Greening Existing Residential Buildings in Saudi Arabia with Mostadam as an Objective

by

Sara Murad Mohamed

A Thesis Presented in Partial Fulfillment
of the Requirements for the Degree
Master of Science

Approved July 2022 by the
Graduate Supervisory Committee:

Kenneth Sullivan, Chair
Oswald Chong
Kristen Hurtado

ARIZONA STATE UNIVERSITY

August 2022

ABSTRACT

Although Saudi Arabia is moving towards a sustainable future, Existing residential buildings in the country are extremely unsustainable. Therefore, there is a necessity for greening the existing residential building. Mostadam green rating systems was developed by the Saudi ministry of housing in 2019 to address the long-term sustainability vision in residential buildings in the country. By setting Mostadam requirements as an objective of the retrofit process, it will ensure that the building achieve sustainability. However, Mostadam is new and there is a lack of knowledge of implementing its requirements on existing buildings. The aim of this research is to develop a framework to green existing residential buildings in Saudi Arabia to achieve Mostadam energy and water minimum requirements. The framework was developed based on an extensive keyword-based search and an analysis of 92 relevant research. The process starts with assessing the building against the minimum requirements of energy and water of Mostadam. After that, optimization phase is conducted. Building information modelling is used in the optimization phase. Energy and water efficiency optimization measures are identified from the analysed literature. Revit is used in the base model authoring and Green building studio cloud is used to simulate the energy and water efficiency measures. Then, payback period is calculated for all the efficiency measured to assess the decision making. A case study of a villa in Riyadh, Saudi Arabia is provided. result shows that the implemented efficiency measures led to an increment of 37.5% in annual energy savings and 26.1% in the annual water savings. Results shows that the application of the proposed framework supports evaluating energy and water efficiency measures to implement it on the buildings to achieve Mostadam minimum energy and water requirements.

Recommendations were made for future work to bridge the knowledge gap.

DEDICATION

I dedicate my thesis work to my family and friends.

TABLE OF CONTENTS

Page

CHAPTER

CASE STUDY

LIST OF TABLES

Table Page

Table Page

LIST OF FIGURES

Figure Page

CHAPTER 1

INTRODUCTION

2.1 Overview

This chapter introduce the study by discussing the research background, research problem, research objectives, aims and scope.

2.2 Background

Global warming is one of the major threats the planet face in the 21st century. According to the united nation, (climate change – united nations sustainable development), 2019 was the second warmest year on the world record and the greenhouse gas emissions had risen into new records. This increment causes extreme weather events and rises the sea levels which disturb national economics and threaten lives. To respond and limit global warming, the Paris agreement was adopted in 2015 and signed by 197 countries. It aims to reduce global warming to be less than two degrees and improve the capability of countries in mitigating its impact. Moreover, the UN general assembly has established the 2030 agenda for sustainable development in 2015. The 17 sustainable development goals (SDGs) focus on the three pillars of sustainability: environmental, social, and economic. The goals are no poverty, zero hunger, good health and well-being, quality education, gender equality, clean water and sanitation, affordable and clean energy, decent work and economic growth, industry, innovation and infrastructure, reduced inequality, sustainable cities and communities, responsible consumption and production, climate action, life below water, life on land, peace, and justice strong institutions, partnerships to achieve the goal (#envision2030: 17 goals to transform the world for persons with disabilities enable). Those goals are integrated where an action in on one goal will affect the outcomes in the others.

The Kingdom of Saudi Arabia is the largest exporter of oil in the world. It was reported for 13.3 percent of the world's total oil export in 2019. Since oil production is associated with green gas emissions and carbon dioxide, this indicates that Saudi Arabia is one of the countries that contribute heavily to the green gas emissions and global warming (Asia House), and one of the major polluters internationally (Aldabesh et al., 2021). Researchers found that in Saudi Arabia, greenhouse emissions had risen to 225% since 1990 (ellaboudy, 2020).

To minimize its carbon emissions, move away from the country's dependence on oil export and fossil fuel extractions (2021), and to address the SDGs, Saudi Arabia has launched the Saudi vision 2030 in 2016 which was designed around three key themes: a vibrant society, a thriving economy, and an ambitious nation (*vision2030*). According to the vision 2030 official website, the national strategy addresses the issues of poverty, inequality, climate change, prosperity, peace, justice, education, health, social, employment and protection, and recognizing the integrated nature of all issues.

To achieve the vision objectives, the vision realization program (VRPS) was established in 2018 to translate the goals into actions with pre-identified goals and KPIs with a 5-year milestone to be reviewed and re-aligned as the vision 2030 moved to further stages to accomplish the need of the country (vision realization program). The housing program is one of the VRPS and it aims to enhance the current and future housing conditions, enabling Saudi families to own suitable houses based on their financial and personal needs, increase the supply of affordable residential units in record time. (2021). However, until recently, constructed residential buildings in Saudi Arabia were highly unsustainable. Sustainable designs were disregarded since the construction practices and owners focus on the building capital cost and ignore the life cycle cost resulting in constructing inefficient buildings. Unsustainable residential buildings are still being built due to the rapid construction methods accompanied by the fast growth of the need for more residential units (Ahmed & Asif, 2021).

2.3 Problem statement

The following knowledge gaps were identified pertaining to greening existing residential buildings in Saudi Arabia based on a comprehensive literature review.

2.3.1 Implementing the Mostadam rating system on existing buildings

Statistics indicate that existing residential buildings in KSA are highly inefficient and there is a significant need to retrofit and green those buildings (general authority of statistics, 2021). Moreover, studies indicated that the inapplicability of available international green rating systems such as LEED and BREEM for buildings in Saudi Arabia (Alyami & Rezgui, 2012). To address this issue, Saudi Arabia has designed and launched MOSTADAM green rating system in 2019 for new and existing residential buildings. It was designed exclusively for Saudi Arabia buildings. However, the rating system is new and there is a lack of knowledge of implementing the Mostadam rating system on existing buildings.

2.3.2 Implementing BIM to green buildings with Mostadam with as an objective:

Previous studies showed that BIM can assist in greening existing residential buildings (Alaidroos & Krarti,2015), (Al-Sanea et al., 2012). Moreover, it is feasible to integrate BIM with green rating systems, calculate the potentials accumulated green credits and select optimum building objects (Jalaei et al., 2020) (Marzouk et al., 2014). Yet, there is an absence of information about implementing BIM to retrofit existing residential buildings to achieve MOSTADAM ratings.

2.4 Research objectives

The main objective of this research is to develop a framework to green existing residential buildings in Saudi Arabia to achieve Mostadam energy and water minimum requirements. Moreover, to provide case studies of retrofitting residential buildings in Saudi Arabia to achieve Mostadam minimum requirements.

2.5 Research methodology summary

The following chapters will explain the two phases research methodology implemented in this research in details.

2.5.1 Phase 1: framework development

The methodological framework for greening existing residential buildings in KSA with Mostadam energy and water keystones as an objective was developed in phase 1. First, the methodology involved two key steps. The first step aimed to assess the existing building condition against Mostadm energy and water keystone credits requirement to benchmark the building performance. Mostadam green rating system for existing residential buildings energy and water requirements were identified through a comprehensive literature review to benchmark the building performance. The second step exhibits building energy and water performance optimization options to achieve Mostadam energy and water minimum requirements. Energy and water efficiency measures were determined through a literature review. BIM is adopted in the optimization phase. Green building studio cloud– based simulation engine was used to run building performance simulation. The third step aimed to calculate the payback period of the implemented measures. Phase 1 details are further explained in chapter 3.

2.5.2 Phase 2: Performing case studies by using the framework

In chapter 3, a case study of an existing residential building in Riyadh, Saudi Arabia was analysed by using the proposed method. Building Data and floor plans were obtained from the owner and a site visit was conducted by the researcher. the first section of the chapter exhibits the collected data. The second section assesses the building against Mostadam energy and water keystone credits. The third section exhibits the process of implementing BIM technology to offer retrofit options to achieve Mostadam energy and water keystone credits. The fourth section exhibits the result of the optimization process. The fifth section exhibit the payback period of the implemented measures. phase 2 details are further explained in chapter 3.

2.6 Research scope

The scope of this thesis is to develop a framework to green existing residential buildings in Saudi Arabia with Mostadam energy and water keystone as an objective. As evidenced by the literature, there is an absence of studies discussing Mostadam green system implementation on existing buildings although it was tailored especially for buildings in

Saudi Arabia. Moreover, there is a significant need to green the existing residential building in Saudi Arabia. Hence, this thesis aims on that perspective.

2.7 Summary of thesis

This thesis develops a methodological framework to retrofit existing residential buildings in Saudi Arabia with Mostadam as an object. The following is a summary of the thesis:

1. Chapter 2: literature review

Presents the literature review of research conducted on the characteristics of existing residential buildings in Saudi Arabia, Mostadam rating system, sustainability, building information modelling in retrofit and retrofit residential buildings in Saudi Arabia.

2. Chapter 3: framework development

Describes the methodology used to develop the proposed framework to green existing residential buildings in KSA with Mostadam energy and water keystones as an objective.

3. Chapter 4: data collection

Present the case study data collected from the owner and the site visit.

4. Chapter 5: data analysis

Describe the method used to analyse the case study collected data.

5. Chapter 6: data analysis results

Describe the result of the case study data analysis. Results include the accumulated Mostadam energy and water credits from the data analysis.

6. Chapter 7: optimization phase

Present the optimization phase of the building. The chapter include BIM authoring, model calibration, energy and water efficiency measures are implemented to optimize the building energy and water efficiency.

7. Chapter 8: optimization phase results

Describe the result of the optimization phase and the implemented measures.

8. Chapter 9: payback period

Present the payback period of the implemented measure

9. Chapter 10: discussion and conclusion

CHAPTER 2

LITERATURE REVIEW

3.1 Overview

The aim of this chapter is to analyze the current studies available of greening existing residential building in Saudi Arabia, with a focus on1) investigating Mostadam applications in regarding of existing residential buildings, 2) highlighting the need for greening existing residential buildings in Saudi Arabia, 2) Demonstrating the outcomes of the retrofit practices in Saudi Arabia ,3) Using BIM to green existing buildings. A literature review of 92 studies correlated to BIM, sustainability, and residential buildings in Saudi Arabia and Mostadam was conducted. The chapter starts with an overview about green buildings industry and Mostadam. Then, analyses exiting residential buildings characterises. Also, Saudi retrofit practices outcomes were reviewed. Finally, BIM implementation into green existing buildings was investigated.

3.1.1 Literature Map

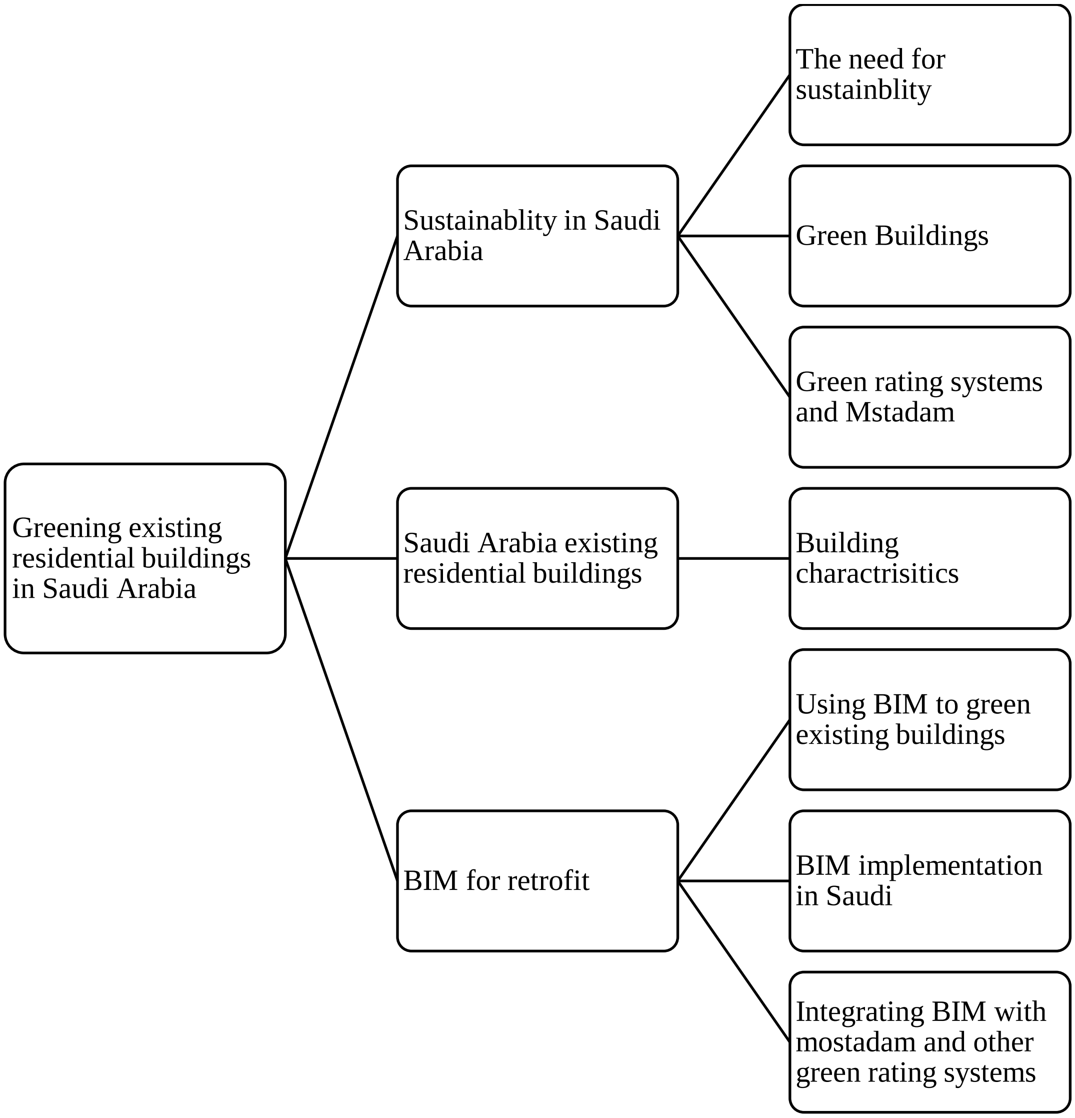

Figure 3.1-1 Literature map

3.2 The need for Sustainable buildings

The construction sector is one of the key contributors to global warming since it is responsible for more than one-third of the global greenhouse gas emission and about 30% of the energy consumption (Ahmed & Asif, 2021). The 2020 Global Status Report for Buildings and Construction reported in 2019 that energy consumption in buildings internationally remained flat year on year. Yet, the energy-related carbon dioxide emissions grew to 9.95 gigatons of carbon dioxide because of the increment in electricity utilization due to the shift away from coal and oil usage toward electricity. “Rising emissions in the buildings and construction sector emphasize the urgent need for a triple strategy to aggressively reduce energy demand in the built environment, decarbonize the power sector and implement materials strategies that reduce lifecycle carbon emissions,” said Inger Andersen (Building sector emissions hit a record high, but low carbon ...).

3.3 Green Buildings:

According to USGBC (What is green building?), green buildings are” the planning, design, construction, and operations of buildings with several central, foremost considerations: energy use, water use, indoor environmental quality, material section and the building's effects on its site”. Green buildings have significant advantages on the triple bottom line of sustainability (The benefits of Green Buildings).

3.4 Green Rating systems

To encourage green building development and adoption, many green building rating systems were established. Those rating systems aim to evaluate and identify buildings meeting the green rating system requirement, reward entities that construct or operate their buildings based on the requirements of the rating system. There are many green building rating systems available (rating tools).

A comparative analysis was conducted by Doan et al. (2017) between LEED (leadership in energy and environmental design), BREEAM (building research establishment assessment method), CASBEE (comprehensive assessment system for building environmental efficiency), and GREEN STAR NZ. The analysis showed that all the rating systems are concentrating on the indoor environmental quality, energy, and materials and none of those rating systems can evaluate a project in all aspects of sustainability. Furthermore, Alyami and Rezgui (2012) compared between (BREEAM, LEED, SBTOOL, and CASBEE). The results indicate that (BREEAM and LEED) are not covering economic, social aspects, and services building quality. More importantly, the study found that international green building systems such as LEED and BREEAM are inapplicable for Saudi Arabia built environment (Alyami & Rezgui, 2012). According to Alrashed & Asif (2014), there are only a few numbers of certified green buildings in Saudi Arabia. Literature shows that in Saudi Arabia, 159 projects were registered for green certification and only 22 got certified (Balabel & Alwetaishi, 2021). Mosly (2015) found that all the certified green buildings in Saudi are certified by the US Green Building Council LEED rating system and that the industry immaturity, lack of sustainability awareness of the public, practitioners, and government officials, and the absence of having a national rating system were the major barriers of found in the study (Mosly, 2015).

3.4.1 Mostadam rating system

To address the long-term sustainability vision in residential buildings in the Kingdom, the Saudi ministry of housing developed the Mostadam guide under the “sustainable building “program in 2019. Mostadam is a Saudi green building rating and certification system for residential and commercial buildings. (Al-Surf et al., 2021). It is aligned with the Saudi building code (SBC), the Saudi green building code (SABC), and the kingdom vision 2030. it was designed to go beyond the minimum requirement of the SBC to achieve a higher level of sustainability. it emphasizes on water, energy and human health, and comfort as the core of the rating system (Mostadam Green Building Rating System,2021).

The main goal of this rating system is to enhance energy and water efficiency and conservation, manage waste, and construction practices environmental impacts. Balabel & Alwetaishi (2021) reviewed the benefits of the Mostadam system and compared LEED v4.1 and the Mostadam rating system. they found that Mostadam indoor thermal comfort evaluation and indoor environmental quality assessment are more effective than LEED v41 and that indicates the strength of this local rating system (Balabel & Alwetaishi, 2021).

Mostadam guide consists of three rating systems, and each system has two components. Each rating system consists of a maximum of 100 points to be achieved through credits points. Five levels of rating levels are available: green > 20-point, Bronze> 35-point, Silver> 50, Gold >65, and Diamond >80 points, and it consists of nine categories: Building Envelope, Indoor Air Quality, Lighting, HVAC, Ventilation, Renewable Energy, Waste, Water and Comfort (Mostadam Rating System Residential Buildings O+E Manual,2019).

Mostadam of residential buildings operation and exiting contains 20 core keystones credit, see

Appendix A. Achieving those credits ensures that the building has accomplished the basic level of sustainability that is mandatory to get certified (Mostadam Rating System Residential Buildings O+E Manual,2019).

3.4.2 About Mostadam certification process

To certify a building with Mostadam rating, an accredited professional is appointed by the owner to register the project with sustainable building (the implementing body) and support the project team in accomplishing the target Mostadam rating. The performance of the existing building is monitored for a minimum of one year with 75% occupancy at a minimum. Monthly energy consumption, water consumption, and waste generation are documented during the period of mentoring. Procedures and policies are developed for certain Keystone credits and then implemented for six months at least. Building retrofit, renovation, or extension work is conducted before starting the monitoring period. Mostadam assessor is appointed by the implementing body to review the project, conduct official site audit visits, asses the AP and the project team submissions, and submit the project to the implementing body for review and certification. To maintain and improve the building performance over time, it can retain Mostadam certification every five years through recertification (2019).

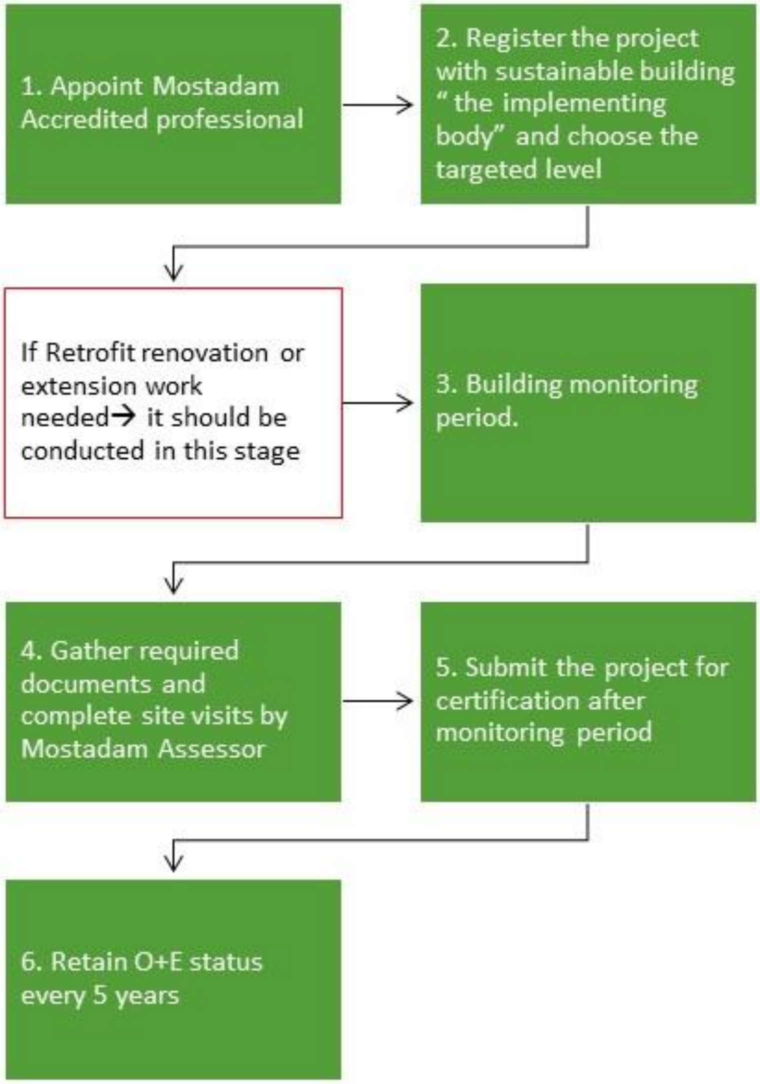

Figure 2 Summary of Mostadam O+E certification process

3.5 Saudi Residential Buildings Characteristics

Based on the recent report of housing survey results that was conducted by the Saudi general authority of statistics in 2018 (2021), the number of dwellings occupied by Saudi families in KSA reached 3,681,927 houses. Types of houses reported in the survey: villas, traditional houses, a floor in a villa, a floor in a traditional house, and apartments. 31% of the houses were 10-20 years old, 25% were 20-30 years old, 21% were 5-10 years old while only 6% were built less than 5 years old. 78% of the reported residential buildings are using the public pipe water as the main source for water, 22% uses water trucks while 0.03% depend on well water as the main water supply for their houses. Only 0.001% of the reported houses utilities a private electricity network as the main sources for power while the remaining are depending on the public grid for energy supply (*general authority of statistics*, 2021).

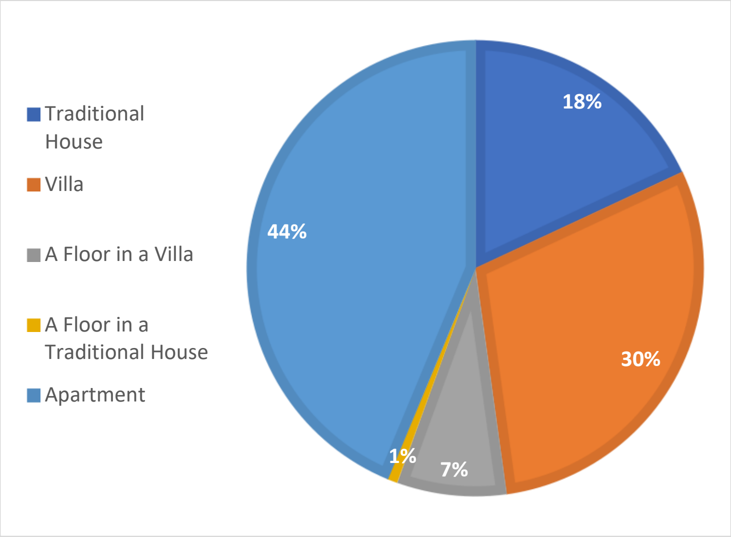

Figure 3.5-1 KSA housing unit types

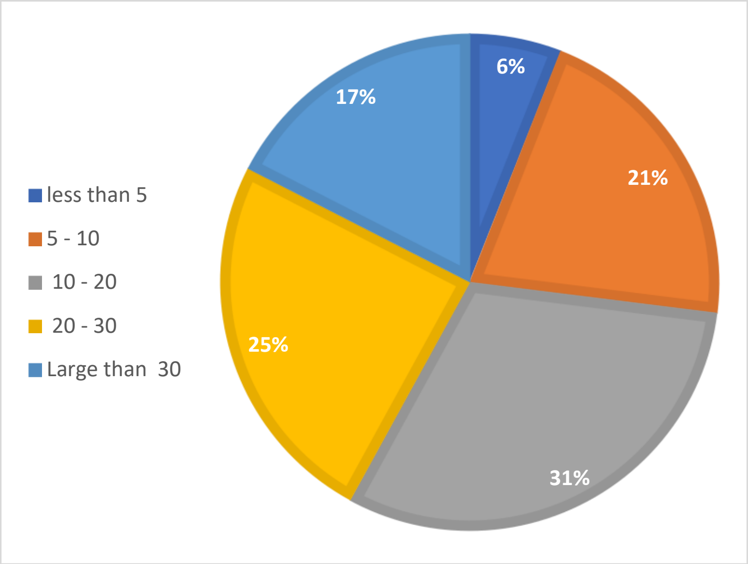

Figure 3.5-2 approximate age of housing units in KSA

3.5.1 Energy

3.5.1.1 Energy consumption:

The residential buildings sector is considered the highest in energy consumption and greenhouse gas emissions producer since it is responsible for almost 50% of the total annual energy consumption (Krarti et al.,2017). Residential buildings in Saudi Arabia utilize around 50% of the national electricity generated from fossil fuels (Al-Qahtani & Elgizawi, 2020). Literature attributes the high consumption of energy to the intensive utilization of air conditions (Almutairi et al., 2015). According to Felimban et al. (2019), residential buildings in KSA need to enhance their energy efficiency since the energy consumption in the country is increasing 5-8% yearly which would lead to equalizing the oil production and oil consumption of the country by 2035.

3.5.1.2 Air conditioners:

According to the Saudi electricity company (2021), air conditions are responsible for 60% of the total energy consumption of the building. All houses reported in the housing survey has several air conditioning systems ranging from 12 AC unit in villa-type buildings to 2.5 unit in apartments (Krarti et al., 2020). This attribute to the high-temperature climate with the poor thermal insulation of the building envelope. Windows air conditioning systems were found as the commonly used system in Saudi residential buildings with a rate of 71.3%, especially in old buildings. This type of air condition increases air infiltration, which is the main reason for energy inefficiency, caused by the air-conditioning unit window loose sealing. On the other hand, 25.8% of the houses use split air conditioning units, 1.8% uses evaporative while 1.1% of the houses use central air conditioning systems (Al-Homoud & Krarti, 2021).

3.5.1.3 Lighting:

According to Al-Homoud & Krarti (2021), the Saudi housing survey shows that 48.7% of the Saudi dwellings utilize candescent lamps while there is an increment in using the light-emitting diode (LED) lighting in 35.1% of the total houses. The operation time of the lighting systems ranges between 37-70% of the time of the day. (Al-Homoud & Krarti, 2021).

3.5.1.4 Domestic Water Heating:

Residential buildings in Saudi Arabia use electricity for domestic water heating. Operation hours range between 27% of the daytime in warm regions of the country and reach 72% of the daytime in cooler regions (Al-Homoud & Krarti, 2021).

3.5.1.5 Household Appliances:

Regarding household appliances, refrigerators and freezers operate 99% of the days' time. On the other hand, the other appliances such as television, washing machines, iron, vacuums cleaners, etc. ranges between 72% of the time for water coolers to 3% for microwaves (Al-Homoud & Krarti, 2021).

3.5.1.6 Thermal insulation

Literature shows the high consumption of air conditions is due to the poor thermal insulation of the buildings. Only 22.7% of the residential buildings exhibit some roof or exterior wall thermal insulation. More than half of the residential buildings in Saudi or 57.05% of the total number of buildings have no thermal insulation,20.25% reported uncertainty while the remaining reported wall and roof insulation. The reason behind This limitation of using thermal insulation in residential buildings is attributed to a tolerance of energy efficiency regulations in the last decades (Al-Homoud & Krarti, 2021).

3.5.2 Water

Saudi Arabia comes in third place after the united states and Canada in the high consumption of water with daily consumption of 7 billion cubic meters (BCM). This is attributed to the low price of water in the country and ineffective agricultural strategies (Krarti & Aldubyan, 2021). For the last decade, the water demand has increased by 9% with 25% dedicated to buildings (Rambo et al., 2017).

3.6 Retrofitting residential buildings:

According to the Cambridge dictionary, retrofit is: “to provide a machine with a part, or a place with equipment, that it did not originally have when it was built” (Retrofit). In the construction industry, it refers to the installation of a new building component or system that the building did not have when it was constructed (Retrofit). Green retrofit aims to increase the efficiency of the building, enhance its operation, and reduce its carbon emissions (Tree, 2021) & (Bu et al., 2015). The process of retrofit might include major or minor work depending on the building, the requirements, and the barriers.

A multi-objective optimization model (MOO) was proposed by Michael et al. (2017). The model was developed by employing LEED green building systems as a guideline and as an objective for the selection of retrofit measures in existing buildings. To optimize the accumulated LEED credit points, energy and water efficiency measures were identified since those categories can contribute up to 50% of the points. The Model of efficiency was validated by a case study since it produced a retrofit plan that optimize the building and its components and enable it to obtain the green building certifications.

3.6.1 Potentials of retrofitting residential buildings in Saudi Arabia

One of the key motivations of green retrofit is to reduce energy and water consumption. As mentioned in section 3.5, the Residential sector in KSA consumes almost half of the daily generated electricity in the country. Krarti & Aldubyan (2021), studied the effect of retrofit measures on energy and water consumption and carbon emissions for Saudi residential units. they found that a basic retrofit can be highly cost-effective for Saudi houses with a return of investment of less than a year. A significant reduction in the electricity consumption reaches 100,000 GWh/yearly, and 76 Million tons/year in carbon emissions. In addition, the study found that using efficient lighting systems in Saudi existing residential units can minimize water consumption needed for electricity production by 15.7% and utilizing highly efficient air conditioning can minimize it to 25.8%. furthermore, the study indicates that upgrading the air conditioning of a residential unit to a more efficient one is high- cost-effective with a payback period of 4.5 years in the western/southern regions while this payback period reduces to 3.5 years when upgrading for an evaporative cooler. (Krarti & Aldubyan, 2021).

3.7 BIM for existing buildings

3.7.1 BIM background

According to the National Institute of Building Sciences (NIBS), BIM has defined as "a digital representation of physical and functional characteristics of a facility. . .and a shared knowledge resource for information about a facility forming a reliable basis for decisions during its life cycle, defined as existing from earliest conception to demolition." BIM facilitates constructing accurate virtual building models digitally that assist the construction, fabrication, and procurement activities required to create the building.

BIM is a 3D modeling software that enables project architects and engineers to develop 3D virtual structures that can integrate their information. The accuracy of the virtual building depends on the drawings, specifications, and construction details that show the geography of the building and its location, building geometry, spaces relationship, and building component quantity, allowing the project team to recognize issues in the design and construction virtual building and take actions before constructing the building in the real world (Kubba et al., 2017).

3.7.2 BIM implementation in Saudi

There is a slow increment in BIM adoption in KSA (ALHUMAYN et al., 2017). According to BIMSMART (2011) report, there is a growing interest and acceptance in BIM technology in Saudi Arabia and the middle east and around 25% of the construction organization are using BIM in their projects. A survey conducted by ALHUMAYN et al, (2018) over 224 construction practitioners in Saudi Arabia to define the barriers and the strategies for BIM implementation. The results indicated that most of the participants assured BIM benefits in enhancing the efficiency of project quality, schedule, and cost. However, many construction organizations have not adopted BIM due to several barriers (University of Salford, 1970). studies point out that there are several barriers to BIM implementation in KSA, including: the lack of interest and demand of the owner and stakeholders due to their lack of awareness of the BIM benefits (Almuntaser et al., 2018) & (Elhendawi et al., 2018), the absence of BIM protocols and guidance (Elhendawi et al., 2018), (ALHUMAYN et al., 2017), shortage of BIM experts and lack of experience(Almuntaser et al., 2018) (Elhendawi et al., 2018), BIM intimal and running cost & the fear of shift from traditional practices (Elhendawi et al., 2018). Almuntaser et al. (2018), found that raising BIM awareness between project stakeholders, enhancing the information technology capabilities, and training the project team can raise the rate of BIM adoption in the Saudi industry.

3.7.3 Using BIM To Green Existing Buildings

BIM offers integrated solutions for green retrofitting. However, its application is still relatively new and need more study and verification (Tzortzopoulos et al., 2019). However, it was found from recent reviews that BIM supports the process of green building evaluation by assisting owners and stakeholders in selecting strategies to accomplish a green building, interpreting the credits of the green building system, and enabling proper documentation management (Liu et al., 2020).

3.7.3.1 Potentials and challenges of implementing BIM in retrofit:

BIM received growing interest for building operation and maintenance, facility management (Love et al., 2014). Since Developing BIM for retrofit residential buildings enable the project to be carried out since it reduces design errors, transparency of the project and its phases to all project team and stakeholders, accurate cost estimation which can be modified easily when changes are made to the project, enable construction site to be organized, accurate work schedules, the BIM model would store all information of the building after completing the project and help the operation of the building (Siniak et al., 2019). Many reviews are demonstrating the benefits of using BIM for existing buildings (Al-Homoud & Krarti, 2021), (A. Khudhair1 & Isik2, 2018), (Krarti & Aldubyan, 2021), (Volk et al., 2014), (Gholami et al., 2015), (Braila et al., 2021), (Baik, 2019). Also, many studied the Challenges of using BIM for existing buildings (Lim et al., 2021), (Volk et al., 2014), (Braila et al., 2021), (mcarthur, 2015) & (Gholami et al., 2015).

3.7.3.2 Using BIM in retrofitting residential buildings in Saudi Arabia:

Although there is limited literature reviewing BIM implementation in retrofitting residential buildings in Saudi Arabia, the available ones look promising. Ahmed & Asif (2021) developed a BIM-based retrofit framework with eight energy efficiency measures (EEMs) including increasing cooling setpoint temperature, using energy-efficient appliances, replacing conventional light with more efficient light, applying window shading, improving glazing type, improving airtightness, using more efficient air conditioning systems and adding envelope insulation. Three-level energy retrofit were conducted: minor, major, and on two case studies in KSA: an apartment building and a villa. The results showed a significate reduction in CO2 emission. Moreover, Energy analysis Implementation of the EEMs has resulted in annual energy consumption reduction for both the case studies.

Another review studied the optimal building envelope design for dwellings in Saudi Arabia using EnergyPlus to simulate the building energy (Alaidroos & Krarti,2015). The results indicated that by enhancing the insulation of the building roof and walls, energy savings can reach up to 25% in Jeddah while it can reach up to 35% in Riyadh. Moreover, the study shows that the government saves up to 47.3% of its annual energy consumption by improving the energy efficiency of residential buildings. Furthermore, Energy consumption and occupants' thermal comfort can be enhanced by several passive cooling systems such as increasing the efficiency of the thermal insulation of the building walls (Al-Sanea et al., 2012).

3.7.4 Implementing BIM to achieve Mostadam and other green rating systems

Although there is an absence of literature reviewing implementing BIM in green retrofit to achieve Mostadam green building requirements, available literature demonstrated the feasibly of integrating BIM with green rating systems with some limits. Jalaei et al. (2020), developed a plug by integrating BIM with LEEDv4 to calculate the potential accumulated green credits by integrating the Application Program Interface (API) of the BIM tool, tools of energy assessment and lighting simulation, Google Map and their associated library In the Revit environment. One of the main benefits of this model in the practice of sustainable buildings is its ability to eliminate the documentation process. The model saves the users time and effort since it deals with all the LEED v4 categories and its associated certification levels, eliminate the need to documentation and improve the documentation process. 6 out 8 required credits were calculated through the plug in by collecting answers from BIM model, google map information for the project location and orientation, the embedded checklist questions in the plug-in to collect answers from user and the energy, lighting and water efficiency analysis results coming from GBS. The proposed plug-in enables users to assess each energy model alternative generated by GBS and chose the best one or modify it to their desired objective (Jalaei et al., 2020).

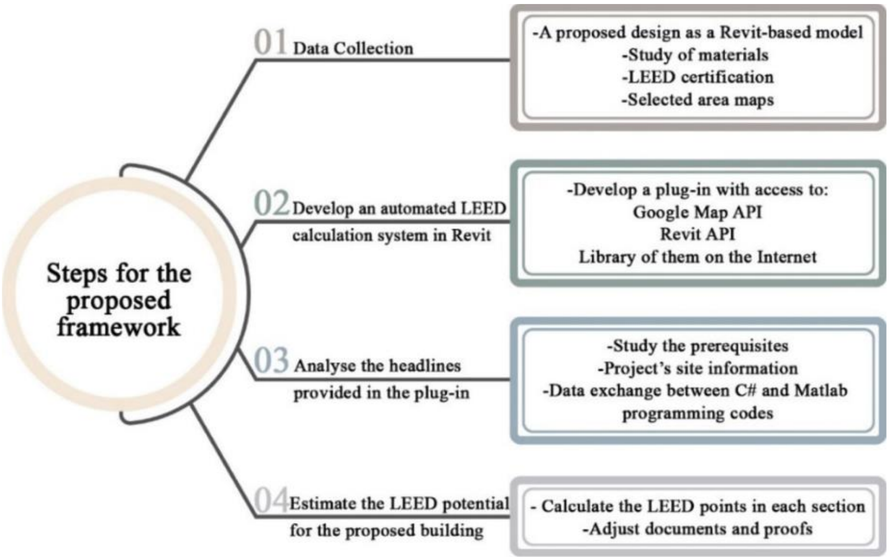

Figure 3.7-1 1Steps for the proposed framework, (Jalaei et al., 2020)

Marzouk et al. (2014) developed a Saudi Arabian green rating system (SAGRS) and created a framework to integrate the green rating system with BIM in a to select optimum green building material. This integration was accomplished by employing C# programming language that automates the data flow and calculations from one system module to another. The framework employs Genetic Algorithms (GA) optimization technique and Life Cycle Cost (LCC) assessment to achieve its designated purposes.

3.8 Conclusion

After a thorough review of the literature including reviewing 92 studies correlated to BIM, sustainability, and residential buildings in Saudi Arabia and Mostadam, it became evident that existing residential buildings in Saudi Arabia are highly unsustainable with the high consumption of energy and water. The Saudi green rating system Mostadam was tailored to address the sustainability needs of the country. Therefore, by setting it as an objective for greening the existing residential buildings, it will ensure that the building achieve sustainability. There is a lack of literature discussing Mostadam implementation on existing residential building. As a result, there is a necessity to develop a framework to green the existing residential buildings to achieve Mostadam.

Current Literature showed that BIM implementation in retrofitting residential buildings in Saudi Arabia is promising and the reviewed case studies results exhibited significant improvement in the building efficiency. Many studies demonstrated the feasibly of implementing BIM to achieve green rating systems requirements. However, there is an absence of research discussing implementing BIM to achieve Mostadam green rating system requirement.

CHAPTER 3

PROPSED FRAMEWORK DEVELOPMENT- LITERATURE REVIEW

4.1 Overview

The chapter aims to develop a framework to green existing residential buildings in KSA with Mostadam energy and water keystones as an objective. First, an extensive literature review was conducted to analyse Mostadam energy and water minimum requirements. Mostadam for residential operation+ existing guide was used as the main source of information. After that, A literature review was conducted to review concepts to optimize existing buildings energy and water performance. The aim of this phase is to elevate the building performance to meet Mostadam energy and water credits.

4.2 Current Mostadam for residential building operation + existing Process

Mostadam O+E rating certification is based on the accumulated points scored in the building rating levels, therefore, Mostadam O+E keystone credit of energy and water minimum performance requirements was identified as the objectives to evaluate the need for building retrofit. Keystone credits are the minimum credits required that ensure that the building achieved a basic level of sustainability. In total, the green rating system has twelve keystone credits including three credits for energy and two credits for water. In the case of not achieving those keystone credits, the building cannot be certificated as Mostadam.

4.3 Proposed framework phase 1: evaluate the building need for retrofit.

In this research, the objective of retrofit is to enhance the energy and water efficiency of residential buildings to meet Mostadam keystone credits. Therefore, to determine the need for energy and water retrofit, the building shall be assessed against the Mostadam rating system. If it achieves the minimum requirement (keystone points), the certification process may proceed. however, in case the building did not achieve the minimum requirement, building performance optimization is conducted. Mostadam certification process was explained in chapter 1. Mostadam Energy and water Keystone credits are briefly explained below in table 1:

Credit category	Keystone credit	Number of keystone points
Energy	Energy performance	4
	Energy metering	1
	Envelope assessment	1
Water	Water performance	4
	Water metering	1

Table 1 Mostadam Keystone credits

4.3.1 Energy

4.3.1.1 Energy performance:

a. Energy consumption assessment

This keystone credit requires to collect the annual electricity bills to confirm the annual energy use intensity of the building. Energy use intensity (EUI) is calculated and compared to the rating system energy consumption benchmarking tool. EUI is calculated as the annual energy consumed per square meter as the following:

$$\text{Energy Use Inensity EUI (kWh/m2)} = \frac{\text{Annual building energy consumption (kWh)}}{\text{Gross internal area (m2)}}$$

b. Energy consumption benchmarking:

Although it is not one of the minimum requirements of Mostadam, this credit is considered in this study to assist evaluating the building energy efficiency. The aim of this credit is comparing the building energy use intensity with the Mostadam efficiency EUI to benchmark to EUI of the building. Table 2 exhibit the rating and credits available.

Energy efficiency rating	Annaul energy consumption /m2	Credits points available
Band A*	less than 120 kWh/m2	7
Band A	less than 150 kWh/m2	5
Band B	less than 185 kWh/m2	3
Band C	less than 225 kWh/m2	1
Band D	less than 265 kWh/m2	0
Band E	less than 320 kWh/m2	0
Band F	more than 320 kWh/m2	0

Table 2 Mostadam Energy consumption benchmarking tool

c. Energy Audit:

Energy audit is conducted by a competent professional who assets registering all systems and appliances that consume energy and provide an energy audit report. The energy audit report includes information and data such as:

1. Date of construction and the applicable energy code at the date of construction.
2. Building operation problems reported by the occupants.

3. Building exterior inspection: air leakage, A/C external equipment units' efficiency and locations, wall framing and insulation type, exterior lighting fixture types and control devices.

4. Comparison between the building envelope specifications and the latest Saudi building code.

5. Comparison between the HVAC system and the latest Saudi building code.

6. Interior visual inspection reporting: electrical systems power consumption, appliances SASO rating, filters of internal A/C units, A/C thermostat settings and type, monitoring energy consumption of process load such as elevator, swimming pool, etc.

4.3.1.2 Energy metering:

To monitor and influence the property's energy consumption, each residential shall has an energy meter in a sealed location with clear energy consumption reading in kWh and a data port for smart monitoring devices, clear label and accessibility, and no functionality for changing the reading manually.

4.3.1.3 Envelope assessment:

A basic Building envelope assessment is conducted to enhance the building energy efficiency and indoor environmental quality and to prevent the acceleration of building fabric deterioration. The assessment includes testing the water infiltration and identifying recommended enhancements.

4.3.2 Water

4.3.2.1 Water performance:

The aim is to decrease the indoor water consumption by 10% at least than the baseline consumption. Baseline water consumption is determined based on Mostadam maximum fixtures flowrate/volume. Flowrate measurements of all water fixtures in the building are benchmarked against the Mostadam maximum flow rate or volume for each water fixture and appliance. In case it did not achieve the required percentage, water fixtures and fittings are replaced with ones that are compatible with Mostadam requirements to achieve the expected improvement over the baseline.

4.3.2.2 Water metering:

To monitor and influence the property's water consumption, each residential shall have an energy meter in a sealed location with clear energy consumption reading in litters and m3 and a data port for smart monitoring devices, have a pulsed output, Measure cold water flow in one direction only, clear label and accessibility, and no functionality for changing the reading manually.

4.3.3 Optimization decision:

To determine the optimization decision, accumulated Mostadam energy and water keystone points are calculated. In the case the building achieved the minimum points or the keystone points, the certification process may proceed. However, if it did not achieve those keystone credits, the building cannot be certificated as Mostadam. Therefore, building optimization shall be conducted to enhance the performance of the building.

4.4 Proposed framework Phase 2: Building performance optimization.

Since Buildings retrofit and optimization requires long-term planning, project team collaboration, and exploring many alternative solutions for the stakeholders to achieve the retrofit objectives (Michael et al., 2017), BIM is implemented in this phase. The literature review conducted in chapter 2 of this research shows that BIM supports the process of greening existing buildings by assisting owners and stakeholders in selecting strategies to accomplish a green building, interpreting the credits of the green building system, and enabling proper documentation management (Liu et al., 2020). The main objective of this phase is to retrofit the building to achieve Mostadam energy and water keystone credits.

4.4.1 Process of implementing BIM in building retrofit.

In this phase, BIMification method workflow for BIM-based retrofitting design is adopted (Scherer & Katranuschkov, 2018). This methodology gathers all pieces together of the retrofit project in three phases: Anamnesis (BIM authoring) phase, Diagnosis (assessment and analysis) phase, and Therapy (optimization) phase to provide an interoperable BIM lab for building retrofit see Figure 4.4-1. The major benefit of this method is that it is not limited to energy retrofit design only. It also can assist in retrofitting other systems with the same BIM model considering the degraded system performance that requires that assessment and retrofit.

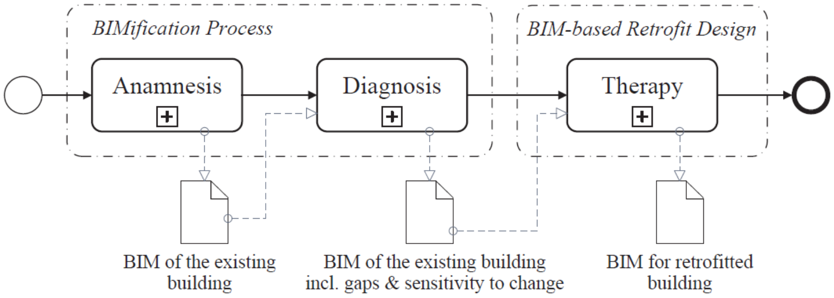

Figure 4.4-1BIMification 3-stage method for BIM-based retrofitting design

(Scherer & Katranuschkov, 2018)

4.4.1.1 BIM Authoring

For an effective BIM- adoption in retrofit, BIM models must be generated from the as-built with very limited available building documents that are usually in 2D drawing format. Therefore, the first phase of the process is to conduct a building survey and collect building information to be able to create the BIM model. BIM models can be developed by many data capturing techniques such as manual data capturing where the BIM model is built based on a building audit or automated data capturing technologies that assist the production of the as-built BIM model for buildings that don’t have BIM models. those technologies include Digital Photogrammetry, Terrestrial Laser Scanner (TLS), and Ground Penetrating Radar (GPR) (Hossain & Yeoh, 2018). BIM authoring (also known as modelling) software such as Autodesk Revit is used to create the building model, assign characteristics, and design properties to the model based on the as-built captured data.

4.4.1.2 BIM assessment

After creating the BIM Base Model, identifying building components with insignificant or bad performance can be achieved using dedicated performance analyses (Scherer & Katranuschkov,2018). Building performance analysis by using simulation can enhance the building efficiency, reduces cost, predict possible issues, and increase occupant satisfaction (Tzortzopoulos et al., 2019). It supports the process of decisions and management, optimize environmental performance of buildings and its competent (Habibi, 2017).

4.4.1.3 Building optimization

4.4.1.3.1 Energy performance optimization

To optimize the energy efficiency of the building, it is essential to upgrade building systems that affect the energy consumption directly or indirectly. Direct energy consumption systems include all components that consume energy to function such as lighting, HVAC, etc. indirect systems are building systems that contribute indirectly to the energy consumption such as building envelope components including wall insulation, glazing type, etc (Martin Holladay, 2019). Based on Ahmed & Asif (2020) study, the following energy efficiency measures (EEMs) are considered as design alternatives to optimize the building energy in this research:

1. Replacement of conventional lights with more efficient light.
2. Increment of the cooling set point temperature.
3. Utilization of energy efficient appliances.

4. Installing window shadings.
5. Enhancing glazing type, enhancing the air tightness.
6. Installing energy efficient HVAC system.
7. Insulating the building envelope.

4.4.1.4 Water performance optimization

Literature indicate that using water-saving equipment is an efficient method to conserve water in residential buildings (Cheng, 2002). In Mostadam, the indoor water consumption is evaluated based on the maximum flow rate/ volume of the water fixtures and appliances. Therefore, upgrading the existing water fixtures with ones that are compatible with the required flow rate /volume in Mostadam, will result in water consumption reduction.

4.4.1.5 Software selection:

There are much simulation software enabling energy and carbon emissions analysis. For this paper, Autodesk® Green Building Studio (GBS) is chose for building assessment and optimization phase. GBS enables performing whole-building analysis and enhances the energy efficiency using the DOE-2 with minimal input.

GBS guides most energy efficiency measures and design alternatives that have the highest impact on energy consumption. It enables optimizing the energy of building by changing characteristics of its components such as walls, insulation, glazing type, roofs, HVAC system, Orientation, Daylighting Efficiency, etc to elevate its efficiency. It also predicts the annual energy consumption based on the changes in the building systems and elements. Additionally, it provides an estimation of water consumption in the building based on its type and number of occupants. It offers calculating the annual water consumption after replacing the water fixtures with more efficient types. This allows the predicting the percentage of reduction of water consumption and assist the retrofit decision.

To perform the building assessment in GBS, the energy model is created in Revit, then the model is exported to the green building XML schema or “gbXML” file to upload it into the GBS cloud. After uploading the file, a base-run analysis is conducted automatically. The building Base model energy and water consumption are simulated. Model calibration is conducted to assure precise measurements by comparing the result of the base model simulation against the actual energy and water consumption.

4.4.2 Payback period

After applying the optimization measures into the model, payback period is calculated. Due to practical and economically feasibility reasons, not all the measures can be applied at the same time (Ahmed & Asif, 2020). To assist determining what measures to implement on the building, payback period of each measure is calculated. Payback period explain the time needed to recover the initial cost of the investment made (Kagan, 2022). Based on Mostadam (2019), the payback period can be calculated as follows:

$$\text{Simple Payback Period (years)} = \frac{\text{Cost of initial investment (SAR)}}{\text{Cost of energy savings per year (SAR)}}$$

4.4.3 Efficiency Measures selections

After analysing the result of the payback period, only measures with a maximum of 6 years payback period are selected.

4.5 Conclusion

The proposed framework was developed to asset optimizing energy and water performance of existing residential buildings in KSA to achieve the minimum sustainability levels. The process starts with assessing the building with the minimum requirements of energy and water of the Saudi green rating system, Mostadam. Based on the result of the assessment, building optimization phase is conducted. BIM is used in the optimization stage. Revit is used in the model creation and Green building studio cloud is used for the energy and water simulation and optimization. Energy and water efficiency measures were identified and implemented. At the final stage, payback period is calculated for all the efficiency measured to assess the decision making.

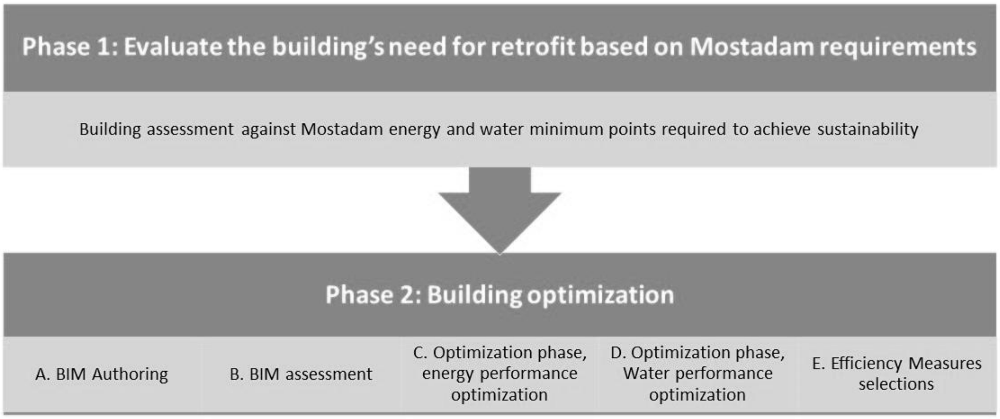

Figure 2 Summary of the proposed framework

CHAPTER 4

CASE STUDY

PROPOSED FRAMEWORK PHASE 1: - DATA COLLECTION

5.1 Overview

Stake (1995) defined case study methodology as an approach of study where the scholar investigates comprehensively a program, experience, activity, method, or entity. For this study, the researcher implemented the proposed framework on private residential villa Riyadh, Saudi Arabia. Data of the building were obtained from the owner of the house and a site visit conducted by the researcher. Then, the collected data were analysed against Mostadam minimum energy and water credits requirements. Building optimization phase is based on the results of the analysis. In the optimization phase, BIM model was created and calibrated. Energy and water efficiency measure were implemented on the building and simulated in Green Building Studio. simulated energy and water consumption and consumption cost were analysed for each implemented measure. After that, Payback period was calculated for all the measure to enable choosing the best options.

5.2 Data Collection

The data were collected by the researcher directly from the owner and a basic site visit. The characteristics of the building, systems, and operating conditions for the building are given in Table 3.

Characteristics	Description
Location	Riyadh, Saudi Arabia (24°38′n 46°43′e)
Type of housing unit	Residential villa, single-family
Number of stories	2 stories
Total height	10.45 m
Building age	10-20 years
Construction year	2008
Energy efficiency code applicable	SBC 601 2007 - Saudi building code
Annaul electricity bill in Saudi Riyal	Sar 23,232.90
Annaul electricity consumption	77443 kwh
Gross floor area	248 m2 (ground floor) + 199 m2 (first floor) = 447 m2
Outdoor area	142 m2
Building envelope area	653.4 m2
External walls	20 mm exterior plaster + 200 mm concrete hollow blocks + 20 mm interior plaster
Interior walls	20 mm plaster + 200 mm concrete hollow blocks + 20 mm interior plaster
Roof	25 mm terrazzo, 25 mm mortar, 5mm bitumen layer, 150 mm cast concrete, 200 mm concrete block, 15 mm Gypsum board, u-value: 1.934 w/ m2-k
Floor	300 mm slab on grade +120 mm porcelain tiles
Windows glazing	Single pane with no tent
Windows glazing area	65 m2
Exterior shading device	None
Occupants	5 people
Source of electricity	Public network
Source of water supply	Public piped water
Type of sewage disposal	Public sewage network
Type of cooking fuel	Electricity
Lighting	Halogen light bulb
HVAC	Cooling, available throughout the year, heating: not applicable
HVAC system type	Split dx system
HVAC thermostat setting	18 °c
Renewable energy	N/a

Table 3 case study collected data

5.2.1 Building architecture drawings:

The building’s architectural plan and elevations are in Appendix B.

5.2.2 Energy

5.2.2.1 Energy consumption

The annual energy bills were collected by the researcher from the owner as required by Mostadam. Table 1 shows the annual energy consumption and cost.

2021- 2022	electricity consumption kWh	cost (without service and tax cost)
January – February	6198	SAR 1,859.40
February- March	6209	SAR 1,862.70
March - April	6161	SAR 1,848.30
April- May	6304	SAR 1,891.20
May -June	6648	SAR 1,994.40
June – July	6894	SAR 2,068.20
July – August	6883	SAR 2,064.90
August -September	6604	SAR 1,981.20
September – October	6908	SAR 2,072.40
October – November	6497	SAR 1,949.10
November – December	6123	SAR 1,836.90
December – January	6014	SAR 1,804.20
Total	77443	SAR 23,232.90

5.2.2.2 Energy Audit

Home Appliances were checked to verify that they have Energy efficiency label from the Saudi standards, Metrology and Quality Organization (SASO) with a minimum rating of B or if they have been certified by energy star. All refrigerators, freezers, washing machines, dishwashers, water coolers and televisions in the building were included in the assessment. Table 4 shows list of appliances found in the building.

Appliance	Number of units	Manufacturer/ model
Refrigerators	2	ClassPro,297 Liters
		Samsung Refrigerator, 10.6 Cu.ft
Freezer	1	Haier Chest Freezer, 3.5 cuft., 100 Ltrs, Door Lock
washing machines	2	Haier Front Load Fully Automatic Washer HW70-BP12829
		Haier Front Load Fully Automatic Washer, HW100-BP14829
Dishwashers	1	Ariston Dishwasher 7 Program
water coolers	2	ClassPro Water Dispenser
		Philips Water Dispenser
televisions	3	TCL 55 Inch
		LG 70 Inch
		LG 70 Inch
Air conditioning	10	York, Models: YHGE12XT3CFE-R4

Table 4 case study list existing appliances

5.2.2.3 Investigating Building operation problem

To understand the building operational problems, occupants were questioned about the problems in the building.

5.2.2.4 Energy Metering checking:

As Required in Mosdam rating system, the building was checked for having its own energy metering system and a sub-meter.

5.2.2.5 Building Envelope Assessment

Due to limitation in the needed equipment to conduct the required water infiltration test, the researcher was not able to conduct the required assessment.

5.2.3 Water

5.2.3.1 Water Performance

Indoor Water consumption of the building was measured using measuring flowrate tool provided in the Mostadam manual (2019). water flowrate is calculated by recording the time that is taken to fill up a known volume container and then taking the median of at least 3 readings for each fixture, and then use the resulted information with the provided formula to calculate the flowrate:

$$\text{Flowrate (lpm)} = \frac{\text{Capacity of container (liters)}}{\text{Time taken to fill container (seconds)}} \times 60$$

5.2.3.2 Water metering

As Required in Mosdam rating system, the building was checked for having its own energy metering system and a sub-meter. Annual water consumption bills were collected Table 5.

2021- 2022	Water consumption m3	cost (without service and tax cost)
January – February	126	SAR 776.25
February- March	130	SAR 812.25
March - April	128	SAR 794.25
April- May	134	SAR 848.25
May -June	132	SAR 830.25
June – July	136	SAR 866.25
July – August	136	SAR 866.25
August -September	141	SAR 911.25
September – October	134	SAR 848.25
October – November	130	SAR 812.25
November – December	127	SAR 785.25
December – January	121	SAR 731.25
Total	1575	SAR 9,882.00

Table 5 Case study annual Water consumption and cost.

CHAPTER 5

PROPOSED FRAMEWORK PHASE 1: - DATA ANALYSIS

6.1 Overview

In this chapter, the collected data are analysed against Mostadam minimum energy and water credits requirements.

6.2 Energy

6.2.1 Energy consumption assessment

The annual energy consumption of the building was reviewed by the researcher to confirm the annual energy intensity (EUI) of the building. Electricity consumption pattern were further analysed to understand the peak months.

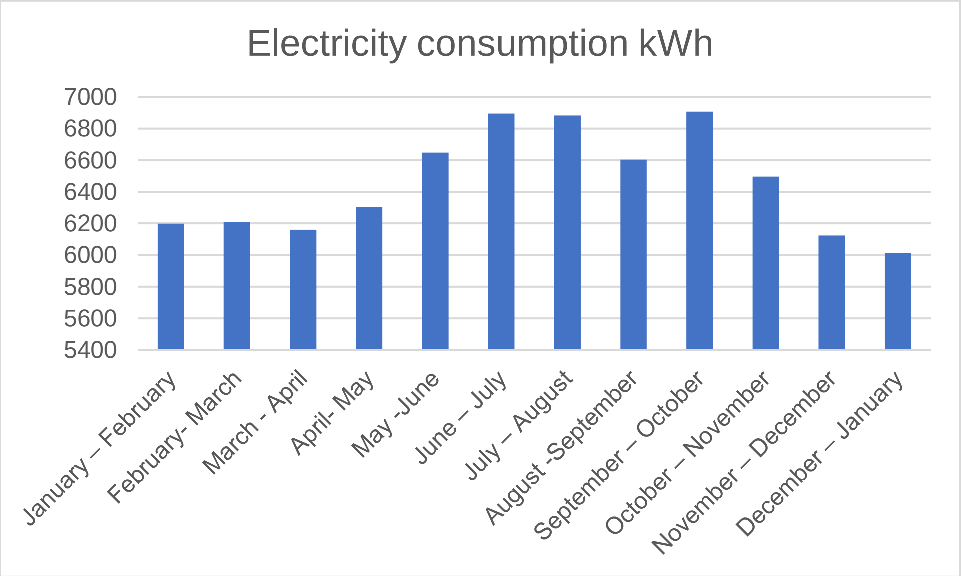

Table 6 Case study annual Electricity consumption pattern

According to Mostadam residential building O+E manual (2021), EUI translates the building energy use as a function of its size. It is calculated based on the annual building energy consumption and its gross area. Therefore:

$$\text{Energyse Intensity EUI}\left(\frac{\text{kWh}}{\text{m2}}\right)=\frac{87143\ (kWh)}{447\ M2}=\ 194.9\ kWh/m2$$

6.2.1.1 Energy Audit

The scholar investigated each appliance energy efficiency certification type and its annual energy consumption. Table 7 shows list of building appliances, manufacturer, and its energy efficiency.

Appliance	Number of units	Manufacturer/ model	energy efficiency certification type	Notes
Refrigerators	2	ClassPro,297 Liters	SASO Energy Efficiency Class: D	310 KWH
		Samsung Refrigerator, 10.6 Cu.ft	SASO Energy Efficiency Class: C	240 KWH
Freezer	1	Haier Chest Freezer, 3.5 cuft., 100 Ltrs, Door Lock	SASO Energy Efficiency Class: D	182 KWH
washing machines	2	Haier Front Load Fully Automatic Washer HW70-BP12829	SASO Energy Efficiency Class: A	96 KWH
		Haier Front Load Fully Automatic Washer, HW100-BP14829	SASO Energy Efficiency Class: A	96 KWH
Dishwashers	1	Ariston Dishwasher 7 Program	SASO Energy Efficiency Class: A++	82 KWH
water coolers	2	ClassPro Water Dispenser	Not found	Not found
		Philips Water Dispenser	Not found	Not found
televisions	3	TCL 55 Inch	Not found	Not found
		LG 70 Inch	Not found	Not found
		LG 70 Inch	Not found	Not found
Air conditioning	10	York, Models: YHGE12XT3CFE-R4	SASO Energy Efficiency Class: D	2511 kWh per unit

Table 7 Case study appliances, manufacturers, and their energy efficiency.

6.2.1.2 Investigating Building operation problem

4 out 5 of the Building occupants reported extreme heat and strong glare during the daytime.

6.3 Water

6.3.1 Water performance

Three water flow recordings were conducted for each water fixture by documenting the volume of the water filled in the container within the one minute, then, the percentage of reduction is calculated by comparing the result with the baseline water flowrate as the following:

Fixture	Reading #1		Reading #2	Reading #3	Average Flowrate (Ipm)	baseline water consumption (maximum)	Reading compared to the baseline
Kitchen faucet		7.21	7.33	7.31	7.28	6.84 lpm at 414 KPa	-6%
Lavatory faucet	#1	6.09	5.93	5.98	6	5.7 lpm at 414 KPa	-5%
	#2	5.80	5.92	5.83	5.85		-2.5%
	#3	6.22	6.3	6.26	6.26		-8.9%
	#4	5.2	5.24	5.19	5.21		+ 8.7%
	#5	5.72	5.69	5.71	5.706667		0
	#6	6.7	6.67	6.62	6.663333		-13%
	#7	5.83	5.82	5.83	5.826667		-1.7%
	#8	5.63	5.61	5.5	5.58		+3.6%
	#9	5.75	5.72	5.73	5.733333		0
Water closet – flushometer type	#1	5.46	5.35	5.41	5.406667	4.86 lpf	-10%
	#2	5.31	5.4	5.34	5.35		-10%
	#3	4.9	4.89	4.94	4.91		-0.02%
	#4	5.41	5.46	5.41	5.426667		-10
	#5	4.98	5.01	4.95	4.98		-0.02%
	#6	5.76	5.63	5.51	5.633333		-14%
Showerhead	#1	7.64	7.61	7.63	7.626667	7.6 lpm	0
	#2	7.28	7.25	7. 3	7.265		+6%
	#3	7.43	7.38	7.5	7.436667		+2.6%

Washing machine	#1	123	123	123	123	125.9 lpc	+1.6%
	#2	125	125	125	125		+0.7%
Dishwasher	10 lpc		10 lpc	10 lpc	10 lpc	24 lpc	+58%

Table 8 Case study water flow recordings

lpm: litters per minute, lpf: liters per flush, lpc: liters per cycle

To calculate the percentage reduction of indoor water consumption, the average flowrate of all the indoor fixtures is calculated and compared with Mostadam requirements. Points are awarded based on the result:

$$\text{Average flowrate percentage}$$

$$= \frac{\text{the percentage of difference between the actual flowrate and the baseline}}{\text{total number of fixtures}}$$

$$= \frac{-6-5-2.5-8.9+8.7-0-13-1.7+3.6-0-10-10-0.02-14-0+6+2.6+1.6+0.7+58\%}{22}$$

$$= 2.88\%$$

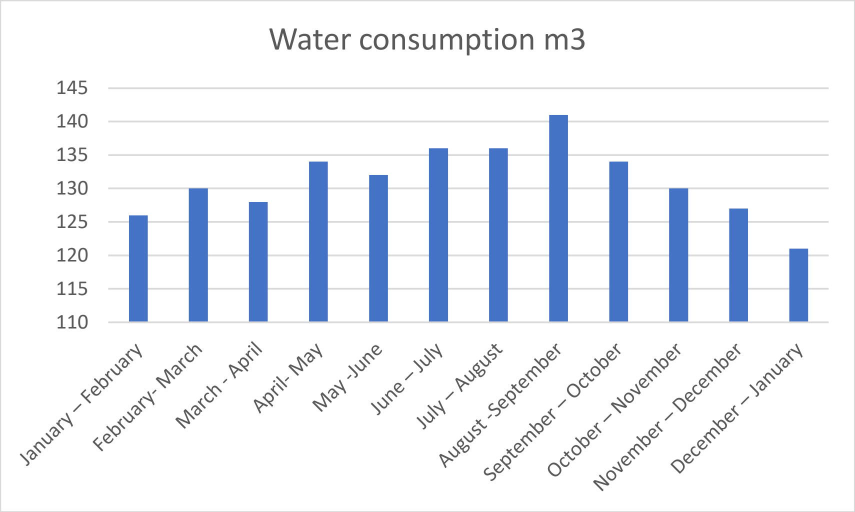

Table 9 Case study annual water consumption pattern

CHAPTER 6

PROPOSED FRAMEWORK PHASE 1: - RESULTS

7.1 Overview

In this section, a comparison is conducted between the building analysis result and Mostadam energy and water keystone requirements to determine the optimization decision.

7.2 Energy performance:

7.2.1 Energy consumption assessment

The annual energy consumption chart shows that the energy consumption increases in the summer months and decreases in the winter. The increment in electricity utilization in the summer months attribute to the high consumption of air conditioning systems to cope with the heat of the summer. 1 point is accumulated from the Energy Consumption Benchmarking credit.

7.2.1.1 Building energy benchmark:

By calculating the energy intensity of the building based on the provided formula in the Mostadam guide, the building scored Band C. However, benchmarking is not a keystone credit

7.2.2 Energy audit

7.2.2.1 Building envelope

The applicable energy efficiency code applied to the building did not require applying thermal insulation to the building envelope. It was found that the building walls did not exhibit any thermal insulation. Moreover, the roof exhibited a 5mm bitumen layer with a U-value of 1.934 W/ m2-K. by comparing the result with the current applied code of energy efficiency required for an air-conditioned residential building (Saudi Energy Conservation Code - Low Rise (SBC 602)) , Based on the building location, it is required a minimum insulation of R-5.0 and a maximum U-value of U-0.202 for the roofs of the residential buildings, and minimum insulation of R-2.92 and a maximum U-value of U-0.342 for the residential building's exterior walls.

The building glazing and windows represent 10.69% of the total area of the building envelope. 58.6% of the windows are in the west elevation and 28.3% are in the south elevation. The used glass in the windows is a single pane with no colour tent. No exterior shading devices for the windows were found. However, blackout curtains were used on the interior side of the building to minimize the sun glare and heat.

7.2.2.2 Appliances and air conditioning:

The air conditioning system used in the building were found to be low energy efficient based on the SASO rating. Also, it was reported as the highest energy-consuming appliance with 2511 kWh energy consumption per unit. Refrigerators came in second place with a D class of SASO energy efficiency and 310 kWh energy consumption. Freezer came in third place with a D class of SASO energy efficiency and 182 kWh energy consumption. Washing machines were found as highly efficient with class A of SASO energy efficiency rating that consumes only 96 kWh. The dishwasher was found as the most energy efficient with an A++ classification of SASO rating and 82-kWh energy consumption. On the other hand, water coolers and television SASO rating and consumption were not available.

Therefore, 1 point is accumulated from the Energy Audit credit.

7.2.3 Energy Metering

The building has its own energy meter. The meter is in the house fence in an easily accessible and sealed location. The reading is in kWh and has a port to connect smart monitoring devices and can be monitored remotely. On the other hand, there is no Energy sub-meters for the building.

Therefore, 1 point is accumulated from the Energy Metering credit.

7.2.4 Envelope Assessment

Due to limitations in the needed equipment to conduct the building envelope water infiltration test, the researcher was not able to conduct the required assessment.

Therefore, no point is accumulated from the Envelope assessment credit.

7.3 Water performance

The average water flow rate of the indoor water fixtures in the building found is 2.88% below the baseline. However, the minimum percentage of indoor water consumption reduction to achieve Mostadam is 10%. By comparing both values, the building is required to increase its indoor water consumption reduction by 7.12%.

Therefore, no point is accumulated in this credit.

7.3.1 Water metering

The building has its own water meter. The meter is in the house fence in an easily accessible and sealed location. The reading is in liters and m3 and has a port to connect smart monitoring devices and can be monitored remotely. On the other hand, there are no water sub-meters for the building.

Therefore, 1 point is accumulated from the water Metering credit.

7.4 Summary of the accumulated keystone points

	#	Keystone credit	Keystone points available	Achieved point
Energy performance	1	Energy Consumption Assessment	1	1
	2	Energy audit	1	1
	3	Energy efficiency measures	1	0
	4	External lighting	1	1
Energy metering	5	Energy meters	1	1
Envelope Assessment	6	Basic audit of the building envelope.	1	0
Water Performance	7	Indoor Water Consumption is at least 10% less than the baseline	4	0
Water metering	8	Water meters are present to facilitate the monitoring and recording of water consumption	1	1

Table 10 Case study phase 1 accumulated keystone points

7.5 Conclusion

After developing the framework, it was implemented on an existing residential building in Riyadh, Saudi Arabia. Data was collected directly from the owner and a site visit. Data included the available architectural drawings, building area, height, number of stories, building date of construction, Energy efficiency code applied on the date of construction, Annual electricity bill and consumption, building envelope area and materials, HVAC system type, thermostat setting, lighting type and appliances, water bill and consumption. The data was analysed and compared with Mostadam energy and water minimum required points. Mostadam Points were collected based on the analysis.

CHAPTER 7

PROPOSED FRAMEWORK PHASE 2: OPTIMIZATION PHASE

8.1 Overview

This phase is conducted to elevate the building energy and water efficiency to achieve Mostadam energy and water minimum requirements. In the first step, BIM model is created and then analysed and calibrated to ensure the results accuracy. Energy and Water efficiency measures are implemented simulated to optimize the building performance and to enable choosing the optimum measures.

8.2 BIM Authoring

The BIM 3D model of the building is developed based on the provided drawings obtained from the from the owner including drawings such as the plans, sections, elevations, and the collected information such as the building material and the location. Two different plans are drawn for the ground floor and the first floor. The structure, interior walls (one type), exterior walls (one type), windows and door types are inserted into the model. Using the software analysis tab, building energy settings are modified. Information such as building type, operation schedule, building materials, HVAC system are modified based on the collected data. Building energy model is created from the analyse tab. Then the file is exported into gbXML format to be able to be imported into the green building studio.

8.3 BIM assessment

To optimize the building performance, a comprehensive analysis of the model is conducted using Autodesk® Green Building Studio (GBS). After creating the project file in the GBS and before uploading the gbXML file of the building model, modifications were conducted to the default electricity cost in the GBS platform. In GBS, Default electricity cost for projects in KSA buildings is 0.14 SAR /kWH. however, based on the official website of Saudi electric company, the actual prices for the electricity are 0.18 SAR/ kWH for 1-6000 kWH electricity consumption category and 0.30 SAR / kWH for more than 6000 kWH electricity consumption category. Modifications to the electricity consumption cost were conducted prior uploading the gbXML file as it can't be changed after uploading the file. Moreover, KSA water supply and sewer prices are different from ones in the GBS. In 2016, the Saudi national water company has raised the block tariff structure for the whole country. Water and sewer tariffs per water unit rise with the consumption. Table 11 shows the new tariff of residential units:

Household usage	Water tariff (SAR/m3)	Sewage tariff (SAR/m3)	Combined tariff (SAR/m3)
0-15	0.1	0.05	.15
16-30	1	0.5	1.5
31-45	3	1.5	4.5
46-60	4	2	6
+61	6	3	9

Table 11 updated water and sewage tariff issued by the Saudi national water company

8.3.1 Model calibration

After uploading the gbXML file, a base run is conducted. Result data of the base run are used to calibrate the simulated model and the original data. Actual energy and water consumption and cost of the building were compared with the result of the GBS predicted energy and water consumption and cost. In actual data, electricity consumption recorded an average of 77443 kWH or 173.25 kWh/m2. On the other hand, the average electricity consumption in the simulated model was 89,473 kWh which is higher than the actual by 0.86%. based on the GBS analysis, 46.1% of the end-use energy consumption is used by the HVAC system. 36% is required by the lighting systems and rest is used by the other building appliances Figure 8.3-1 .

For water, actual water shows an average annual consumption of 1575 m3, and the simulated consumption indicate that the average consumption of water is 1613.496 m3 which is higher by almost 2.3% than the water consumption.

	Actual annual consumption	Actual annual cost in SAR	GBS simulated annual consumption	GBS simulated annual cost in SAR
Energy	77443 kwh	23,232.90 SAR	89,473 kwh	26,941 SAR
Water (consumption & sewer)	1575 m3	6,570 SAR	1613.496 m3	2,594 SAR

Table 12 A comparison between the actual annual energy and water consumption and cost and the GBS simulated annual consumption and cost of the energy and water.

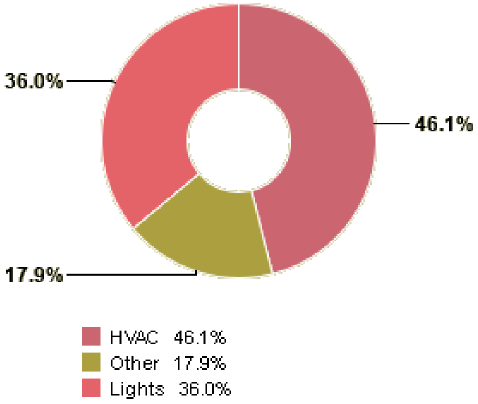

Figure 8.3-1 End-use energy consumption of the building

8.4 Optimization phase: energy performance optimization.

Each of the EEMs that were defined from the literature were implemented as a design alternative option in GBS to identify its benefits and the amount of reduced energy consumption and cost as the following :

8.4.1 Replacement of conventional lights with more efficient light

Halogen lights were found as the most common lighting type in the building. In the first design alternative of the lighting EEM, the researcher replaced the halogen lighting system by LED light bulb that last ten times longer than halogen light and use 85% less energy (1970). In the second design alternative, occupancy sensors were added to the LED light. In the third, day light sensors and controls were added to the LED light. In the fourth option, both daylight sensors and occupancy sensors were added to the LED light. In the fifth option, only occupancy sensors were added to the building. In the sixth alternative, only daylight sensors were added to the building, in the seventh option, only both sensors (occupancy and day light sensors) were added to the model.

8.4.2 Increment of the cooling set point temperature

The building cooling set point is 18 C °. According to Alshahrani & Boait (2018), a small increment of the thermostat setting can significantly save energy. In the first design alternative. Cooling setpoint was adjusted to 20 C°. in the second alternative, cooling setpoint was adjusted to 22 C°. in the third option, cooling setpoint was set on 24 C°.

8.4.3 Windows:

8.4.3.1 Enhancing glazing type:

High-performance, energy-efficient window and glazing systems can significantly minimize the building energy consumption (Ander, 2016). In the first design alternative of the windows and glazing system, windows glazing was replaced with super insulated glazing. In the second design alternative, it was changed to insulated reflective double pane low-e glazing.

8.4.3.2 Installing window shadings:

In this measure, windows shading devices were examined in enhancing the building energy efficiency. In the first option, shading devices with projection depth equal to ¼ of the windows height were added to the building windows. In the second option, shading devices with projection depth equal to 1/3 of the windows height were added to the building windows. In the third option, shading devices with projection depth equal to ½ of the windows height were added to the building windows.

8.4.4 Installing energy efficient HVAC system

The current HVAC system used the in the building is split A/C for both cooling and heating. Based on SASO energy efficiency rating, the used system is classified as D. In the design alternative, the current HVAC system was replaced with a higher energy efficiency ratio (EER) and Coefficient of Performance (COP) system.

8.4.5 Insulating the building envelope.

The current building status exhibited no insulated for both the exterior walls and the roof. In the first design alternative, the researcher added R19 on the 200 mm thickness exterior concrete walls. In the section option, the researcher increased the R-value to R30. For the roof, an alternative design was developed by adding R30 insulation to the existing roof structure.

8.5 Optimization phase: water performance optimization.

To optimize the water efficiency of the building, the researcher replaced the existing water fixtures such as toilets, sinks, showers, clothes waters, and dishwashers in GBS with a more efficient types.

8.6 Conclusion

To optimize the building performance, Optimization phase was conducted. First, the 3D Revit model of the building was initiated based on the collected data. The file was converted to gbXML format and uploaded to the green building studio, GBS. Modification was made for the default cost of energy consumption based to comply with the current Saudi energy tariff. Second, a base run was conducted to compare the energy and water consumption of the uploaded model with the actual energy and water consumption. It was found that the energy consumption in the base run was higher by 0.45% than the actual annual consumption. for the water, the based run was higher by 2.3% than the actual consumption. After that, design alternatives were applied in GBS to optimize the building efficiency. energy efficiency measures implemented included: Replacement of conventional lights with more efficient light, increment of the cooling set point temperature, enhancing windows glazing type, installing window shadings, installing energy efficient HVAC system, insulating the building envelope. On the other hand, to optimize water efficiency, building water fixtures were replaced by more efficient ones.

CHAPTER 8

PROPOSED FRAMEWORK PHASE 2: OPTIMIZATION PHASE RESULTS

9.1 Overview

In this chapter, the results of the energy and water optimization measures are exhibited and analysed. Simulated annual energy consumption and cost are calculated, and efficiency are explained.

9.2 Design alternative to optimize Energy efficiency

9.2.1 Replacement of conventional lights with more efficient lighting systems

It was found that Replacing existing lighting with LED light can save up to 35.8% of the existing lighting energy consumption. Moreover, by adding occupancy sensors to LED light energy efficiency can increase to 37.2%. however, adding daylight sensors and controls to the LED light only increase the LED light efficiency by 0.2%. on the other hand, adding occupancy sensors to the existing halogen lighting system can increase the energy efficiency by 6.9%.

#	Design alternative	Simulated Energy consumption	Simulated annual Energy cost (SAR)	Efficiency %
Base	Base model	89,473 kWh	26,941 SAR	N/A
1	Replacing light to LED lights	49,907 kWh	17,511.65 SAR	35.8 %
2	Replacing light to LED lights + adding occupancy sensors	48,883 kWh	16.918.9 SAR	37.2%
3	Replacing light to LED lights + adding daylight sensors and controls	49,907 kWh	17,511.65 SAR	35.8%

4	Replacing light to LED lights + adding occupancy sensors+ adding daylight sensors and controls	48,883 kWh	16.918.9 SAR	37.2%
5	Adding occupancy sensors	72,449 kWh	25,082 SAR	6.9%
6	Adding daylight sensors and controls	77,659 kWh	26,402 SAR	0.2%
7	Adding occupancy sensors +adding daylight sensors and controls	72,449 kWh	25,082 SAR	6.9%

Figure 9.2-1 Replacement of conventional lights with more efficient lighting systems

9.3 Increment of the cooling set point temperature

Increasing the cooling setpoint of the building HVAC system can save energy. In the base run of the building with the actual cooling set point of 18 C °, the simulated annual energy consumption was 89,473 kWh. 3.8% of the annual energy consumption can be saved by increasing the setpoint into 20 C °. The percentage of energy efficiency can grow into 7.23% by setting the setpoint into 22 C ° and can grow further into 12.57% by increasing the setpoint to 24 C °.

#	Design alternative	Simulated Annual Energy consumption (kWh)	Simulated annual Energy cost (SAR)	Efficiency %
Base	Base model: cooling setpoint = 18 C °.	89,473 kWh	26,941 SAR	N/A
1	cooling setpoint = 20 C °.	86,073 kWh	25,927 SAR	3.80%
2	cooling setpoint = 22 C °.	83,003 kWh	25,014 SAR	7.23%
3	cooling setpoint = 24 C °.	78,229 kWh	23,575 SAR	12.57%

Figure 9.3-1 Increment of the cooling set point temperature

9.3.1 Windows:

9.3.1.1 Enhancing glazing type

Based on the GBS simulation and the purposed design alternatives, 5.84% of the annual energy consumption can be saved by replacing the existing glazing system by Super insulated glazing. By replacing it to Low-E hot climate glazing system, energy efficiency can achieve 6.32% and it can reach up to 6.48% if it was replaced by Insulated low-E glazing. However, it was found that the most efficient glazing alternative was the Insulated Reflective Low-E glazing system that can save up to 11.24 % of the annual energy consumption.

#	Design alternative	Simulated Annual energy consumption	Simulated annual Energy cost (SAR)	Energy efficiency
Base	Clear glazing- single panel	89,473 kWh	SAR 26,941	N/A
1	Super insulated glazing	84,247.77 kWh	SAR 25,368	5.84%
4	Insulated Reflective Low-E glazing	79,941.60 kWh	SAR 24,071	11.24 %

Figure 9.3-2 enhancing glazing type

9.3.1.2 Installing window shadings

Installing windows shading devices can add more energy efficient to alternative designs. By adding shading devices that are 1/4 of the window height, it can save 1.09% more of the annual energy consumption. While shading devices that are 1/3 of the window height can save 1.11% of energy consumption and shading devices that are 1/2 of the window height can contribute to save 1.35% of annual energy consumption.

#	Design alternative	Building Simulated Annual energy consumption	Energy efficiency
Base	No shading devices	89,473 kWh	N/A
1	1/4 of the Window Height	88,499 kWh	1.09%
2	1/3 of the Window Height	88,480 kWh	1.11%
3	1/2 of the Window Height	88,268 kWh	1.35%

Figure 9.3-3 installing window shadings

9.3.2 Installing energy efficient HVAC system

The design alternative of the HVAC system exhibited a significant increment in the energy savings. By replacing the existing HVAC system by a more efficient one, energy efficiency reached up to 30%. The alternative design used a system that is higher in the energy efficiency ratio and the Coefficient of Performance than the existing system.

	HVAC type	EER	COP	Building simulated annual energy consumption	Building simulated annual energy cost (SAR)	Energy efficiency
Base system	Split unit	10	3.1	89,473 KWH	SAR 26,941	N/A
Design alternative	Split unit	11.9	3.5	62,631.1 KWH	SAR 18,858.7	30%

Figure 9.3-4 Installing energy efficient HVAC system

9.3.3 Insulating the building envelope.

Insulating the building envelope shows major savings in energy efficiency. different insulation levels and energy savings were examined. insulating the building’s exterior walls by adding R19 insulation to the concrete wall resulted in 8.1% reduction of the building’s building annual energy consumption. By optimizing the exterior wall insulation into R30, annual building energy consumption can be reduced by 8.8%. on the other hand, insulating the roof by adding R30 to the existing roofing structure shows a 1.3% reduction in the simulated energy consumption.

#	Design alternative	Building Simulated Annual energy consumption	Building Simulated annual Energy cost (SAR)	Energy efficiency
Base	200 mm heavy concrete wall with no insulation	89,473 kWh	SAR 26,941	N/A
1	200 mm heavy concrete wall + R19 insulation	82,241 kWh	SAR 24,760	8.1%
2	200 mm heavy concrete wall + R30 insulation	81,623 kWh	SAR 24,574	8.8%
3	Existing roof structure +R30 insulation	78,181.3 kWh	SAR 23,541	12.6%

Figure 9.3-5 Insulating the building envelope.

9.4 Design alternative to optimize water efficiency

Based on GBS water tool, the building's annual water consumption can be reduced by 36.1% when replacing the existing water fixtures with a more efficient type in GBS.

	Building simulated annual water consumption m3.	Efficiency
Base model	1615.302 m3	N/a
Optimized	1033.22 m3	36.1%

Figure 9.4-1 replacing the existing water fixtures with a more efficient type

9.5 Conclusion

By analysing the results, the measure that scored that highest energy efficiency was replacing the existing lighting with LED light and occupancy sensors that can save up to 35% of the total building energy consumption. The second highest energy efficiency measure is replacing the existing HVAC system with an efficient one. by doing that, it can save up to 30% of the building energy consumption. Installing R30 insulation to the roof come in the third place with 12.6% of energy efficiency. Setting the cool point on 24 C comes in the fourth place since it can save up to 12.57% of the energy consumption. the least energy efficiency measures are installing windows shadings with an a 1.09 - 1.35% range of energy efficiency. On the other hand, water efficiency can improve by up to 36.1% only by replacing the existing fixture to a more efficient ones.

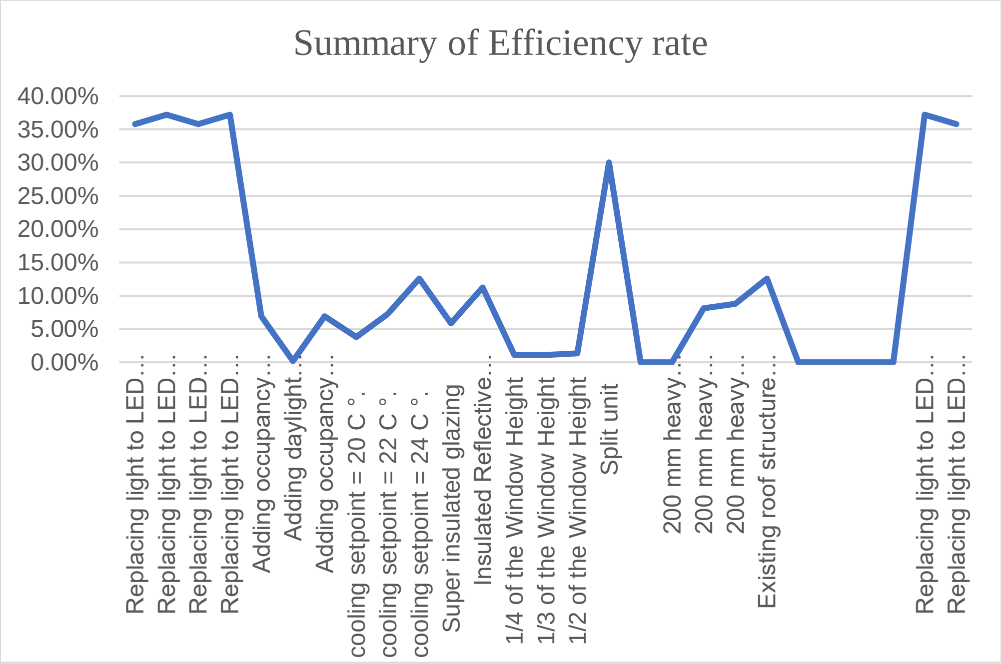

Figure 9.5-1Summary of energy efficiency measures efficiency rate

CHAPTER 9

PROPOSED FRAMEWORK PHASE 2: EFFICIENCY MEASURES SELECTIONS

10.1 Overview

In this chapter, payback of each efficiency measure is calculated to select the measures that are compatible with Mostadam requirements.

10.2 Replacement of conventional lights with more efficient light

The calculation indicates that replacing the lighting system results as the highest annual energy savings with a two-month payback period. Adding Ceiling Mount Occupancy Sensor has a payback period of a two years while combining the Ceiling Mount Occupancy and daylight Sensor payback is 3 years.

	Cost of the investment	Cost of annual energy savings	Payback period (years)	Simple payback
Lighting	SAR 1,190.00	SAR 8,329.00	0.142874295	2 months
Ceiling Mount Occupancy Sensor	SAR 3,144.50	SAR 1,597.00	1.969004383	23 months
Ceiling Mount Occupancy and daylight Sensor	SAR 4,891.36	SAR 1,597.00	3.06284283	3 years

Table 13 replacement of conventional lights with more efficient light payback period

10.3 Increment of the cooling set point temperature

Although changing the A/C set point tempertuer does not cost any money, it saves in the cost of energy consuption. Seting the A/C point tempetuer at 20 C ° will result in saving

SAR 1,014.00 annually, setting it on 22 C ° will save SAR 1,927.00 annually. while setting the cooling set point at 24 C ° has the highest saving annually with SAR 3,366.00.

Cooling set point temperature	Cost of the investment	Cost of annual energy savings	Payback period (years)
20 C °	SAR 0.00	SAR 1,014.00	0
22 C°	SAR 0.00	SAR,927.00	0
24 C °	SAR 0.00	SAR ,366.00	0

Table 14 increment of cooling set point payback period

10.4 Windows:

10.4.1 Enhancing glazing type

In this measure, the cost of Replacing the existing widow glazing to a more efficient types calculated. In the first option, the glazing was replaced with an Insulated double-glazing type. the cost of investment in this type of glazing is SAR 24,388.00. with SAR 1,573.00 as the cost of the annual energy saving, the payback period length is 15 years and six months. In the second option, the glazing was replaced with an Insulated Reflective Low-E double glazing type. the cost of investment in this type of glazing is SAR 134,095.00. with SAR 2,870.00 as the cost of the annual energy saving, the payback period length is 47 years.

Glazing type	Cost of the investment	Cost of annual energy savings	Payback period (years)	Simple
Insulated double glazing	Sar 24,388.00	Sar 1,573.00	15.50413223	15 years and half
Insulated reflective low-e double glazing	Sar 134,095.00	Sar 2,870.00	46.72299652	47 years

Table 15 Enhancing glazing type payback period

10.4.2 Installing window shadings

In this measure, the cost of installing windows shadings to the windows of the buildings was calculated. In the first option, the cost of installing shading devices with a 1/4 of the Window Height was calculated. the cost of investment in this type of shading is SAR 3,490.30. with SAR 293.66 as the cost of the annual energy saving, the payback period length is 11 years. In the second option, the cost of installing shading devices with a 11/3 of the Window Height was calculated. the cost of investment in this type of shading is SAR 3,930.00. with SAR 299.05 as the cost of the annual energy saving, the payback period length is 13 years. In the third option, the cost of installing shading devices with a 1/2 of the Window Height was calculated. the cost of investment in this type of shading is SAR 5,240.00. with SAR 363.70 as the cost of the annual energy saving, the payback period length is 14 years.

	Cost of the investment	Cost of annual energy savings	Payback period (years)	Simple
1/4 of the Window Height	SAR 3,490.30	SAR 293.66	11.88563933	11 year
1/3 of the Window Height	SAR 3,930.00	SAR 299.05	13.14183045	13 years
1/2 of the Window Height	SAR 5,240.00	SAR 363.70	14.40734004	14 years

Table 16 Installing window shadings payback period

10.5 Installing energy efficient HVAC system

In this measure, the cost of replacing the energy efficiency HVAC system into the buildings was calculated. The cost of investment in the Energy efficient A/C split is SAR 31,990.00. With SAR 8,082.30 as the cost of the annual energy saving, the payback period length is 4 years.

	Cost of the investment	Cost of annual energy savings	Payback period (years)	Simple
Energy efficient A/C split units	SAR 31,990.00	SAR 8,082.30	3.958031748	4 years

Table 17 Installing energy efficient HVAC system payback period

10.6 Insulating the building envelope.

In this measure, the cost of insulating buildings was calculated. Two types of wall insulation and one type of roof insulation was tested. In the first option of the wall insulation, the cost of adding a R19 insulation to the exterior walls of the building was calculated. The cost of investment in this type of insulation is SAR 71,874.00. With SAR 2,181.00 as the cost of the annual energy saving, the payback period length is 32 years. In the second option of the wall insulation, the cost of adding a R30 insulation to the exterior walls of the building was calculated. The cost of investment in this type of insulation is SAR 84,942.00. With SAR 2,367.00 as the cost of the annual energy saving, the payback period length is 35 years. On the other hand, In the option of the roof insulation, the cost of adding a R30 insulation to the exterior walls of the building was calculated. The cost of investment in this type of insulation is SAR 4,975.00. With SAR 2,367.00 as the cost of the annual energy saving, the payback period length is 35 years.

Insulating type	Cost of the investment	Cost of annual energy savings	Payback period (years)	Simple
Wall: R19 insulation	SAR 71,874.00	SAR 2,181.00	32.95460798	32 years
Wall: R30 insulation	SAR 84,942.00	SAR 2,367.00	35.88593156	Years 35
Roof: R30 insulation	SAR 4,975.00	SAR 3,400.00	1.463235294	1 year and 6 months

Table 18 insulating the building envelope.

10.7 Design alternative to optimize water efficiency

In this measure, the cost of replacing the building water fixtures with a highly efficient ones were calculated. Cost of each type of the high efficiency water fixtures were calculated, see Appendix 0 . The cost of investment is SAR 4,740.25. With SAR 3,558.00 as the cost of the annual water-saving, the payback period length is 1 years and 4 months.

Fixtures	Cost of the investment	Cost of annual water-savings	payback period (years)	Simple
High efficiency fixtures	Sar 4,740.25	Sar 3,558.00	1.33227937	1 year and 4 months

Table 19 replacing the building water fixtures with a highly efficient ones

10.7.1 Efficiency Measures with a payback period that is less than 6 years:

The following are the energy efficiency measures that are compatible with Mostadam requirement of having a payback period of 6 years :

1. Setting the cooling set point at either 20, 22 or 24 C °.
2. Replacing the building light to LED light.
3. Adding R30 roof insulation to the roof.
4. Adding Ceiling Mount Occupancy, and daylight Sensor to the LED light.
5. Replacing A/C with efficient models.

10.8 Summary

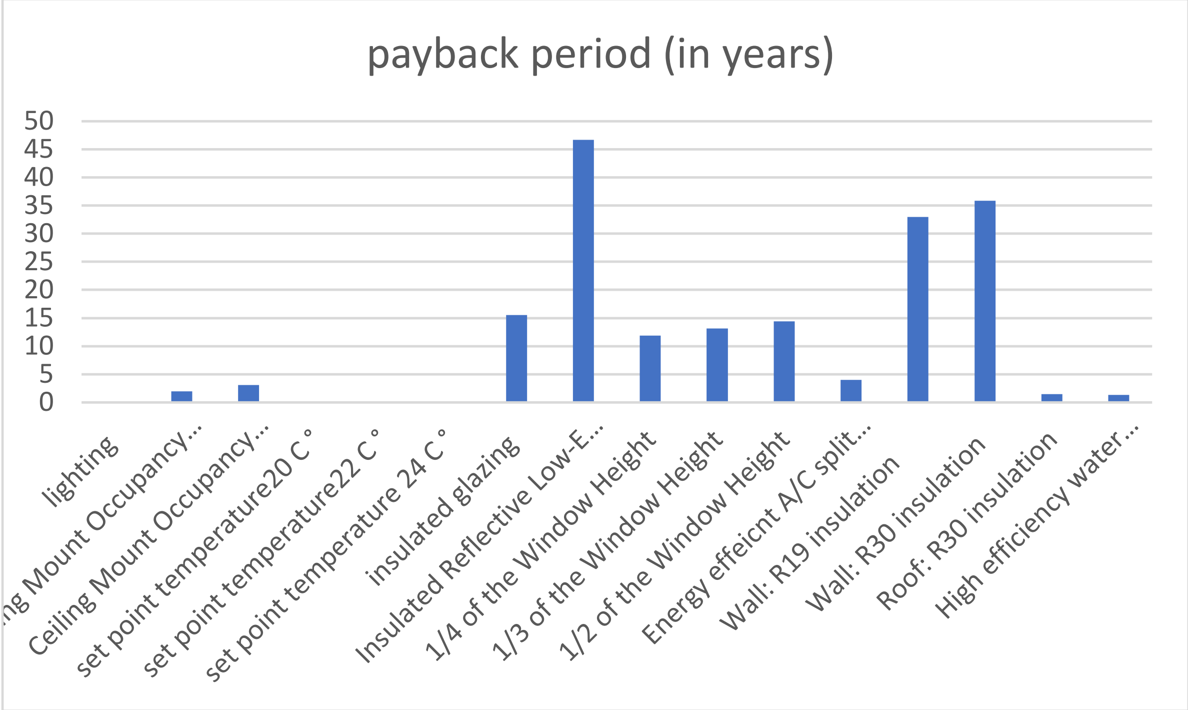

Figure 10.8-1 Summary of all measure’s payback period

After calculating the payback period of each energy efficiency measure implemented in the research, it was found that setting the cooling set point at either 20.22 or 24 C ° has the lowest payback period. Replacing the building light to LED light comes in the second places with a payback period of 2 months. In the third place, Adding R30 roof insulation to the roof has a payback period of 1 year and a half. in the fourth place, Adding Ceiling Mount Occupancy, and daylight Sensor to the LED light with a payback period of 3 years. Replacing A/C with efficient models has a payback of 4 years. Adding shading devices to the windows range between 11 t0 14 years. replacing insulated glazing has a payback period of 15 years and half. Flowing that is installing wall insulation with a range of payback period of 32 to 35 years. finally, the measure with the longest payback period was replacing windows glazing with insulated triple pane reflective low E glass with a payback period of 47 years. Regarding water efficiency measure, replacing the water fixtures with a highly efficient ones has a payback period of 1 year and 4 months.

CHAPTER 10

DISCUSSION, CONCLUSION, LIMITATION & FUTURE WORK

11.1 Discussion

The proposed framework was developed to asset optimizing energy and water performance of existing residential buildings in KSA to achieve the minimum sustainability levels. In the first phase, the framework assesses the building against the minimum requirements of energy and water credits of the Saudi green rating system, Mostadam. Minimum energy requirements found were: 1) energy performance including energy consumption assessment, energy audit, energy efficiency measures and external lighting. 2) energy meters. 3)Basic audit of building envelope. For the water: 1) water performance. 2) water meter. It was found that to accumulate the energy consumption assessment keystone credit in Mostadam, it is required to confirm the annual energy use intensity by analysing the annual electricity bill. Benchmarking the building EUI is not required as keystone. Based on that, the building can achieve the minimum requirements of Mostadam even if it has a high energy consumption.

In the second phase of the framework, the suggested building energy and water optimization phase starts with initiating the base model of the building in BIM. The method used in the case study to author the base model is not considered as the best practice and might result in multiple errors. Best practices of BIM authoring for existing buildings were discussed in chapter 3.

After simulating energy and water efficiency measures in Green Building Studio, only measure with a maximum payback period of 6 years were selected. Payback period was calculated to assist choosing the efficiency measures to be implement based on its cost effectiveness. Out the 20-energy efficiency tested measures in the case study, only 5 were selected based on its payback period. The design alternatives or the efficiency measures results have showed that retrofit of existing residential buildings in Saudi Arabia will lead to significant energy and water savings. For the energy efficiency, the measures that scored that highest energy efficiency were replacing the existing lighting with LED light and occupancy sensors that can saving up to 35% of the total building energy consumption. This percentage can increase 37.2% only by adding occupancy sensors to the lighting systems. The second highest energy efficiency measure is replacing the existing HVAC system with an efficient one. By doing that, it can save up to 30% of the building energy consumption. Installing R30 insulation to the roof come in the third place with saving up to 12.6% of energy consumption. Setting the cool point on 24 C comes in the fourth place since it can save up to 12.57% of the energy consumption. Table 20 shows that possible Mostadam energy efficiency rating and credit points by implementing each studied measure.

However, the result of the comparison between the building envelope and the existing Saudi building code requirements shows that the building exhibit no existing exterior wall insulation while the Existing Saudi building code required a minimum insulation of R-2.92 and a maximum U-value of U-0.342 for residential buildings exterior wall insulation. Therefore, although exterior wall insulation energy efficiency measures is not compatible with Mostadam requirements for the energy efficiency measure since its payback period is more that 6 years, exterior wall insulation should be considered to achieve the combability with the existing Saudi building code.

For the water, the implemented water efficiency measures can save by up to 36.1% of the building water consumption, which exceed the minimum required rate of water consumption in Mostadam by 26.1%.

In summary, the application of the proposed framework helps evaluating energy and water efficiency measures to implement it on the buildings to achieve Mostadam requirements.

Energy measure	Efficiency rate	Energy intensity (EUI) kwh/m2	Mostadam energy efficiency rating	Credits points (not Keystones)
None	N/a	173.2505593	Band B	3
Replacing light to led lights + adding occupancy sensors	37.20%	108.8013512	Band A*	7
Replacing light to led lights	35.80%	111.2268591	Band A*	7
Split unit	30%	121.2753915	Band A	5
Existing roof structure +r30 insulation	12.60%	151.4209888	Band A	5
Cooling setpoint = 24 c °.	12.57%	151.472964	Band A	5
Installing R19 wall insulation	8.10%	159.217264	Band B	3

Table 20 possible Credits points and Mostadam ratings when implementing the EEM

11.2 Research limitations

11.2.1 Time limitation

Mostadam rating system for operation and existing buildings contain 7 credit categories, 5 of the credits categories involve credits that are the minimum requirements to achieve sustainability. Those credits are policing management and maintenance, energy, water, health and comfort, education, and innovation. Due to time limitation, the researcher focused on evaluating only the energy and water minimum credit categories.

11.2.2 Lack of literature

In this study, the researcher reviewed more than 92 studies correlated to BIM, sustainability, and residential buildings in Saudi Arabia and Mostadam. At the time of the research, only 2 studies were found that are correlated to Mostadam the first study focus on the awareness of the stakeholders in the country regarding LEED and Mostadam application (al-surf et al., 2021) . The second research study building construction impact on the indoor environmental quality and thermal comfort. Mostadam was compared with LEED to investigate its benefits on (Balabel & alwetaishi, 2021). Hence, there is a lack of literature reviewing Mostadam implementation.

11.2.3 Building envelope assessment data collection

The required building envelope audit data in the envelop assessment credit was not collected by the researcher. The basic building envelop audit required water infiltration testing. This test requires to wet the tested windows with a spray rack for 15 minutes after putting the windows under specific air pressure (Horton, 2019). Due to lack of equipment, the researcher was not able to conduct the test. Therefore, building envelope assessment credit was not able to be collected.

11.3 Conclusion

To address the Saudi Arabia vision of sustainably. The proposed framework is developed in this research is to asset optimizing energy and water performance of existing residential buildings in KSA to achieve the minimum sustainability levels in the local green rating system “Mostadam”. The process starts with assessing the building with the minimum requirements of energy and water of the Saudi green rating system, Mostadam. Based on the result of the assessment, building optimization phase is conducted. BIM is used in the optimization stage. Revit is used in the model creation and Green building studio cloud is used for the energy and water simulation and optimization. At the final stage, payback period is calculated for all the efficiency measured to assess the decision making. The developed framework was implemented on a case study in Riyadh, Saudi Arabia. The results show the implemented efficiency measures lead to significant savings in the energy and water consumption. Payback period of each implemented measure was calculated to enable selecting the measures with the required payback period.

11.4 Recommendation for future work

1. Have the proposed framework evaluated and reviewed by an expert panel.
2. Developing a framework to green residential buildings to achieve the remaining credits of Mostadam: In this research, the objective of the developed framework is to achieve Mostadam energy and water minimum requirements. Future research should include the remaining credits to achieve Mostadam green certificate.
3. Labour and demolish cost: Due to limited data, labour cost, and demolish cost were ignored in payback period investment cost. Therefore, labour cost and demolish cost should be calculated for accurate results in the payback period.
4. Building envelope assessment: the building envelope assessment is one of the keystones requirements to achieve Mostadam rating. Therefore, it should be conducted in future research.
5. Study the strength and weakness of Mostadam rating system and highlight its compatibility with the regional specifications and the local codes.

11.5 Research Contribution

The present study attempts to address multiple gaps and in doing so makes important contribution. First, Statistics indicates that Existing residential buildings in Saudi Arabia are highly inefficient. On the other hand, literature shows that retrofitting residential building can be highly cost effective with the significant reduction of the annual energy consumption. Mostadam green rating system for existing residential building was launched in 2019 exclusively for Saudi Arabia existing residential buildings. However, there is an absence of studies discussing Mostadam green rating system implementation on existing residential buildings and no existing framework was found. The proposed framework in this study assists the process of greening existing residential buildings in KSA that require retrofit. Second, it was found that there is an absence of peer-reviewed studies discussing Retrofitting residential buildings in Saudi Arabia using BIM to achieve Mostadam green rating requirements. The proposed framework implies BIM to simulate the efficiency measures effect on the existing building performance. Therefore, the study provides guidelines to owners and developers in selecting the efficiency measures with the highest efficiency and minimum payback period in order to achieve Mostadam requirements.

REFERENCES

1. Ade Bilau, A., Witt, E., & Lill, I. (2018). Research methodology for the development of a framework for managing post-disaster Housing Reconstruction. *Procedia Engineering*, *212*, 598–605. https://doi.org/10.1016/j.proeng.2018.01.077

2. Ahmed, W., & Asif, M. (2020). BIM-based techno-economic assessment of energy retrofitting residential buildings in Hot Humid Climate. *Energy and Buildings*, *227*, 110406. https://doi.org/10.1016/j.enbuild.2020.110406

3. Ahmed, W., & Asif, M. (2021). A critical review of energy retrofitting trends in residential buildings with particular focus on the GCC countries. *Renewable and Sustainable Energy Reviews, 144*, 111000. https://doi.org/10.1016/j.rser.2021.111000

4. Al-Homoud, M. S., & Krarti, M. (2021). Energy efficiency of residential buildings in the Kingdom of Saudi Arabia: Review of status and future roadmap. *Journal of Building Engineering*, *36*, 102143. https://doi.org/10.1016/j.jobe.2020.102143

5. Al-Qahtani, L. A., & Elgizawi, L. S. (2020). Building envelope and energy saving case study: A residential building in Al-Riyadh, Saudi Arabia. *International Journal of Low-Carbon Technologies*, *15*(4), 555–564. https://doi.org/10.1093/ijlct/ctaa024

6. Al-Sanea, S. A., Zedan, M. F., & Al-Hussain, S. N. (2012). Effect of thermal mass on performance of insulated building walls and the concept of energy savings potential. *Applied Energy*, *89*(1), 430–442. https://doi.org/10.1016/j.apenergy.2011.08.009

7. Al-Sulaihi, I. A., Al-Gahtani, K. S., Al-Sugair, A. M., & Abadel, A. A. (2018, May 1). *Development of a roadmap for assessment the sustainability of buildings in Saudi Arabia using building information modeling*. Zenodo. Retrieved November 3, 2021, from https://zenodo.org/record/1316843#.YYH4yJ7P1PY

8. Al-Surf, M., Balabel, A., Alwetaishi, M., Abdelhafiz, A., Issa, U., Sharaky, I., Shamseldin, A., & Al-Harthi, M. (2021). Stakeholder’s perspective on green building rating systems in Saudi Arabia: The case of LEED, Mostadam, and the sdgs. *Sustainability*, *13*(15), 8463. https://doi.org/10.3390/su13158463

9. Alaidroos, A., & Krarti, M. (2015). Optimal design of Residential Building Envelope Systems in the Kingdom of Saudi Arabia. *Energy and Buildings*, *86*, 104–117. https://doi.org/10.1016/j.enbuild.2014.09.083

10. Aldabesh, A., Soufi, J., Omer, S., & Haredy, A. (2021). Unlocking the residential retrofitting potential in a three-degree world: A holistic approach to passive design in hot climates. *Buildings*, *11*(6), 228. https://doi.org/10.3390/buildings11060228

11. Aldubyan, M., & Krarti, M. (2022). Impact of stay home living on energy demand of residential buildings: Saudi Arabian case study. *Energy*, *238*, 121637. https://doi.org/10.1016/j.energy.2021.121637

12. AlHashmi, M., Chhipi-Shrestha, G., Ruparathna, R., Nahiduzzaman, K. M., Hewage, K., & Sadiq, R. (2021). Energy Performance Assessment Framework for residential buildings in Saudi Arabia. *Sustainability*, *13*(4), 2232. https://doi.org/10.3390/su13042232

13. Alhumayn, S. A. (2018, October 1). *Developing a framework for BIM implementation in the Saudi Arabian Construction Industry*. WIRE HOME. Retrieved October 29, 2021, from https://wlv.openrepository.com/handle/2436/621927

14. ALHUMAYN, S. A. U. D., CHINYIO, E. Z. E. K. I. E. L., & NDEKUGRI, I. S. S. A. K. A. (2017). The barriers and strategies of implementing BIM in Saudi Arabia. *Building Information Modelling (BIM) in Design, Construction and Operations II*. https://doi.org/10.2495/bim170061

15. Almuntaser, T., Sanni-Anibire, M. O., & Hassanain, M. A. (2018). Adoption and implementation of BIM – case study of a saudi arabian AEC firm. *International Journal of Managing Projects in Business*, *11*(3), 608–624. https://doi.org/10.1108/ijmpb-05-2017-0046

16. Almuntaser, T., Sanni-Anibire, M. O., & Hassanain, M. A. (2018). Adoption and implementation of BIM – case study of a saudi arabian AEC firm. *International Journal of Managing Projects in Business*, *11*(3), 608–624. https://doi.org/10.1108/ijmpb-05-2017-0046

17. Almutairi, K., Thoma, G., Burek, J., Algarni, S., & Nutter, D. (2015). Life cycle assessment and economic analysis of residential air conditioning in Saudi Arabia. *Energy and Buildings*, *102*, 370–379. https://doi.org/10.1016/j.enbuild.2015.06.004

18. Alrashed, F., & Asif, M. (2014). Saudi building industry's views on sustainability in buildings: Questionnaire survey. *Energy Procedia*, *62*, 382–390. https://doi.org/10.1016/j.egypro.2014.12.400

19. Alrashed, I., & Kantamaneni, K. (2018). A 5D building information model (BIM) for potential cost-benefit housing: A case of kingdom of Saudi Arabia (KSA). *Infrastructures*, *3*(2), 13. https://doi.org/10.3390/infrastructures3020013

20. Alshahrani, J., & Boait, P. (2018). Reducing high energy demand associated with air-conditioning needs in Saudi Arabia. *Energies*, *12*(1), 87. https://doi.org/10.3390/en12010087

21. Alyami, S. H., & Rezgui, Y. (2012). Sustainable building assessment tool development approach. *Sustainable Cities and Society*, *5*, 52–62. https://doi.org/10.1016/j.scs.2012.05.004

22. Ander, G. D. (2016, November 11). *Windows and glazing* . WBDG. Retrieved April 17, 2022, from https://www.wbdg.org/resources/windows-and-glazing

23. Ansah, M. K., Chen, X., Yang, H., Lu, L., & Lam, P. T. I. (2019). A review and outlook for integrated BIM application in Green Building Assessment. *Sustainable Cities and Society*, *48*, 101576. https://doi.org/10.1016/j.scs.2019.101576

24. Asia House. (n.d.). *Saudi Arabia's environmental sustainability strategy*. Asia House. Retrieved October 26, 2021, from https://asiahouse.org/news-and-views/saudi-arabias-environmental-sustainability-strategy/

25. Autodesk. (n.d.). *About green building studio*. Home. Retrieved March 6, 2022, from https://knowledge.autodesk.com/search-result/caas/CloudHelp/cloudhelp/ENU/BPA-Help/files/GUID-DC7557C2-FAD9-499B-84B9-E6E978AD347C-htm.html

26. Azhar, S., Brown, J. W., & Sattineni, A. (2010). A case study of building performance analyses using building information modeling. *Proceedings -- The 27th International Symposium on Automation and Robotics in Construction*. https://doi.org/10.22260/isarc2010/0023

27. Azhar, S., Carlton, W. A., Olsen, D., & Ahmad, I. (2011). Building Information Modeling for Sustainable Design and LEED® Rating Analysis. *Automation in Construction*, *20*(2), 217–224. https://doi.org/10.1016/j.autcon.2010.09.019

28. Baik, A. (2019). From point cloud to existing BIM for modelling and simulation purposes. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, *XLII-5/W2*, 15–19. https://doi.org/10.5194/isprs-archives-xlii-5-w2-15-2019

29. Baik, A. (2019). From point cloud to existing BIM for modelling and simulation purposes. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, *XLII-5/W2*, 15–19. https://doi.org/10.5194/isprs-archives-xlii-5-w2-15-2019

30. Balabel, A., & Alwetaishi, M. (2021). Towards sustainable residential buildings in Saudi Arabia according to the conceptual framework of “Mostadam” rating system and Vision 2030. *Sustainability*, *13*(2), 793. https://doi.org/10.3390/su13020793

31. Barlish, K., & Sullivan, K. (2012). How to measure the benefits of BIM — a case study approach. *Automation in Construction*, *24*, 149–159. https://doi.org/10.1016/j.autcon.2012.02.008
32. *The benefits of Green Buildings*. World Green Building Council. (n.d.). Retrieved October 26, 2021, from https://www.worldgbc.org/benefits-green-buildings
33. *Bim dimensions*. BIM dimensions - Designing Buildings. (n.d.). Retrieved October 29, 2021, from https://www.designingbuildings.co.uk/wiki/BIM_dimensions
34. Braila, N., Panchenko, N., & Kankhva, V. (2021). Building information modeling for existing sustainable buildings. *E3S Web of Conferences*, *244*, 05024. https://doi.org/10.1051/e3sconf/202124405024
35. Bu, S., Shen, G., Anumba, C. J., Wong, A. K. D., & Liang, X. (2015, September 21). *Literature Review of Green Retrofit Design for commercial buildings with bim implication*. Smart and Sustainable Built Environment. Retrieved October 27, 2021, from https://www.emerald.com/insight/content/doi/10.1108/SASBE-08-2014-0043/full/html
36. *Building information modelling bim*. Building information modelling BIM - Designing Buildings. (n.d.). Retrieved October 28, 2021, from https://www.designingbuildings.co.uk/wiki/Building_information_modelling_BIM
37. *Building sector emissions hit record high, but low-carbon ...* (n.d.). Retrieved October 26, 2021, from https://www.unep.org/news-and-stories/press-release/building-sector-emissions-hit-record-high-low-carbon-pandemic
38. Carter, S. M., & Little, M. (2007). Justifying knowledge, justifying method, taking action: Epistemologies, methodologies, and methods in qualitative research. *Qualitative Health Research*, *17*(10), 1316–1328. https://doi.org/10.1177/1049732307306927
39. Chen, X., Yang, H., & Lu, L. (2015). A comprehensive review on passive design approaches in Green Building Rating Tools. *Renewable and Sustainable Energy Reviews*, *50*, 1425–1436. https://doi.org/10.1016/j.rser.2015.06.003
40. Cheng, C.-L. (2002, April 21). *Evaluating water conservation measures for green building in Taiwan*. Building and Environment. Retrieved June 26, 2022, from https://www.sciencedirect.com/science/article/pii/S0360132302000628?casa_token=9QsylCmR9o0AAAAA%3AR3Sw4dSBG8M9GiXY0wYgPpEo64doiOmehwSAGmrZn6WFpqgIKXiqed47W2IwA7x7MT_e2tO_pGc#TBL1
41. Cleary , K., & Palmer, K. (2020). *Energy efficiency 101*. Resources for the Future. Retrieved April 12, 2022, from https://www.rff.org/publications/explainers/energy-efficiency-

101/#:~:text=Energy%20efficiency%20refers%20to%20using,to%2080%20percent%20less%20electricity.

42. *The cost analysis of electric power generation in Saudi Arabia*. Taylor & Francis. (n.d.). Retrieved October 27, 2021, from https://www.tandfonline.com/doi/full/10.1080/15567249.2016.1248874
43. Doan, D. T., Ghaffarianhoseini, A., Naismith, N., Zhang, T., Ghaffarianhoseini, A., & Tookey, J. (2017). A critical comparison of Green Building Rating Systems. *Building and Environment*, *123*, 243–260. https://doi.org/10.1016/j.buildenv.2017.07.007
44. Elhendawi, A., Smith, A., & Elbeltagi, E. (2018). Methodology for BIM implementation in the Kingdom of Saudi Arabia. *International Journal of BIM and Engineering Science*, 01–20. https://doi.org/10.54216/ijbes.020101
45. Ellaboudy, A. A. and A. (2020, December 21). *Saudi Arabia greenhouse gas emissions have increased by 225% since 1990*. Climate Scorecard. Retrieved October 26, 2021, from https://www.climatescorecard.org/2020/12/saudi-arabia-greenhouse-gas-emissions-have-increased-by-225-since-1990/
46. Felimban, A., Prieto, A., Knaack, U., Klein, T., & Qaffas, Y. (2019). Assessment of the current energy consumption of residential buildings in Jeddah, Saudi Arabia. https://doi.org/10.20944/preprints201906.0299.v1
47. Friedman, C., Becker, N., & Erell, E. (2014). Energy retrofit of residential building envelopes in Israel: A cost-benefit analysis. *Energy*, *77*, 183–193. https://doi.org/10.1016/j.energy.2014.06.019
48. Gerrish, T., Ruikar, K., Cook, M., Johnson, M., & Phillip, M. (2017). Using BIM capabilities to improve existing building energy modelling practices. *Engineering, Construction and Architectural Management*, *24*(2), 190–208. https://doi.org/10.1108/ecam-11-2015-0181
49. Gholami, E., Kiviniemi, A., & Kocaturk, T. (2015). *EXPLOITING BIM IN ENERGY EFFICIENT DOMESTIC RETROFIT: EVALUATION OF BENEFITS AND BARRIERS*.
50. *Green Rating Systems*. Green rating systems - Designing Buildings. (n.d.). Retrieved October 26, 2021, from https://www.designingbuildings.co.uk/wiki/Green_rating_systems
51. Habibi, S. (2017). The promise of Bim for improving building performance. *Energy and Buildings*, *153*, 525–548. https://doi.org/10.1016/j.enbuild.2017.08.009
52. Hammond, R., Nawari, N. O., & Walters, B. (2014). BIM in sustainable design: Strategies for retrofitting/renovation. *Computing in Civil and Building Engineering (2014)*. https://doi.org/10.1061/9780784413616.244

53. *Home Best, A60 led bulb, 9 watts, day light*. Home Best, A60 Led Bulb, 9 Watts, Day Light - eXtra Saudi. (n.d.). Retrieved June 23, 2022, from https://www.extra.com/en-sa/accessories/electrical/bulbs/home-best-a60-led-bulb-9-watts-day-light/p/100308424?algoliaQueryId=dd4c684963e47d855cae9b92cc2b90d3

54. Horton, D. (2019, February 21). *Air and water fenestration testing*. Building Envelope Technologies, Inc. Retrieved June 26, 2022, from https://www.buildingenvelopetech.com/2018/02/08/air-and-water-testing/#:~:text=Water%20infiltration%20testing%20is%20typically,a%20duration%20of%2015%20minutes.

55. Hossain, M. A., & Yeoh, J. K. (2018). Bim for existing buildings: Potential opportunities and barriers. *IOP Conference Series: Materials Science and Engineering*, *371*, 012051. https://doi.org/10.1088/1757-899x/371/1/012051

56. *Housing program*. Vision 2030. (n.d.). Retrieved October 26, 2021, from https://www.vision2030.gov.sa/v2030/vrps/housing/

57. *Insight: Building performance analysis software*. Autodesk. (2021, June 4). Retrieved March 2, 2022, from https://www.autodesk.com/products/insight/overview#features

58. Jalaei, F., Jalaei, F., & Mohammadi, S. (2020). An integrated BIM-LEED application to Automate Sustainable Design Assessment Framework at the conceptual stage of building projects. *Sustainable Cities and Society*, *53*, 101979. https://doi.org/10.1016/j.scs.2019.101979

59. Kagan, J. (2022, June 3). *What is the payback period?* Investopedia. Retrieved June 22, 2022, from https://www.investopedia.com/terms/p/paybackperiod.asp#:~:text=Understanding%20the%20Payback%20Period,-The%20payback%20period&text=It%20helps%20determine%20how%20long,judgment%20about%20an%20investment%20venture.

60. Khoshdelnezamiha, G., Liew, S. C., Shin Bong, V. N., & Ong, D. E. (2020). Evaluation of BIM application for Water Efficiency Assessment. *Journal of Green Building*, *15*(4), 91–115. https://doi.org/10.3992/jgb.15.4.91

61. Krarti, M., & Aldubyan, M. (2021). Mitigation analysis of water consumption for power generation and air conditioning of residential buildings: Case study of saudi arabia. *Applied Energy*, *290*, 116767. https://doi.org/10.1016/j.apenergy.2021.116767

62. Krarti, M., Aldubyan, M., & Williams, E. (2020). Residential building stock model for evaluating energy retrofit programs in Saudi Arabia. *Energy*, *195*, 116980. https://doi.org/10.1016/j.energy.2020.116980

63. Krarti, M., Dubey, K., & Howarth, N. (2017). Evaluation of building energy efficiency investment options for the Kingdom of Saudi Arabia. *Energy*, *134*, 595–610. https://doi.org/10.1016/j.energy.2017.05.084

64. Kubba, S. (2017). In *Handbook of Green Building Design and construction: LEED, BREEAM, and Green Globes*. essay, Elsevier Butterworth-Hein.

65. *Led vs halogen: Is LED or halogen better?* LED Hut. (1970, March 7). Retrieved April 13, 2022, from https://ledhut.co.uk/blogs/news/led-vs-halogen-is-led-or-halogen-better

66. Lee, W. L., & Burnett, J. (2008). Benchmarking energy use assessment of HK-Beam, BREEAM and LEED. *Building and Environment*, *43*(11), 1882–1891. https://doi.org/10.1016/j.buildenv.2007.11.007

67. Lim, Y.-W., Chong, H.-Y., Ling, P. C. H., & Tan, C. S. (2021). Greening existing buildings through building information modelling: A review of the recent development. *Building and Environment*, *200*, 107924. https://doi.org/10.1016/j.buildenv.2021.107924

68. Lim, Y.-W., Chong, H.-Y., Ling, P. C. H., & Tan, C. S. (2021). Greening existing buildings through building information modelling: A review of the recent development. *Building and Environment*, *200*, 107924. https://doi.org/10.1016/j.buildenv.2021.107924

69. Liu, Z., Wang, Q., Gan, V. J. L., & Peh, L. (2020). Envelope thermal performance analysis based on building information model (BIM) cloud platform—proposed Green Mark Collaboration environment. *Energies*, *13*(3), 586. https://doi.org/10.3390/en13030586

70. Liu, Z., Zhang, C., Guo, Y., Osmani, M., & Demian, P. (2019). A building information modelling (BIM) based Water Efficiency (BWE) framework for Sustainable Building Design and Construction Management. *Electronics*, *8*(6), 599. https://doi.org/10.3390/electronics8060599

71. Liu, Z., Zhang, C., Guo, Y., Osmani, M., & Demian, P. (2019). A building information modelling (BIM) based Water Efficiency (BWE) framework for Sustainable Building Design and Construction Management. *Electronics*, *8*(6), 599. https://doi.org/10.3390/electronics8060599

72. Love, P. E. D., Matthews, J., Simpson, I., Hill, A., & Olatunji, O. A. (2014). A benefits realization management building information modeling framework for asset owners. *Automation in Construction*, *37*, 1–10. https://doi.org/10.1016/j.autcon.2013.09.007

73. Martin Holladay | March 5, & Holladay, M. (2019, July 31). *The energy-efficiency pyramid*. GreenBuildingAdvisor. Retrieved April 13, 2022, from https://www.greenbuildingadvisor.com/article/the-energy-efficiency-pyramid

74. Marzouk, M., Metawie, M., Hisham, M., Al-Sulahi, I., Kamal, M., & Al-Gahtani, K. (2014). Modeling sustainable building materials in Saudi Arabia. *Computing in Civil and Building Engineering (2014)*. https://doi.org/10.1061/9780784413616.192

75. McArthur, J. J. (2015). A building information management (BIM) framework and supporting case study for existing building operations, maintenance and Sustainability. *Procedia Engineering*, *118*, 1104–1111. https://doi.org/10.1016/j.proeng.2015.08.450

76. Michael, M., Zhang, L., & Xia, X. (2017). An optimal model for a building retrofit with LEED Standard as Reference Protocol. *Energy and Buildings*, *139*, 22–30. https://doi.org/10.1016/j.enbuild.2017.01.006

77. Montiel-Santiago, F. J., Hermoso-Orzáez, M. J., & Terrados-Cepeda, J. (2020). Sustainability and energy efficiency: Bim 6d. study of the BIM methodology applied to hospital buildings. value of interior lighting and daylight in energy simulation. *Sustainability*, *12*(14), 5731. https://doi.org/10.3390/su12145731

78. Mosly, I. (2015). Barriers to the diffusion and adoption of green buildings in Saudi Arabia. *Journal of Management and Sustainability*, *5*(4), 104. https://doi.org/10.5539/jms.v5n4p104

79. *Mostadam Green Building Rating System*. Alpin Limited. (2021, October 10). Retrieved November 2, 2021, from https://www.alpinme.com/mostadam/

80. *Mostadam Rating System Residential Buildings O+E Manual*. Sustainable Building. (2019). Retrieved October 28, 2021, from https://www.mostadam.sa/page/163

81. Newsroom. (2021, July 12). *The 7 dimensions of BIM - 3D, 4d, 5D, 6d, 7D bim explained*. BibLus. Retrieved October 29, 2021, from http://biblus.accasoftware.com/en/bim-dimensions/

82. Prates, G. A. (2014). Methods of costing - target (target costing) and Kaizen (Kaizen costing) supported by QFD (quality function deployment) as a tool for cost reduction in development product and production. *Nucleus*, *11*(1), 7–20. https://doi.org/10.3738/1982.2278.982

83. Pricena. (n.d.). *Leviton OSC04-I0W ceiling mount occupancy sensor, PIR, 360 degree, 450 sq. ft. coverage, self-adjusting, white price in Saudi Arabia: Compare prices*. price in Saudi Arabia | Compare Prices. Retrieved June 23, 2022, from https://sa.pricena.com/en/product/leviton-osc04-i0w-white-price-in-saudi-arabia-30203475

84. Pricena. (n.d.). *Philips Hue motion sensor with Daylight Sensor UAE price in Saudi Arabia: Compare prices*. price in Saudi Arabia | Compare Prices. Retrieved June 23, 2022, from https://sa.pricena.com/en/product/philips-hue-motion-sensor-with-daylight-sensor-uae-price-in-saudi-arabia-34565352

85. Rahmani Asl, M., Zarrinmehr, S., Bergin, M., & Yan, W. (2015). BPOPT: A Framework for BIM-based performance optimization. *Energy and Buildings, 108,* 401–412. https://doi.org/10.1016/j.enbuild.2015.09.011

86. Rambo, K. A., Warsinger, D. M., Shanbhogue, S. J., V, J. H., & Ghoniem, A. F. (2017). Water-energy nexus in Saudi Arabia. *Energy Procedia*, *105*, 3837–3843. https://doi.org/10.1016/j.egypro.2017.03.782

87. Randolph, J. (n.d.). *A guide to writing the Dissertation Literature Review*. ScholarWorks@UMass Amherst. Retrieved February 20, 2022, from https://scholarworks.umass.edu/pare/vol14/iss1/13/?utm_source=scholarworks.umass.edu%2Fpare%2Fvol14%2Fiss1%2F13&utm_medium=PDF&utm_campaign=PDFCoverPages

88. *Rating tools*. World Green Building Council. (n.d.). Retrieved October 26, 2021, from https://www.worldgbc.org/rating-tools

89. *Retrofit*. Cambridge Dictionary. (n.d.). Retrieved October 27, 2021, from https://dictionary.cambridge.org/dictionary/english/retrofit

90. *Retrofit*. Retrofit - Designing Buildings. (n.d.). Retrieved October 27, 2021, from https://www.designingbuildings.co.uk/wiki/Retrofit

91. *Saudi electricity company - SE*. (n.d.). Retrieved October 27, 2021, from https://www.se.com.sa/en-us/Pages/ResidentialSector.aspx

92. *Saudi Vision 2030: What are Saudi Arabia's plans for the future?: Earth.org - past: Present: Future*. Earth.Org - Past | Present | Future. (2021, September 21). Retrieved October 26, 2021, from https://earth.org/saudi-vision-2030/

93. Saunders, M., Lewis, P., & Thornhill, A. (2012). *Research methods for business students*. Pearson.

94. SBC. (n.d.). *Saudi Energy Conservation Code - Low Rise (SBC 602)*. Saudi Building Code National Committee. Retrieved June 26, 2022, from https://www.sbc.gov.sa/en/Pages/default.aspx

95. Scherer, R. J., & Katranuschkov, P. (2018). Bimification: How to create and use BIM for retrofitting. *Advanced Engineering Informatics*, *38,* 54–66. https://doi.org/10.1016/j.aei.2018.05.007

96. Siniak, N., Źróbek, S., Nikolaiev, V., & Shavrov, S. (2019). Building information modeling for housing renovation - example for Ukraine. *Real Estate Management and Valuation*, *27*(2), 97–107. https://doi.org/10.2478/remav-2019-0018

97. Taleb, H. M., & Sharples, S. (2010, September 3). *Developing sustainable residential buildings in Saudi Arabia: A case study*. Applied Energy. Retrieved October 31, 2021, from https://www.sciencedirect.com/science/article/pii/S0306261910002989

98. Tree, J. (2021, March 1). *GREEN RETROFIT: WHAT IS IT AND WHAT DOES IT MEAN FOR THE DEVELOPMENT INDUSTRY?* penningtons manches cooper. Retrieved October 27, 2021, from https://www.penningtonslaw.com/news-publications/latest-news/2021/green-retrofit-what-is-it-and-what-does-it-mean-for-the-development-industry

99. Tzortzopoulos, P., Ma, L., Soliman Junior, J., & Koskela, L. (2019). Evaluating social housing retrofit options to support clients' decision making—simpler bim protocol. *Sustainability*, *11*(9), 2507. https://doi.org/10.3390/su11092507

100. United Nations. (n.d.). *#ENVISION2030: 17 goals to transform the world for persons with disabilities enable*. United Nations. Retrieved October 26, 2021, from https://www.un.org/development/desa/disabilities/envision2030.html

101. United Nations. (n.d.). *Climate change – united nations sustainable development*. United Nations. Retrieved October 26, 2021, from https://www.un.org/sustainabledevelopment/climate-change/

102. United Nations. (n.d.). *Sustainability*. United Nations. Retrieved October 26, 2021, from https://www.un.org/en/academic-impact/sustainability

103. University of Salford, M. (1970, January 1). *A framework for successful implementation of it for the construction organizations in Saudi Arabia*. University of Salford Institutional Repository. Retrieved October 30, 2021, from http://usir.salford.ac.uk/26545/

104. usgbc. (n.d.). *Benefits of green building*. Press: Benefits of green building | U.S. Green Building Council. Retrieved October 26, 2021, from https://www.usgbc.org/press/benefits-of-green-building

105. *Vision Realization Program*. Vision 2030. (n.d.). Retrieved October 26, 2021, from https://www.vision2030.gov.sa/v2030/vrps/

106. *vision2030*. Vision 2030. (n.d.). Retrieved October 26, 2021, from https://www.vision2030.gov.sa/

107. Volk, R., Stengel, J., & Schultmann, F. (2014). Building Information Modeling (BIM) for existing buildings — literature review and future needs. *Automation in Construction*, *38*, 109–127. https://doi.org/10.1016/j.autcon.2013.10.023

108. Wang, C., Cho, Y. K., & Kim, C. (2015). Automatic bim component extraction from point clouds of existing buildings for Sustainability Applications. *Automation in Construction*, *56*, 1–13. https://doi.org/10.1016/j.autcon.2015.04.001

109. Wang, Z., & Liu, J. (2020). A seven-dimensional building information model for the improvement of construction efficiency. *Advances in Civil Engineering*, *2020*, 1–17. https://doi.org/10.1155/2020/8842475

110. *Weatherspark.com*. Riyadh Climate, Weather By Month, Average Temperature (Saudi Arabia) - Weather Spark. (n.d.). Retrieved June 25, 2022, from https://weatherspark.com/y/104018/Average-Weather-in-Riyadh-Saudi-Arabia-Year-Round

111. Wehbe, R., & Shahrour, I. (2019). Use of BIM and smart monitoring for buildings' Indoor Comfort Control. *MATEC Web of Conferences*, *295*, 02010. https://doi.org/10.1051/matecconf/201929502010

112. *What is green building?* U.S. Green Building Council. (n.d.). Retrieved October 26, 2021, from https://www.usgbc.org/articles/what-green-building

113. Winchester, C. L., & Salji, M. (2016). Writing a literature review. *Journal of Clinical Urology*, *9*(5), 308–312. https://doi.org/10.1177/2051415816650133

114. Yuan, Z., Zhou, J., Qiao, Y., Zhang, Y., Liu, D., & Zhu, H. (2020). Bim-ve-based optimization of green building envelope from the perspective of both energy saving and life cycle cost. *Sustainability*, *12*(19), 7862. https://doi.org/10.3390/su12197862

115. *الهيئة العامة للإحصاء*. General Authority for Statistics. (2021, November 9). Retrieved October 27, 2021, from https://www.stats.gov.sa/en/node

APPENDIX A

MOSTADAM RESIDENTIAL BUILDINGS OPERATION AND EXITING KEYSTONE (MINIMUM) CREDITS.

Credit category	Keystone credit	Points of credits	Requirements
Policies, management & maintenance	Annual audit	2 points	Annual internal audits to verify the sustainable performance of the building, including: • Energy consumption: monthly energy consumption and onsite renewable generation • Water consumption: monthly indoor and outdoor water consumption • Waste generation: monthly waste generation • Systems servicing: a summary based on a short description of the systems • Envelope assessment: a summary based on a short description and images from the annual walkaround
	Residential waste management	1 point	A residential waste operational system is established and executed which convert at least 30% of operational waste from landfill via reprocessing or recycling. Each residential unit should have clearly labelled waste bins for recyclable trash and general trash
	Sustainable maintenance & servicing	1 point	Periodically maintenance and fault assessments to be undertaken for systems and building components.
	Sustainable procurement	1 point	Developing and implementing sustainable procurement policy (spp) to encourage purchasing sustainable materials for the building o&m
Energy	Energy performance	4 point	Energy consumption assessment: an annual energy consumption assessment to analyse the previous 12-month fossil fuel electricity consumption to confirm the annual energy use intensity of the building in kwh Energy audit: the competent professional performs the energy audit and provides cost-effective energy efficiency measures for the operation Energy efficiency measures: measures listed in the energy assessment statement that have a simple payback period of fewer than 6 years are executed. External lighting: a control system for turning on/off the external lighting at its operational hours
	Energy metering	1 point	Energy meters are available to assist the monitoring and logging the energy consumption
	Envelope assessment	1 point	A basic audit must be conducted on the building envelope by a competent professional, including water infiltration and defining any required enhancement.

Water	Water performance	4 point	Building indoor water consumption is 10% less than the bassline
	Water metering	1 point	Water meters are available to assist the monitoring and logging the water consumption
Health and comfort	Outdoor thermal comfort	2 point	Providing shade covers to at least 50% of the following areas: front entrances, patios, and courtyards, hard-standing amenity spaces (including balconies and roof amenity spaces and excluding pedestrian walkways and playgrounds) Providing shade covers to at least 75% of the following areas where they exist within the land boundary: pedestrian walkways, playgrounds, and car and bicycle parking
	Indoor thermal comfort	1 point	Perform on-site calibration and testing of temperature controls and occupancy sensors.
Education and innovation	Mostadam guide	1 point	Communicates the building’s sustainable credentials to residents and the facility manage by Mostadam guide
Total	point		

Table 21 Mostadam 20 Keystone credits

APPENDIX B

CASE STUDY ARCHITECTURAL DRAWAINGS

Ground floor first floor

Figure 11.5-1 building floor plans

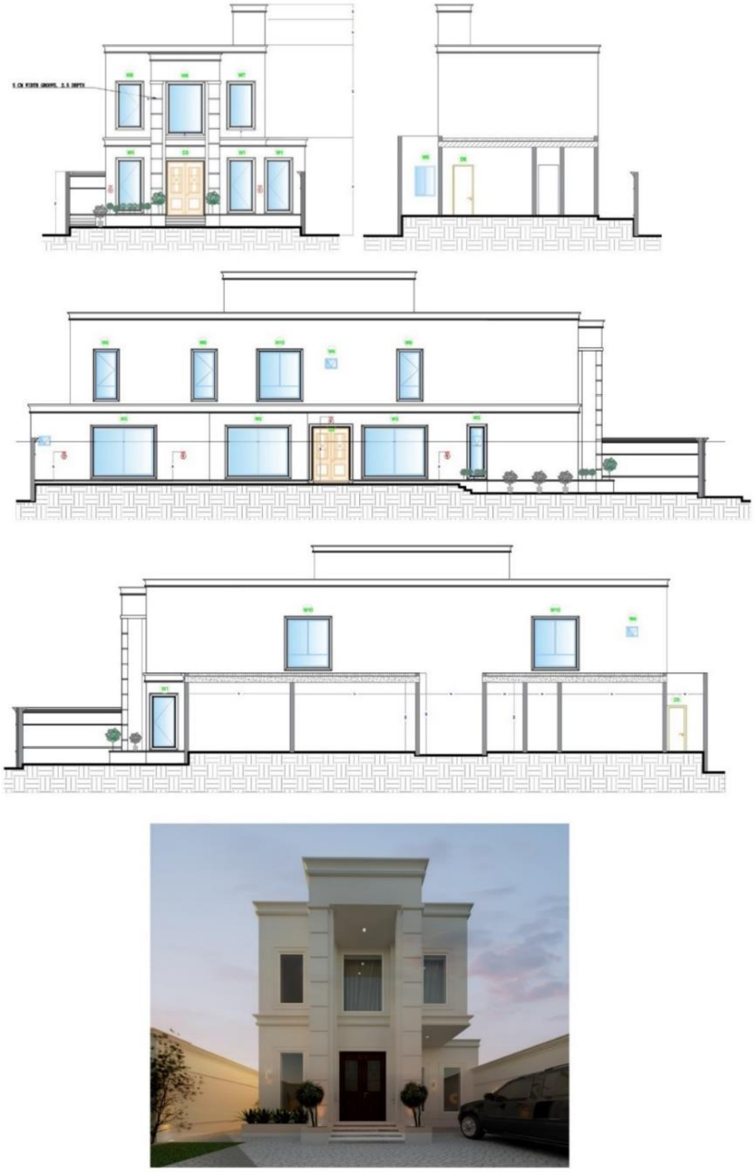

Figure 11.5-2 Building exterior elevations and 3D render

APPENDIX C

EFFECINCY MEASURES COST

A. Efficient lighting cost

Room	Area sqm	Required Lux	Number of units	Price: unit =35 SAR
Entrance	9	270	1	SAR 35.00
Men Guest (living)	38	570	2	SAR 70.00
Women Guest (living)	33	495	2	SAR 70.00
Dining	20	500	2	SAR 70.00
Living -Ground floor	70	1050	4	SAR 140.00
Living -First floor	62.5	937.5	3	SAR 105.00
Kitchen	22	550	2	SAR 70.00
Storage	8	120	1	SAR 35.00
Laundry	10	250	1	SAR 35.00
Master bedroom	39	975	4	SAR 140.00
Bedroom -1	20	500	2	SAR 70.00
Bedroom -2	20	500	2	SAR 70.00
Bedroom -3	20	500	2	SAR 70.00
Toilet -1	4.3	129	1	SAR 35.00
Toilet -2	5.2	260	1	SAR 35.00
Toilet -3	3.2	96	1	SAR 35.00
Toilet -4	9.3	279	1	SAR 35.00
Toilet -5	6.8	204	1	SAR 35.00
Toilet -6	4.7	141	1	SAR 35.00
Total	405	8326.5	34	SAR 1,190.00

Table 22 Required Lighting Calculation

B. Ceiling Mount Occupancy Sensor cost

Room	Number of units	Price
Entrance	1	SAR 165.50
Men guest (living)	1	SAR 165.50
Women guest (living)	1	SAR 165.50
Dining	1	SAR 165.50
Living -ground floor	1	SAR 165.50
Living -first floor	1	SAR 165.50
Kitchen	1	SAR 165.50
Storage	1	SAR 165.50
Laundry	1	SAR 165.50
Master bedroom	1	SAR 165.50
Bedroom -1	1	SAR 165.50
Bedroom -2	1	SAR 165.50
Bedroom -3	1	SAR 165.50
Toilet -1	1	SAR 165.50
Toilet -2	1	SAR 165.50
Toilet -3	1	SAR 165.50
Toilet -4	1	SAR 165.50
Toilet -5	1	SAR 165.50
Toilet -6	1	SAR 165.50
Total	19	SAR 3,144.50

Table-Installing Ceiling Mount Occupancy Sensor cost

C. Ceiling Mount occupancy and daylight Sensor cost

Room	number of units	price
Entrance	1	SAR 257.44
Men Guest (living)	1	SAR 257.44
Women Guest (living)	1	SAR 257.44
Dining	1	SAR 257.44
Living -Ground floor	1	SAR 257.44
Living -First floor	1	SAR 257.44
Kitchen	1	SAR 257.44
Storage	1	SAR 257.44
Laundry	1	SAR 257.44
Master bedroom	1	SAR 257.44
Bedroom -1	1	SAR 257.44
Bedroom -2	1	SAR 257.44
Bedroom -3	1	SAR 257.44
Toilet -1	1	SAR 257.44
Toilet -2	1	SAR 257.44
Toilet -3	1	SAR 257.44
Toilet -4	1	SAR 257.44
Toilet -5	1	SAR 257.44
Toilet -6	1	SAR 257.44
total	19	SAR 4,891.36

Table 23 Ceiling Mount occupancy and daylight Sensor cost

D. Replacing windows glazing cost

glazing type	price range per sqm	total price range
insulated glazing	SAR 375.20	SAR 24,388.00
Insulated low-E glazing	SAR 2,063.00	SAR 134,095.00

Table 24 windows glazing cost

E. Adding shading devices cost

	Total material required (sqm)	Total price
1/4 of the Window Height	SAR 87.33	SAR 349.33
1/3 of the Window Height	SAR 98.25	SAR 393.00
1/2 of the Window Height	SAR 131.00	SAR 524.00

Table 25 shading devices cost

F. Adding insulation to the building envelope cost

Insulation type	Price per m2	Total price
R19 wall insulation	110 SR	SAR 71,874.00
R30 wall insulation	130 SR	SAR 84,942.00
R30 roof insulation	25 SR	SAR 4,975.00

Table 26 insulation to the building envelope cost

G. Replacing existing water fixtures with water efficient fixtures

Fixture	Type	Unit price	Required units	Total price
Toilet	1.6 gallons per flush (gpf)	SAR 1,539.00	6	SAR 9,234.00
Wash-basin mixer	tap with sensor	SAR 849.00	9	SAR 7,641.00
Head/hand shower	Kit with diverter	SAR 479.00	3	SAR 1,437.00
Kitchen faucet	Highly efficient	SAR 649.00	1	SAR 649.00
Total				SAR 4,740.25

Table 27 water efficient fixtures cost