On the other hand, the present need for economic buildings in the Saudi Public Sector needs to be linked with the need to use Saudi Arabia natural resources efficiently (Al-Yami & Price, 2006). Besides, extreme economic growth in the countries of the Arabian Peninsula has created a notable imbalance of water resources and demand. Furthermore, sustainable construction seems not to have been sufficiently considered in Saudi Arabia and there is a lack of knowledge amongst key decision-makers in Saudi Arabia Public Sector. Based on the above, more extensive consideration requires to be given to sustainability by the Saudi Arabia construction industry (Al-Yami & Price, 2006).

In conclusion, weather conditions, building structure, the operation of sub-level elements like lighting and air conditioning systems, and the behaviour of the residents has an impact on the energy performance in buildings (Zhao & Magoulès, 2012).

Recently, seven European countries have adopted a working definition of a low-energy house (Aldossary et al., 2017). These definitions are most often applied to both new houses and existing houses and it could be used and applied for residential buildings in the country. The energy reduction required to be classified as meeting these definitions ranges from 30% to 50%, depending on the special condition of the design of the building (Aldossary et al., 2017).

In recent years, Saudi Arabia has experienced increased economic growth due to strong oil prices and continuing improvements in the country such as the construction sector (Al-Yami & Price, 2006; Mahmood et al., 2019). This growth has also has been stimulated by government construction projects and an increase of infrastructure and building projects such as hospitals and schools (Al-Yami & Price, 2006; Mahmood et al., 2019).

6.4. Important requirements for implementing sustainable house design in Saudi Arabia

Over the last decade, Building Research Establishment Environmental Assessment Method (BREEAM) and Leadership in Energy and Environmental Design (LEED) have tried to make their assessment tools compatible with conditions of different regions around the world even the Middle East. In the United Kingdom, BREEAM is leading the list of sustainability assessments; between 2013 and 2017, more than 10,800 certified assessments were issued in both Design and Post Construction phases (María M Serrano-Baena, Triviño-Tarradas, Ruiz-Díaz, & Hidalgo Fernández, 2020). The method was started in the United Kingdom in 1990 by the Building Research Establishment (BRE), originally intended to focus mainly on environmental features, then it highlighted economic and social aspects during the last decade. This assessment has been applied over 77 countries (María M Serrano-Baena et al., 2020). Moreover, BREEAM considers many categories to estimate sustainable value, including energy, land use and environment, health and wellbeing, management, transport, pollution and innovation, water, materials, and waste. Each of those categories is divided within a range of assessment issues with its aims and targets (María M Serrano-Baena et al., 2020). BREEAM is continually updated to guarantee that it reaches the sustainability requirements of buildings and it used for public and private projects that relevant to residential and commercial buildings. In some cases, it is a mandatory requirement to comply with specific planning conditions or regulations, especially for public projects. In different cases, it is used for recognition due to its international prestige and is highly valued when it comes to showing the carbon emissions of commercial buildings (María M Serrano-Baena et al., 2020).

However, in Saudi Arabia, it has been found that they have not been able to completely incorporate social and cultural elements into the sustainability assessment criteria (Raji Banani et al., 2016). For example, BREEAM delivered a BREEAM Gulf/Middle East assessment system, which was completely influenced by BREEAM-UK, which estimated buildings based in the United Kingdom (Alyami & Rezgui, 2012).

Other studies have shown the importance of considering social, economic, and cultural factors for the development of domestic rating methods in developing countries (Mao, Lu, & Li, 2009; Sinou & Kyvelou, 2006). Moreover, the importance of considering these elements in the environmental and sustainable assessment tools have also been addressed in several studies in the field of sustainability (Raji Banani et al., 2016).

Some Arab countries in the Middle East have started domestic building assessment tools. For instance, Estidama has begun in the United Arab Emirates (UAE) also the Qatar Sustainability Assessment System (QSAS) is used in Qatar (Raji Banani et al., 2016). It would therefore be helpful for Saudi Arabia to develop its assessment method, which should ideally consider many factors, such as social and economic contexts and vernacular architecture and cultural (Alyami & Rezgui, 2012).

Recently, the Saudi Green Building Council (SGBC) has used the US Green Building Council's LEED criteria as its official assessment tool for estimating building performance. However, currently, there are no assessment tools that cover the economic, social, and cultural phases of the assessment criteria (Raji Banani et al., 2016).

In terms of using green building concepts and tools in Saudi Arabia, most attention has been to private and residential buildings (Raji Banani et al., 2016). However, new government policies supporting international investment to guarantee the development of both private and national industries which have stimulated commercial construction in the Saudi construction field (Raji Banani et al., 2016).

As a result, there is a rising demand for non-residential buildings across the country. To guarantee success in achieving the concept of sustainability in the construction field. Architects, engineers, environmental engineers, and clients should have a much Saudi understanding of the connection between the different phases of sustainability in non-residential construction projects (Raji Banani et al., 2016).

6.5. Possible culture factors that could impinge upon sustainable design

In academic literature, the home environment is conceptualized in many ways. Some designers consider a home in terms of the rich interdependent psychological meaning for the residents (Stafford, 2011). Different designers advise that a home represents a typical social communication that describes an interpersonal creative expression and style, also, describes the social network and social class of its homeowner (Zulkeplee Othman et al., 2015). According to a study by Heathcote (2012), the interior decoration or the design of the furniture in the home shows the lifestyle and goals, as well as the personal life journey of the homeowner (Heathcote, 2012). Furthermore, the same study identified some architectural elements for example windows, doors, and bedrooms as features that are functional and useful but also exert much impact on human domestic behaviours and actions inside the house environment. Despite the size, the number of rooms, style, or real estate value, each house provides its residents or owners with objects that help both their social and personal needs (Heathcote, 2012).

Culture has a clear impact on how buildings are constructed (Vatan, 2017). When humans are engaged, even when the equipment and materials are the same, cultural differences and process preferences result in diversity, which is known as architectural innovation (Vatan, 2017). Residential buildings are utilised as a sample because as an architectural product, they are most sensitive to being changed under cultural impact. Different cultural groups require different residential typologies, space designs and visual expressions (Zejnilovic & Husukic, 2018).

Specifically, in the Middle East, the architectural styles and materials utilised in houses are different from houses in other predominantly Muslim countries, for instance, Malaysia, because of climate factors and the locally available materials in the country. Despite these factors, houses in predominantly Muslim countries tend to share a "humility in design" approach, such that houses are built with more sustainable and economical materials that additionally give thermal comfort inside the building (Zulkeplee Othman et al., 2015). However, Muslims who live in different countries are also affected by cultural factors that operate within their home country (Zulkeplee Othman et al., 2015). These factors have led to the shaping of architectural styles and usage of space within Muslim houses in different forms (Zulkeplee Othman et al., 2015).

Saudi Arabian culture is characterized by the teachings of Islam, represented by the Hadith and the Qur'an. Islam is a broad lifestyle in which every human activity, i.e. business, education, social, and science are driven and administered by God (Moritz, 2013). Saudi Arabian culture has been described as the most conservative culture in the world (Nordin, 2018). The religion of Islam is followed by 100 percent of the native population in Saudi Arabia, and Islam governs all aspects of Saudi Arabian life (Nordin, 2018). The Qur'an and the Hadith of the Prophet Muhammad (PBUH) are followed and applied on a regular basis (Sulandari et al., 2017). Islam is reflected in the structure of the Saudi Arabian or Muslim houses because of the cultural requirement for separation between male and female members of the family (Sulandari et al., 2017).

The culture of the Kingdom of Saudi Arabia differs from many other countries. For example, the usage of spatial walls and boundaries are an essential design aspect for inhabitants, as these are the major way of achieving privacy (Abu-Gaueh, 1995). Specifically, architects in Saudi Arabia create physical barriers using walls, curtains, and other kinds of barriers (Abu-Gaueh, 1995). Furthermore, Islamic culture has influenced two major design factors in Saudi Arabia: (a) function and (b) gender. Adopting these design factors means architects encounter difficulties in controlling boundaries and designing structures with reduced energy use (Abu-Gaueh, 1995). This requires building developers in Saudi Arabia to negotiate both cultural and technological realities to produce buildings that achieving sustainable design principles and have a low impact on the physical environment and decrease energy consumption while still fulfilling cultural expectations (Pushkar, Becker, & Katz, 2005).

Islam has strong religious traditions that are directly applicable to the construction and organization of life within the home and its environment (Zulkeplee Othman et al., 2015). The design of traditional Muslim houses is subject to guidelines from principles outlined in Islamic Sharia Law, which is obtained from the Quran as well as hadiths and sunnah (Zul Othman, Buys, & Aird, 2014). Following three main principles have developed from these guidelines: Privacy, hospitality, and modesty. In order, these three principles form the primary considerations of those who aim to build a traditional Muslim house. However, the migration of Muslims around the world also exposes them to the traditions and cultures of their host nations (Zul Othman et al., 2014). Several studies have focused on how Muslims can achieve privacy and increase hospitality within their houses. However, about the importance of domestic spaces for performing religious ceremonies and the practice of humility in the context of house design (Zul Othman et al., 2014).

Moreover, privacy according to Abu-Gaueh (1995), is central to the design of any Saudi house, and this critical aspect of the building must be considered by all individuals involved in development projects in Saudi Arabia, such as urban designers, designers, stage planners and social researchers (Abu-Gaueh, 1995).

Privacy in the traditional Islamic house contains four central layers: (a) privacy between gender (male and female), (b) privacy between neighbours, (c) privacy between family members inside the house, and (d) personal privacy. Such privacy conditions are usually met by a very careful design by making sure that the safety of the family and separating the private life from public associations (Memarian & Ranjbar-Kermani, 2011).

Moreover, since privacy is the most significant aspect that could affect any Muslim house. This means the designer must consider the privacy of residents at all design stages of the house (Zulkeplee Othman et al., 2015; Zul Othman et al., 2014). In Saudi Arabia, some studies showed that the privacy and hospitality are the most important factors that could impact the designing process for any Saudi house (Abu-Gaueh, 1995; Giddings, Almehrej, & Cresciani, 2023).

A specific issue in Saudi Arabia is its low-quality building stock. This has come about because of a history of poorly designed buildings (Elnabawi, 2021). In these buildings the largest elements of passive energy consumption are for heating, ventilation, and air conditioning, which accounts for about 35% of the consumption, compared to lighting (11%) and major devices (18%) (Elnabawi, 2021).

Furthermore, the residential sector is booming in Saudi Arabia because of rapid population growth and increased urbanization. From 1981 to 2019, the total population of Saudi

Arabia has risen from 10 million to 34 million, and by 2030 the population is estimated to reach 41 million (Rahman et al., 2022). Moreover, Saudi Arabia electricity generation is entirely reliant on the unsustainable practice of burning fossil fuels, which has significant environmental consequences for the climate, air, land, and water (Kamal, 2014; H. Taleb, 2009; H. M. Taleb & Sharples, 2011).

6.6. The current sustainability of Saudi Arabian buildings

Saudi Arabia has a noticeably lower percentage of green buildings than other Gulf countries (Balabel & Alwetaishi, 2021). The current Saudi Arabian buildings are massively dependent on the air conditioning which wastes significant amounts of energy. This has occurred because of poorly designed buildings in the Gulf countries, which include Saudi Arabia, approximately 80% of the building's electricity is used for air conditioning and cooling purposes (Elnabawi, 2021; H. M. Taleb & Sharples, 2011). Furthermore, because of fast population increase and grown urbanisation, not only the residential sector expanding, but it also creates more than half of the country’s energy need (Kamal, 2014). The design of modern homes in Saudi Arabia is no longer depending on vernacular architecture. The vernacular architecture leads to emphasise the utilisation of local building supplies, also, the use of passive and low-energy strategies that could begin to decrease the need for air conditioning and lighting requirements (H. M. Taleb & Sharples, 2011).

It is unfortunate to note that the electricity in Saudi Arabia is entirely dependent on the practice of burning fossil fuels, which has major environmental impacts on air, climate, water, and land because it is an unsustainable practice (Kamal, 2014; H. Taleb, 2009; H. M. Taleb & Sharples, 2011). Also, the use of sustainable energy technologies, such as solar photovoltaics (PV), is particularly rare in oil-rich Saudi Arabia, despite the abundant availability of renewable energies (Kamal, 2014; H. M. Taleb & Sharples, 2011).

Many scholars have discussed and supported the fact that establishing a coherent set of these codes and standards is one of the most important and cost-effective ways of promoting widespread sustainable practices, particularly in terms of reducing household energy and water consumption (H. M. Taleb & Sharples, 2011). Following the energy crises of the 1970s, such building codes have been generally adopted in developed countries, and more recently in developing countries such as China, Argentina, and Taiwan. However, the sustainable building regulations in many countries of the European Union are amongst the most stringent ones (H. M. Taleb & Sharples, 2011).

According to Shohan and Gadi (2020), the air conditioning systems consume approximately 65% of energy in all types of Saudi buildings to manage the level of indoor thermal comfort (Shohan & Gadi, 2020). Compering this percentage with some developed countries, such as the USA and Australia the percentage of using air conditioning is about 21%, and in the UK, it is around 22%. In addition, it is noted that the reduction of the initial costs of buildings comes at the expense of the quality of the building envelopes, by cancelling some of the building materials and elements, such as insulation (Shohan & Gadi, 2020). It is very important to consider both insulation and natural high-quality materials in the element of the building such as walls, doors, roofs, and the best orientation when designing a building in general (Shohan & Gadi, 2020). That could be beneficial for the country economy when considering the money saved to decrease heating and cooling requirements for buildings, as well as helping to protect the environment by decreasing the amount of CO_2 emissions when reducing the energy used by heating and cooling systems (Shohan, 2015).

Due to changes in urban governance, strategies have historically been constrained by a highly centralized policy-making process, in Saudi Arabia, the form of urban governance has an impact on urban management and sustainable urban development (Aina, Wafer, Ahmed, & Alshuwaikhat, 2019). The administration of urban development has been centralized, with little or no environmental assessment of policies and plans. Planning of the cities is influenced and supported by a central body, the Ministry of Municipal and Rural Affairs, while the five-year national development plan will be then supported by the Ministry of Economy and Planning (MOEP) (Aina et al., 2019). Urban planning reports make only limited references to the environment. There are environmental issues in Saudi Arabia for example greenhouse gas (GHG) emission, high energy and water consumption, seawater pollution, groundwater consumption and loss of vegetation to consider. However, the 2012 environmental performance index report showed that Saudi Arabia is one of the countries with the worst record in environmental review (ranked 82 out of 132 countries) (Emerson et al., 2012). In the 2018 environmental performance index report, Saudi Arabia no longer on the list of worst performers, it is ranked 86 out of 180 countries with a rank of 158 in air pollution (Aina et al., 2019).

6.6.1. The importance of sustainable buildings for Saudi Arabia

According to Sayigh (2013) and Kibert (2016), sustainable buildings are being understood and recognised across the world (Kibert, 2016; Sayigh, 2013). In the Gulf countries, the concept of sustainable buildings has been getting significant attention especially with the extensive energy consumption and the water scarcity (Alnaser, 2008; Awadh, 2017). The data that were given by the Leadership in Energy and Environmental Design (LEED) and the US Green Building Council records that the total number of projects being registered to be rated by LEED in the Gulf countries is 866 only 4 are from Saudi Arabia (Alnaser, 2008). Despite having the largest share in the construction sector at the Gulf countries level the situation with regards to sustainable buildings is thus not excellent. The efforts being made in Saudi Arabia need to realise and expedited (Alrashed & Asif, 2014).

Sustainable Development is a recent idea in Saudi Arabia, having been formalized by King Abdullah's initiative in 2010 when the only sustainable project was King Abdullah University of Science and Technology (KAUST). In 2013, the number of sustainable and green projects increased to 140 projects around the country, with 40 of them located in Riyadh (M. S. Al Surf & Mostafa, 2017). In study conducted by Al surf and Mostafa (2017) in titled “Will the Saudi’s 2030 Vision Raise the Public Awareness of Sustainable Practices”, Saudi Arabia is one of the developing countries in the Middle East and Gulf countries that developed its own development plans, claiming that implementing sustainability will be easier because the country is still in the development phase and the construction rate is higher than ever (M. S. Al Surf & Mostafa, 2017). Many issues are raised during this process; the integration of local materials and the methodology of how historical buildings were built must be considered together to deliver the full result of having sustainable and affordable buildings, as well as the use of natural resources (M. S. Al Surf & Mostafa, 2017). Recently, as the new Saudi Vision 2030 was officially adopted and announced in June 2016, local engineering bodies and the government began collaborating to legislate the principle of sustainability to protect future generations. The community's awareness and knowledge of the idea of sustainability and how it can be implemented are also significant to the success of the implementation (M. S. Al Surf & Mostafa, 2017). Moreover, the new Saudi Vision calls for economic diversification and the protection of available natural resources. One of the current Housing strategy's policies is to adhere to a Sustainable Development (SD) plan (M. S. Al Surf & Mostafa, 2017).

The Energy Information Agency said that between 2006 and 2010 the CO2 emissions from the energy consumption in Saudi Arabia are on increase and it is the highest in the world emissions (Alrashed & Asif, 2014). Moreover, the electricity consumption which is completely depending on fossil fuel is also rising quickly due to factors like urbanization, burgeoning population, subsidized tariffs, and increased use of energy-intensive appliances. Because of these factors, the electricity need is expected to be double by the year 2025 (Alrashed & Asif, 2014).

Through the last years, the Saudi government has paid significant attention to achieve sustainability which is one of the main objectives of the economic and social development plan in the country (Alrashed & Asif, 2014). The United Nations Development Program said the goal was to achieve sustainable development throughout the eighth development plan (2006-2010) and eliminate the negative impacts on natural resources, quality of life and public health, as well as to protect the environment from harmful activities or practices. Moreover, The Ninth Development Plan (2010-2014) emphasizes the conservation and protection of the environment from pollution, and the conservation and development of wildlife, as well as the conservation and rational use of natural resources, in line with the drive to achieve sustainable development (Alrashed & Asif, 2014).

6.6.2. Sustainable Development National Strategy of Saudi Arabia

The Eighth Five-Year Development Plan (2005-2009) was developed, providing a comprehensive strategic vision that aimed to achieve sustainable development (Issa & Al Abbar, 2015). The main purpose of this was to meet people's material, cultural, and spiritual needs, as well as their health and quality of life (Issa & Al Abbar, 2015). The development strategy's goals are to achieve sustainable development and destroy any negative effects on natural resources, quality of life, and public health, while also protecting the environment from harmful activities and practices (Issa & Al Abbar, 2015).

The objective of this strategy is to protect the environment from pollution. Also, improve both the quality of life and public health for people. In addition, grow and protect wildlife to secure their sustainability. Moreover, achieving sustainable development by bringing human activities and natural resource security closer together; keeping non-renewable natural resources while also looking for alternative resources (Issa & Al Abbar, 2015).

According to a study by Al-Shihri (2013), Saudi Arabia would get significant environmental and socioeconomic benefits if such sustainability concepts were integrated into its regional, and local development strategies (Al-Shihri, 2013). Moreover, the government has supported the development of friendly environmental buildings through the Saudi Green Buildings Forum in a conference in Riyadh in 2012 (Al-Shihri, 2013). The government has supported and funded study on developing alternative renewable energy technologies and has ambitious plans to turn to solar energy to reach a significant share of energy demand (Al-Shihri, 2013). According to a senior Kingdom official, has indicated that the government has programs to match 100% powered by renewable and low-carbon forms of energy within decades (Al-Shihri, 2013). Relevant ministries are developing strategies and policies based on sustainability concepts, but there are still some weaknesses in the system for translating written statements into practical action. For instance, Urban Growth Boundaries, which were designed to manage urban sprawl, have become irrelevant because the studies used to determine the boundaries were either inadequate or non-existent (Al-Shihri, 2013).

Based on Saudi Arabia's Vision 2030 for reaching sustainability in all aspects of life, particularly in the residential buildings and construction sector, the "Mostadam" rating system for the evaluation of existing as well as new residential buildings was recently adopted by the government (Balabel & Alwetaishi, 2021). Mostadam is a standard that contains three green building rating systems dependent on the type of built asset being examined: (a) residential buildings, (b) neighbourhoods and residents, and (c) commercial buildings. Each rating system has two parts: (a) design and construction, and (b) operation (Balabel & Alwetaishi, 2021).

However, there are some essential challenges which have resulted in a low number of registered projects and buildings in Saudi Arabia for instance, international sustainable building rating systems do not consider regional differences and different climates. As a result, it is important to adopt local rating systems such as Mostadam for each city in Saudi Arabia (Balabel & Alwetaishi, 2021). Additionally, it is essential to investigate the lack of development in the Saudi building industry by considering modern building materials and techniques (Balabel & Alwetaishi, 2021). Therefore, it is suggested to highly enhance the local building industry to overcome this problem and improve the implementation of the Mostadam rating system throughout the country. However, Mostadam rating system is still not been used in the country and is still a recommendation (Balabel & Alwetaishi, 2021).

According to a study by Al-Tamimi (2017), the government should address the lack of professional engineers and technicians who have experience in the sustainability area. There needs to be an increase in the amount of education offered in climatic and sustainable design (Al-Tamimi, 2017). Also, the sustainable growth of buildings in Saudi Arabia requires the implementation of energy-efficient principles. The government must adopt some sustainability concepts such as Energy efficient design, energy conservation, green technology, and the use of renewable energy sources, such as wind catchers and solar panels (Al-Tamimi, 2017).

6.7. Conclusion

This Chapter has analysed relevant literature in a progress design to elicit: (1) the important requirements for achieving sustainable building design in Saudi Arabia and (2) the impact of cultural issues on sustainable building design, focusing specifically on the case of Saudi Arabia.

This Chapter has shown that privacy is the most significant aspect that could affect any Muslim household. This means the designer must consider the privacy of residents at all design stages (Zulkeplee Othman et al., 2015; Zul Othman et al., 2014). Also, this Chapter has noted that implementing privacy for the design will increase the level of indoor comfort of residents (Abu-Gaueh, 1995; Tharim & Samad, 2016). This Chapter has also found that the construction sector needs to be more proactive and better at encouraging sustainable practices (Babalola et al., 2019; Bal et al., 2013). The energy performance in buildings is influenced by multiple factors, such as weather conditions, building fabric, lighting, and air conditioning systems. Also, the residents must consider as a reason affecting on energy consumption (Zhao & Magoulès, 2012).

Thus, this review has focused on the following topics:

The effect and importance of sustainable design on human comfort (As discussed in Section 6.2): The literature review has found that there is a connection between indoor environment quality and residents' comfort (temperature, privacy, humidity, and natural light) (Abu-Gaueh, 1995; Tharim & Samad, 2016) and that the indoor environment is very important for people's health and happiness (Abu-Gaueh, 1995; Tharim & Samad, 2016).

Occupant health and comfort is one of the most important factors of people-centric building design and has a strong correlation with occupant productivity (Ghaffarianhoseini et al., 2018). However, perspectives on well-being and healthy environments are starting to change, both within the governments and the community. Tackling human comfort through the development of green and smart buildings, has attracted increasing interest (Ghaffarianhoseini et al., 2018). This change is being accompanied by a commitment to the design of healthy environments that would provide productive workplaces, benefit occupants' health, and improve the natural environment and ecosystems. These changes deliver chances to guarantee healthier lifestyles, sustain urban development, protect ecological integrity, and help better resilient places in the low carbon future (Ghaffarianhoseini et al., 2018).

One of the solutions to provide comfort for residents is adopting the green buildings which is seeking to reduce the environmental impact, increase the safety, health, and productivity of a building resident (Gambatese et al., 2007; Jami et al., 2019).

Other solution to achieve a more comfortable design for the resident is building envelope such as the external walls, the foundation of the building, the windows, doors, as well as roof systems (Straube & Burnett, 2005). Many researchers believed that the design of the building façade, such as the orientation and shape of the building as well as the material types of the building envelope, will affect positively on buildings by achieve suitable temperature inside the building and reduce the energy consumption of the building.

The literature review elicited the following key findings for the importance of sustainable design on human comfort:

1. There is a connection between indoor environment quality and residents' comfort, work performance, happiness, and health (Tharim & Samad, 2016).
2. The adoption of green buildings is seeking to reduce the environmental impact, increase the safety, health, and productivity of building occupants (Gambatese et al., 2007; Jami et al., 2019).
3. Improving the quality of the building envelope (i.e. external walls, foundation, windows, doors, and roof systems) will also improve comfort for the residents by influencing the quality of indoor environment, energy efficiency, as well as improving the air quality (Mirrahimi et al., 2016; Straube & Burnett, 2005).

The effect and importance of sustainable design on energy consumption (As discussed in Section 6.3): The literature review has found that the construction sector needs to be more proactive and better at encouraging sustainable practices (Babalola et al., 2019; Bal et al., 2013). The energy performance in buildings is affected by multiple factors, such as weather conditions, building structure, building fabric, building systems, the operation of sub-level elements like lighting, and air conditioning systems, however, the residents must consider as another reason affecting on energy consumption (Zhao & Magoulès, 2012).

However, changing from the traditional methods to sustainable design in the construction sector will need more action on many phases and support from the government (Hanna, 2011).

Recently, seven European countries have adopted a working definition of a low-energy house (Aldossary et al., 2017). These definitions are most often applied to both new houses and existing houses and it could be used and applied for residential buildings in the country. The energy reduction required to be classified as meeting these definitions ranges from 30% to 50%, depending on the special condition of the design of the building (Aldossary et al., 2017).

Usually, buildings in Saudi Arabia have thicker walls and roofs for better thermal insulation. Many vernacular architecture techniques such as wind catchers, windows shades, and fountains were used for cooling and daylighting the building. The vernacular architecture leads to an emphasis on the utilisation of local building resources, and the use of passive and low-energy strategies that could begin to minimise the need for air-conditioning and lighting requirements (Alrashed & Asif, 2014).

The literature review elicited the following key findings for the importance of sustainable design on energy consumption:

1. Excessive energy consumption is a major problem for many buildings (Alrashed & Asif, 2014; Özer et al., 2020).
2. The construction sector needs to be more proactive and better encouraging sustainable practices through activities such as implementation of the lean production approach such as analysis of building models to ensure compliance with the code for sustainable houses, and to plan for continual maintenance, before construction begun to reduce the energy wastage in the building (Arayici et al., 2011; Babalola et al., 2019; Bal et al., 2013).
3. The energy performance in buildings is affected by multiple factors, such as weather conditions, building structure, the operation of sub-level elements like lighting and air conditioning systems, and the behaviour of the residents (Zhao & Magoulès, 2012).

Important requirements for achieving a sustainable house design in Saudi Arabia (As discussed in Section 6.4): The literature review has found that there are many building certification schemes/tools that calculate the environmental performance of buildings. However, changing from the traditional methods to sustainable design in the construction sector will need increased action across many domains along with support from the government (GamalEldine & Corvacho, 2022). These schemes, and other literature, have outlined some general requirements (GamalEldine & Corvacho, 2022):

1. The residential energy code must cover both new and refurbished buildings. When refurbished buildings are covered it should supply clear retrofit suggestions.
2. A training program must be set up for those responsible for energy efficiency code compliance in buildings.
3. Develop awareness campaigns for residents to emphasise the value of enabling the energy efficiency code in buildings to enable residents to make informed decision when they decide to refurbish or move to a new building for both public and private buildings.
4. Implement a plan for retrofitting all currently existing government buildings and follow the European method such as BREEAM, which help decrease energy consumption and set a high standard for the private sector.

In recent years, Saudi Arabia has experienced increased economic growth due to strong oil prices and continuing improvements in the country such as the construction sector (Al-Yami & Price, 2006; Mahmood et al., 2019). This growth has also has been stimulated by government construction projects and an increase of infrastructure and building projects such as hospitals and schools (Al-Yami & Price, 2006; Mahmood et al., 2019). The literature review elicited the following key findings for Saudi Arabia specifically:

1. In Saudi Arabia electricity generation is entirely reliant on the unsustainable practice of burning fossil fuels, which has significant environmental consequences for the climate, air, land, and water (Kamal, 2014; H. Taleb, 2009; H. M. Taleb & Sharples, 2011).
2. Sustainability assessment criteria have been not able to completely incorporate social and cultural elements into the assessment in Saudi Arabia (Raji Banani et al., 2016).
3. The version of BREEAM delivered to Middle East and Gulf countries "a BREEAM Gulf/Middle East assessment system" was overwhelmingly influenced by BREEAM-UK, which was produced for buildings based in the United Kingdom (Alyami & Rezgui, 2012).
4. There is a need for Saudi Arabia to develop its assessment method, which should ideally consider many factors, such as social and economic contexts and vernacular architecture and cultural (Alyami & Rezgui, 2012).
5. In terms of using green building concepts and tools in Saudi Arabia, most attention so far has focused on private and residential buildings. However, architects, engineers, environmental engineers, and clients should have a much wider understanding of the connection between the different phases of sustainability in non-residential construction projects (Raji Banani et al., 2016).

Possible cultural factors that could impinge upon sustainable design (As discussed in Section 6.5): The literature review has found that culture has a clear impact on how buildings are constructed (Vatan, 2017). When humans are engaged, even when the equipment and materials are the same, cultural differences and process preferences result in diversity, which is known as architectural innovation (Vatan, 2017). In Saudi Arabia specifically, the primary influence is the religion of Islam. Islam is followed by 100 percent of the native population in Saudi Arabia, and Islam governs all aspects of Saudi Arabian life (Nordin, 2018). In Middle Eastern countries such as Saudi Arabia, Iran, and Turkey, special focus is placed on privacy through the segregation of male and female rooms; this requirement influences the layout and design of these houses (Zulkeplee Othman et al., 2015).

The literature review found that:

1. Privacy is central to the design of any Saudi house, and this critical aspect of the building must be considered by all individuals involved in development projects in Saudi Arabia, such as urban designers, designers, stage planners and social researchers (Abu-Gaueh, 1995).
2. Some architectural elements for example windows, doors, and bedrooms as features that are functional and useful but also exert much impact on human domestic behaviours and actions inside the house environment (Heathcote, 2012).
3. Different cultural groups require different residential typologies, space designs and visual expressions (Zejnilovic & Husukic, 2018).
4. In the Middle East, the architectural styles and materials used in houses are different from houses in other predominantly Muslim countries (Zulkeplee Othman et al., 2015).
5. Saudi Arabian culture has been described as the most conservative culture in the world (Nordin, 2018). Furthermore, Islam is reflected in the structure of the Saudi Arabian or Muslim houses because of the cultural requirements for separation between male and female members of the family (Sulandari et al., 2017).

The current sustainability of Saudi Arabian buildings (As discussed in Section 6.6): The literature review has found that buildings in Saudi Arabia are responsible for the majority of the city's carbon emissions and represent nearly 40% of its overall energy consumption (Balabel & Alwetaishi, 2021). This is because Saudi Arabia has witnessed rapid urban growth in recent years, particularly in its big cities, due to excellent economic and social growth (Babalola et al., 2019). some Arab countries in the Middle East have started domestic building assessment tools. For instance, the Estidama rating system has begun to be used in the United Arab Emirates (UAE) also the Qatar Sustainability Assessment System (QSAS) is used in Qatar (Raji Banani et al., 2016).

The Saudi Green Building Council (SGBC) has used the US Green Building Council's LEED criteria as its official assessment tool for estimating building performance. However, currently, there are no assessment tools that cover the economic, social, and cultural phases of the assessment criteria (Raji Banani et al., 2016). It would therefore be helpful for Saudi Arabia to develop its own assessment method, which should ideally consider many factors, such as social and economic contexts and vernacular architecture and cultural (Alyami & Rezgui, 2012).

Based on Saudi Arabia's Vision 2030 for reaching sustainability in all aspects of life, particularly in the residential buildings and construction sector, the "Mostadam" rating system for the evaluation of existing as well as new residential buildings was recently adopted by the government (Balabel & Alwetaishi, 2021). Mostadam is a standard that contains three green building rating systems dependent on the type of built asset being examined: (a) residential buildings, (b) neighbourhoods and residents, and (c) commercial buildings. Each rating system has two parts: (a) design and construction, and (b) operation (Balabel & Alwetaishi, 2021).

The importance of sustainable buildings for Saudi Arabia (As discussed in Section 6.6.1): The literature review has found, the number of sustainable and green projects is currently only 140 projects across Saudi Arabia, with 40 of them located in Riyadh (M. S. Al Surf & Mostafa, 2017). According to Sayigh (2013) and Kibert (2016), sustainable buildings are being understood and recognised across the world (Kibert, 2016; Sayigh, 2013). In the Gulf countries, the concept of sustainable buildings has been getting significant attention especially with the extensive energy consumption and the water scarcity (Alnaser, 2008; Awadh, 2017).

The Energy Information Agency state that between 2006 and 2010 the CO2 emissions from the energy consumption in Saudi Arabia are on increase and are the highest in the world (Alrashed & Asif, 2014; Alshehry & Belloumi, 2015). Moreover, the electricity consumption, which is completely depending on fossil fuel, is also rising quickly due to factors like urbanization, burgeoning population, subsidized tariffs, and increased use of energy-intensive appliances. Because of these factors, the electricity need is expected to be double by the year 2025 (Alrashed & Asif, 2014). Another study confirms that, according to projections for industrial electricity use through 2025, consumption will be more influenced by population growth than by price increases (Hasanov, 2019).

According to Alshehry and Belloumi, to provide sustainable economic growth, Saudi Arabia should invest in clean power such as solar panels and wind catchers, and adopt standards of energy efficiency (Alshehry & Belloumi, 2015). Since global warming is becoming a serious problem, investment in renewable energy and more efficient energy use is required to minimize CO2 emissions across Saudi Arabia. Additionally, it is important to encourage all industries to adopt advanced technology which can reduce pollution (Alshehry & Belloumi, 2015).

In conclusion, the results of all these above findings are integrated to answer the third research question of this thesis (What are the suitable requirements for achieving sustainable building design in Saudi Arabia and what are the cultural factors that could impinge on their adoption). To answer this research question, the following requirements are presented:

1. The implementation of the Saudi Arabian specific standards within the construction sector to reduce environmental pollution and energy waste using both new technologies and improved building design. These standards should set out key requirements that are achievable for the construction industry in Saudi Arabia in the short to medium term.
2. The development of a Saudi Arabian standard must consider the culture as one of the sustainability principles which is influencing in a good way for the environment, society and communities and will provide an improvement in energy conservation.
3. The adoption of the Mostadam rating system for the evaluation of new as well as refurbished residential buildings to be used for all the project across Saudi Arabia.
4. The Mostadam rating system must be amended to consider the privacy of the residents as it is a central idea of any design in Saudi house.

In relation to point one above, to make the adoption of formal standards for sustainability in Saudi Arabia achievable for the Saudi Arabian construction sector, they must incorporate key requirements that are adoptable by the industry. This is required because the Saudi Arabian construction sector is not yet ready to adopt more sustainable constructions (as found in Chapter 5). For example, the survey of experts (Chapter 5) showed that 24% of the participants believe that the Saudi construction sector will not adopt sustainable design in the near future, meanwhile 7% of the participants say they do not know if the Saudi construction sector will ever adopt and deliver an increasing level of adoption of sustainable design. More specifically, it also found that depending on the technique as low as 29% of expert respondents were not aware of its use and application in Saudi Arabia.

These are especially important as the Saudi Arabian government has included in the 2030 vision of Saudi Arabia that both green buildings and sustainable design will be encouraged (Balabel & Alwetaishi, 2021).

Based on literature (Alhumayn et al., 2017; Alyami & Rezgui, 2012; Awadh, 2017; R Banani et al., 2013; Raji Banani et al., 2016; Hamedani & Huber, 2012; Hanna, 2011; Maria M Serrano-Baena, Hidalgo Fernández, Carranza-Cañadas, & Triviño-Tarradas, 2021; María M Serrano-Baena et al., 2020; H. M. Taleb & Sharples, 2011; Tharim & Samad, 2016; Zanni et al., 2017), initial key requirements that should be incorporated are:

1. A full specification of each applicable building element including its materials, their sourcing and their sustainability should be produced and considered as part of the building design.
2. Full consideration of the location of the building, its local climate i.e., temperature, wind direction, and level sun radiation should be considered in the design phase of the project in order to achieve maximum sustainability.
3. The quality of the indoor environment, comfort, health, and productivity of residents should be considered by providing thermal comfort, air quality, and acoustic comfort.
4. The constructor should ensure there is recycling system in place during all the project phases for new buildings.
5. The CO2 emission of the building should be reduced by using higher energy efficiency products throughout.
6. Occupants should be empowered to employ more efficient building maintenance and management practices to decrease the costs of operation and maintenance of the buildings.
7. Design should limit air leakage and cooling losses must be decreased in the hot weather to prevent the cooled air from escaping from the building.
8. Monitoring and management systems should be installed to avoid wastage of energy and water.
9. On-site renewable generation should be provided.
10. Install smarter building systems which can control the internal temperature and thus, increase energy efficiency.
11. Install cooling and heating systems that are more efficient and can reduce carbon emissions to improve the building performance.
12. Designs should minimize the solar radiation entering the building.
13. Air Conditioning should be replaced with natural ventilation, increasing energy efficiency, comfort and causing less noise for residents.

In summary, these three specific key findings of this Chapter will be utilized in the framework.

1. It is required to implement a specific standard for Saudi Arabia considering reduce pollution and energy waste to protect the environment, the developed framework

must consider this as a primary criterion. This will be realized through the incorporate of the key requirements defined above.

2. Culture, especially privacy, has a clear impact on how buildings are constructed and must be considered in the framework to achieve comfort for the residents, in a balance with sustainability.
3. The “Mostadam” rating system which adopted by the government must been used for all the project across Saudi Arabia.

These findings of this Chapter, along with requirements proposed above will feed into the development of a framework in Chapter 7 to assist construction industry professionals and domestic property owners to increase the level of adoption of sustainable design in their buildings in Saudi Arabia.

The framework will build upon the “Mostadam” rating system to understand the sustainability requirements of domestic properties.

All these key findings will support the proposed framework in the next Chapter to come up with an excellent outcome to achieve a more sustainable design in Saudi Arabia. Based on the findings, this framework must consider the culture and the residents' privacy as inputs during the design process of the building as well as sustainability. However, it must also consider locality specific factors such as the climate in Saudi Arabia and available building materials and technology.

Chapter 7: The Saudi Housing Sustainability Framework (SHSF) to improve the construction processes for buildings to become more sustainable design

7.1. Introduction

This Chapter will answer the fourth research question (**RQ4:** *How can the experts in the sustainability field understand the resident requirements considering the achievement of sustainability in Saudi Arabia*) This will be done through a systematic literature review.

The literature review will provide the following:

1. An overview of framework that helps to achieve more sustainable design,
2. List of sustainable design interventions in Saudi Arabia,
3. Sustainable design and existing building in Saudi Arabia,
4. List of requirements to achieve the sustainable design in Saudi Arabia.

Saudi Arabia's Vision 2030 adopts complete development standards in all fields of Saudi civilisation (Balabel & Alwetaishi, 2021). To achieve this, many industries and programs have been launched to achieve sustainable goals while fulfilling the requirements of the present without compromising the needs of future generations (Balabel & Alwetaishi, 2021).

The framework is important to apply because there is a lack of knowledge of sustainability and differing viewpoints on sustainability between professionals involved in sustainable design and members of the public (Alhumayn et al., 2017; Cardenas, 2016). A framework is required to assist professionals overcome these issues by:

1. Providing them with a structured approach along with guidance and standards to create more sustainable buildings.
2. Provide a formalised approach to help professionals in Saudi Arabia understand occupants' requirements and consider their views in selecting sustainability measures.

The choice of a framework as the methodological tool to implement this approach is made because its ability to interduce a completable design for occupants (Jabareen, 2008).

In this Chapter, Section 7.2 presents an overview of the Saudi Housing Sustainability Framework (SHSF). Section 7.3 will describe the factors considered by the SHSF, starting from a set of sustainability interventions. Section 7.4 presents removal of unsuitable combinations, enabling the selection of the appropriate combinations of measures. Finally, Section 7.5 will describe interfacing with the SHSF. Section 7.6 will conclude this Chapter.

7.2. Overview of the Saudi Housing Sustainability Framework (SHSF)

The goal of the SHSF is to guide building professionals and designers in specifying appropriate sustainability design factors which will, in turn, provide suggestions of design interventions to the occupants. However, in order to develop the sustainability of buildings across Saudi Arabia this framework must also consider the culture of the residents' privacy and locality specific factors such as the climate in Saudi Arabia as inputs during the design process as well as more common standard sustainability decision making factors such as energy savings, economics and building characteristics. Furthermore, this framework is required to ensure that implementing specific standards for Saudi Arabian buildings considering reduce carbon mission and energy waste to protect the environment.

The development of this framework will help construction industry professionals and domestic property owners to increase the level of adoption of sustainable design in buildings across the country to understand the buildings interventions, understand the occupants needs, and study the climate situation.

The factors considered by the Saudi Housing Sustainability Framework (SHSF) are:

1. Sustainable Building Design Interventions will be discussed in Section 7.3.1.
2. Building requirements, will be discussed in Section 7.3.2.
3. Cultural factors will be discussed in Section 7.3.3.
4. Economic factors will be discussed in Section 7.3.4.
5. Climate impact will be discussed in Section 7.3.5.
6. Sustainability impact will be discussed in Section 7.3.6.
7. Data requirements will be discussed in Section 7.3.7.

The content of each of these factors, has been derived through intensive literature review, and how this has been done will be described in each detail in the factor's respective Sections.

Figure 4 shows the elements in detail for the framework. This Figure shows the overall process that the framework will follow.

1. Owner and designer discuss and framework guides designer in gathering information related to building design with more sustainability concern, with a consideration of different factors such as the culture of residents, the climate, and the economic factor.
2. The information is used to filter and prioritise a set of sustainable design interventions.

3. Unsuitable combinations are removed.
4. Based on this, the designer can use the framework propose a set of initial design ideas to the owner.
5. This can be further refined iteratively between the owner and the designer with the framework assisting.

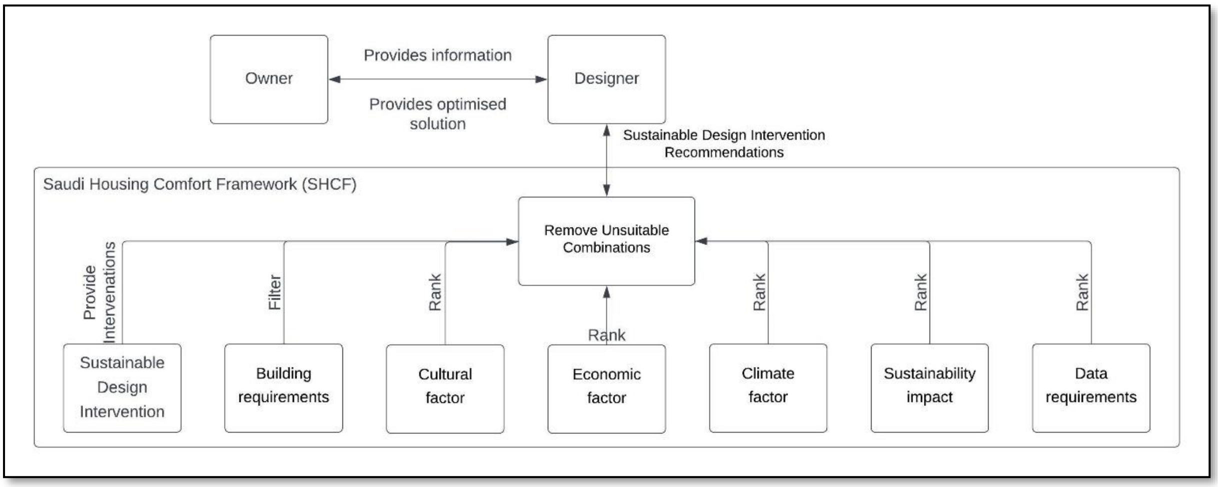


Figure 4: Saudi Housing Sustainability Framework (SHSF)

Previous studies have shown the importance of adopting different factors in the framework such as economic factors, sustainability impact, and building requirements. Specifically, the factors in this framework are:

1. **Sustainable design interventions:** This is important because the designer needs to understand the interventions that can be applied to positively impact the sustainability of a domestic building.
2. **Cultural factors:** These are important because the designer needs to understand both; (a) resident's privacy which is a central point of any Islamic design and (b) the impact of the interventions.
3. **Economic factors:** These are important because the designer needs to understand the cost-effectiveness, lifecycle cost of interventions in the context of the available budget**.**
4. **Data requirements:** These are important because it is about formalizing the needed data to the designer which will help the designer to make the decisions.
5. **Sustainability impact:** These are to enable designers to understand the positive sustainability impact of the interventions.
6. **Building requirements:** There are important because the designer needs to identify the interventions that cannot be deployed on a given building.

7. **Climate requirements:** This is important because the designer needs to understand which of the Saudi climate zones an intervention can be implemented in.

All of these factors were extracted from literature reviews of previous studies in Saudi Arabia, and different sustainability standards such as BREEAM and LEED (Alhumayn et al., 2017; Asif, 2016; Awadh, 2017; R Banani et al., 2013; Raji Banani et al., 2016; Brem, Cusack, Adrita, O'Sullivan, & Bruton, 2020; Hamedani & Huber, 2012; Richard Hyde, 2013; Lee & Burnett, 2008; Nugraha Bahar et al., 2013; Reed, Clouston, Hoque, & Fisette, 2010; Schweber, 2013; María M Serrano-Baena et al., 2020).

7.3. Factors considered by Saudi Housing Sustainability Framework (SHSF)

This Section will describe the factors considered by the Saudi Comfort Housing (SCHF) framework. Each of the Sections below will cover one of the key concepts descried above.

7.3.1. Sustainable Building Design Interventions

Countries such as the UAE, and Qatar, face is trying to influence overconsumption patterns. Although these countries have their green building rating systems and appear to have higher levels of awareness than other countries, they are notorious for their overconsumption patterns (Issa & Al Abbar, 2015). Other country such as Jordan and Lebanon focuses on tourism sector, which has a negative impact on sustainable development (Issa & Al Abbar, 2015). While there have been important successes in the region with the implementation of green building codes and rating systems, there is a significant challenge in dealing with the existing building stock that was constructed before the implementation of these codes (Issa & Al Abbar, 2015).

Retrofitting existing buildings to be more energy and water efficient has shown to be a financially rewarding investment that reduces operating costs significantly within a short payback time. Despite this, there are barriers to the general implementation of retrofit programs, most notably the availability of funding and building owner awareness (Issa & Al Abbar, 2015). Significant progress is being made in this field in Dubai, for example, with the establishment of a comprehensive framework named 'Efficiency' by the Dubai Supreme Council of Energy to support energy-efficient building retrofitting. The primary goal of this agency is to combat rising energy demands in the city and reduce them by 30% by 2030 (Issa & Al Abbar, 2015). The comprehensive implementation of retrofitting existing buildings is critical for the region to produce a path of sustainable development, and more initiatives are hoped to lead to further programs of this type throughout the region (Issa & Al Abbar, 2015).

The final list of sustainable design interventions has been derived through a literature review conducted through examining each of the important requirements for sustainability in Saudi Arabia defined in Chapter 6, to determine a set of practical interventions that can be deployed to meet each requirement.

1. **A full specification of each applicable building element including its materials, their sourcing and their sustainability should be produced and considered as part of the building design:** This requirement will ensure that new building and major renovations conform to applicable building energy efficiency requirements.
2. **Full consideration of the location of the building, its local climate i.e., temperature, wind direction, and level sun radiation should be considered in the design phase of the project to achieve maximum sustainability:** This requirement will enable provision of a suitable temperature inside the building for the occupants, taking local climate into consideration.
3. **The quality of the indoor environment, comfort, health, and productivity of residents should be considered by providing thermal comfort, air quality, and acoustic comfort:** This requirement will increase the quality of the indoor and outdoor environment for the residents with consideration of sustainable design.
4. **The constructor should ensure there is recycling system in place during all the project phases for new buildings:** This requirement will ensure construction is performed in an environmentally sustainable way.
5. **The CO2 emission of the building should be reduced by using higher energy efficiency products throughout:** This requirement will increase the quality of the indoor environment for the residents, reduce the environmental impact of the building and reduce utility bills for occupants.
6. **Occupants should be empowered to employ more efficient building maintenance and management practices to decrease the costs of operation and maintenance of the buildings:** This requirement will empower residents to better maintain and operate their buildings. This will decrease the lifetime costs of the building and improve their operational practices.
7. **Design should limit air leakage and cooling losses must be decreased in the hot weather to prevent the cooled air from escaping from the building:** This

requirement will help to reduce the energy bills of the building and retain suitable internal temperatures without wasting energy.

8. **Monitoring and management systems should be installed to avoid wastage of energy and water:** This requirement will save more money and reduce utility bills.
9. **On-site renewable generation should be provided:** This requirement will save more money and reduce utility bills.
10. **Install smarter building systems which can control the internal temperature and thus, increase energy efficiency:** This requirement will provide comfort for residents and will save more money and reduce utility bills.
11. **Install cooling and heating systems that are more efficient and can reduce carbon emissions to improve the building performance:** This requirement will provide comfort for residents and will save more money and reduce utility bills.
12. **Designs should minimize the solar radiation entering the building:** This requirement will save money and will help to reduce the energy bills of the building and keep the suitable internal temperature.
13. **Air Conditioning should be replaced with natural ventilation, increasing energy efficiency, comfort and causing less noise for residents:** This requirement will result in building systems operating with less noise, more comfort, and increased energy efficiency. Moreover, this should be controlled by the occupants through some level of automation.

Each of these key requirements where then studied and a literature review performed to identify interventions that can solve these requirements. These interventions were gathered from various environmental standards such as BREEAM and LEED. To gather them, literature that reviews and summarises these standards was analysed, and the interventions extracted. Table 41 provides a list of interventions that solve each requirement for sustainability (Awadh, 2017; Brem et al., 2020; Doan et al., 2017; Lee & Burnett, 2008; Reed et al., 2010; Reeder, 2010; Retzlaff, 2009; Roderick, McEwan, Wheatley, & Alonso, 2009; Schwartz & Raslan, 2013; Schweber, 2013; Schweber & Haroglu, 2014; Turner, Frankel, & Council, 2008; Vierra, 2016).

Table 41: List of Sustainable design interventions

No	Key Requirement	Sustainable Design Intervention	Origin Standard
1	A full specification of each applicable building element including its materials, their sourcing and their sustainability should be produced and considered as part of the building design.	Ensure of the availability of the required materials for the building to avoid delays and wastage.	BREEAM + NAHB
		Select materials with lowest manufacturing environmental costs.	
		Select high performance materials to save on operation costs.	
		Select material with appropriate life span to avoid having to replace during building lifetime.	
2	Full consideration of the location of the building, its local climate i.e., temperature, wind direction, and level sun radiation should be considered in the design phase of the project in order to achieve maximum sustainability.	Use openable windows on appropriate sides of building to improve the building performance and to achieve comfort for residents.	BREEAM
		Reduce the amount of glass in the façade on appropriate building facades to decrease solar radiation.	
		Install sun shading on the windows to minimize heat gain inside the building.	

		Specify heating/cooling systems capacities based on anticipated temperatures for the region concerned.	
3	The quality of the indoor environment, comfort, health, and productivity of residents should be considered by providing thermal comfort, air quality, and acoustic comfort.	Specify insulation level to provide the suitable internal temperature.	BREEAM
		Install sun shading on the windows to minimize heat gain inside the building.	
		Deploy a green roof on the building.	
		Install suitably smart heating and/or air conditioning system that can control the internal temperature automatically to prevent under or overheating.	
		Install water storage tank insulation to the water tank to provide a suitable temperature for the water to the residents.	
4	The constructor should ensure there is recycling system in place during all the project phases for new buildings.	Install facilities to allow for waste separation.	BREEAM
		Install a bin to recycle construction waste which protect the Environment.	

		Design the recycling bins place to be close to the building.	
5	The CO2 emission of the building should be reduced by using higher energy efficiency products throughout.	Change bulbs inside the house to LED.	BREEAM
		Replace the old air conditioning devices to new devices that suitable with the Saudi energy efficiency scheme with rating A.	
		Replace the old heating devices to new devices that suitable with the Saudi energy efficiency scheme with rating A.	
		Replace the old boiler device to new boiler that suitable with the Saudi energy efficiency scheme with rating A.	
		Replace old devices such as TV, fridge, washing machine, and dish washer that suitable with the Saudi energy efficiency scheme with rating A.	
6	Occupants should be empowered to employ more efficient building maintenance and	Provide the maintenance information to the owner.	BREEAM

	management practices to decrease the costs of operation and maintenance of the buildings.	Install smart technologies to monitor the status of the building elements.	
		Install sensors to monitor the status of the building elements.	
7	Design should limit air leakage and cooling losses must be decreased in the hot weather to prevent the cooled air from escaping from the building.	Reduce the amount of glass in façade in hot areas.	BREEAM
		Install solid wall insulation.	
		Install solid roof insulation.	
		Install low-e glass	
		Installing double glazing.	
8	Monitoring and management systems should be installed to avoid wastage of energy and water.	Install flow control devices that control the water supply to the WC facilities to minimise undetected wastage and leaks from sanitary fittings and supply pipework.	BREEAM + LEED
		Using toilet facilities which can detect the leakage of water.	
		Install water saving devices for toilet facilities.	
		Aerated/Water Saving Shower head.	
9		Deploy a green roof on the building.	BREEAM

	On-site renewable generation should be provided.	Install solar panels.	+
		Improve the cross ventilation.	LEED
		Install solar hot water heating panels.	
		Deploy the wind catchers.	
10	Install smarter building systems which can control the internal temperature and thus, increase energy efficiency.	Buy a new smart boiler which can control the water temperature.	BREEAM + LEED
		Add a timer to existing boiler.	
		Install a smart air conditioning that control the internal temperature automatically.	
		Install smart heating system which control the internal temperature automatically.	
11	Install cooling and heating systems that are more efficient and can reduce carbon emissions to improve the building performance.	Install solar hot water heating panels.	BREEAM + LEED
		Install a smart air conditioning system that suitable with the Saudi energy efficiency scheme with rating A.	
		Install a smart heating system that suitable with the Saudi energy efficiency scheme with rating A.	

12	Designs should minimize the solar radiation entering the building.	Increase insulation levels for external walls.	LEED
		Deploying a green roof on the building which can reduce the temperature inside the building.	
		Install double glazing.	
		Install sun shading on the windows to minimize heat flow inside the building.	
13	Air Conditioning should be replaced with natural ventilation, increasing energy efficiency, comfort and causing less noise for residents.	Use openable windows on appropriate sides of building to improve the building performance and to achieve comfort for residents.	ENERGY STAR
		Improve the natural ventilation system.	
		Install a smart air conditioning system that suitable with the Saudi energy efficiency scheme with rating A.	

These sustainability interventions will form the initial for the SHSF, these interventions will be filtered and ordered by the other sustainability factors within the SHSF.

7.3.2. Building requirements

Many studies have shown the importance of building requirements for the development of domestic rating methods in developing countries (Mao et al., 2009; Sinou & Kyvelou, 2006).

Moreover, the importance of considering these elements in the environmental and sustainable assessment tools have also been addressed in several studies in the field of sustainability (Raji Banani et al., 2016; Hamedani & Huber, 2012).

Table 42 lists the same interventions in Section 7.3.1, to provide a list of building requirements for each of these interventions. The purpose of this Table is to inform the framework as to what restrictions are placed on the deployment of each sustainable design intervention. These restrictions were summarised from literature reviews from a previous studies in Saudi Arabia in the area of sustainability and different sustainability standards such BREEAM in the UK and LEED in the USA (Ahn, Jung, Suh, & Jeon, 2016; Al-Saggaf, Nasir, & Taha, 2020; Alyami & Rezgui, 2012; Awadh, 2017; Raji Banani et al., 2016; Chitchyan et al., 2016; Hamedani & Huber, 2012; Liu, Luo, Zhang, & Hang, 2018; Loftness, Hakkinen, Adan, & Nevalainen, 2007; Montazeri & Montazeri, 2018; Rahman et al., 2022; Saputri & Lee, 2016; N. Sun, Cui, & Jiang, 2018; Tharim & Samad, 2016; Yussof & Ho, 2022; Zanni et al., 2017).

Table 42: List of building requirements

NO	Sustainable Design Intervention	Building Requirements
1	Ensure of the availability of the required materials for the building to avoid delays and wastage.	None
2	Select materials with lowest manufacturing environmental costs.	None
3	Select high performance materials to save on operation costs.	None
4	Select material with appropriate life span to avoid having to replace during building lifetime.	None

5	Use openable windows on appropriate sides of building to improve the building performance and to achieve comfort for residents.	Sufficient area of glass façade.
6	Reduce the amount of glass in the façade on appropriate building facades to decrease solar radiation.	Sufficient area of glass on other facades.
7	Install sun shading on the windows to minimize heat gain inside the building.	Sufficient area of glass façade.
		Sufficient structural strength in external walls to install shadings.
8	Specify heating/cooling systems capacities based on anticipated temperatures for the region concerned.	Sufficient space/infrastructure to install sensors
		Sufficient space to install heating/cooling devices.
		Sufficient space to install automatic control system
9	Specify insulation level to provide the suitable internal temperature.	Correct wall types to allow for installation of insulation.
10	Deploy a green roof on the building.	Suitable roof strength.

11	Install suitably smart heating and/or air conditioning system that can control the internal temperature automatically to prevent under or overheating.	Sufficient space/infrastructure to install sensors.
		Sufficient space to install heating/cooling devices.
12	Install water storage tank insulation to the water tank to provide a suitable temperature for the water to the residents.	Sufficient area on roof, ground or in roof space to place the water tank.
13	Install facilities to allow for waste separation.	Sufficient outdoor space.
14	Install a bin to recycle construction waste which protect the Environment.	None
15	Design the recycling bins place to be close to the building.	Sufficient outdoor space.
16	Change bulbs inside the house to LED.	None
17	Replace the old air conditioning devices to new devices that suitable with the Saudi energy efficiency scheme with rating A.	None
18	Replace the old heating devices to new devices that suitable with the Saudi energy efficiency scheme with rating A.	None
19	Replace the old boiler device to new boiler that suitable with the Saudi energy efficiency scheme with rating A.	None

<table>
<tr><td>20</td><td>Replace old devices such as TV, fridge, washing machine, and dish washer that suitable with the Saudi energy efficiency scheme with rating A.</td><td>None</td></tr>
<tr><td>21</td><td>Provide the maintenance information to the owner.</td><td>None</td></tr>
<tr><td rowspan="2">22</td><td rowspan="2">Install smart technologies to monitor the status of the building elements.</td><td>Sufficient space/infrastructure to install sensors.</td></tr>
<tr><td>A suitable location to install the control unit.</td></tr>
<tr><td rowspan="2">23</td><td rowspan="2">Install sensors to monitor the status of the building elements.</td><td>Access to main supply in appropriate locations for sensor installation</td></tr>
<tr><td>A suitable location to install the control unit.</td></tr>
<tr><td>24</td><td>Install solid wall insulation.</td><td>None</td></tr>
<tr><td rowspan="2">25</td><td rowspan="2">Install solid roof insulation.</td><td>Access to the roof via a staircase.</td></tr>
<tr><td>A suitable thickness of the roof slab.</td></tr>
<tr><td>26</td><td>Install low-e glass</td><td>Sufficient area of glass façade.</td></tr>
</table>

27	Install thermal mass	None
28	Stack ventilation by using temperature differences to move air.	Sufficient area of glass façade.
29	Installing double glazing.	None
30	Install flow control devices that control the water supply to the WC facilities to minimise undetected wastage and leaks from sanitary fittings and supply pipework.	Access to mains electricity supply in appropriate locations for sensor installation.
		Sufficient space volume cisterns in appropriate locations reduce the amount of used water.
31	Using toilet facilities which can detect the leakage of water.	Access to main supply in appropriate locations for sensor installation.
32	Install water saving devices for toilet facilities.	Access to main supply in appropriate locations for sensor installation.
33	Aerated/Water Saving Shower head.	Must have a shower
34	Install solar panels.	Sufficient roof area.
		Sufficient outside area.

35	Install solar hot water heating panels.	Sufficient roof area. Sufficient outside area.
36	Deploy the wind catchers.	Sufficient roof area. Sufficient outside area.
37	Buy a new smart boiler which can control the water temperature.	None
38	Add a timer to existing boiler.	None
39	Improve the natural ventilation system.	Sufficient façade area

7.3.3. Cultural factors

Several of these sustainable design interventions will thus be more or less desirable depending on the culture of the homeowner. This is primarily because, the culture of the Kingdom of Saudi Arabia differs from many other countries. For example, the usage of spatial walls and boundaries are the most essential design aspect for inhabitants, as these are the major way of achieving privacy (Abu-Gaueh, 1995). This requires building developers in Saudi Arabia to negotiate both cultural and technological realities to produce buildings that implement sustainable design principles while still fulfilling cultural expectations (Abu-Gaueh, 1995; Pushkar et al., 2005). These factors are assessed, and the impact is formalised numerically in the cultural impact column.

In Saudi Arabia and the Gulf countries because of poorly designed buildings, nearly 80% of the electricity in the house is used for air conditioning and cooling purposes (Akbari et al., 1996; Elnabawi, 2021; H. M. Taleb & Sharples, 2011) (as described in Section 6.6). Furthermore, the residential sector is booming because of rapid population growth and increased urbanization, accounting for more than half of the country's energy needs (Al-Shehri, 2008; Rahman et al., 2022). Moreover, Saudi Arabia electricity generation is entirely reliant on the unsustainable practice of burning fossil fuels, which has significant environmental consequences for the climate, air, land, and water (Kamal, 2014; H. Taleb, 2009; H. M. Taleb & Sharples, 2011).

The following Table lists the same interventions in Section 7.3.1 and provides a list of cultural considerations for each of these interventions. This list of cultural considerations has been derived through the literature review conducted in Chapter 6 which described the requirements for achieving more sustainable designs with more consideration of resident's culture in Saudi Arabia. Chapter 6 found that, culture, especially privacy, has a clear impact on how buildings are designed and constructed and, thus, it must be considered in the framework to achieve comfort for the residents, in a balance with sustainability. To summarise, the key aspects of culture that should be considered are:

1. Privacy in Saudi Arabia is central to the design of any house (Abu-Gaueh, 1995). For example, the usage of spatial walls and boundaries is an essential design aspect for residents to achieve privacy which is a religious duty for Muslims (Abu-Gaueh, 1995).
2. Saudi Arabian culture has been described as the most conservative culture in the world (Nordin, 2018). For example, architects in Saudi Arabia create physical barriers using walls, curtains, and other kinds of barriers to separate between residents and gusts, which is required by Islam (Abu-Gaueh, 1995).
3. Because privacy is important to Islamic domestic buildings, some elements in the design, for example, the size of windows also affect the comfort of the residents and actions inside the house. This is because, the ability to see into the house, especially from the street, is highly undesirable for residents, due to their need to maintain their privacy (Heathcote, 2012).
4. Different cultural groups require different residential typologies, space designs and visual expressions (Zejnilovic & Husukic, 2018).

Table 43 shows the cultural impact of achieving more sustainable designs in Saudi Arabia. The purpose of this Table is to inform the framework of what restrictions are placed on the deployment of each sustainable design intervention.

The Table below was generated based on an analysis of the interventions against the cultural factors described above.

In the Table 43 the sustainable design intervention will be rated from 1 to 3 (1= Acceptable, 2= Neutral, 3= Not acceptable) for the cultural impact. This rating was extracting from a literature review conducted in the area of the impact of culture on buildings (as discussed in Chapter 6) and surveys for both public and experts (as discussed and answered in Chapter 4 and 5). The specific questions asked were (E represents a question from expert survey, P a question from public survey):

- P-Q8 - Do you have separate guest rooms for females and males?
- P-Q9 - How many guest rooms do you have for females in your property?
- P-Q11-Q17 - Have you heard about the following sustainability concepts: (Green roof, Solar panels, Double glazing, Cross ventilation, Wind catchers, Thermal mass, Concrete with quality temperature control (CCTC))?
- P-Q19 - If you were to change the windows in your house, would you considered using windows that would achieve more natural light and air circulation?
- P-Q20 - If you were to change your current house in your future, do you prefer to a design with internal walls or open plan?
- P-Q21 - If you were to change your current house in your future, do you prefer comfort features or focus more on consideration of sustainable design?
- P-Q22 - Would you consider buying a new house of a different size/shape/orientation to help contribute to a more sustainable environment?
- E-Q22 - Considering privacy requirements of Saudi Arabian culture, will changing the design basis of buildings from internal boundaries to open plan prove successful?
- P-Q23 - Would you consider buying a new house with different colour/ materials/finishing to contribute to a more sustainable environment?

Table 43: The effect of culture on the Saudi buildings

NO	Sustainable Design Intervention	Rating of Cultural Impact
1	Ensure of the availability of the required materials for the building to avoid delays and wastage.	1
2	Select materials with lowest manufacturing environmental costs.	1
3	Select high performance materials to save on operation costs.	1
4	Select material with appropriate life span to avoid having to replace during building lifetime.	1

5	Use openable windows on appropriate sides of building to improve the building performance and to achieve comfort for residents.	3
6	Reduce the amount of glass in the façade on appropriate building facades to decrease solar radiation.	1
7	Install sun shading on the windows to minimize heat gain inside the building.	1
8	Specify heating/cooling systems capacities based on anticipated temperatures for the region concerned.	1
9	Specify insulation level to provide the suitable internal temperature.	1
10	Deploy a green roof on the building.	1
11	Install suitably smart heating and/or air conditioning system that can control the internal temperature automatically to prevent under or overheating.	1
12	Install water storage tank insulation to the water tank to provide a suitable temperature for the water to the residents.	1
13	Install facilities to allow for waste separation.	1
14	Install a bin to recycle construction waste which protect the Environment.	1
15	Design the recycling bins place to be close to the building.	1

16	Change bulbs inside the house to LED.	1
17	Replace the old air conditioning devices to new devices that suitable with the Saudi energy efficiency scheme with rating A.	1
18	Replace the old heating devices to new devices that suitable with the Saudi energy efficiency scheme with rating A.	1
19	Replace the old boiler device to new boiler that suitable with the Saudi energy efficiency scheme with rating A.	1
20	Replace old devices such as TV, fridge, washing machine, and dish washer that suitable with the Saudi energy efficiency scheme with rating A.	1
21	Provide the maintenance information to the owner.	2
22	Install smart technologies to monitor the status of the building elements.	3
23	Install sensors to monitor the status of the building elements.	3
24	Install solid wall insulation.	1
25	Install solid roof insulation.	1
26	Install low-e glass	2
27	Install thermal mass	1
28	Stack ventilation by using temperature differences to move air.	2
29	Installing double glazing.	2

30	Install flow control devices that control the water supply to the WC facilities to minimise undetected wastage and leaks from sanitary fittings and supply pipework.	1
31	Using toilet facilities which can detect the leakage of water.	1
32	Install water saving devices for toilet facilities.	1
33	Aerated/Water Saving Shower head.	1
34	Install solar panels.	1
35	Install solar hot water heating panels.	1
36	Deploy wind catchers.	1
37	Buy a new smart boiler which can control the water temperature.	1
38	Add a timer to existing boiler.	1
39	Improve the natural ventilation system.	3

7.3.4. Economic factors

The main concept of sustainability has been categorized into the environmental, social and economic dimensions (Berardi, 2013). In the Middle East sustainability is faced the most challenging circumstances to be achieved. Middle Eastern countries have tried to find the sources to understand and implement sustainability in the countries (Issa & Al Abbar, 2015).

Table 44 provides a list of the same interventions in Section 7.3.1, to provide a summary of economic impact of implementing them. The Table is summarised by conducting a literature review to analyse the economic impact of implementing the various sustainability interventions. In the Table the sustainable design intervention will be rated from 1 to 3 (1= Low cost, 2= Medium cost, 3= High cost). This rating was extracting from literature review in the area of the impact of buildings on economy and the impact of these interventions on achieving more sustainable designs and surveys for both public and experts (as discussed and answered in Chapter 4 and 5). The specific questions were (E represents a question from expert survey, P a question from public survey):

- P-Q11, Q12, Q13, Q14, Q15, Q16, Q17 - Have you heard about the following sustainability concepts: (Green roof, Solar panels, Double glazing, Cross ventilation, Wind catchers, Thermal mass, Concrete with quality temperature control (CCTC))?
- P-Q20 - If you were to change your current house in your future, do you prefer to a design with internal walls or open plan?
- P-Q21 - If you were to change your current house in your future, do you prefer comfort features or focus more on consideration of sustainable design?
- P-Q22 - Would you consider buying a new house of a different size/shape/orientation to help contribute to a more sustainable environment?
- P-Q23 - Would you consider buying a new house with different colour/ materials/finishing to contribute to a more sustainable environment?
- E-Q25 - Will changing the location and the size of the windows of a building help improve its sustainability?
- E-Q26 - Do Saudi Arabian families prefer to homes built in comfort features more than ones built with more on consideration of sustainable design?

(Abubakar et al., 2014; Ahn et al., 2016; Alhumayn et al., 2017; Alshehry & Belloumi, 2015; Asif, 2016; Berardi, 2013; Issa & Al Abbar, 2015; Kamal, 2014; Langston & Mackley, 1998; Mahmood et al., 2019; Pérez-Lombard, Ortiz, & Pout, 2008; Sow, 2014; Zhao & Magoulès, 2012; Zhou et al., 2015).

Table 44: The effect of economy on the Saudi buildings

NO	Sustainable Design Intervention	Economic factors
1	Ensure of the availability of the required materials for the building to avoid delays and wastage.	1
2	Select materials with lowest manufacturing environmental costs.	2
3	Select high performance materials to save on operation costs.	2

4	Select material with appropriate life span to avoid having to replace during building lifetime.	3
5	Use openable windows on appropriate sides of building to improve the building performance and to achieve comfort for residents.	2
6	Reduce the amount of glass in the façade on appropriate building facades to decrease solar radiation.	1
7	Install sun shading on the windows to minimize heat gain inside the building.	3
8	Specify heating/cooling systems capacities based on anticipated temperatures for the region concerned.	3
9	Specify insulation level to provide the suitable internal temperature.	2
10	Deploy a green roof on the building.	3
11	Install suitably smart heating and/or air conditioning system that can control the internal temperature automatically to prevent under or overheating.	2
12	Install water storage tank insulation to the water tank to provide a suitable temperature for the water to the residents.	2
13	Install facilities to allow for waste separation.	1
14	Install a bin to recycle construction waste which protect the Environment.	1

15	Design the recycling bins place to be close to the building.	1
16	Change bulbs inside the house to LED.	2
17	Replace the old air conditioning devices to new devices that suitable with the Saudi energy efficiency scheme with rating A.	1
18	Replace the old heating devices to new devices that suitable with the Saudi energy efficiency scheme with rating A.	1
19	Replace the old boiler device to new boiler that suitable with the Saudi energy efficiency scheme with rating A.	1
20	Replace old devices such as TV, fridge, washing machine, and dish washer that suitable with the Saudi energy efficiency scheme with rating A.	1
21	Provide the maintenance information to the owner.	1
22	Install smart technologies to monitor the status of the building elements.	2
23	Install sensors to monitor the status of the building elements.	2
24	Install solid wall insulation.	1
25	Install solid roof insulation.	1
26	Install low-e glass	3
27	Install thermal mass	2
28	Stack ventilation by using temperature differences to move air.	1

29	Installing double glazing.	2
30	Install flow control devices that control the water supply to the WC facilities to minimise undetected wastage and leaks from sanitary fittings and supply pipework.	2
31	Using toilet facilities which can detect the leakage of water.	2
32	Install water saving devices for toilet facilities.	2
33	Aerated/Water Saving Shower head.	1
34	Install solar panels.	3
35	Install solar hot water heating panels.	3
36	Deploy wind catchers.	3
37	Buy a new smart boiler which can control the water temperature.	2
38	Add a timer to existing boiler.	2
39	Improve the natural ventilation system.	1

7.3.5. Climate requirements

Saudi Arabia is one of the hottest countries in the world with lower humidity, except in summer months along the coastal regions and mountainous regions (Krishna, 2014). The climate of Saudi Arabia is comprised of extreme heat and aridity. It is one of a few countries in the world where the temperature during summer gets above 50°C (Krishna, 2014). In inland regions, the average temperature ranges from 27°C to 43°C while coastal cities such as Jeddah city experience from 27 to 38°C (Krishna, 2014). In addition, in 2010, Jeddah which is next to Mecca measured a record-breaking temperature of 52◦C with a very high percentage of humidity (Abdou, 2014; Almazroui, Islam, Dambul, & Jones, 2014; Krishna, 2014).

However, the mountainous regions in the southwest cities such as Abha and Albaha experience mild temperatures from 22°C to 30°C in the summer months and the temperature is reduced from 7°C to 14°C in winter months (Krishna, 2014).

Therefore, selecting appropriate architectural design features will provide a significant chance to control heat flows from outside to inside of the building, to decrease energy consumption costs, and maximize building energy performance, and to keep a comfortable temperature for residents (Al-Saggaf et al., 2020).

Table 45 provides a list of some interventions from Section 7.3.1 to provide a summary of climate impact of implementing them. The Table was developed by conducting a literature review to analyse the climate requirements of implementing the various sustainability interventions. In the Table the sustainable design intervention will be rated to be implemented or not implemented depending on the weather of different regions in Saudi Arabia (as described previously).

(Abdou, 2014; Al-Saggaf et al., 2020; M. Al Surf et al., 2012; Almazroui et al., 2014; Alrashed & Asif, 2015; Change, 2007; GamalEldine & Corvacho, 2022; R Hyde, 2000; Richard Hyde, 2013; Krishna, 2014; Mirrahimi et al., 2016; Shohan & Gadi, 2020).

Table 45: List of climate requirements

NO	Sustainable Design Intervention	Climate requirements
1	Ensure of the availability of the required materials for the building to avoid delays and wastage.	Can be implemented in hot and dry, hot and humid, and cold Saudi Arabian Climates.
2	Select materials with lowest manufacturing environmental costs.	Can be implemented in hot and dry, hot and humid, and cold Saudi Arabian Climates.
3	Select high performance materials to save on operation costs.	Can be implemented in hot and dry, hot and humid, and cold Saudi Arabian Climates.

4	Select material with appropriate life span to avoid having to replace during building lifetime.	Can be implemented in hot and dry, hot and humid, and cold Saudi Arabian Climates.
5	Use openable windows on appropriate sides of building to improve the building performance and to achieve comfort for residents.	Can be implemented in hot and dry, hot and humid, and cold Saudi Arabian Climates.
6	Reduce the amount of glass in the façade on appropriate building facades to decrease solar radiation.	Can be implemented in both hot and dry, and hot and humid Saudi Arabian Climates.
7	Install sun shading on the windows to minimize heat gain inside the building.	Can be implemented in both hot and dry, and hot and humid Saudi Arabian Climates.
8	Specify heating/cooling systems capacities based on anticipated temperatures for the region concerned.	Can be implemented in hot and dry, hot and humid, and cold Saudi Arabian Climates.
9	Specify insulation level to provide the suitable internal temperature.	Can be implemented in hot and dry, hot and humid, and cold Saudi Arabian Climates.
10	Deploy a green roof on the building.	Can be implemented in hot and dry, hot and humid, and cold Saudi Arabian Climates.

11	Install suitably smart heating and/or air conditioning system that can control the internal temperature automatically to prevent under or overheating.	Can be implemented in hot and dry, hot and humid, and cold Saudi Arabian Climates.
12	Install water storage tank insulation to the water tank to provide a suitable temperature for the water to the residents.	Can be implemented in both hot and dry, and hot and humid Saudi Arabian Climates.
13	Install facilities to allow for waste separation.	Can be implemented in hot and dry, hot and humid, and cold Saudi Arabian Climates.
14	Install a bin to recycle construction waste which protect the Environment.	Can be implemented in hot and dry, hot and humid, and cold Saudi Arabian Climates.
15	Design the recycling bins place to be close to the building.	Can be implemented in hot and dry, hot and humid, and cold Saudi Arabian Climates.
16	Change bulbs inside the house to LED.	Can be implemented in hot and dry, hot and humid, and cold Saudi Arabian Climates.
17	Replace the old air conditioning devices to new devices that suitable with the Saudi energy efficiency scheme with rating A.	Can be implemented in hot and dry, hot and humid, and cold Saudi Arabian Climates.

18	Replace the old heating devices to new devices that suitable with the Saudi energy efficiency scheme with rating A.	Can be implemented in hot and dry, hot and humid, and cold Saudi Arabian Climates.
19	Replace the old boiler device to new boiler that suitable with the Saudi energy efficiency scheme with rating A.	Can be implemented in hot and dry, hot and humid, and cold Saudi Arabian Climates.
20	Replace old devices such as TV, fridge, washing machine, and dish washer that suitable with the Saudi energy efficiency scheme with rating A.	Can be implemented in hot and dry, hot and humid, and cold Saudi Arabian Climates.
21	Provide the maintenance information to the owner.	Can be implemented in hot and dry, hot and humid, and cold Saudi Arabian Climates.
22	Install smart technologies to monitor the status of the building elements.	Can be implemented in hot and dry, hot and humid, and cold Saudi Arabian Climates.
23	Install sensors to monitor the status of the building elements.	Can be implemented in hot and dry, hot and humid, and cold Saudi Arabian Climates.
24	Install solid wall insulation.	Can be implemented in both hot and dry, and hot and humid Saudi Arabian Climates.

25	Install solid roof insulation.	Can be implemented in both hot and dry, and hot and humid Saudi Arabian Climates.
26	Install low-e glass	Can be implemented in both hot and dry, and hot and humid Saudi Arabian Climates.
27	Install thermal mass	Can be implemented in hot and dry, hot and humid, and cold Saudi Arabian Climates.
28	Stack ventilation by using temperature differences to move air.	Can be implemented in both hot and dry, and hot and humid Saudi Arabian Climates.
29	Installing double glazing.	Can be implemented in cold Saudi Arabian Climate.
30	Install flow control devices that control the water supply to the WC facilities to minimise undetected wastage and leaks from sanitary fittings and supply pipework.	Can be implemented in hot and dry, hot and humid, and cold Saudi Arabian Climates.
31	Using toilet facilities which can detect the leakage of water.	Can be implemented in hot and dry, hot and humid, and cold Saudi Arabian Climates.

32	Install water saving devices for toilet facilities.	Can be implemented in hot and dry, hot and humid, and cold Saudi Arabian Climates.
33	Aerated/Water Saving Shower head.	Can be implemented in hot and dry, hot and humid, and cold Saudi Arabian Climates.
34	Install solar panels.	Can be implemented in hot and dry, hot and humid, and cold Saudi Arabian Climates.
35	Install solar hot water heating panels.	Can be implemented in hot and dry, hot and humid, and cold Saudi Arabian Climates.
36	Deploy wind catchers.	Can be implemented in hot and dry, hot and humid, and cold Saudi Arabian Climates.
37	Buy a new smart boiler which can control the water temperature.	Can be implemented in hot and dry, hot and humid, and cold Saudi Arabian Climates.
38	Add a timer to existing boiler.	Can be implemented in hot and dry, hot and humid, and cold Saudi Arabian Climates.

39	Improve the natural ventilation system.	Can be implemented in hot and dry, hot and humid, and cold Saudi Arabian Climates.

7.3.6. Sustainability impact

Major research effort has been expended in recent years to investigate ways to decrease the environmental effects around the world of both the built environment and products. Most of this work has concentrated on decreasing the effects of the manufacturing and disposal phases of the lifecycle, resulting in useful work in design for environmentally friendly products, and dematerialisation (Lilley, Wilson, Bhamra, Hanratty, & Tang, 2017).

However, little attention has been paid to the effect of the usage process of the lifecycle and the environmental influences that can occur there, especially because of how the consumer interacts with the product. This is beginning to change as more research shows that without considering the operational phase, especially the user behaviour element, sustainable designs will not be able to achieve the full potential. Moreover, a new research area known as Design for Sustainable Behaviour has developed, which is involved with the application of behavioural theory to understand consumers, as well as behaviour changing techniques to design products, facilities, and systems that promote more sustainable usage in life (Lilley et al., 2017).

Table 46 provides a list of the same interventions in Section 7.3.1, to provide a summary of sustainability impact of implementing them. The Table is summarised by conducting a literature review to analyse the sustainability impact of implementing the various sustainability interventions. In this section the primary impact of sustainability is judged based on the energy saving impact of the intervention, this was done because the energy saving potential of the intervention will have significant impact in the operational energy consumption of the building and thus its sustainability (Akadiri et al., 2012; M. Al Surf et al., 2012; Balabel & Alwetaishi, 2021; Raji Banani et al., 2016; Giddings et al., 2023).

In the Table, the sustainable design intervention will be rated from 1 to 3 (1= Low energy impact, 2= Medium energy impact, 3= High energy impact). This rating was extracting from literature review in the impact of buildings on energy saving, economy, and the impact of these interventions on achieving more sustainable designs and surveys for both public and experts (as discussed and answered in Chapter 4 and 5). The specific questions were (E represents a question from expert survey, P a question from public survey):

- P-Q11, Q12, Q13, Q14, Q15, Q16, Q17 - Have you heard about the following sustainability concepts: (Green roof, Solar panels, Double glazing, Cross ventilation, Wind catchers, Thermal mass, Concrete with quality temperature control (CCTC))?
- P-Q20 - If you were to change your current house in your future, do you prefer to a design with internal walls or open plan?
- P-Q21 - If you were to change your current house in your future, do you prefer comfort features or focus more on consideration of sustainable design?
- P-Q22 - Would you consider buying a new house of a different size/shape/orientation to help contribute to a more sustainable environment?
- P-Q23 - Would you consider buying a new house with different colour/ materials/finishing to contribute to a more sustainable environment?
- E-Q24 - Will changing colours, materials, and finishing of the building help improve its sustainability?
- E-Q25 - Will changing the location and the size of the windows of a building help improve its sustainability?
- E-Q26 - Do Saudi Arabian families prefer to homes built with comfort features more than ones built with more on consideration of sustainable design?

(Abubakar et al., 2014; Ahn et al., 2016; Alhumayn et al., 2017; Alshehry & Belloumi, 2015; Asif, 2016; Elnabawi, 2021; GamalEldine & Corvacho, 2022; Giddings et al., 2023; Issa & Al Abbar, 2015; Kamal, 2014; Langston & Mackley, 1998; Lilley et al., 2017; Mahmood et al., 2019; Mahmud, 2009; Onososen & Musonda, 2022; Rahman et al., 2022; Sow, 2014; Zhao & Magoulès, 2012; Zhou et al., 2015).

Table 46: The effect of energy saving on the Saudi buildings

NO	Sustainable Design Intervention	Energy saving impact		
		Hot + Dry	**Hot + Humid**	**Cold**
1	Ensure of the availability of the required materials for the building to avoid delays and wastage.	1	1	1
2	Select materials with lowest manufacturing environmental costs.	2	2	2
3	Select high performance materials to save on operation costs.	3	3	3
4	Select material with appropriate life span to avoid having to replace during building lifetime.	3	3	3
5	Use openable windows on appropriate sides of building to improve the building performance and to achieve comfort for residents.	3	3	1
6	Reduce the amount of glass in the façade on appropriate building facades to decrease solar radiation.	3	3	NA

7	Install sun shading on the windows to minimize heat gain inside the building.	3	3	NA
8	Specify heating/cooling systems capacities based on anticipated temperatures for the region concerned.	3	3	3
9	Specify insulation level to provide the suitable internal temperature.	3	3	2
10	Deploy a green roof on the building.	3	3	1
11	Install suitably smart heating and/or air conditioning system that can control the internal temperature automatically to prevent under or overheating.	3	3	3
12	Install water storage tank insulation to the water tank to provide a suitable temperature for the water to the residents.	3	3	NA
13	Install facilities to allow for waste separation.	1	1	NA
14	Install a bin to recycle construction waste which protect the Environment.	NA	NA	NA
15	Design the recycling bins place to be close to the building.	NA	NA	NA
16	Change bulbs inside the house to LED.	3	3	3

17	Replace the old air conditioning devices to new devices that suitable with the Saudi energy efficiency scheme with rating A.	3	3	1
18	Replace the old heating devices to new devices that suitable with the Saudi energy efficiency scheme with rating A.	1	1	3
19	Replace the old boiler device to new boiler that suitable with the Saudi energy efficiency scheme with rating A.	1	1	3
20	Replace old devices such as TV, fridge, washing machine, and dish washer that suitable with the Saudi energy efficiency scheme with rating A.	3	3	3
21	Provide the maintenance information to the owner.	2	2	2
22	Install smart technologies to monitor the status of the building elements.	3	3	3
23	Install sensors to monitor the status of the building elements.	3	3	3
24	Install solid wall insulation.	3	3	NA
25	Install solid roof insulation.	3	3	NA
26	Install low-e glass	3	3	NA

27	Install thermal mass	1	1	3
28	Stack ventilation by using temperature differences to move air.	3	3	NA
29	Installing double glazing.	2	2	3
30	Install flow control devices that control the water supply to the WC facilities to minimise undetected wastage and leaks from sanitary fittings and supply pipework.	1	1	1
31	Using toilet facilities which can detect the leakage of water.	1	1	1
32	Install water saving devices for toilet facilities.	2	2	2
33	Aerated/Water Saving Shower head.	3	3	3
34	Install solar panels.	3	3	2
35	Install solar hot water heating panels.	3	3	2
36	Deploy wind catchers.	1	1	3
37	Buy a new smart boiler which can control the water temperature.	1	1	3
38	Add a timer to existing boiler.	1	1	3
39	Improve the natural ventilation system.	3	3	3

7.3.7. Data requirements

Data requirements need to be identified within the framework in order to formalise what data must be collected in order for it to function. Table 47 provides a list of the same interventions in Section 7.3.1, to provide a list of data requirements for implementing them. The Table is summarised by conducting a literature review to analyse the data requirements of implementing the various sustainability interventions. The table will present the source of data needed to assess the suitability of each of these interventions:

1. **Survey:** Collecting data by have a discussion with the occupants.
2. **Site survey:** Collecting data by visiting the site to do measurements/conduct and inspection.
3. **BIM:** Accessing data from provided BIM models.
4. **Simulation/BIM linkage:** Use of BIM data and automated translation technologies to conduct simulation (Yeung et al., 2023).

Table 47: List of data requirements

NO	Sustainable Design Intervention	Data Requirements	Source of data
1	Ensure of the availability of the required materials for the building to avoid delays and wastage.	Climate.	Site survey / BIM
		Occupant Budget.	Survey
		Locally available suppliers.	Survey
2	Select materials with lowest manufacturing environmental costs.	Climate.	Site survey / BIM
		Occupant Budget	Survey
		Full measurements and orientation of the site.	Site survey / BIM
3		Occupant Budget.	Product Data

	Select high performance materials to save on operation costs.		Survey
		Full measurements and orientation of the site.	Site survey / BIM
4	Select material with appropriate life span to avoid having to replace during building lifetime.	Occupant Budget	Survey
		Climate.	Site survey / BIM
5	Use openable windows on appropriate sides of building to improve the building performance and to achieve comfort for residents.	Area of glass façade.	Site survey / BIM
		Location of the glass facades.	Site survey / BIM
		Number of Spaces Requiring renewable energy equipment.	Site survey / BIM
		Renewable energy equipment’s location.	Site survey / BIM
		Cultural views of the occupants.	Survey
		Climate.	Site survey / BIM
6	Reduce the amount of glass in the façade on appropriate	Climate.	Site survey / BIM
		Occupant Budget	Survey
			Simulation / BIM Linkage

	building facades to decrease solar radiation.	Comfort levels inside the building.	Survey
		Light level inside the building.	Simulation / BIM Linkage
			Survey
		Natural light level inside the building.	Simulation / BIM Linkage.
			Survey
7	Install sun shading on the windows to minimize heat gain inside the building.	Light level inside the building.	Simulation / BIM Linkage
		Natural light level inside the building.	Simulation / BIM Linkage
			Survey
		Comfort levels inside the building.	Simulation / BIM Linkage
			Survey
		Climate.	Site survey / BIM
		Occupant Budget	Survey

		Full measurements and orientation of the site.	Site survey / BIM
		Structural strength in external walls	Site survey / BIM
8	Specify heating/cooling systems capacities based on anticipated temperatures for the region concerned.	Existing systems.	Site survey / BIM
		Available area for the renewable energy equipment's.	Site survey / BIM
		Climate.	Site survey / BIM
9	Specify insulation level to provide the suitable internal temperature.	Climate.	Site survey / BIM
		Wall types.	Site survey / BIM
		Wall area.	Site survey / BIM
		Average Internal Temperature.	Simulation / BIM Linkage.
			Survey
		Type of insulation already installed.	Site survey / BIM
		Window Area.	Site survey / BIM
10	Deploy a green roof on the building.	Roof strength.	Site survey / BIM
			Simulation / BIM Linkage

		Average Internal Temperature.	Survey
		Thermal characteristics of the roof.	Simulation / BIM Linkage.
			Survey
		Climate.	Site survey / BIM
11	Install suitably smart heating and/or air conditioning system that can control the internal temperature automatically to prevent under or overheating.	Area available for the renewable energy devices.	Site survey / BIM
		The type of air conditioning.	Site survey / BIM
		Existing sensors.	Site survey / BIM
		Climate.	Site survey / BIM
12	Install water storage tank insulation to the water tank to provide a suitable temperature for the water to the residents.	Area on roof to place the water tank.	Site survey / BIM
		Area on ground to place the water tank.	Site survey / BIM
		Type of water tank installed.	Site survey / BIM
		Climate.	Site survey / BIM

13	Install facilities to allow for waste separation.	Outdoor space available	Site survey / BIM
14	Install a bin to recycle construction waste which protect the Environment.	None	NA
15	Design the recycling bins place to be close to the building.	Outdoor space available.	Site survey / BIM
16	Change bulbs inside the house to LED.	Type of lights installed.	Site survey / BIM
		Number of lights.	Site survey / BIM
		Occupant Budget.	Survey
17	Replace the old air conditioning devices to new devices that suitable with the Saudi energy efficiency scheme with rating A.	Type of devices already installed.	Site survey / BIM
		Quantity of devices installed.	Site survey / BIM
		Capacity of devices already installed.	Site survey / BIM
18	Replace the old heating devices to new devices that suitable with the Saudi energy efficiency scheme with rating A.	Type of devices already installed.	Site survey / BIM
		Quantity of devices installed.	Site survey / BIM

		Capacity of devices already installed.	Site survey / BIM
19	Replace the old boiler device to new boiler that suitable with the Saudi energy efficiency scheme with rating A.	Number of Spaces requiring heating.	Site survey / BIM
		Type of devices already installed.	Site survey / BIM
		Quantity of devices installed.	Site survey / BIM
		Capacity of devices already installed.	Site survey / BIM
20	Replace old devices such as TV, fridge, washing machine, and dish washer that suitable with the Saudi energy efficiency scheme with rating A.	Number of devices.	Site survey / BIM
		Specification of existing devices.	Site survey / BIM
21	Provide the maintenance information to the owner.	Maintenance dates.	Site survey / BIM
		Occupant budget.	Survey
		Specification of existing components.	Site survey / BIM
		Performance information of the building.	Simulation / BIM Linkage
			Survey

		Contact information for maintenance.	Site survey / BIM
		The cultural issues of the occupants, such as the privacy.	Survey
22	Install smart technologies to monitor the status of the building elements.	Available space/infrastructure to install sensors.	Site survey / BIM
		Sensors already installed.	Site survey / BIM
		Available space to install the control unit.	Site survey / BIM
		Existing building elements.	Site survey / BIM
23	Install sensors to monitor the status of the building elements.	Available space/infrastructure to install sensors.	Site survey / BIM
		Occupant budget.	Survey
		List of building elements.	Site survey / BIM
		Available location to install the control unit.	Site survey / BIM

24	Install solid wall insulation.	Occupant budget.	Survey
		Climate.	Site survey / BIM
		Existing Wall insulation.	Site survey / BIM
		Wall area.	Site survey / BIM
		Compatible wall type.	Site survey / BIM
25	Install solid roof insulation.	Occupant budget.	Survey
		Roof strength.	Site survey / BIM
		Compatible roof material.	Site survey / BIM
		The type of roof already installed.	Site survey / BIM
		Climate	Site survey / BIM
26	Install low-e glass	Occupant budget.	Survey
		Full measurements and orientation of the site.	Site survey / BIM
		Structural strength in external walls	BIM
		Climate	Site survey / BIM

27	Install thermal mass	Occupant budget.	Survey
		Full measurements and orientation of the site.	Site survey / BIM
		Structural strength in external walls	BIM
		Climate	Site survey / BIM
28	Stack ventilation by using temperature differences to move air.	Occupant budget.	Survey
		Full measurements and orientation of the site.	Site survey / BIM
		Structural strength in external walls	BIM
		Climate	Site survey / BIM
29	Installing double glazing.	Current properties of existing windows.	Site survey / BIM
		Occupant budget.	Survey
		Climate.	Site survey / BIM
30	Install flow control devices that control the water supply to the WC facilities to minimise	Smart technologies already installed.	Site survey / BIM
		Occupant budget.	Survey

	undetected wastage and leaks from sanitary fittings and supply pipework.	Sanitary facilities installed	Site survey / BIM
31	Using toilet facilities which can detect the leakage of water.	Toilet facilities installed	Site survey / BIM
32	Install water saving devices for toilet facilities.	Toilet facilities installed	Site survey / BIM
		Water saving devices installed.	Site survey / BIM
33	Aerated/Water Saving Shower head.	Existing shower head installed.	Site survey / BIM
34	Install solar panels.	Roof area.	Site survey / BIM
		Climate.	Site survey / BIM
		Outside area available	Site survey / BIM
35	Install solar hot water heating panels.	Roof area.	Site survey / BIM
		Roof weight limit.	Site survey / BIM
		Hot water capacity.	Site survey / BIM
36	Deploy the wind catchers.	Sufficient outside area which not close to facade.	Site survey / BIM

		Sufficient area which not close to facade.	Site survey / BIM
37	Buy a new smart boiler which can control the water temperature.	Capacity of current boiler.	Site survey / BIM
		Environmental efficiency of current boiler.	Site survey / BIM
38	Add a timer to existing boiler.	Type of boiler installed.	Site survey / BIM
39	Improve the natural ventilation system.	Climate.	Site survey / BIM
		Spaces Requiring Ventilation.	Simulation / BIM Linkage
			Survey
		Current average Internal Temperature.	Simulation / BIM Linkage.
			Survey
		Windows Area.	Site survey / BIM
		Current ventilation installed.	Site survey / BIM
		Façade area.	Site survey / BIM

7.4. Removal of unsuitable combinations

Installing energy efficiency measures on any existing or new building will have a positive impact on the performance of the building. However, in some cases applying some measures without appropriate care could seriously have a negative impact and will affect the building's functionality. In certain cases, some interventions may simply be incompatible. Two examples are documented below:

- When comparing intervention 5 against intervention 6 – this shows that reducing the amount of glass in the façade will have an impact on using more openable windows which will affect the natural ventilation system.
- When comparing intervention 5 against intervention 7 – this shows that installing sun shading on the windows will minimize heat gain inside the building but also will affect negatively on the natural ventilation.
- When comparing intervention 10 against intervention 25 – this shows that installing solid roof insulation could affect the deployment of a green roof on the top of the building.
- When comparing intervention 5 against intervention 24 – this shows that installing solid wall insulation could affect using openable windows which effect on the building performance.

Figure 5 shows the full list of unsuitable combinations between the interventions from Section 7.3.1. The Figure is summarised by conducting a literature review to analyse the sustainability impact of implementing the various sustainability interventions. In the Figure the sustainable design intervention will be rated against each other, which is (Green = Yes, Yellow = With Adaption, Red = No).

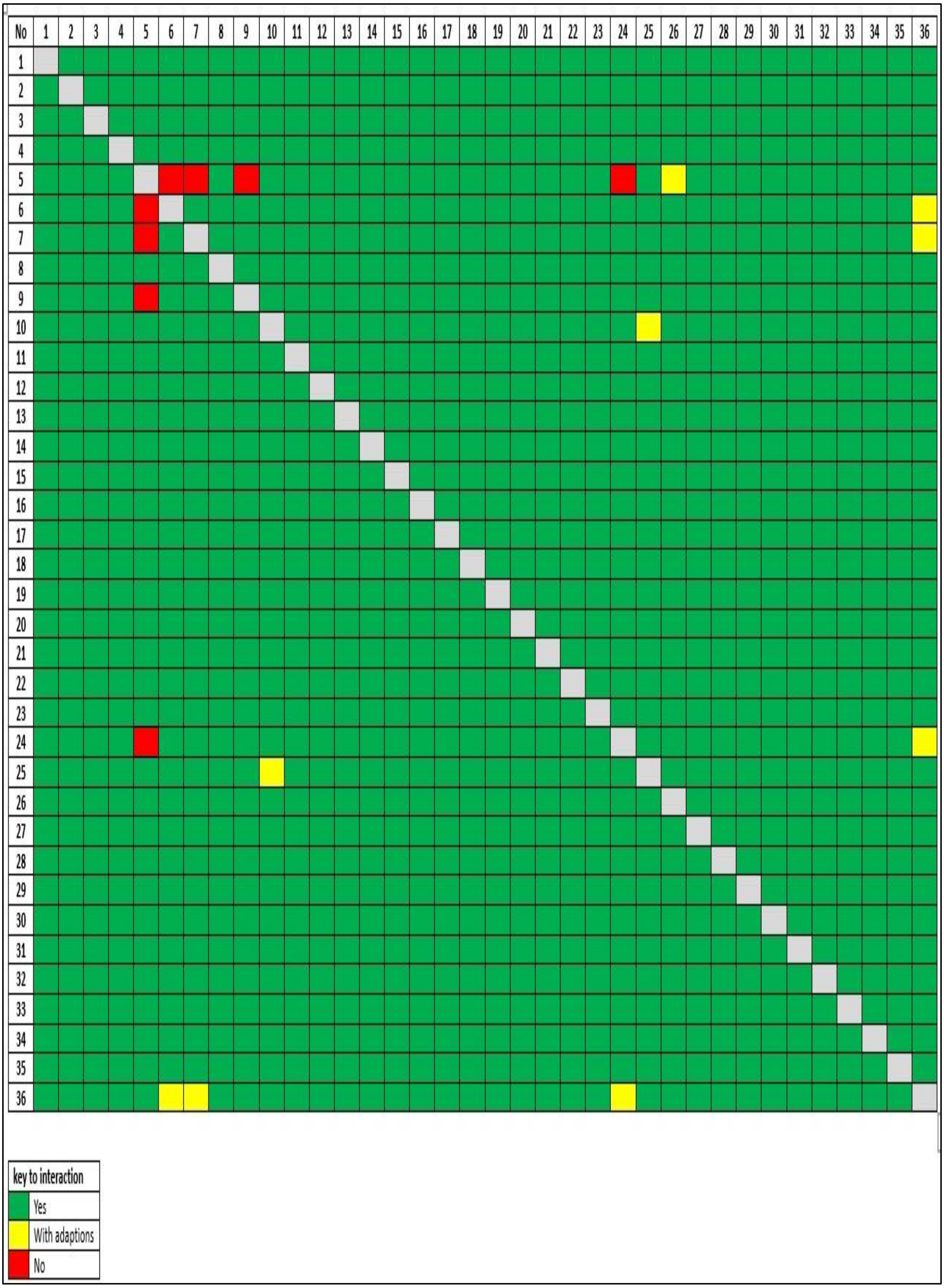


Figure 5: List of unsuitable combinations between the interventions

7.5. Interfacing with the SHSF

This Section will outline how the target framework users i.e., designers and construction professionals will interact with the SHSF, to achieve a more sustainable design for the occupants. Utilizing the framework will allow built environment professionals within Saudi Arabia to, despite the common lack of sustainable design knowledge among them, suggest appropriate sustainable design interventions for homeowners, and understand the importance of sustainable design on the residents' quality of life. Figure 6 shows the following sequence for their interaction with the framework. The list below explains the key points in more detail.

1. Project start by a discussion between the owner and designer, and the framework guides the designer in gathering information related to building design with more sustainability concerns.
2. The designer considers the different factors such as the culture of residents, the climate, and the economic factor and collects data by different ways such as the examples shown in Table 48. In case BIM data is not available, using simulation applications and measurements could be a suitable way to collect the needed data.

Table 48: Example of collecting data

No	Source of Data	Example Data Requirements	Number of Data Points
1	Survey	• Occupant Budget. • The cultural issues of the occupants, such as the privacy. • Locally available suppliers.	11 / 71
2	Site Survey	• Climate. • Full measurements and orientation of the site. • Available area for the renewable energy equipment's.	60 / 71

3	BIM Linkage	• Spaces Requiring Ventilation. • Current average Internal Temperature. • Performance information of the building.	8 / 71
4	BIM	• Windows area. • Façade area. • Current ventilation installed. • Type of boiler installed.	60 /71
5	Simulation	• Spaces Requiring Ventilation. • Current average Internal Temperature. • Performance information of the building.	8 / 71

3. Unsuitable combinations between the interventions are removed.
4. A prioritised list of interventions is developed, firstly eliminating any interventions that are individually outside of the occupant budget.
5. The owner and designer discuss these factors and come up with suitable solutions with more sustainability concerns and the used information will be to filter and prioritise a set of sustainable design interventions. This is done by weighing the energy savings achieved against the budget available and making a selection that provides the best energy savings potential for the available budget.
6. Based on this, the designer can use the framework to propose a set of initial design ideas to the owner.
7. Designers can start the designing process by using BIM tools such as Revit, which can help both owner and designer to achieve a more sustainable design. This can be further refined iteratively between the owner and the designer with framework assistance.

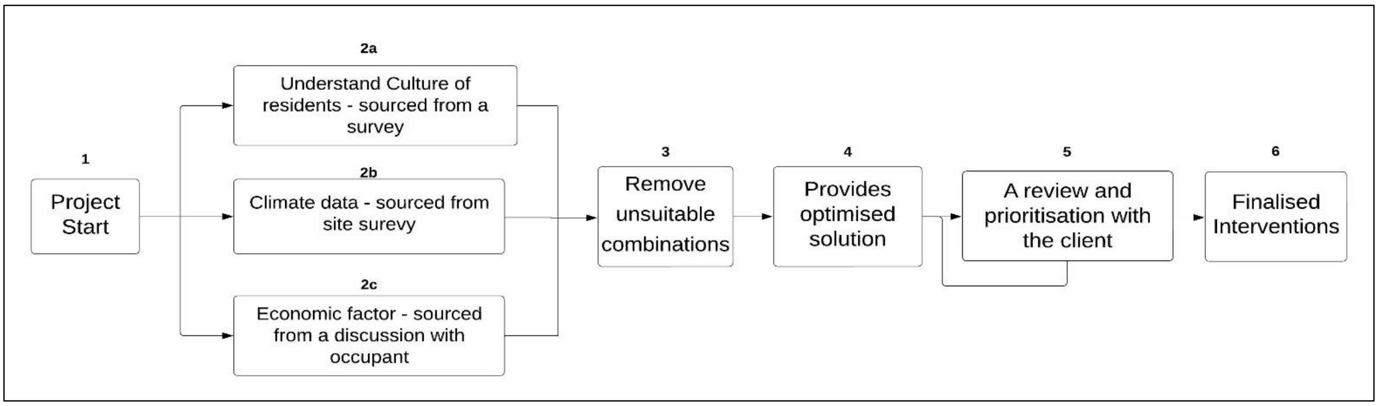


Figure 6: Framework Interface

7.6. Impact of Leveraging BIM in the SHSF

The SHSF is able to leverage BIM data to automate aspects of data collection. For instance, drawings and measurements can be done through BIM tools. More specifically, given a fully populated BIM model 60 of 71 datapoints could be answered through the use of BIM. With some of the remaining datapoints (8 out of 71) BIM tools can help provided there is the technical capability to use BIM models to drive the simulation of building performance such as in (Yeung et al., 2023).

In summary there are only 3 / 71 (occupant budget, locally available suppliers, and cultural views of the occupants) data points that cannot make use of BIM data, mainly these are where there is a need to interact directly with the building occupants.

This summary has shown that a large amount of data collection can saved if a well specified BIM model is present, when the SHSF is utilised. This will pave the way to enabling the refurbishment of many more buildings, should BM adoption increase in Saudi Arabia.

7.7. Conclusion

This Chapter has focused on design of the framework based on systematic literature review and analysis of previous questionnaires results (Chapter 4 and 5) to provide a more sustainable design. The framework derived contains the following aspects:

1. A list of sustainable design interventions for Saudi Arabia,
2. Ratings and rankings of these based on the following criteria:
   (a) Building requirements.
   (b) Cultural factors.
   (c) Economic factors.
   (d) Climate requirements.

(e) Sustainability impact.

(f) Data requirements.

3. The ability to remove incompatible configuration of interventions.

Furthermore, this Chapter has answered the fourth research question (RQ4: How can the experts in the sustainability field understand the resident requirements considering the achievement of sustainability in Saudi Arabia).

To answer the RQ, the Chapter has developed the SHSF which can enable experts in the sustainability field to understand resident requirements by guiding building professionals and designers in specifying appropriate sustainability design requirements which will, in turn, provide suggestions for design to achieve a more sustainable design. It does this by incorporating its set of Saudi Arabia suitable design interventions, rankings, and ratings of these interventions appropriate to Saudi Arabia, based on data collected through a variety of structured means from the residents of the target buildings. Finally, it is able to differentiate, and select between measures based on how they interact with each other.

However, to develop the sustainability of buildings across Saudi Arabia this framework must also consider the culture of the residents' privacy and locality specific factors such as the climate in Saudi Arabia as inputs during the design process as well as more common standard sustainability decision making factors such as energy savings, economics and building characteristics.

BIM can control the data to validate the SHSF to reach a sustainable design for the residents. Moreover, using BIM in the projects can help to refurbish many more buildings. Also, a large number of data can be saved and linked between co-workers by using BIM. All of these data will help to reduce spending time in all the project stages.

The next Chapter (Chapter 8) will provide the validation of the framework by a survey distributed to experts in the engineering field. The questionnaire is examining information required by designers, and possible data sources required by designers in Saudi Arabia on the following:

(a) Buildings interventions.

(b) Building requirements.

(c) Cultural factors.

(d) Climate factors.

(e) Data requirements.

Chapter 8: Validation of the Saudi Housing Sustainability Framework (SHSF)

8.1. Introduction

This Chapter will answer the fifth research question (RQ5: *How can the construction/refurbishment processes of existing traditional Saudi Arabian buildings be changed and improved to achieve a more sustainable design*). This will be answered through, the verification and validation of the framework:

1. Verification that the framework produces expected results for an exemplar building.
2. Validation of the contents of the framework (ratings, information required and data sources) via a questionnaire to an expert group.
3. Respondents from experts showing this framework is effective and has the potential to be used to achieve a more sustainable design in Saudi Arabia.

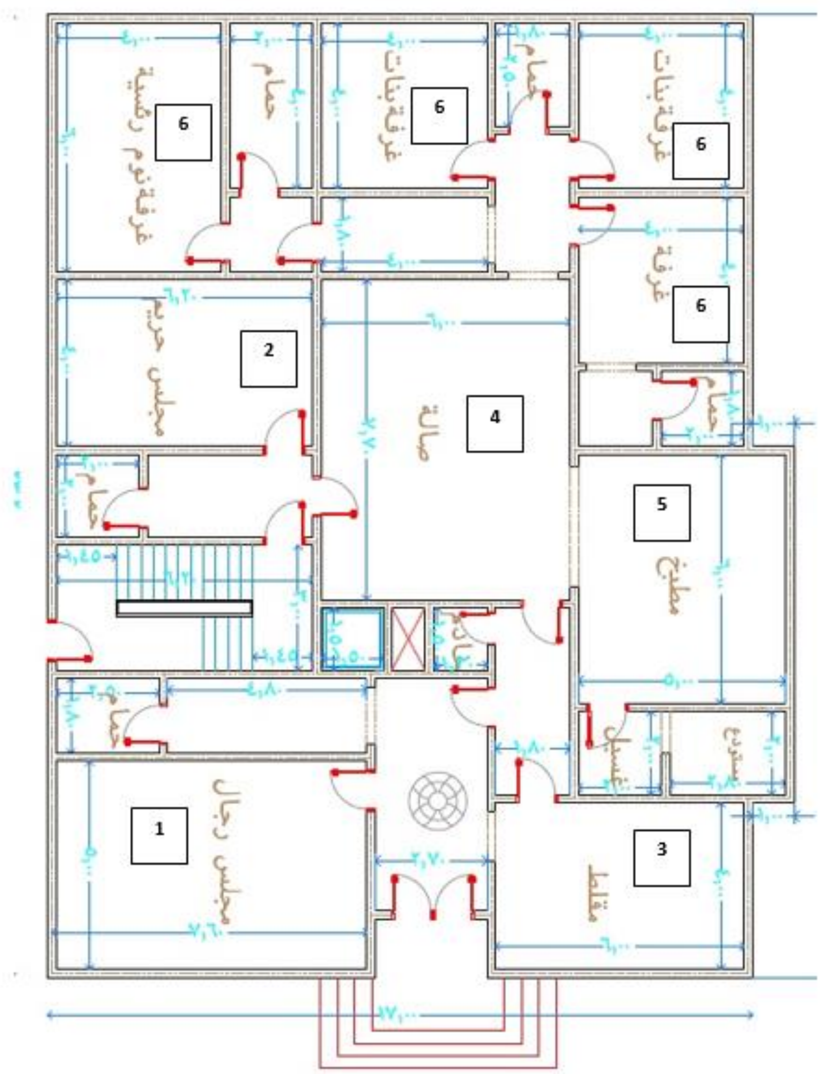
In this Chapter, Section 8.2 presents a verification of the SHSF. Section 8.3 describes information of the expert survey conducted. Section 8.4 will present the validation of the SHSF – Building Interventions. Section 8.5 will validate the need and ability for the SHSF to bridge the gap between occupants, designers, and core sustainability concepts. Section 8.6 will show analyse the effectiveness and potential of SHSF and, finally, Section 8.7 will conclude this Chapter.

8.2. Verification of the SHSF – Use on Exemplar Building

This section will use a typical domsitic building in Albaha City as an exemple building to illustrate and verify the use of the SHSF on a typical domestic property.

Figure 7 shows a typical domestic property in Albaha City in the southwest region of Saudi Arabia. This house is located in Albaha City. This is a mountainous region and experiences milder temperatures from 22°C to 30°C in the summer months and the temperature is reduced to 7°C to 14°C in the winter months (Krishna, 2014).

This means that data from within the framework for the cold Saudi Arabian climate zone has been used. So, choosing a house in this location will shows the advantages of considering the Saudi Arabian climate zones within the framework.



1: Men Sitting.
2: Women Sitting.
3: Guest Dinning Table.
4: Family Living Room.
5: Kitchen.
6: Bedroom.

Figure 7: Typical domestic property in Albaha City

The building has been selected because it is typical of Saudi Arabian dwellings. The floor plan (shown in Figure 7) shows that the men's sitting room and women's sitting room which are separate from each other. This is designed as such due to privacy requirements of Islam. The family living room is in the middle of the house, which is isolated from guests, this achieves privacy for residents but at the cost of being without natural light, or natural ventilation.

Overall, this design means that the energy consumption of the house will be high for lighting and ventilation. Moreover, since Albaha City is very cold in winter, Figure 8 shows the small size of the windows, and shading is applied to keep the privacy of the family from outside the building.

Figure 8: The elevation of the typical house in Saudi Arabia

Table 49 presents same interventions as shown in Section 7.3.1 to identify if these interventions meet the buildings requirements are compatible with occupants' cultural values and meet the climate requirements.

The cultural considerations have been derived by asking the occupants questions about their culture. A BIM model of the building has been used to understand the current state of the building. Moreover, an online weather service has been used to determine the climate.

The culture survey posed to occupants contains the following question:

1. Do you need a separate guest room for females and males?
2. How many separate guests room do you need for females and males?
3. Would you consider using windows that would achieve more natural light and wind circulation?
4. Do you prefer to have internal separating walls or an open plan design?
5. Do you see it as important to prevent unwanted contact between guests and members of the host family in your home?

Table 49: Ranking the sustainable design intervention

No	Sustainable Design Intervention	Meets Building Requirement	Compatible with Occupant Cultural Values	Meeting Climate Requirements	Ranking
1	Ensure of the availability of the required materials for the building to avoid delays and wastage.	NA	Yes	Yes	2
2	Select materials with lowest manufacturing environmental costs.	NA	Yes	Yes	2
3	Select high performance materials to save on operation costs.	NA	Yes	Yes	2
4	Select material with appropriate life span to avoid having to replace during building lifetime.	NA	Yes	Yes	2
5	Use openable windows on appropriate sides of building to improve the building performance and to achieve comfort for residents.	Yes	No	Yes	NA
6	Reduce the amount of glass in the façade on appropriate building facades to decrease solar radiation.	Yes	Yes	No	NA

7	Install sun shading on the windows to minimize heat gain inside the building.	Yes	Yes	No	NA
8	Specify heating/cooling systems capacities based on anticipated temperatures for the region concerned.	Yes	Yes	Yes	1
9	Specify insulation level to provide the suitable internal temperature.	Yes	Yes	Yes	1
10	Deploy a green roof on the building.	Yes	Yes	Yes	1
11	Install suitably smart heating and/or air conditioning system that can control the internal temperature automatically to prevent under or overheating.	Yes	Yes	Yes	1
12	Install water storage tank insulation to the water tank to provide a suitable temperature for the water to the residents.	Yes	Yes	No	NA
13	Install facilities to allow for waste separation.	Yes	Yes	Yes	1
14	Install a bin to recycle construction waste which protect the Environment.	NA	Yes	Yes	2

15	Design the recycling bins place to be close to the building.	Yes	Yes	Yes	1
16	Change bulbs inside the house to LED.	NA	Yes	Yes	2
17	Replace the old air conditioning devices to new devices that suitable with the Saudi energy efficiency scheme with rating A.	NA	Yes	Yes	2
18	Replace the old heating devices to new devices that suitable with the Saudi energy efficiency scheme with rating A.	NA	Yes	Yes	2
19	Replace the old boiler device to new boiler that suitable with the Saudi energy efficiency scheme with rating A.	NA	Yes	Yes	2
20	Replace old devices such as TV, fridge, washing machine, and dish washer that suitable with the Saudi energy efficiency scheme with rating A.	NA	Yes	Yes	2
21	Provide the maintenance information to the owner.	NA	Yes	Yes	2

22	Install smart technologies to monitor the status of the building elements.	Yes	No	Yes	NA
23	Install sensors to monitor the status of the building elements.	Yes	No	Yes	NA
24	Install solid wall insulation.	NA	Yes	No	NA
25	Install solid roof insulation.	Yes	Yes	No	NA
26	Install low-e glass	Yes	Yes	Yes	1
27	Install thermal mass	Yes	Yes	Yes	1
28	Stack ventilation by using temperature differences to move air.	Yes	Yes	Yes	1
29	Installing double glazing.	NA	Yes	Yes	2
30	Install flow control devices that control the water supply to the WC facilities to minimise undetected wastage and leaks from sanitary fittings and supply pipework.	Yes	Yes	No	NA
31	Using toilet facilities which can detect the leakage of water.	Yes	Yes	Yes	1
32	Install water saving devices for toilet facilities.	Yes	Yes	Yes	1

33	Aerated/Water Saving Shower head.	Yes	Yes	Yes	1
34	Install solar panels.	Yes	Yes	Yes	1
35	Install solar hot water heating panels.	Yes	Yes	Yes	1
36	Deploy wind catchers.	Yes	Yes	Yes	1
37	Buy a new smart boiler which can control the water temperature.	NA	Yes	Yes	2
38	Add a timer to existing boiler.	NA	Yes	Yes	2
39	Improve the natural ventilation system.	Yes	No	Yes	NA

8.2.1 Removal of unsuitable combinations

After analysing it can be seen there are no unsuitable combinations to remove.

8.2.2 Selection of Final Interventions

This Section will provide a list of the final interventions that have been derived from using the framework. These are the highest ranked from Table 49, weighed against the occupant's budget.

As mentioned previously, the main goals of the SHSF are to bridge the gap between occupants and designers and to provide ranked recommendations to occupants which help to reduce the amount of spending money which leads to achieving more sustainable designs. Table 50 will identify all of the intervention that are applicable and identify those that are recommended to be deployed. It will also illustrate the cost of these interventions as discussed in Chapter 7. This table documents the process of intervention selection in conjunction with the residents. This takes as input; (a) the energy saving impact of each applicable intervention and (b) the economic impact (i.e. costs). Based on this the prioritised list of interventions is presented, firstly eliminating any interventions that are individually outside of the occupant budget. Then a prioritised list will be selected with the residents considering that total budget.

This is done by weighing the energy savings achieved against the budget available and making a selection that provides the best energy savings potential for the available budget.

Table 50: The selection of Final Interventions

Intervention Name	Energy Saving Impact (1-3)	Economic Impact (1-3)	Budget Comparison	Selected (Yes/No)
Select material with appropriate life span to avoid having to replace during building lifetime.	3	3	Too expensive for resident budget	No.
Install sun shading on the windows to minimize heat gain inside the building.	3	3	Acceptable	Yes
Specify heating/cooling systems capacities based on anticipated temperatures for the region concerned.	3	3	Too expensive for resident budget	No
Deploy a green roof on the building.	3	3	Too expensive for resident budget	No
Install solar panels.	3	3	Yes	No – including this in excess of total budget
Install solar hot water heating panels.	3	3	Too expensive for resident budget	No

Specify heating/cooling systems capacities based on anticipated temperatures for the region concerned	3	3	Too expensive for resident budget	No
Select high performance materials to save on operation costs.	3	2	Too expensive for resident budget	No
Specify insulation level to provide the suitable internal temperature.	3	2	Acceptable	Yes
Install suitably smart heating and/or air conditioning system that can control the internal temperature automatically to prevent under or overheating.	3	2	Acceptable	Yes
Change bulb inside the house to LED.	3	2	Acceptable	Yes
Buy a new smart boiler which can control the water temperature.	3	2	Acceptable	Yes
Replace the old air conditioning devices to new devices that suitable with the Saudi energy efficiency scheme with rating A.	3	1	Acceptable	Yes
Replace old devices such as TV, fridge, washing machine, and dish washer that suitable with the Saudi energy efficiency scheme with rating A.	3	1	Acceptable	Yes
Install solid wall insulation.	3	1	Acceptable	Yes
Install solid roof insulation.	3	1	Acceptable	Yes

Aerated/Water Saving Shower head.	3	1	Acceptable	Yes
Improve the natural ventilation system.	3	1	Acceptable	Yes
Select materials with lowest manufacturing environmental costs.	2	2	Acceptable	Yes
Installing double glazing.	2	2	Acceptable	Yes
Install water saving devices for toilet facilities.	2	2	Acceptable	Yes
Provide the maintenance information to the owner.	2	1	Acceptable	Yes
Deploy wind catchers.	1	3	Too expensive for resident budget	No
Using toilet facilities which can detect the leakage of water.	1	2	Acceptable	Yes
Add a timer to existing boiler.	1	2	Acceptable	No – only marginal energy saving benefit.
Ensure of the availability of the required materials for the building to avoid delays and wastage.	1	1	Acceptable	No – difficult to implement when considering energy savings achieved.
Install facilities to allow for waste separation.	1	1	Acceptable	Yes

Replace the old heating devices to new devices that suitable with the Saudi energy efficiency scheme with rating A.	1	1	Acceptable	Yes
Replace the old boiler device to new boiler that suitable with the Saudi energy efficiency scheme with rating A.	1	1	Acceptable	Yes
Design the recycling bins place to be close to the building.	NA	1	Acceptable	Yes

Since the Saudi Housing Sustainability Framework (SHSF) provides ranked sustainability interventions and suggestions to the designer in order to deliver an increasing level of adoption of sustainable design. This then enables a discussion between the designer and occupants to be held to which interventions an occupants' budget will allow them to undertake.

8.2.3 Conclusion

This Section shows how the framework has been applied to a typical domestic property in Albaha City in the southwest region of Saudi Arabia.

This property has a separate men's sitting room and women's sitting room to keep the privacy as a requirement of Islam. Also, the living room is in the middle of the house, this achieves privacy for residents but will cost spending more money for light and ventilation.

When operating the SHSF on this property the following factors have been considered: (a) building requirements, (b) climate requirements, (c) cultural requirements. The building has been assessed using a cultural survey, online climate analysis and a BIM model.

Specifically, using a BIM model has helped to understand the current state of the building, without the use of the BIM model a total of 60 data points would needed to have been captured via an on-site visit. Additionally, BIM can be the bridge to cover the gap between designer and occupants. Moreover, BIM can reduce the time taken to assess the building.

These interventions were the best to applied to the building:

1. Install facilities to allow for waste separation.
2. Design the recycling bins place to be close to the building.
3. Buy a new water saving shower head.

4. Specify heating/cooling systems capacities based on anticipated temperatures for the region concerned.
5. Specify insulation level to provide the suitable internal temperature.
6. Install suitably smart heating and/or air conditioning system that can control the internal temperature automatically to prevent under or overheating.
7. Using toilet facilities which can detect the leakage of water.
8. Install solar panels.
9. Install water saving devices for toilet facilities.
10. Deploy a green roof on the building.
11. Install solar hot water heating panels.
12. Deploy wind catchers.

Furthermore, SHSF have presented sensible results which will improve the building by understanding occupants' culture and needs and consider climate. The SHSF has produced the suitable interventions for the building equally with understanding the occupant's budget and needs.

8.3. SHSF Expert Survey

This Section will present the design and sampling methodology for the SHSF expert survey that will be used to validate and analyse the framework in Section 8.4 and 8.5.

8.3.1. Questionnaire design and development

Since this research is using mixed method, this research question will use a survey to collect the needed data. The questionnaire includes several questions that have been pre-formulated and designed to extract the data from experts in the engineering field to answer this research question to provide the validation of the framework by a survey distributed to experts in the engineering field. The questionnaire will examine the experts' views on the following elements of the framework:

1. The building interventions.
2. The need and ability of the SHSF to bridge the gap between occupants, designers, and core sustainability concepts.
3. Overall views on the SHSF.

The survey was made using Microsoft forms. The questionnaire was distributed and received responses from 75 experts in Saudi Arabia via the Internet (Email and social media such as LinkedIn, Twitter, and Facebook).

8.3.2. Respondent Selection and Survey Distribution

The survey was distributed to a selection of experts in the engineering field, across Saudi Arabia. The aim was to get a response from 50 to 80 experts in the engineering field.

The Snowball sampling was used in this study, and it is technique that used for the large-scale distribution of the questionnaires. The technique of snowball is an academic approach used to collect data and has always been used for large-scale participants in Saudi Arabia (Biernacki & Waldorf, 1981).

To achieve this the survey was first distributed to a set of known experts, and then, the snowball approach was used by suggesting to the experts that they send the survey to their colleagues. An initial set of 15 experts was chosen based on their experience and knowledge to be the initial respondents. These experts were then encouraged to distribute the survey to their colleagues.

8.3.3. Methods of Analysis

The quantitative data collected from the surveys were exported into Excel and transferred to the Statistical Package for the Social Sciences (SPSS) Software. Later, all the data was coded and cleaned in preparation for the analysis stage. When the data was ready, it was analysed using descriptive and frequency statistics. This was especially helpful in explaining and summarising the data in a significant way, which helped the understanding of the results (Hinton & McMurray, 2017). The techniques used here are the same as those used in Chapter 4 – so are explained in more detail in Section 4.3.

8.4. Validation of SHSF - Building Interventions

This Section describes the results of the validation of the SHSF's (Described in Chapter 7) building interventions. This will validate to interventions that have been selected and included in the framework. More specifically it will describe the results of the questionnaire related to the building interventions. It will document the importance of these interventions derived from the expert responses to a series of questions. This would form part of the validation of the proposed SHSF by identifying if the interventions included in the framework are correct and appropriate.

Table 50 shows the results from the questionnaire related to the building interventions. The Table shows each question, the building interventions linked to that question. Finally, it shows the ratings that the experts gave (not important, somewhat not important, somewhat important, and important).

Table 51: Link interventions to experts' response

Question	Linked Interventions	Not Important	Somewhat not important	Somewhat Important	Important
Improving the natural ventilation system to be more efficient, for example, extend the area of the window.	36	3%	7%	38%	52%
Apply shading to reduce the sun's radiation.	3 / 6 / 7	1%	5%	31%	63%
Ensure air conditioning is at a minimal level to meet requirements.	11/ 17 / 21 / 24 / 25	3%	3%	34%	60%
Ensure the heating system is at a minimal level to meet requirements.	11 / 18 / 21 / 24 / 25	8%	11%	47%	34%
Use of smart controllers for air conditioning and heating system to set the temperature at an appropriate level.	3 / 11 / 21	1%	9%	27%	63%

Reduce air leakage to prevent cooled air from escaping from home.	6 / 9	0%	4%	21%	75%
Installation of LED lighting.	21 / 16	2%	4%	19%	75%
Make use of smart controllers and other intelligent system.	11 / 22 / 23	2%	16%	40%	42%
Installation of an intelligent boiler with a smart programmer.	3 / 19 / 25 / 34	7%	17%	42%	34%
Considering energy efficiency rating when specifying devices for example, fridge, freezer, or TV depending on the Saudi energy rating.	3 / 21 / 20	0%	7%	23%	70%
Install a smart energy meter.	11 / 22 / 23	2%	9%	43%	46%
How importantly do you consider incorporating technology to reduce water loss for the building.	28	0%	8%	28%	64%
How importantly do you consider design features to help occupants manage domestic waste and recycling.	13 / 14 / 15	5%	11%	46%	38%

Deploying a green roof for the building.	10 / 25	8%	23%	37%	32%
How importantly do you consider ensuring the external fabric for the building is appropriate for the environment.	1/ 2 / 4	0%	9%	27%	64%
Installing solar panels.	3 / 21 / 31	4%	13%	40%	43%
Installing double glazing especially, for the exterior boundaries of the building.	3 / 26	2%	11%	27%	60%
Installing the turbine of wind which is a clean source of cooling.	3 / 21 / 33	19%	38%	31%	12%
Use the solar water heating system technology.	21 / 32	8%	19%	37%	36%
Provide better ventilation and natural light for the building.	5 / 8 / 36	0%	0%	15%	85%
Provide a suitable internal temperature for the occupants using approaches such as double glazing, the size of the windows, and the internal boundaries.	5 / 7 / 8 / 12 / 26 / 36	0%	2%	28%	70%
Install water-saving devices.	3 / 12 / 21 / 25 / 29 / 30	0%	1%	21%	78%

Customized the toilet facilities to separate waste.	27	5%	27%	36%	32%
Fixed or replace any leak in the building.	28	0%	2%	9%	91%
Exploit grey water and rainwater collection, especially for green area irrigation.	27	7%	17%	34%	42%

Table 51 shows that, 52% of the experts agreed that the natural ventilation of the building is extremely important and 85% of the experts agreed that it is extremely important to provide better ventilation and natural light for the building. Also, 63% of the experts agreed that applying shading to reduce the sun radiation is extremely important. Moreover, 60% of the experts agreed that it is extremely important to optimise air conditioning in the buildings and 34% of the participants agreed it is extremely important to optimise heating system in the buildings. Furthermore, 63% of the experts agreed that it is extremely important to use of smart controllers for air conditioning and heating system to set an appropriate temperature in the buildings. Also, 75% of the experts agreed that it is extremely important to reduce air leakage to prevent cooled air from escaping from home. Additionally, 70% of the experts agreed that it is extremely important to consider energy efficiency rating when specifying devices such as freezer or TV. As well, 37% of the experts agreed that it is somewhat important to deploying a green roof for the building.

In conclusion, the results show that the interventions utilised within the framework are correct and appropriate. Thus, from the results it can be seen that 75% of the experts see that reducing air leakage to prevent cooled air from escaping from home is important, thus justifying the inclusion of interventions such as No 6 and 9. Additionally, 85% of the responses agreed that providing better ventilation and natural light for the building is important justifying the inclusion of intervention numbers 5, 8, and 36. Finally, 75% of responses agreed that installing LED lighting in the building (interventions 21 and 16) is important way to achieve a more sustainable design. However, a high percentage of the expert’s responses were either somewhat important or important which is interpreted to positively support these interventions. For example, 60% of the experts agreed that installing double glazing especially, for the exterior boundaries of the building is important to achieve a sustainable design. Additionally, 60% of the experts agreed that installing solar panels is an important way to achieve a sustainable design. to achieve a sustainable design. Finally, 78% of the experts agreed that installing water-saving devices will help the sustainable design.

Overall, the experts predominantly agreed that most of these interventions are important and will help the construction sector across Saudi Arabia. However, in one element the experts did disagree with the contents of the framework. This was regarding the importance of installing a wind turbine. In addition, experts were also given the option to provide additional suggested interventions, but no suggestions were made.

8.5. Validation of SHSF - The need and ability for the SHSF to bridge the gap between occupants, designers, and core sustainability concepts.

This Section describes the results of validating the framework's understanding of occupants' culture and understanding climatic requirements. This Section will also describe the results of validating the framework's understanding the requirements of sustainable design interventions and managing the collection of site data (Described in Chapter 7), which will contribute to answering RQ5.

8.5.1. Understanding Occupant Culture

As stated in Chapter 6, culture, especially privacy, has a clear impact on how buildings are constructed in Saudi Arabia. This means that culture must be considered in the framework to achieve comfort for the residents, in a balance with sustainability.

This Section describes the results of validating the framework's understanding of occupants' culture (Described in Chapter 7). More specifically it will describe the results of the questionnaire related to the cultural factors. It will document the importance of occupant's culture which derived from the expert responses to a series of questions. This forms part of the validation of the proposed SHSF by identifying if the culture of the occupants included in the framework are correct and appropriate.

Tables shows the results from the questionnaire related to the culture factor. The Table shows each question answered by (Yes and No) by the experts. The questions are:

1. Do you currently consider the cultural factors of the occupants such as separation between guests and family members when producing design?

2. If the previous question is yes, how do you gather information on the cultural beliefs of the occupants?
3. In your opinion, do you consider the cultural views of Saudi families to be a challenge for the designer?

All the above questions will show the importance and the impact of culture on buildings in Saudi Arabia.

Table 52: Do you currently consider the cultural factors of the occupants such as separation between guests and family members when producing design.

Consider cultural factors (N= 75)	Frequency	Percentage
No	11	15
Yes	64	85

Table 53: If the previous question is yes, how do you gather information on the cultural beliefs of the occupants.

Consider cultural factors (N= 64)	Frequency	Percentage
Experience	17	23
Interview	33	44
Customer Request	5	7
Internet	4	5
Questionnaire	3	4
Others	2	2

Table 54: In your opinion, do you consider the cultural views of Saudi families to be a challenge for the designer.

Consider cultural views to be challenge (N= 75)	Frequency	Percentage
No	13	17
Yes	62	83

In conclusion, the Tables show that, 85% of the experts consider the cultural factors of the occupants. In addition, 44% of the experts consider cultural factors from interviews with the residents, 23% from the experience, 7% from customers request, 5% from the Internet, 4% from the questionnaires. Moreover, 83% of the experts consider the cultural views of Saudi families to be a challenge for the designer.

However, 15% of the participants are not considering any cultural of the residents and 17% of the participants are not considering any cultural challenging for the designer.

All the results show the huge impact of the culture of the occupants on buildings in Saudi Arabia. Tables 52 and 54 (which show 85% of the experts consider the cultural factors of the occupants and 83% of the experts consider the cultural views of Saudi families to be a challenge for the designer) validates the framework's consideration of the culture of occupants as an important factor. This will help the designer to understand occupant needs which will help achieve a more sustainable design.

8.5.2. Understanding Climactic Requirements

This Section describes the results of validating the framework's understanding climatic requirements (Described in Chapter 7). More specifically it will describe the results of the questionnaire related to the climate factor. This would form part of the validation of the proposed SHSF by identifying if the climate factor included in the framework are correct and appropriate.

Tables shows the results from the questionnaire related to the climate factor. The Table shows each question answered by (Yes and No) by the experts. The questions are:

1. Have you ever used simulation tools to measure the internal temperature of the building?
2. Would you normally consider the local climate characteristics in forming your design?
3. Have you ever been directly asked by the owner to consider the climate information?
4. Have you ever visited the site to observe the local climate conditions?

All the above questions will serve to validate the framework's ability to understand climatic requirements for buildings in Saudi Arabia.

Table 55: Have you ever used simulation tools to measure the internal temperature of the building.

Used simulation tools (N= 75)	Frequency	Percentage
No	49	65
Yes	26	35

Table 56: Would you normally consider the local climate characteristics in forming your design.

Consider local climate (N= 75)	Frequency	Percentage
No	6	8
Yes	69	92

Table 57: Have you ever been directly asked by the owner to consider the climate information.

Asked directly to consider climate (N= 75)	Frequency	Percentage
No	55	73
Yes	20	27

Table 58: Visit the site to observe the local climate conditions.

Visit sites to observe local climate (N= 75)	Frequency	Percentage
No	24	32
Yes	51	68

In conclusion, the Tables show that, 35% of the experts have used simulation tools to measure the internal temperature of the building. Moreover, 92% of the experts would consider the local climate characteristics of the design. In addition, only 27% of the owners asking to consider the climate information. Furthermore, 68% of the experts are visiting websites to observe the local climate conditions.

Meanwhile, 65% of the participants have never used any simulation tool to measure the internal temperature of the building. Also, 8% of the participants have ever not consider the local climate characteristics in the design. Moreover, 73% of owners not asking to consider the climate information. Additionally, 32% of experts are not visiting websites to observe the local climate conditions.

The results show that considering the climate is important to include in the framework for buildings in Saudi Arabia. For instance, Tables 56, 57, and 58, show that 92% of the experts see a need to consider the local climate in the design, and 73% of owners not understanding the need to consider the local climate information. These results validate the framework's consideration of local climate as an important factor to be considered by designers. This is important as it will help designers to understand occupants needs and comfort requirements to achieve more sustainable design.

8.5.3. Understanding the Requirements of Sustainable Design Interventions

This Section describes the results of validating the framework's understanding the requirements of sustainable design interventions (Described in Chapter 7). More specifically it will describe the results of the questionnaire related to the requirements of sustainable design interventions. It will document the importance of these requirements which derived from the expert responses to a series of questions. This would form part of the validation of the proposed SHSF by identifying if these requirements included in the framework are correct and appropriate.

Tables shows the results from the questionnaire related to the requirements of sustainable design interventions. The Table shows each question answered by (Yes and No) by the experts. The questions are:

1. Have you ever provided documentation to the house owner that shows a full description of the building elements and materials that have been used for the house?
2. Has an occupant/owner ever requested documentation that shows a full description of the building elements and materials that have been used for the house?

All the above questions will validate the framework's understanding of the requirements of sustainable design intervention specific to buildings in Saudi Arabia.

Table 59: Have you ever provided documentation to the house owner that shows a full description of the building elements and materials that have been used for the house.

Provide description documentation (N= 75)	Frequency	Percentage
No	33	44
Yes	42	56

Table 60: Has an occupant/owner ever requested documentation that shows a full description of the building elements and materials that have been used for the house.

Requested description documentation by the owner (N= 75)	Frequency	Percentage
No	41	55
Yes	34	45

In conclusion, from the Tables, 56% of the experts are providing documentation of all the description of the building to the owners. Also, 45% of the owners requested documentation that shows a full description of the building elements and materials.

However, 44% of the experts are not providing any documents to the owners and 55% of owners are not asking for any documents.

The results show that understanding the building requirements of sustainable design interventions is important to include within the SHSF framework. Tables 59 and 60 (which show 44% of experts are not routinely providing any documents such as specifications, manuals, or drawings to occupants, and conversely 55% of occupants are not asking for any such documents) validate the framework understanding the building-based requirements of sustainable design interventions as an important factor. Understanding these requirements is important to enable designers to select appropriate sustainable design interventions for the building being considered.

8.5.4. Managing the Collection of Site Data

This Section describes the results of validating the framework's managing the collection of site data (Described in Chapter 7). More specifically it will describe the results of the questionnaire related to the collection of site data. It will document the importance of these data which derived from the expert responses to a series of questions. This would form part of the validation of the proposed SHSF by identifying if these data included in the framework are correct and appropriate.

Tables shows the results from the questionnaire related to managing the collection site data. The Table shows each question answered by (Yes and No) by the experts. The questions are:

1. Have you ever visited the site to take measurements?
2. Have you ever visited the site to meet with and discuss plans with the occupants?

3. Have you used the existing plans/ drawings?
4. Have you ever used existing BIM models?
5. What is your current use of BIM for building design in Saudi Arabia?

All the above questions will be validating the framework's ability to manage and guide the collection of data on buildings in Saudi Arabia.

Table 61: Visit the site to take measurements.

Visit sites to take measures (N= 75)	Frequency	Percentage
No	25	33
Yes	50	67

Table 62: Visit the site to meet with and discuss plans with the occupants.

Visit sites to discuss plans (N= 75)	Frequency	Percentage
No	31	41
Yes	44	59

Table 63: Make use of existing plans/ drawings.

Make use of existing plans/ drawings (N= 75)	Frequency	Percentage
No	6	8
Yes	69	92

Table 64: Make use of existing BIM models.

Make use of existing BIM models (N= 75)	Frequency	Percentage
No	31	41
Yes	44	59

Table 65: What is your current use of BIM for building design in Saudi Arabia

Current use of BIM in SA (N= 75)	Frequency	Percentage
Never used	36	48
1-2 projects	12	16
Used occasionally	20	27
Used Frequently	7	9

Table 66: Allow for the use of BIM data as part of the specification of your work.

Usefulness of BIM data in work (N= 75)	Frequency	Percentage
Not Useful	2	3
Somewhat not useful	2	3
Somewhat useful	31	41
Extremely useful	40	53

In conclusion, the Tables show that, 67% of the experts are visiting the project sites to take measurements and 59% of the experts are visiting the project sites to discuss the building plans. Also, 92% of the experts are using existing plans. Moreover, 59% of the experts are using existing BIM models, 27% of the experts are using BIM occasionally, and 9% of the experts are using BIM frequently for projects in Saudi Arabia.

However, 33% of experts are not visiting the project sites to take measurements and 41% of experts are not visiting the project sites to discuss the building plans. In addition, 8% of experts are not using existing plans. Furthermore, 41% of experts are not using existing BIM models and 48% of the experts have never used BIM for building design in Saudi Arabia.

The results show that managing the collection of site data is important in the framework on buildings in Saudi Arabia. Tables 62 and 64 show that 41% of experts are not visiting the project sites to discuss the building plans with occupants, which if done will improve the design of the building. Additionally, 41% of experts are not using existing BIM models, which shows there is a lack of digital structured information available for properties in Saudi Arabia. These responses serve to validate the framework's consideration of formalizing the data requirements needed for making decisions about a building's sustainability is important to deliver an increasing level of adoption of sustainable design. This is because there is too little data being exchanged between owners and designers.

Using BIM in SHSF will help to take measurements and discuss the drawings with occupants with no need to visit the site which means the project will be constructed quicker with low cost.

8.6. Analysing the effectiveness and potential of SHSF

This Section describes the results of the survey question that sought to analyse the effectiveness and potential of SHSF (Described in Chapter 7), this question will provide the final information needed to answer RQ5. The purpose of this question is to understand the expert's opinion about using the framework as a design tool to achieve increasing adoption of sustainable buildings in Saudi Arabia.

Table 67: Would you use such a design tool as part of your business.

Would you use BIM as a design tool in your business (N= 75)	Frequency	Percentage
No	15	20
Yes	60	80

This result shows that experts see the framework as important achieve sustainable buildings in Saudi Arabia. This serves to validate the framework's importance in helping the designer to understand these data which will help the designer to reach a sustainable design.

8.7. Conclusion

This Chapter has focused on the validation of SHSF which aims to help designers to achieve a more sustainable design. Specifically, this Chapter has answered RQ5 by validating the building interventions, as well as the need and ability for the SHSF to bridge the gap between occupants, designers, and core sustainability concepts, and, finally, analyse the effectiveness and potential of SHSF with experts.

The RQ being considered by this Chapter is How can the construction/refurbishment processes of existing traditional Saudi Arabian buildings be changed and improved to achieve a more sustainable design.

The methodology taken to answers this research question is by developing (in Chapter 7) and validating (in this Chapter) the SHSF.

The validation of this framework has followed the following areas:

1. The building interventions.
2. The need and ability of the SHSF to bridge the gap between occupants, designers, and core sustainability concepts.
3. Overall views on the SHSF.

Validation of building interventions: The key findings in this area were that out of the 36 design interventions elicited the experts rated 35 to be either somewhat important or important. However, it should be noted that one element the experts did disagree with the contents of the framework. This was regarding the importance of installing of a wind turbine.

These findings have served to validate the framework to provide guidance for the designer by following the data in the framework to improve the construction sector in Saudi Arabia and achieve sustainability, showing that the selected interventions are appropriate and required for sustainable construction in Saudi Arabia.

Validation of understanding occupant culture: The results in this Chapter have shown that, 85% of the experts consider the cultural factors of the occupants (Table 52). Moreover, 83% of the experts (Table 54) consider the cultural views of Saudi families to be a challenge for the designer. However, currently only 44% (Table 53) of the experts consider cultural factors from interviews with the residents and 4% from questionnaires distributed to occupants.

These findings help to validate the framework as a means for providing guidance for the designer in understanding occupants culture enabling this to be better considered as part of sustainable design processes, as is necessitated by the fact that the culture of occupants have a huge impact on building design in Saudi Arabia.

Validation of understanding climactic requirement: Currently, only 35% of the experts have used simulation tools to measure the internal temperature of the building (Table 55). In addition, only 27% of the owners asking to consider the climate information (Table 57). Furthermore, 68% of the experts are visiting websites to observe the local climate conditions (Table 58).

These findings contribute to validating the framework as a means for providing guidance for the designer by understating the climate requirement that they must consider in order to improve the sustainable design of buildings because of the multiple climates present within Saudi Arabia; a desert climate in the middle and north of the country, in the south, a semi-arid climate, and, in the west of the country, the climate is very hot and humid.

Validation of understanding the requirements of sustainable design intervention: Currently, 44% of the experts are not providing any documents to the owners and 55% of owners are not asking for any documents (Tables 59 and 60). This has served to validate the framework as a means for providing guidance for the designer in understanding the requirements of sustainable design interventions because we have shown that designers do not seem to understand sustainability (as described in Chapter 5).

Validation of understanding managing the collection of site data: 33% of experts are not visiting the project sites to take measurements and 41% of experts are not visiting the project sites to discuss the building plans with occupants (Tables 61 and 62). In addition, 8% of experts are not using existing plans (Table 63). Furthermore, 41% of experts are not using existing BIM models and 48% of the experts have never used BIM for building design in Saudi Arabia (Tables 64 and 65). BIM has been identified as a solution which can be used during the project life cycle, which can help the quality of the design from the early stage of design until the demolition of the building. BIM tools can provide simulation and measure the performance of the buildings which makes the execution of the building quicker. This is a start of moving the construction industry into the digital age and will help to achieve the sustainable design in Saudi Arabia.

These findings contribute to validating the framework as a means for providing guidance for the designer to manage the exchange of data between the designer and the occupier because data exchanges are currently poor and little structural data available about properties in Saudi Arabia.

Overall, the findings show the importance of the framework to guide the designer in Saudi Arabia to improve the construction sector. Moreover, it can bridge the gap between buildings owners and designers which has a positive impact on buildings. Furthermore, BIM tools can be the path for the designer to achieve that.

In conclusion, from the findings in this Chapter, it has been shown that the SHSF is a good way to achieve a more sustainable design in Saudi Arabia. This specifically provides an s answer to RQ5.

Chapter 9: Conclusion

9.1. Introduction

This Chapter will conclude the thesis by showing the research findings as answers to the research questions, which are provided in Chapter 1. Furthermore, this Chapter will share the conclusions reached during the research process and illustrate the results. Finally, this Chapter will offer recommendations for the Saudi construction sector and further recommendations for future researchers working in this area. It will also present future work in this area.

In the remain of this Chapter, Section 9.2 presents research questions and hypothesis. Section 9.3 shows key findings from the research and recommendations, and Section 9.4 presents future work to be undertaken by the researcher.

9.2. Research Questions and Hypothesis

The hypothesis of this research was:

That the wider adoption of BIM based tools that facilitate the consideration of both climate and cultural contexts have the potential to achieve an increased level of sustainable construction in Saudi Arabia.

Based on the hypothesis, the research questions elicited were:

1. What is the current level of BIM adoption in Saudi Arabia?
2. What is the current awareness level of the general public in Saudi Arabia and sustainable building design?
3. What are the suitable requirements for achieving sustainable domestic building design of housing in Saudi Arabia and how could privacy factors impinge on their adoption?
4. How can the experts in the sustainability field understand the resident requirements considering the achievement of sustainability in Saudi Arabia?
5. How can the construction/refurbishment processes of existing traditional Saudi Arabian buildings be changed and improved to achieve a more sustainable design?

Research Question One: ***What is the current level of BIM adoption in Saudi Arabia?***

This question aimed to examine the level of adoption of BIM in Saudi Arabia and to examine the main factors that are causing delays in adopting BIM in Saudi Arabia. The results of the questionnaire showed that the level of BIM adoption, as well as BIM teaching, is low in the Saudi Arabian construction sector. Also, it showed that based on the expert's views, BIM, if adopted, will have a positive impact on buildings and will develop the construction sector in Saudi Arabia.

Research Question Two: ***What is the current awareness level of the general public in Saudi Arabia and sustainable building design?***

This question has examined the level of awareness of sustainable design for both experts and the public in Saudi Arabia. It also examined the main factors which causing the delay in achieving sustainability in Saudi Arabia and how cultural of residents have an impact on the design of buildings in Saudi Arabia. It has done this via two questionnaires, one targeted at experts and one at members of the general public. The results of the questionnaire showed that the level of sustainable design awareness for general public in Saudi Arabia is low as, is the awareness of the principles of sustainable design. Additionally, the results also indicated that there is no support available to help households to achieve more sustainable buildings in Saudi Arabia.

Research Question Three: ***What are the suitable requirements for achieving sustainable domestic building design of housing in Saudi Arabia and how could privacy factors impinge on their adoption?***

This question focused on identifying the important requirements for achieving sustainable buildings design in Saudi Arabia. The important future requirements that have been identified are:

1. There is a need for the development and implementation of Saudi Arabian specific standards within the construction sector to reduce energy waste. These standards should set out key requirements that are achievable for the construction sector in Saudi Arabia in the short to medium term.
2. There is a need for the development of a Saudi Arabian sustainability standard or framework, to aid construction professionals and their customers in making informed

decisions about sustainability within their projects. Additionally, this framework must consider culture as one of its key factors.

3. There is a need to adopt the suggested rating system for the evaluation of residential buildings "Mostadam" to be used for all the project in Saudi Arabia. Furthermore, the Mostadam rating system must be modified to consider the culture of the residents to see wide adoption within Saudi Arabian communities.

The aim of this was to understand theories the impact of culture on sustainable design and general, and, in more detail, understand the impact on culture in the adoption of sustainable design in Saudi Arabian buildings.

Furthermore, culture, especially privacy, has a clear impact on how buildings are constructed and must be considered by the designer to achieve comfort for the residents, in a balance with sustainability. Additionally, the “Mostadam” rating system has been introduced as a suggestion from the government without adoption yet must be applied and used for all the projects across Saudi Arabia, However, with little adoption so far, and a lack of skills in sustainability amongst professionals in Saudi Arabia its impact is far from certain.

Research Question Four: ***How can the experts in the sustainability field understand the resident requirements considering the achievement of sustainability in Saudi Arabia?***

To answer the RQ, Chapter 7 has developed and validated that there is a need to enable experts in the sustainability field to understand resident requirements and to then specify appropriate sustainability design interventions. To test how this can be achieved the Saudi Housing Sustainability Framework (SHSF) was developed. This framework works by incorporating a set of Saudi Arabia suitable design interventions, rankings, and ratings of these interventions appropriate to Saudi Arabia, based on data collected through a variety of structured means from the residents of the target buildings. Finally, it can differentiate, and select between measures based on how they interact with each other. From previous studies it has been shown that the possible option to achieve sustainability will be by installing a framework which can influence positively on sustainable building. The framework cover first the building interventions with the occupants, then can consider both culture of the residents and the climate by visiting the project site to collect data. Also, it could cover both data and economic requirements by a dissection with occupants or distributing a survey.

<u>Research Question Five:</u> ***How can the construction/refurbishment processes of existing traditional Saudi Arabian buildings be changed and improved to achieve a more sustainable design?***

The process of answering this question has focused on the validation of SHSF. Specifically, the results have answered RQ5 by demonstrating how a suitable framework can bridge the gap between occupants and designers along with formalizing the data collection requirements whether site survey, simulation applications, BIM, or direct discussion with occupants.

More specifically this question has also answered by demonstrating that the developed SHSF can meet this need. This has been done by validating the building interventions, as well as the need and ability for the SHSF to bridge the gap between occupants, designers, and core sustainability concepts, and, finally, analyse the effectiveness and potential of SHSF with experts.

BIM can improve the quality of the project from the early stage of design until the demolition of the building. As well, the increase in BIM adoption will begin the process of moving the Saudi Arabian construction industry into the digital age and will help to achieve the sustainable design in Saudi Arabia. This will help to improve the quality of buildings, enable building assessment processes to scale and encourage the use of simulation tools which can influence positively on the design.

Finally, in response to the hypothesis:

That the wider adoption of BIM based tools that facilitate the consideration of both climate and cultural contexts have the potential to achieve an increased level of sustainable construction in Saudi Arabia.

BIM can be the suitable way to deliver an increasing level of adoption of sustainable design in Saudi Arabia. Because BIM can be the bridge to cover the gap between designer and occupants. Also, BIM can assist to select products and materials of construction that could be suitable with Environment which can have a positive impact on Environment. Furthermore, BIM can formalise the needed data from the designer to owner which help to understand all provided data such as site data, climate data, and economy data. Also, BIM can help to understand occupants view by collecting data from the project site, discussion with occupants, and distributing a survey. From Table 47 it can be seen that BIM data can be used for 60 out of the 71 of the require data points for using the SHSF. This means using BIM in the projects will enable the assessment many more buildings as each can be done with far less data collection and by providing far more automation. All of these factors will help to reduce time across the design and assessment within each refurbishment project.

These findings contribute to validating the framework as a means for providing guidance for the designer in selecting sustainable design interventions as well as managing the exchange of data between the designer and the occupier because data exchanges are currently poor and little structural data available about properties in Saudi Arabia.

Overall, the findings show that the framework is important to guide the designer in Saudi Arabia to improve the construction sector. Moreover, the framework can bridge the gap between buildings owners and designers which has a positive impact on buildings. In addition, BIM tools can be the path for the designer to achieve a more sustainable design in Saudi Arabia.

9.3. Key Findings and Recommendations

This thesis has produced the following key findings:

1- The level of BIM adoption is low in the Saudi construction sector. (As discussed in Chapter 4).
2- Increasing the adoption of BIM will have a positive impact on sustainable development in the construction sector in Saudi Arabia. This will be through assist in selecting products with a lower environmental impact, additionally, BIM can help to understand occupants needs and can help to achieve a more comfortable design. That means BIM tools can help designers to understand occupants needs, provide a basis for simulation activities, and provide for structured data exchange. (As discussed in Chapter 4).
3- The level of sustainability awareness for general public in Saudi Arabia is low awareness of the techniques of sustainable design that could be relevant to them. (As discussed in Chapter 5).
4- The support to help designers and households to achieve more sustainable building design in Saudi Arabia need to be increased. (As discussed in Chapter 5).
5- The culture has a huge impact on the design of Saudi buildings and privacy is central to the design of any Saudi house. (As discussed in Chapter 5 and 6). Furthermore, most Saudi families choose to build with comfort features as opposed to building with consideration for sustainability. (As discussed in Chapter 5).
6- The findings showed that the developed SHSF framework provides a means for providing guidance to the designer to enable them to manage the selection of the exchange of data between the designer and the occupier because data exchanges are

currently poor and little structural data is available about properties in Saudi Arabia. (As discussed in Chapter 8).

7- The findings showed that the developed SHSF framework enable the designer to select appropriate building interventions with occupants, consider occupants views, and understanding the occupant's culture to improve the building design. (As discussed in Chapter 8).

8- The developed SHSF framework provides structured consideration of the required data, collected in different ways, that enable the designers to understand occupants need and provide quality of life for occupants. (As discussed in Chapter 8).

9- Overall, the findings show the importance of the framework to guide the designer in Saudi Arabia to improve the construction sector. Moreover, it can bridge the gap between buildings owners and designers which has a positive impact on buildings. Furthermore, BIM tools can be the path for the designer to achieve that. (As discussed in Chapter 8).

In response to all the above keys finding a set of recommendations can then be derived to help both the engineers and the general public adopt more sustainable design in the construction field. These recommendations are:

1. The Saudi Arabian government should require the adoption technologies such as energy simulation as part of regulatory processes to require both public and private construction sectors to reach a more sustainable design.
2. The government must encourage and provide materials to enable families to increase their level of awareness of the importance of sustainable design.
3. Saudi Arabian universities should adopt sustainability courses and demonstrate the benefit of sustainable design to the Saudi Arabian construction sector.
4. The Saudi Arabian government and industry experts should collaborate to develop and adopt a framework similar to the SHSF for sustainability in domestic properties and must work to develop a framework for non-domestic construction projects. This will support government, construction professionals and building owners/operators in achieve more sustainable building design, one of the key Saudi Arabia 2030 vision goals.
5. The Saudi Arabian government should implement and update the standard and protocols to require the adoption of BIM especially for the public and government projects.

6. Saudi Arabian universities should adopt BIM courses and demonstrated the benefit of BIM to the Saudi Arabian construction sector.
7. The barriers of adopting BIM in the country must be acknowledge by both the government and the private sector in Saudi Arabia.
8. A government backed plan must be put in place to overcome barriers of adopting BIM. This should at a minimum include: (a) identification of the reasons for the delay in adopting BIM, (b) disseminate and demonstrate the benefit of BIM through the use of expert experience, especially those who studied in countries supporting BIM such as the UK and the USA and (c) encourage further adoption of BIM through the provision of funding, similar to strategies employed by the UK and other countries.

9.4. Future Work

Based on the work conducted in this thesis the following future work is proposed:

Development of a Non-Domestic Framework: One element of this work that should be continued is to extend this work to implement a framework for non-domestic properties. This will support government, construction professionals and building owners/operators in achieve more sustainable building design, one of the key Saudi Arabia 2030 vision goals (M. S. Al Surf & Mostafa, 2017; Balabel & Alwetaishi, 2021).

Increase the level of adopting BIM: Another the key Saudi Arabia 2030 vision goals (M. S. Al Surf & Mostafa, 2017; Balabel & Alwetaishi, 2021) is to increase sustainability in construction sector. However, the findings of this work have shown that BIM is the appropriate way to achieve this. Thus, a detailed study in required into the barriers of BIM adoption in Saudi Arabi which will be the tool to achieve a more sustainable design in Saudi Arabia.

Increase the level of sustainable design awareness: Findings have shown that the level of sustainable design awareness for the public is low. So, in this thesis the SHSF has studied the reasons for this problem and proposed a short-medium term solution. The next step will be finding the best way to increase designer awareness of sustainable design in the long term. This is important as it is having the possibility to increase more widely the energy performance of existing and new buildings, which will the reflect positively on the Environment.

Increasing the level of use of simulation approaches: Findings have shown that there is a lack of adoption of technologies such as energy simulation as part of regulatory processes in Saudi Arabia. This requires increasing research to find the reason for this and develop strategies to enable the Saudi Arabian government to encourage the adoption of these technologies for both public and private construction sectors.

9.5. Conclusion

This thesis has developed and validated the SHSF. The purpose of the SHSF is to help understand occupants need and bridge the gap between designer and occupants, in terms of sustainability knowledge, data capture and culture.

Such a framework is needed in Saudi Arabia because studies have shown that most domestic buildings have a poor design with a negative impact on Environment. Also, culture of residents has a huge impact on buildings in Saudi Arabia. On the other hands, the findings have shown that there is a lack of knowledge about sustainable design by building designers within Saudi Arabia

If actively deployed in Saudi Arabia, then the SHSF has the potential to impact positively on building sustainability providing, in the future, more sustainable buildings with a consideration of different factors such as culture, economy, and climate (As discussed in Chapter 8).

Finally based on the validation of the framework a set of recommendations have been proposed that are able to improve the quality of building design, understanding of occupants needs, bridge the gap between designer and occupants, consider culture of residents, and consider climate requirements.

BIM can improve the quality of the design from the early stage of design until the demolition of the building. Moreover, BIM can be the streamline to communicate between co-works in the project. In addition, BIM is the start of moving the construction industry into the digital age which can the path to achieve the sustainable design in Saudi Arabia.

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APPENDIX A - Public Survey Questionnaire

Managing BIM based Sustainable Construction Adoption in Saudi Arabia.

I would like to introduce myself as Mushref Saad Alghamdi, PhD candidate at Cardiff School of Engineering, Cardiff University, United Kingdom. This questionnaire is focused on sustainable in Saudi Arabia.

All data collected in this survey will be held securely in accordance with the data protection act and GDPR regulations. Personal data collected (your e-mail address) will only be used to contact you in follow up to this survey, and this will only happen if you allow it.

Cookies and personal data stored by your Web browser, are not used in this survey. The collected data will be analysed by only the research team and any personal information provided by you will be anonymised. The anonymised findings of this study will be included in the PhD these and publications of the researcher.

By completing this questionnaire, I confirm that I have understood the above research project and that I have had the opportunity to ask questions and that these have been answered satisfactorily. Therefore, I agree to take part in this project.

1. Please provide your gender
    - Male
    - Female
    - Do not wish to say.

2. Please provide your age
    - From 18 to 28
    - From 29 to 39
    - From to 40 to 50
    - From 51 to 61
    - More than 61
    - Do not wish to say.

3. What is your employment status?
    - Employed
    - Self-employed
    - Student
    - Retired
    - Not employed/Other

4. What is your level of education?
    - High school
    - Diploma
    - Bachelor’s degree
    - Master’s degree
    - PhD degree

5. How would you describe your house?
    - One floor house
    - Two floor houses
    - Villa duplex
    - Flat
    - Other, please provide …

6. What is the age of your house?
    - From 1 to 5 years
    - From 6 to 10 years
    - From 11 to 15 years
    - From 16 to 20 years
    - More than 20 years
    - Not sure

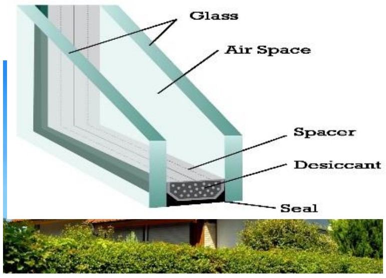
7. How many people live in your house?
    - From 1 to 3
    - From 4 to 7
    - From 8 to 11
    - From 12 to 15
    - From 16 to 19
    - More than 20

8. Do you have a separate guest room for females and males?
    - Yes
    - No

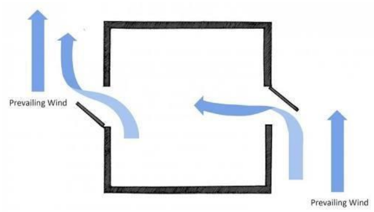
9. How many guest rooms do you have for males in your property?
    - 1
    - 2
    - More than 2

10. How many guest rooms do you have for females in your property?
    - 1
    - 2
    - More than 2
11. Before this survey, have you heard about the following sustainability concepts:
    1. Green roof, design to look beautiful appeal, while ensuring that a building has excellent energy performance.
       (Yes/ No)

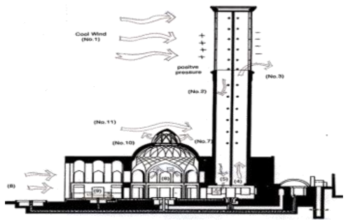
2. Solar panels.
   (Yes/ No)
3. Double glazing, that combines two or three glass panels reducing heat transfer from one side of the building to the next.
   (Yes/ No)



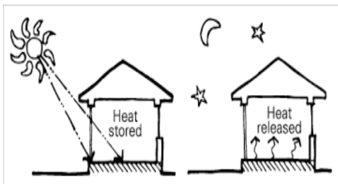
4. Cross ventilation, that takes advantage of wind to cool buildings.
   (Yes/ No)



5. Wind catchers, which takes advantage of wind energy to cool the building.
   (Yes/ No)



6. Thermal mass is designing a building to store heat in winter months.
   (Yes/ No)



7. Concrete with quality temperature control (CCTC), the idea of this technique is that the building stores thermal energy and then delivering it if needed.
   (Yes/ No)

12. If you were to change your house in your future, which of these factors would be your primary consideration?
    - Privacy, to prevent unwanted contact between guest and certain members of the host family.
    - Cultural Objections
    - The site, which means directions, entrance and exit, and the area of the site.
    - Cost of finishing, especially with the new additional VAT (15%).

13. If you were to change the windows in your house, would you considered using windows that would achieve more natural light and wind circulation?
    - Yes
    - No
    - Not interested

14. If you were to change your current house in your future, do you prefer to build in internal walls or open plan?
    - Yes
    - No

15. If you were to change your current house in your future, do you prefer comfort features more than a functionality consideration?
    - Yes
    - No
    - Not known

16. Would you consider buying a new house of a different size/shape/orientation to help contribute to a more sustainable environment?
    - Yes
    - No
    - Not known

17. Would you consider buying a new house of a different colours/ materials/ finishing to contribute to a more sustainable environment?
    - Yes
    - No
    - Not known

Please feel free to contact me via email address AlghamdiMS2@cardiff.ac.uk if you have any further questions about this feedback form or the project.

Name …

Email …

APPENDIX B - Experts Survey Questionnaire

Part 1: Level of BIM Adoption in Saudi Arabia.

I would like to introduce myself as Mushref Saad Alghamdi, PhD candidate in the subject of Building Information Modelling and Sustainability studying at Cardiff School of Engineering, Cardiff University, United Kingdom.

This questionnaire is in two parts. The first aims to collect data to understand the level of BIM adoption in Saudi Arabia, the second is focused on the implementation of sustainable design principles in Saudi Arabia.

All data collected in this survey will be held securely in accordance with the data protection act and GDPR regulations. Personal data collected (your e-mail address) will only be used to contact you in follow up to this survey, and this will only happen if you allow it. Cookies and personal data stored by your Web browser, are not used in this survey. The collected data will be analysed by only the research team and any personal information provided by you will be anonymised. The anonymised findings of this study will be included in the PhD these and publications of the researcher.

I confirm that I have understood the above research project and that I have had the opportunity to ask questions and that these have been answered satisfactorily. Therefore, I agree to take part in this project.

- Yes
- No

<u>Questions for part one as follows:</u>

1- How best would you describe your profession?
   - Architect
   - Engineer (Civil - Structural)
   - Engineer (M - E)
   - Project manger
   - BIM manger
   - Other …

2- Please provide your area of business
   - Designing
   - Construction
   - Consultation

- Operation and Maintenance
- Other …

3- How many years' experience do you have in your field?
   - Less than a year
   - From 1 year to 5 years
   - From 6 years to 10 years
   - From 11 years to 15 years
   - From 16 years to 20 years
   - From 21 years to 25 years
   - More than 25 years

4- Please provide the size of your organization (Number of employees)
   - Less than 10
   - From 11 to 50
   - From 51 to 250
   - From 251 to 500
   - From 501 to 1000
   - More than 1000

5- Approximately what is the percentage of projects have you used BIM for in the last 5 years?
   - Not at all
   - Currently considering adoption
   - Only for R&D purposes
   - Up to 25%
   - Up to 50%
   - Up to 75%
   - Up to 99%
   - 100%

6- How would you like to describe your organisation's current and future use of BIM?
   - We currently using BIM
   - We aim to fully adopt BIM in one year
   - We aim to fully adopt BIM in the next three years
   - We aim to fully adopt BIM in the next five years
   - No current plans
   - Not known

7- On which type of projects type has your organisation used BIM on in Saudi Arabia?
   - Education projects
   - Health projects
   - Transportation projects

- Public housing projects
- Private housing projects
- Industrial projects
- None

8- In your view BIM can help to achieve …
    - Architecture designs include all the design phases
    - Construction field
    - MEP field
    - Operation and maintenance
    - Sustainability
    - Fully integrated use
    - Not known

9- Thinking of the projects you were working into over the last 12 months, did you ever
    - Produce 2D digital drawings
    - Produce 3D digital drawings
    - Work collaboratively on design
    - Share models with design team members outside your organization
    - Federate a model that did not depend on one piece of software

10- While studying at university has BIM been taught in any of your courses
    - Has not been taught
    - Has been mentioned in some classes
    - Has been completely taught and adopted
    - Not known

11- In what country did you study?
    …

12- What BIM software tools have you used?
    - Revit
    - ArchiCAD
    - AutoCAD
    - Navisworks
    - AutoCAD MEP
    - Other, please provide ….

13- In your opinion, what is the benefit of using BIM now and in the near future
    - Increase the quality of work
    - Easy to work internationally
    - Increase the amount profit
    - Achieving accuracy in design, construction, operation, and maintenance

- All the above

14- In your view, how significant are the following barriers for your organisation in adopting BIM (Likert scale)

    1- Cost of hardware

    2- Cost of software

    3- Cost of training

    4- Lack of standards and protocols

    5- Lack of training

    6- Lack of house expertise

    7- Lack of collaboration between those involved in design process

    8- Lack of university courses

    9- Low level of BIM understanding in wider industry

    10- Lack of client demand

    11- No established contractual framework for working with BIM

    12- Differences in expertise among collaborating parties in a project

    13- Individuals do not see the benefit of using BIM

    14- Other, please specify

15- Please provide any additional comment on your organization’s adoption of BIM.

Part 2: Sustainable design principles in Saudi Arabia

Sustainable Design is defined as development which meets the needs of the present generations without compromising the ability of the future generations to meet their own needs. This definition implies the need to achieve a balance between economic growth and development, and natural resource conservation and social balance. Also, sustainable construction refers to the practice of creating structures and using processes that are environmentally responsible and resource-efficient throughout a building's life cycle, from siting to design, construction, operation, maintenance, renovation, and deconstruction.

<u>Questions for part Two as follows:</u>

1- In your view, how significant are the following barriers for your organization not adopting the concept of sustainable design (Likert scale)
    1- The quality of the design process
    2- Lack of university courses
    3- Lack of standards and protocols
    4- No client demands
    5- The background for the client of the importance of sustainable design

2- Have the government implemented and considered technology to help both designers and households to reach more sustainable designs in Saudi Arabia?
- Yes
- No
- Not known

3- What is currently implemented and considered by the government to help both designers and households to reach more sustainable designs in Saudi Arabia?
    1- Green roofs
    (Yes/No)
    2- Double glazing
    (Yes/No)
    3- Cross ventilation
    (Yes/No)
    4- Solar panels
    (Yes/No)
    5- Wind catchers
    (Yes/No)

6- Thermal mass
   (Yes/No)
7- Concrete with quality temperature control (CCTC)
   (Yes/No)

4- If you have not yet implemented any of the above in your opinion, why have you not yet implemented them in the Saudi construction sector?
   1- Political Blockers
      Please provide any additional comments…
   2- Technical Blockers
      Please provide any additional comments…
   3- Commercial Blockers
      Please provide any additional comments…
   4- Cultural Objections
      Please provide any additional comments…
   5- All the above
   6- Other …

5- In what timescale are specific measured could be adopted?
   1- From 1 to 2 years
   2- From 2 to 5 years
   3- From 5 to 10 years
   4- From 10 to 20 years
   5- More than 20 years

6- In your opinion, changing the design idea of the buildings from internal boundaries to open plan will provide internal airflow?
   - Yes
   - No
   - Not known

7- With privacy in Saudi Culture, changing the design idea of the buildings from internal boundaries to open plan will help to provide internal airflow?
   - Yes
   - No
   - Not known

8- In your opinion, changing size, shape, and orientation of the building help to reach a sustainable design?
   - Yes
   - No
   - Not known

9- In your opinion, changing colours, materials, and finishing of the building help to reach a sustainable design?
   - Yes
   - No
   - Not known

10- In your opinion, changing the place and the size of the window of the building help to reach a sustainable design?
   - Yes
   - No
   - Not known

11- In your opinion, do most of the Saudi families prefer to build with comfort features more than build with a functionality consideration?
   - Yes
   - No
   - Not known

12- In the near future do you think Saudi construction sector will adopt and achieve the sustainable design?
   - Yes
   - No
   - Not known

13- What can Saudi do further to adopt sustainable design?

14- Please provide any additional comment that will help to achieve a sustainable design in Saudi Arabia …

Please feel free to contact me via email address AlghamdiMS2@cardiff.ac.uk if you have any further questions about this feedback form or the project.

Name …

Email …

Thank you

APPENDIX C - Experts Survey Validation

The improvements of construction processes for existing traditional Saudi Arabian buildings to become more sustainable design.

I would like to introduce myself as Mushref Saad Alghamdi, PhD candidate in the subject of Building Information Modelling and Sustainability studying at Cardiff School of Engineering, Cardiff University, United Kingdom. My email address is AlghamdiMS2@cardiff.ac.uk.

This questionnaire is collecting data to analyse possible improvements in construction/refurbishment processes to enable existing traditional Saudi Arabian buildings to become more sustainable design.

All data collected in this survey will be held securely in accordance with the data protection act and GDPR regulations. Personal data collected (your e-mail address) will only be used to contact you in follow-up to this survey, and this will only happen if you allow it. Cookies and personal data stored by your Web browser are not used in this survey. The collected data will be analysed by only the research team and any personal information provided by you will be anonymised. The anonymised findings of this study will be included in the PhD thesis and publications of the researcher.

When answering the questions below focus on occasions when you have undertaken the design of either a new project or the renovation of an existing building.

1. How important do you consider using the following are to ensure the provision of a suitable internal temperature as part of the building design? (Use a scale of 1-4).
    1. Improving the natural ventilation system to be more efficient, for example, extend the area of the window.
    2. Apply shading to reduce the sun's radiation.
    3. Ensure air conditioning is at a minimal level to meet requirements.
    4. Ensure the heating system is at a minimal level to meet requirements.
    5. Use of smart controllers for air conditioning and heating system to set the temperature at an appropriate level.
    6. Reduce air leakage to prevent cooled air from escaping from home.

Are there any other technologies you consider? (Free Text)

2. How important do you consider minimizing non-renewable energy consumption for house occupants? (Use a scale of 1-4).
    a. Installation of LED lighting.
    b. Make use of smart controllers and other intelligent systems.
    c. Installation of an intelligent boiler with a smart programmer.
    d. Considering energy efficiency rating when specifying devices example, fridge, freezer, or TV depending on the Saudi energy rating.
    e. Install a smart energy meter.

Are there any other technologies you consider? (Free Text)

3. Have you ever used simulation tools to measure the internal temperature of the building? (Yes or No).

4. Would you normally consider the local climate characteristics in forming your design? (Yes or No).

5. Have you ever been directly asked by the owner to consider the climate information? (Yes or No).

6. How importantly do you consider incorporating technology to reduce water loss for the building? (Use a scale of 1-4).

7. Have you ever provided documentation to the house owner that shows a full description of the building elements and materials that have been used for the house? (Yes or No).

8. Has an occupant/owner ever requested documentation that shows a full description of the building elements and materials that have been used for the house? (Yes or No).

9. Do you routinely control or recycle the construction waste when planning projects? (Use a scale of 1-4).

10. How important do you consider design features to help occupants manage domestic waste and recycling? (Use a scale of 1-4).

11. How important do you consider ensuring the external fabric for the building is appropriate for the environment? (Use a scale of 1-4).

12. How important do you consider maximizing renewable energy generation as a part of the building design using the following technologies: (Use a scale of 1-4).
    a. Deploying a green roof for the building.
    b. Installing solar panels.
    c. Installing double glazing especially, for the exterior boundaries of the building.
    d. Installing a heat pump and ensure that is at a minimal level to meet requirements.
    e. Installing the turbine of wind which is a clean source of cooling.
    f. Use the solar water heating system technology.
    g. Are there any other technologies you consider? (Free Text)

13. How important do you consider enhancing both indoor and outdoor environmental quality as a part of the building design by doing the following: (Use a scale of 1-4).
    a. Provide better ventilation and natural light for the building
    b. Provide a suitable internal temperature for the occupants using approaches such as double glazing, the size of the windows, and the internal boundaries.
    c. Are there any other technologies you consider? (Free Text)

14. How important do you consider conserving water as a part of the building design by following: (Use a scale of 1-4).
    a. Install water-saving devices.
    b. Customized the Toilet facilities to separate waste.
    c. Fixed or replace any leak in the building.

    d. Exploit grey water and rainwater collection, especially for green area irrigation.
    e. Are there any other technologies you consider? (Free Text)

15. Do you routinely do any of the following: (Yes or No).
    a. Visit the site to take measurements?
    b. Visit the site to meet with and discuss plans with the occupants?
    c. Visit the site to observe the local climate conditions?
    d. Make use of existing plans/ drawings?
    e. Make use of existing BIM models?
    f. Are there any other similar activities that you perform that have not been mentioned?

16. Do you currently consider the cultural factors of the occupants such as separation between guests and family members when producing designs? (Yes or No).

17. If (21) is yes, how do you gather information on the cultural beliefs of the occupants? (Free Text).

18. In your opinion, does you consider the cultural views of Saudi families to be a challenge for the designer? (Yes or No).

19. What is your current use of BIM for building design in Saudi Arabia?
    a. Never Used BIM
    b. Used BIM on 1-2 projects
    c. Use BIM occasionally on projects
    d. Use BIM Frequently

20. How useful do you think a design aid tool would be that allowed: (Use a scale of 1-4).
    a. Allow for the use of BIM data as part of the specification of your work.
    b. Guidance in capturing the needs of the occupant.
    c. Guidance in understanding the cultural views of the building owner.

21. Would you use such a design tool as part of your business? (Yes or No)

22. Do you have any other comments you would like to make on any of the questions in this survey?

Thank you