EVALUATING ENVIRONMENTAL IMPACTS OF RELOCATING HISTORIC STRUCTURES: THE CASE OF PRESERVING MEMORY IN BISRI VALLEY

A Thesis

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the Ramez G. Chagoury

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In Partial Fulfillment

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Master in Architecture in Sustainable Architecture

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by

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The thesis is extensively dedicated to admire my lovely supportive family.

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ABSTRACT

Design excellence seeks architectural solutions that respect historic buildings and sites. Marj Besri dam project is one of the many proposed projects addressing the ongoing water availability problem, in Lebanon. On the one hand, finite resources and high cost restrict the potential of the no-dam alternative for water management such as rainwater harvesting, waste water reuse and groundwater storage (Council for Development and Reconstruction, 2014). On the other hand, several studies focus on the impact of the dam project on the excessive greenhouse gas emissions in the early stages of the dam's construction. Add to that, those studies have also emphasized the alteration of natural habitat, loss of biodiversity, and the relocation of historic buildings such as, in the case of Bisri valley, Mar Moussa Church and Saint Sophia Monastery beyond the sustainable framework. This framework discusses the cultural value, environmental protection, economic growth and social aspects. These dimensions are the pillars of sustainable development that are reframed by political challenges and should not be underestimated (Burford and et al, 2013). Part of a proper planning of the dam construction is to preserve the memory and the historical remains of the valley.

This thesis discusses the effects of the demolition of Mar Moussa Church and Saint Sophia Monastery. This includes the reassembly of the church's main walls and the replacement of its interior vaulting, in addition to the reassembly of the monastery. It also explores the embodied energy, the embodied CO_2 emitted from both mentioned historic structures, and their significance as a cultural value. The cultural aspect of sustainability addressed in this thesis defines the tangible and the intangible values of the built heritage. Tangible cultural heritage preservation is concerned with physical culture such as monuments and historic buildings, while the intangible cultural

heritage is the memory preservation of the heritage (Allison and Allison, 2008). The thesis question is twofold: the cultural tangible values and the cultural intangible values. The first goal of the research is to explore the tangible values of the church and the monastery. This is related to the conditions required to consider the relocation of the mentioned structures as a sustainable historic preservation strategy. The second goal reflects the intangible values to emphasize on the cultural role of the church and the monastery as a memory. The findings of the research show that demolished and relocated buildings, using the same materials, have additional energy consumed for the relocated building and with more CO_2 emitted to the environment.

Keywords: *Mar Moussa Church- Saint Sophia Monastery- embodied energy- carbon emissions- memory*

Chapter One

INTRODUCTION

The Marj Besri dam has become a controversial project since 2002 when it was proposed, prior to having environmental assessment. The construction of Bisri dam and creation of the reservoir has effects on various levels. The project is located in Shouf that is a historic region of Lebanon, as well as an administrative district in the governorate of Mount Lebanon (Medomed, n.d.). Marj Besri dam is 15 km from the Mediterranean coastline of Saida and 35 km from Central Beirut. The dam aims to guide the development policy throughout the water sector, regardless of its impact from a sustainable aspect (Council for Development and Reconstruction, 2014). This thesis focuses on Marj Besri archeological remains (Mar Moussa Church and Saint Sophia Monastery) reflecting different cultures and the physical environment which embody the tangible values of the valley (Munjeri, 2004). 'The very physical existence of the historic-built environment is a tie to the past' (Milligan, 2007, p 17). Old constructions, historical or traditional, relate to people as a memory.

The thesis sheds light on the the impact of the dam construction on its context and the role of a building on its built environment, social fabric and nature. The proposal of the dam construction at Marj Besri has put the environment of Shouf area, its immediate surroundings and the archeological significance of the valley in the Lebanese community, under threat, affecting the history of the valley. The Besri sites represent almost full span of human history, from paleolithic times prior to 8,300 BCE to the present day. The valley prospered in the Roman times when it became a major route between Tyr and Sidon which became known as Lebanese coast and Damascus (Council for Development and Reconstruction, 2014). This introductory chapter

provides background on the research topic, explains the various disciplines addressing the topic, then presents the research purpose, scope and research question.

1.1 Sustainability and Historic Preservation

This section addresses the management of heritage sites adopting a sustainable approach. This includes water resource management, economic growth, social aspects, and environmental concerns, with the purpose of identifying the approach adopted for this thesis. This section starts by defining sustainable development and then explains the four pillars of sustainability within the perspective of heritage sites' management. Historic preservation is then tackled as part of the sustainable strategies applied to show the significance of preserving heritage sites.

The core idea of sustainability and development in dam projects is to manage resource consumption by considering the economic, ecological, social, cultural and political factors (Manatunge et al., n.d.). However, Terrapon-Pfaf et al. (2017) mentioned that the impacts of dam construction affecting the social, cultural and political spheres were often considered more significant than impacts affecting the physical and material livelihood dimensions. Few benefits are studied as a result of the dam construction, encompassing flood control, irrigation benefits, maximization of recreational activities, economic and energy efficiency and use for domestic water (Tahmiscioglu et al, n.d.). Concerns in dam projects are related to the social political feasibility of new concessions, due to the difficulty of coordination with environmental and other government institutions involved in social development (Verocai, 2009). This also stresses the economic development that should be compatible with political and social institutions (Manatunge et al., n.d.).

In 1987, the World Commission on Environment and Development defined sustainable development and published the Brundtland Report which is one of the earliest documents on

sustainability (Srour et al., 2010). The concept of sustainability has a long history and has evolved over time. Importantly, this evolution has been affected by different "intellectual and political streams of thought that have molded concepts of sustainability" (Giovannoni and Fabietti, 2014; Kidd, 1992, p.3). Firstly, the Brundtland report described the three pillars of sustainability, which are interrelated dimensions, as: the social, economic and environmental (McChesney, 1991). Then, with the continuous research of sustainability approaches in our recent era, different models are elaborated encompassing the three dimensions. According to Othman and Elsaay (2018, p. 2), 'the interaction between these pillars creates three new pillars: namely, social–environmental, environmental–economic, and economic–social'.

Sustainability to Kuhlman and Farrington (2010) is a matter of resources, by which some consider that the loss of natural resources is inevitable and may be compensated. However, others oppose the idea to substitute natural resources thinking that sustainability is a matter of preserving resources. This developed two views of weak and strong sustainability as part of the sustainability framework of this thesis (Kuhlman and Farrington, 2010). 'Sustainable development objectives have been widely defined along three dimensions: economic, environmental and social or ecology, economy and equity' (United Nations Department of Economic and Social Affairs, 2014).

Cultural heritage plays a marginal role in the sustainable development (Nocca, 2017). The role of cultural heritage as a fertile ground for sustainable development has driven it to be considered as the fourth pillar (Kou et al., 2018).

> 'The recommendations of UNESCO Adoption and Promotion of the Historic Urban Landscape (HUL) (2011), and the Johannesburg World Summit on Sustainable Development (2002) have recognized the significance of culture, as the fourth pillar of sustainable development, in the process of creating sustainable development-characterized

destinations' (Amer, n.d., p 4 ; Hosagrahar, Soule, Girard, and Potts, 2016, pp. 18, 19; ICOMOS, 2011, p. 2; Torggler et al., 2015, p. 8).

The cultural heritage, including the tangible and intangible heritage, is an important factor in sustainable development because it represents the past and culture (Nocca, 2017). If culture is considered from a narrow perspective as corresponding to cultural heritage, then cultural rights could include the protection of such cultural heritage (Donders, 2010). It is about the need to enforce a variety of human rights, which is mainly the right to cultural diversity (Transnational Cooperation Programme, 2012). In this role, culture is considered an instrument that helps to clarify the challenges that the world faces, especially the ecological ones (Voetmann, n.d.).

The ecology pillar deals with the health and preservation of the ecosystem (Solh, 2010). As explained in the UN Nations Department of Economic and Social Affairs (2014), ecology and environmental dimensions share similar definitions in the three pillars of sustainability. The World Heritage Convention promotes sustainable development, and in particular environmental sustainability, by valuing places of outstanding natural heritage value, which are essential for human well-being (World Heritage Committee, 2015). Accordingly, ecology is a holistic thinking of the environmental pillar and is recognized as an advanced way to describe the concept of nature. Callicott and Mumford (1997) defined the term ecology as integrated ecosystems and its definition also reflects what is known as biological conservation. Natural resources exploitation, exploration, mining and processing have caused different types of environmental damages which include ecological disturbances, air and water pollution (Gutti, Aji, and Magaji, 2012). The environmental degradation due to human activities has resulted from the failure to put any value on the environment. It is distinguished as such because environmental assets are underpriced and tend to be overused or abused, resulting in environmental damage (Beder, 2000).

Environmental sustainability and human relationships with the natural world have been a dominant topic within international politics in the last few decades (Clapperton and Piper, 2016). Environmental politics examines relationships between political forces and environmental changes (Bernstein et al., 2018). As an example, the pollution due to greenhouse gas emissions, has caused climate change. Its impacts are distributed across the jurisdictions of the states of the international political system (Atkins and Nunez, 2016). In case the steps to curb greenhouse gas emissions are not taken soon, environmental matters will become a central topic to the contemporary international politics and their academic study (Dalby, 2016; Webersik, 2010). Meanwhile, the presence of environmental policies can promote the development of a strict approach to environmental protection (Atkins and Nunez, 2016).

The economic pillar is central in analyzing sustainable development. This pillar is linked to the previous ecological dimension, as it shows whether it is possible to achieve environmental goals while simultaneously sustaining economic growth (McChesney, 1991). 'Due to historic reasons, Europe has rich cultural heritage that reflects development and decline of civilizations' (Žarnić, Rajčić, and Skordaki, 2015, p 1). As an example, the UK strategy on sustainable development integrates economic growth, careful use of natural resources with environment protection and social responsibility. For Sabou (2012), tourism takes an advantage of this economic growth in the heritage tourism analysis. "Socially and Environmentally Sustainable Development (ESSD)" consider investments for the preservation of historic areas to be viable strategies, by means of projects which favor the creation of new jobs, resulting in greater social inclusion (Penna and Taylor, n.d.).

The social pillar refers to the fair distribution between and within generations, and between and within nation states (McChesney, 1991). The social dimension deals with the health and

preservation of social and cultural systems (Solh, 2010). In social equity, there should be a minimum level of environmental quality below which nobody surpasses, and everyone should have equal access to community resources (Beder, 2000). Social inclusion is becoming part of the field of historic preservation through enhancing community engagement (Avrami, n.d.).

The previous paragraphs of the background shed light on the sustainable development, identifying the cultural, ecological, economic, and social dimensions of sustainability. The following paragraphs discuss the significance of historic preservation and energy conservation within the field of sustainable development.

Sustainability begins with preservation. On the one hand, John Ruskin insisted that preservation was the proper way to preserve the built environment for future generations to appreciate monuments for their age-value (Jackson, 2004). On the other hand, 'adaptive reuse seems to be an increasingly promising strategy for preserving cultural heritage' (Bottero et al., 2019, p 1). The Venice Charter defines adaptive reuse with conservation practice as 'a conservation of monument is facilitated by making use of them for socially useful purpose' (Cleempoel and Plevoets, 2012, p 4). Preservation maximizes the use of existing materials, reduces waste, and preserves the historic character of older towns and cities (WBDG Historic Preservation Subcommittee, 2019).

'With the OPEC embargo in 1979 historic preservation advocates began to develop new arguments for historic preservation as energy conservation' (McMurry, 2016, pp. 6). According to Ding and Ying (2019), the Ministry of Construction recognizes that the conservation of existing buildings is the best way to preserve materials and reduce environmental pollution. One way to preserve historic buildings for future generations is to reduce energy consumption and carbon emissions (Webb, 2017).

The thesis will shed light on weak and strong sustainability, to stop consuming natural resources and find alternatives to be preserved. It will reflect the strategies in Marj Bisri dam construction by neither compensating the loss of natural resources nor substituting it. The thesis will then examine the relation of sustainability and historic preservation as a way to reduce energy consumption and carbon emissions. It will continue to show the importance of preserving cultural heritage, and the tangible and intangible values in sustainable development. Next, the research scope and the purpose are presented.

1.2 Research Purpose and Scope

'In considering the energy already embedded in the buildings together with the associated CO_2 emission, preserving existing buildings is a more viable and practical strategy to address challenges of energy conservation' (Ding and Ying, 2019, p. 8). Mar Moussa church and Saint Sophia monastery will be discussed in relation to the embodied energy, replacement cost, and carbon emissions of its demolition and relocation. This relocation of the church and the monastery, which is part of the dam project in Marj Bisri's historical context, will be analyzed with respect to the environmental politics. In addressing the replacement decision, the demolition energy of the same construction materials used from the existing church and that of the monastery has a distinctive impact as carbon emissions. It takes many years of energy saving to compensate the waste of the embodied energy resulted from demolition and rebuilding (Ding and Ying, 2019). It is the human activities that harm the environment and/or put in danger the cultural heritage assets (Petronela and Sandu, 2017). 'The human activities of the last two centuries - primarily the burning of fossil fuels and the clearing of forests - have greatly intensified this natural greenhouse effect, initiating a chain of events which, as we are now starting to realize, can lead to drastic climate change' (Choi, May 2017, p. 26).

The greenhouse gas analysis will be an integral part of this thesis by justifying the impact of human activity and the embodied energy embedded in the construction material. The church and the monastery are then analyzed to be historically preserved due to their cultural integrity and significance, as a means of collective memory. The operating energy and the embodied energy are of utmost importance in the building's energy assessment. However, this church is used once per year, on 28th of August on Mar Moussa's day, and neither of the active systems are installed. This means the operating energy is negligible to be calculated. As for the monastery, it is an abandoned structure. Different stakeholders benefit from this thesis including archeologists who study heritage sites, preservationists who are architects interested in studying ways to preserve historical buildings, and urban planners who encounter similar study areas. Accordingly, the practitioners who implement the social impact assessment and the environmental impact assessment can take advantage of this thesis. This thesis will be a guide to those interested in the specific historic site, Bisri valley, analyzing its embodied energy to preserve its existence, then showing its relation to the community and its impact on the environment from a sustainable aspect. The next section presents the research question and objectives.

1.3 Research Question and Objectives

The research question asks:

What are the conditions required to consider the relocation of historic buildings as a sustainable historic preservation strategy? What is the impact of relocating the Mar Moussa Church and Saint Sophia Monastery, on the environment?

The research question aims to answer the five objectives:

1- To demonstrate the cultural significance of historic preservation. This will be achieved by reviewing the literature on cultural heritage and more specifically on the inclusion of culture in both its tangible and intangible forms among the dimension of sustainability.

2- To understand the context of the studied site, the vagaries around the project of the "Bisri" dam and its future impacts on the region's environment, secondary resources related to the problem of water shortage in Lebanon and the availability of other options than the dam projects will be reviewed. The analysis of the cultural, social, economic, and environmental will be performed.

3- To develop a framework to assess the embodied energy and carbon emissions in historic sites, existing methodologies in the literature, based on Revit and Tally software applications to compute the life cycle assessment of historic buildings will be reviewed. This will underpin the analysis to be applied for the case study the "Bisri" dam.

4- To assess the embodied energy and carbon emissions embedded in the structures of Mar Moussa church and Saint Sophia Monastery. An approximate value of the embodied energy and carbon emissions will be defined using the Revit modeling and Tally plug-in simulation software.

5- To indicate whether the relocation of the church and the monastery is sustainable in cultural, social, environmental and economic terms. The results of the application will allow understanding whether the relocation is a preservation strategy in the case of historic buildings.

1.5 Thesis Organization

The following chapter is the literature review. This chapter will address the sustainable development by discussing the four pillars of sustainability in relation to environmental politics. Then, it will highlight the importance of historical sites, with the purpose of identifying the importance of cultural heritage between the tangible and the intangible cultural values. This will emphasize the significance of historic preservation. The literature review will then tackle the energy conservation strategies and after that define embodied energy and carbon emissions in historical buildings as terminology to be used in the empirical work of this thesis.

Chapter three will present the case study and contexualize it. The failure and success dam projects in Lebanon will be discussed prior to the analysis of Bisri Dam. Then, it will present the historical overview on the Bisri valley, and the cultural, environmental, social and economic impact of the dam project on the valley.

Chapetr four will introduce the methodology used to assess the embodied energy and carbon emissions. It will define the different techniques for evaluating the environmental impact. This will justify the selection of the life cycle assessment (LCA) as the adopted methodology. Afterwards, the steps of the implemented methodology for the Tally LCA tool will be described to assess the carbon emissions and embodied energy.

Chapter five will show the application of the adopted mehodology for the selected case study. This will present the applied modelling and software simulation after collecting the datasets. The results will be analyzed and compared to determine the environmental impacts of relocating historic structures.

Chapter six is the conclusion chapter. This chapter will state if the relocation of historic strategies is a sustainble historic preservation strategy, the limitation that were encountered, and will open a new question to expand on the current study and build further researches.

Chapter Two

LITERATURE REVIEW

2.1 Introduction

This chapter will achieve the first objective by investigating previous studies done on preserving and conserving cultural heritage in historic sites. It acknowledges the literature analyzed on these subjects and develops a platform that will underpin my research work. The importance of historic preservation and energy conservation of the tangible and intangible values of cultural heritage buildings (CHB), falling within new development projects, will be the focus of this section. The emphasis; however, will be recognized on CHB located in the context of water scarcity and on the construction of dams. As such, the first section will define the three pillars of sustainability in historic sites. It consists of shifting the debate towards strong and weak sustainability, and assuming that the natural and cultural resources should be preserved rather than diminished or replaced by human control. The fourth pillar of sustainability, as tangible and intangible cultural heritage, will be addressed in the second section. The energy conservation strategies which were extensively discussed in the Advisory Council on Historic Preservation (1979), will be unfolded in the context of dam construction as one solution for water shortage. Those strategies encompass the environmental assessments of the embodied energy and carbon emissions. Different case studies of dam projects in rural areas in Lebanon and abroad will be analyzed to present the successful projects and the reasons behind the failed ones. Finally, the case of Bisri dam in the Shouf area in Lebanon will be the emphasis of this study.

2.2 Sustainable Strategies in Historic Sites

The three pillars of sustainability, specifically the environmental pillar, are overshadowed by political agendas. The political structure plays a role in framing the natural resources whether it is exploited and substituted or preserved. As Mazlum (2004) mentioned, the interpretation of the political structure is one of the factors to achieve sustainability. Meanwhile, with the growth of thinking about sustainable development, political goals concerning environmental, economic and social dimensions were applied (Scoones, 2016). Feil and Schreiber (2017) identified the various meanings of sustainability arising from the integration of different political currents. Such integration is related first to the biological aspect as defense of correct exploitation of natural resources. Second, it is related to the ecology which is linked to the preservation of individual species in ecosystems subjected to human intervention. Third, the integration is connected to the economy which adheres to economic growth without compromising natural resources. And the fourth reason is related to sociology which is linked to a development that preserves society while maintaining social relations.

The idea of sustainability was mentioned during the nineteenth century, when issues of the finitude of natural resources and problems of environmental friendly land use were intensively discussed in Germany (Ott, 2011). The concept of sustainability, introduced in Brundtland Report in 1987, refers to a development which meets the needs of this generation without compromising the needs of future generation to meet their needs (High Level Panel on Global Sustainability, 2010). Sustainability is set as a multidimensional concept which was first considered as a ‘concept that was originally coined in forestry, where it means never harvesting more than what the forest yields in new growth’ (Kuhlman and Farrington, 2010, p. 2). Added to that, it was defined by the United Nations as a way to fulfill the economic goals, preserve the environment, and contribute to

society (Stojanović et al., 2018). Hence, sustainability encompasses three conceptual pillars: the economic, the environmental and the social pillar (Mensah and Casadevall, 2019).

As provided by various researches, social responsibility has an essential role in providing an integrated multidimensional concept of sustainability. In line with that, the UNESCO (2015) integrated the sustainable development perspective into the World Heritage Convention in order to enable social responsibility. When applying sustainable development, social responsibility is referred to respect this balance between economic growth, social development and environmental protection (Bakardjieva, 2016). In addition to the aforementioned three pillars, the cultural heritage was then identified as the fourth pillar and a key factor to achieve sustainability. In other words, in implementing the World Heritage Convention; it is therefore essential to respect, protect and promote these environmental, social, economic, and cultural values (UNESCO, 2015).

The cultural value represented by heritage can be considered alongside other sustainability concerns as the fourth cultural pillar in the sustainability model (Skrede and Berg, 2019). In the 2030 Agenda for Sustainable Development, cultural heritage was explicitly mentioned having a marginal role to protect and safeguard the cultural and natural heritage; thus, considering the cultural heritage as the fourth pillar (De Medici, De Toro, and Nocca, 2019). Mergos and Patsavos (2017, p. 24) defined cultural heritage 'as a part of the historical past, it is an element of the living present, as well as constituent of the future to be created'.

This section highlights the purpose of the integration between the pillars of sustainability as a way to manage the tensions between the various dimensions, especially in the presence of political agendas. As a result, this explains whether natural resources are exploited or preserved to identify weak and strong sustainability.

2.2.1 Three Pillars of Sustainability

The environmental dimension is subjected to many changes and challenges as result of deforestation, degradation of natural resources and activation of political agendas. According to Giovannoni and Fabietti (2014), the term sustainability began to be widely used during the 1970s, in relation to environmental problems. Sustainability calls for improving living standards without causing environmental problems such as deforestation, water and air pollution (Mensah and Casadevall, 2019). The environmental problems are caused by manmade activities. However, the concept of environmental sustainability has referred to the relationships between men and nature, which is also associated with human impact on natural systems. This has developed the concept of ecology to integrate all the factors and the interdependent elements within one system (Morelli, 2011).

The term ecology is linked to the concept of conservation (Callicott and Mumford, 1997). This concept connects human needs and ecosystem services as a way to "meet human needs without compromising the health of ecosystems" (Morelli, 2011). No doubt that the political agendas are part of this system affecting the environment and leading to several changes. Okba and Embaby (2013) emphasized on the environmental concerns that have placed sustainability at the forefront of the political agenda. Howes et al. (2017) explained that the environmental issues are becoming highly politicized leading to failure of environmental policy. In that manner, the natural resources should be efficiently distributed within the confines of a finite ecosystem and cooperated with the socio-economic activities, in light of the sustainability paradigm (Mensah and Casadevall, 2019). There cannot be environmental sustainability alone; it has to be implemented in conjunction with socioeconomic. The reason behind that is the impossibility of having one without the other in our present economic system which requires inter-generational thinking

(Davies, 2013; Meadows et al., 1972). The Brundtland Report connected the environmental development with economic, social, and political forces, recognizing that solutions to environmental degradation must be economically feasible (Haley, 2016).

The environmental balance in sustainable development is contrasted with an economy (Wiesmann and Liechti, 2004). The economic sustainability should involve analysis to meet the standards for protecting the environment (Morelli, 2011). However, the goal of the 1992 Rio Conference on environment and development failed to fulfill economic growth and environmental stability, due to its failure to achieve the equal optimization and balance between pillars of sustainability (Heinrichs and Biermann, 2016). For Dalby (2016), the environmental constituencies are able to protect nature and achieve economic growth. This is achieved through exerting political pressure as a main factor. There are different ways to achieve economic growth especially in sites having historical properties. Tourism has been recognized as a dominant factor of the economy to target sustainable economic growth (Wiesmann and Liechti, 2004). It has the potential to contribute to the sustainable development goals, and has an impact on World Heritage properties (UNESCO, 2020). To ensure benefit sharing in and around World Heritage properties, it is important to engage with community-based initiatives as sustainable forms of tourism development accompanied by economic investment (UNESCO, 2015). In addition, sustainable economic activities include the craftsmanship in which skills are applied to sustain cultural traditions. Craftsmanship has been associated with heritage conservation (UNESCO, 2015), and should be further developed because it has provided economic growth and increased the social relations within a complex context having natural environment.

The third dimension of sustainability was an effort at guaranteeing social well-being. Social sustainability can be understood as a prerequisite to support the processes of achieving the

environmental and economic sustainability goals (Kosanović et al., 2018). Heinrichs and Biermann (2016) stated that this development toward a sustainable society remains an ongoing challenge. From this standpoint, sustainability brings into focus the socio-economic activities and the human activities and their ability to satisfy human needs without depleting resources (Mensah and Casadevall, 2019). A significant asset of socio-economic activities as part of the local, regional and national public development strategies includes cultural heritage (kupisz, 2012). Activities and policies on economic use of natural resources require considerations to socio-cultural values (Axelsson et al., 2013). Randall Mason (2002) views the social, historical and cultural values as some main socio-cultural values (Dastgerdi and De Luca, 2018).

The importance of the ecology pillar as a concept of conservation of natural resources, has placed sustainability at the political agenda, with a trial to achieve social and economic balance.

2.2.2 Weak and Strong Sustainability

Thinking about sustainability as a paradigm of protecting and preserving the resources has shifted the analysis towards different levels of debate between weak and strong sustainability. This has developed two views known as weak and strong sustainability (Barua and Khataniar, 2015). On one side, Hediger (2004) characterized weak sustainability as some non-decreasing social welfare and strong sustainability as constant environmental quality, identifying both definitions under the title of ‘what should be sustained’. On the other side, Davies (2013) stated that there are many different worldviews of sustainability and this illustrated the wide range of differences between a strong or weak approach to sustainability. These approaches are concerned with the future of mankind and the need to put constraints on economic activities. Such activities stem from both humans and the interactions between the economy and the environment, developing a debate on whether natural resources can be substituted for human control. The concept of weak and strong

sustainability brings uncertainty about the concentration of greenhouse gases which affect all life (Vitalis, 20 June 2003).

The first viewpoint, which is weak sustainability, claims that "it does not matter whether the current generation uses up non-renewable resources or dump CO_2 in the atmosphere as long as enough machineries, roads and ports are built in compensation" (Pelenc, 2015, p. 1; Neumayer, 2003, p1). This signifies that the weak sustainability paradigm considers the manmade capital more important than the natural capital; therefore, it is possible to substitute natural for man-made capital (Davies, 2013; Neumayer, 2003). As for the second viewpoint which is the strong sustainability paradigm, it states that the set of natural goods should be neither reduced nor diminished or substituted over time, but overall kept constant or even increased (Ott, 2011). That means, it is significant to highlight whether the total capital passed on to the next generation is constant or growing (Davies, 2013). The cultural importance of natural capital has given a significant debate and is known as strong sustainability (Ott, 2011).

The debate of weak and strong sustainability was highlighted to define whether natural resources, in their cultural significance, are either preserved or compensated and substituted. This debate paved the way for the assessment of carbon emissions.

2.3 Cultural Heritage in Historic Sites

Cultural heritage is identified as the fourth pillar of sustainability, having its own significance in historic sites. This pillar is presented in this section followed by discussing the cultural heritage as means of tangible and intangible heritage.

2.3.1 Cultural Heritage: Fourth Pillar of Sustainability

Culture establishes diverse linkages among environmental, economic, and social dimensions (Kosanović et al., 2018). In 2014, Walker mentioned that sustainable development depends on culture and people and their physical manifestation. In 2007, Rapaport emphasized the influence of culture on the mechanisms that link people and environments (Kosanović et al., 2018). Culture shows the evolution and the development of various physical forms in a certain area from historical properties, edifices, crafts and landscapes. 'Culture thus includes any kind of heritage from the past, ranging from how people interact and do things to any kind of object, or environments that are a result of human constructions or use of the landscape' (Axelsson et al., 2013, p. 6). The Concept Note on cultural heritage, issued by the International Council on Monuments and Sites (ICOMOS) (1999) defined the broad concept of heritage as cultural in addition to the natural environments. This also encompasses historic places, sites and built environments, past, cultural practices and living experiences. ICOMOS stresses the importance of cultural heritage in sustainable development (Kou et al., 2018). Cultural heritage was considered to strengthen efforts to protect and safeguard the world's cultural and natural heritage (Nocca, 2017). Considering the cultural heritage as one of the pillars of sustainability, it has a distinctive connection with each of the social, economic, and environmental pillars, with a considerate attention to the role of political tensions. Over time, it passed to generations across cultures and to the whole of mankind (Axelsson et al., 2013; UNESCO, 1989), combining historical, cultural, economic, social and political dimensions (Mergos and Patsavos, 2017; Rizzo and Mignosa, 2013). This is revealed through the consideration of how socio-economic and environmental benefits can be optimized by integrating cultural heritage into sustainable development, despite the political tensions from social inequality (British Council, 2018). Aside from the social and environmental

link with cultural heritage, there are direct economic impacts of cultural heritage related to the income which boosts economic growth, resulting from activities linked to heritage preservation and conservation (kupisz, 2012). The conservation within the dimensions of sustainable development will enable all those concerned to better engage with World Heritage (UNESCO, 2015). Based on this widespread understanding, sustainability is defined by four parameters - environmental, economic, social and cultural (Walker, 2014).

The cultural heritage in historic sites safeguards the natural and cultural assets, thus showing its interlinkage with the natural heritage and the three pillars of sustainability.

2.3.2 Tangible Cultural Heritage

Cultural heritage can be defined with regard to the economic, social, environmental, and cultural developmental potential (Hribar, Bole, and Pipan, 2015). Culture is recognized as a priority component to safeguard a diverse range of tangible and intangible cultural heritage (Nocca, 2017). According to ICOMOS (1999), all cultures and societies are rooted in the particular forms of tangible and intangible expression which constitute their heritage. 'It is important to consider that tangible and intangible heritages are often interconnected: The former provides the physical support for the latter, while the latter could contribute to the preservation and conservation of the former' (Patru-Stupariu, Pascu, and Bürgi, 2019, p. 2). Discussing the tangible cultural heritage, it includes architectural historic structures and monuments, archeological nature and human-made landscapes (Axelsson et al., 2013; UNESCO, 1972). Preservationists see historic structures significant for their existence as intact and as part of the authentic fabric and to damage them is to damage a piece of the whole (Milligan, 2007). 'Buildings are understood to have qualities worth preserving: they are made of certain materials, designed in a certain way, and built

with craftsmanship' (Milligan, 2007, p. 107). This illustrates that the tangible values are linked to the physical consistency of the heritage (Vecco, 2010).

2.3.3 Intangible Cultural Heritage

From a sustainable development perspective, recognizing the potential of heritage as a development resource took into account not only tangible but also intangible heritage of place (Kupisz, 2012). Intangible heritage focuses on the collective memory of cultural-level understandings and memories of historic communities, landmarks, well-known historic houses and sites, and historically significant events and individuals (Milligan, 2007). The particular heritage and collective memory of each locality or community is irreplaceable and an important foundation for development (ICOMOS, 1999). In the Krakow Charter's opinion (2000), the intangible value is defined as a "clearly determined entity, the bearer of values, which represent a support to memory. In it, memory recognizes the aspects that are pertinent to human deeds and thoughts, associated with the historic time-line" (Vecco, 2010, p. 323).

Cultural heritage resulted in identifying the importance of preserving memory as intangible cultural heritage, which contributed to the preservation of the physical intact structure as tangible cultural heritage.

2.4 Historic Preservation

Sustainability begins with preservation. This section discusses the concept of sustainability as the mean of historic preservation. The important historic building attributes which are age, integrity, and significance are then highlighted.

2.4.1 Preservation of Historic Properties

The four-bottom line in Elefante and Smith's analysis (2009) is sustainably understood to preserve historic buildings as foundation and as future strategies. 'The lack of this equilibrium, among historic preservation and environmental, economic, social, and cultural aspects, has often led to the irreversible decay and destruction of heritage assets along time' (Sabou, 2012 , p. 5). The concept of sustainable development is applicable to the heritage preservation in general and the preservation of architectural heritage in particular. Historic preservation has this interconnection with the sustainability pillars. This link includes the cultural values as an aim to protect the cultural heritage, the collective memory from the social viewpoint, the sources of income to boost the economy, and the energy consumption from the environmental viewpoint. Meanwhile, to avoid negative environmental impacts, the sustainable historic preservation includes minimizing the energy consumption, preserving architectural history, reducing construction waste and maintaining the structural integrity of older buildings than that relocated (El-Enein, El Rayes, Mostafa, and Refaey, 2015). 'Preservation saves energy by taking advantage of the energy embodied in an existing building and extending the use of it' (Advisory Council on Historic Preservation, 1979, p. 15). Opponents of preservationism often claim that preservationists care about 'buildings, not people' and that they privilege protection of historic structures over the needs and rights of community residents (Milligan, 2007). 'Regardless of the historical and aesthetic values, there is no greener building than the one that is already built' (Baca and López, 2018, p 7).

Heritage preservation has significant environmental dimensions, as well as the long and familiar socio-cultural one (Dastgerdi and De Luca, 2018). 'Sustainable development requires cultural and social dimensions, and historic preservation that can act as a vehicle for identifying

and including these aspects' (Haley, 2016, p. 9). The cultural and the social aspects play a role in identifying the aim of preservation. According to Kaufman, the aim of historic preservation is not only to repair or save old properties but also to create places where citizens can live comfortably, create a living experience and connect to meaningful narratives about history, culture and identity (Dastgerdi and De Luca, 2018). Historic preservation is described as cultural identity and continuity (Liusman, Ho, and Ge, 2013); hence, preserving the materials and features that convey the significant history of a place and its experiences (Dastgerdi and De Luca, 2018). According to Nocca (2017), in order to create a living experience and conserve cultural heritage, a personal memory should be constructed and; therefore, the identity will be conserved. Similarly, Milligan (2007) considered historic preservation to be inherently concerned with collective memory. This implies that sustainable development considered historic preservation as an integral part of it (Ghazyaryan and Nazaretyan, 2016), and was introduced in the field of cultural heritage preservation in order to preserve the culture for future generations (Kou et al., 2018). For that reason, historic property under the jurisdiction or control of the agency should be managed and maintained in a way that considers the preservation of its historic, archeological, architectural, and cultural values (Senate and Representatives of U.S in Congress, 2014).

The historic preservation is within the field of sustainability. It is defined as preserving the cultural heritage and minimizing the energy consumption within the environmental dimension.

2.4.2 Importance of Historic Properties: Age, Integrity and Significance

A historic building or historic site is defined as an official location where pieces of political, cultural, or social history have been preserved due to their cultural heritage values (Othman and Elsaay, 2018). The first indication for the importance of a historic property is its age. A building must be older than a specified age threshold, usually around 50 years, to be considered historic

(Webb, 2017). Historic buildings of valuable assets symbolize the advancement made by humankind (Ding and Ying, 2019); hence, reflecting the range of cultures and time periods (Milligan, 2007). A property within a historic context needs to identify the themes, geographical limits, and chronological period that provide a perspective to evaluate property's significance (National Register, History and Education, 1995).

The main purpose behind the focus on assessment of heritage is its integrity. Bennett (2010) defines integrity as the interior and exterior form of a historic property that should be seamlessly interconnected. He adds that the construction methods should reflect the nature of their materials, and engineering systems and architecture should be mutually supportive. This reflected the historic site which was showing its interconnection with nature, the usage of local construction material and the symbolic value the historic property had on the social fabric. The historic sites must be the object of special care in order to safeguard their integrity and ensure that they are cleared and presented in a seemly manner (ICOMOS, 1999). Many scholars highlighted the definition of integrity. Dastgerdi and De Luca (2018, p. 33) defined integrity as 'a measure of the wholeness and intactness of the natural and/or cultural heritage and its attributes'. Whereas, integrity to Milligan (2007) is defined as the authenticity of a historical resource's physical identity evidenced by survival of characteristics that existed during the resource's period of significance. This attribute is evidenced by the survival of physical characteristics that existed during the property's historic period. Not only must a property resemble the historic appearance but also it must retain physical materials, design features and aspects of construction dating from the period when it attained significance (Gupta and Prakash, 2018). Integrity of historic resources can suffer of inappropriate treatment through extensive removal, alteration, or deferred maintenance of significant features (Park, 2006).

Understanding what is significant about a historic property is the first step in the project's analysis. According to the National Register, History and Education (1995), retaining historic integrity of those features is necessary to convey its significance. It is crucial to define the category of the historic property, determine the historic context to which the property belongs, and the context significance in the history. Historic significance is the importance of a property to the history, architecture, archaeology and culture of a community. Webb (2017) emphasized the evidential, historical, aesthetic, and communal value for the significance of a historic building. In selecting a building, particular attention should be paid to the associated events, activities, important persons and distinctive physical characteristics of design, construction or form (Gupta and Prakash, 2018). A property can also be deemed significant if it embodies distinctive characteristics of a type, period, method of construction or if it is the work of a master (Park, 2006), which are meant to be associated with person(s) or event(s) or to its built form (Milligan, 2007). Based on the intricate features that historic buildings have, it is important to safeguard its age, integrity, significance and physical characteristics through historic preservation and energy conservation. Those buildings have a stored embodied energy that should be conserved (Hasenfus, 2013).

Historic properties reflect range of cultures, survival of physical characteristics, method of construction and associated activities; hence, all must be taken into consideration in case of properties' removal.

2.5 Energy Conservation

The historic conservation strategies are implemented to reduce energy consumption and wastes in case of demolishing historic structures to be relocated or constructing another building; therefore, increasing the environmental benefits from a sustainable viewpoint. This section will

then identify the embodied energy and carbon emission's impact on the environment and the life cycle. These are essential factors to be assessed in historic buildings to be able to further select the proper dataset for the energy assessment.

2.5.1 Historic Conservation Strategies

'The historic conservation and preservation would maintain and increase the value of historic buildings by keeping their original architectural elements and built forms' (Ren and Han, 2018, p. 7). Larsen and Marstein have claimed that sustainability has in fact always been a central concept in building conservation (Berg, Icon, and Fuglseth, 2018). Conservation strategies include avoiding negative environmental impacts, avoiding additional energy consumption, saving water and reducing local water impacts, and preserving architectural history (El-Enein, El Rayes, Mostafa, and Refaey, 2015). The Burra charter states that 'conservation is based on respect for the existing fabric, use, associations and meanings' (Dastgerdi and De Luca, 2018). However, El-Enein et al. (2015) regarded the existing characteristics of a historic building to be assessed before implementing any energy conservation measures. As for the characteristics, it includes the following: the design, materials, type of construction, size, shape and surrounding landscape. Further aspects such as processing, transporting, and putting construction materials in place, were discussed by the Advisory Council on Historic Preservation (1979) to assess energy measures. Shreve (2018) proposed some conservation strategies referring to a study conducted by the International Energy Agency's Energy in Buildings and Communities Program, which are:

- Reduction in the quantity of building material through the whole building life cycle,
- Substitution of traditional building materials having high embodied energy and carbon emissions with lower environmental ones, and
- Reduction in the environmental impacts of the construction phase.

The energy assessments are studied as conservation strategies to identify the impacts of historic properties from the four pillars of sustainability. It is of utmost importance to recognize the interrelationship between sustainable development and heritage conservation (Ghazyaryan and Nazaretyan, 2016). Sustainable management strategies which respect cultural heritage require the integration of conservation attitudes with economic and social goals (ICOMOS, 1999). As for the environmental goals, the conservation of cultural heritage is now recognized as resting within the general field of cultural and environmental development (ICOMOS, 1999).

The conservation strategies were analyzed to assess the impacts of energy consumption on the environment as a result of processing, transportation, construction material, design, size and the surrounding.

2.5.2 Embodied Energy and Carbon Emissions

Historic buildings are valuable assets for conservation because the embodied energy and carbon emissions are already embedded in the buildings (Ding and Ying, 2019). They are one part of the overall energy and carbon measured over its life cycle (Menzies, 2011). Conserving buildings rather than demolishing and rebuilding them avoids greenhouse gas emissions and energy consumption (Pullen and Bennetts, 2011). On one hand, the embodied greenhouse gas emissions represent the emissions associated with the energy consumption for the production, construction, maintenance, repair, replacement, refurbishment and energy consumption (International Energy Agency, 2016). 'The emission of these gases is the result of intensive environmentally harmful human activities such as the burning of fossil fuels, deforestation and land use changes' (Khasreen, Banfill, and Menzies, 2009, p. 675). On the other hand, the embodied energy can be defined as the energy consumed throughout the production, processing, putting materials of construction in place, maintenance and demolition of a building. It increases with the

amount of processing (Advisory Council on Historic Preservation, 1979). It also differs according to geolocation, since it is highly dependent on the type of fuel of a country, or on the sources of material of raw materials and distances to transport them, amongst other affecting variables (Waldron et al., 2013). Embodied energy from a detailed viewpoint analysis is the energy consumed in life cycle stages of a building other than the operation, such as space conditioning, water heating, lighting, and operating building appliances and other similar operational activities (International Energy Agency, 2016; Dixit et al., 2013). However, Webb (2017) considers the embodied energy as a measure of environmental impact that has long been embraced by the historic preservation community. To evaluate the environmental impact of buildings based on energy use in the operational phase, excluding the rest of the building life cycle, results in operating with unsustainable policies (Berg, Icon, and Fuglseth, 2018).

> ‘Williamson and Pullen (2009) proposed a link between embodied energy and the cultural value of historic constructions. Such a link reflects the theory approach to sustainable development where the connection between man-made and social capital indicated by the embodied energy would suggest significant cultural benefits from built environments with higher embodied energy. Generally, older historic buildings that survive in good condition today are of higher embodied energy resulting from solid and durable construction (Pullen, 2010). Williamson and Pullen (2009) concluded that the concept might be incorporated into practice guidelines for promoting sustainability in buildings’ (Pullen and Bennetts, 2011, p. 2).

Aside from the correlation of the embodied energy to the environmental, social and cultural dimension of sustainability, the economic dimension includes the operational energy and replacements costs of historic structures (Jackson, 2005). Because the energy embodied in an

existing building was invested long ago, its economic value is not adequately recognized by normal economic comparisons of preservation versus new construction (Advisory Council on Historic Preservation, 1979).

The historic buildings showed higher carbon emission and embodied energy within its life cycle assessments, especially in case of relocation or demolishing historic structures. These factors affect the cultural and environmental assets in any historic site.

2.5.3 Life Cycle Assessment

The assessment of the embodied energy and carbon emissions can be considered as part of the life cycle. The amount of embodied energy in the life cycle of a building has become an important criterion in the environmental performance assessment (International Energy Agency, 2016). Life cycle assessment (LCA) is a method which focuses on energy as the only measure of environmental impact of buildings or products (Menzies, 2011). However, Berg et al. (2018) considered all the environmental impacts caused throughout the life cycle of the building, and not just in the operational phase. 'The assessment includes the entire life-cycle of a product, process, and processing of raw materials, manufacturing, transportation and distribution, use, reuse, maintenance, recycling and final disposal' (Khasreen, Banfill, and Menzies, 2009, p. 676).

It is important to assess the whole life cycle of a historic building, because 'historic buildings should be sustained by respecting the existing materials and construction, discouraging the removal or replacement of materials which require reinvestment of resources and energy with additional carbon emissions' (Berg, Icon, and Fuglseth, 2018, p. 155; Cen, 2017). The conservation strategies in historic buildings are of utmost importance because the embodied energy is mostly embedded in the structure of a building, thus the life cycle should be assessed in case any adjustments were implemented. Meanwhile, energy savings over the expected life of the

structures are the result of conservation of existing buildings, rather than demolition and new construction (Advisory Council on Historic Preservation, 1979).

The conservation strategies must be implemented to sustain resources and historic buildings of cultural values, hence discouraging their removal or replacement in developmental projects, which require additional carbon emissions and energy consumption.

2.6 Water Scarcity and Rural Development

Water is one of the natural resources which has lately shown lots of challenges in general, especially when development projects are implemented. This section provides an overview on water scarcity worldwide and specifically in the MENA region, identifying different solutions proposed for this problem, such as dam projects. The impacts of dam projects in rural areas are then addressed from a sustainable viewpoint, moving to discuss the mitigation measures needed and analyze different case studies around the world.

2.6.1 Three Sustainability Pillars: Impact of Rural Dam Projects

The 2030 Agenda for Sustainable Development is an overarching vision for the transformation of societies. These Sustainable Development Goals are all critical to adopt holistic approaches that lead to inclusive transformation (International Fund for Agricultural Development, 2018). The three-pillar model of sustainable development consists of the environmental, economic, and social dimensions (Burford et al., 2013). The progress in advancing social and environmental sustainability has rarely kept pace with economic progress, resulting in loss and degradation of natural resources. This increases competition for ever-scarcer resources, including water, energy, and land (International Fund for Agricultural Development, 2018). Sustainability requires an action to conserve, protect, and enhance natural resources (Maestu,

2015). In the understanding of natural resources, the water conservation behavior has many gaps especially when the threat of water scarcity is no longer preeminent in people's minds (Moglia, Cook, and Tapsuwan, 2018).

Much emphasis has been placed on the status of water, including water scarcity. The Middle East and North Africa (MENA) is considered as one of the weak and challenging regions in terms of shared surface and groundwater resources between two or more countries (Kibaroglu, 2016). The chronic water shortage in the MENA region is a perplexing issue and the existing water quantification agreements have been deemed inefficient to solve the problem of naturally diminishing water resources (Zyadin, 2013). Accessing enough clean water and sanitation, as well as benefitting from water for economic, social, and cultural development is in jeopardy. This is due to human-induced climatic changes in the MENA region, as a result of an increase in temperature of the Middle East in the coming years (Kibaroglu, 2016). However, the post-2015 sustainable development agenda requires water resources management, operation and maintenance, and control of water and wastewater quality. And this leads to a significant increase in investment in infrastructure (Maestu, 2015).

Largescale infrastructure, such as the dam projects, has various impacts when discussed from a sustainable viewpoint that is related to the economic benefits, natural assets, and social equity. It is important to avoid and mitigate negative social and environmental impacts of large-scale infrastructure, such as upstream flooding effects caused by dams (International Fund for Agricultural Development, 2018). As for the economic pillar, it is claimed that the economic benefits expected from the projects designed to utilize water resources, such as the dam projects, could not be gained. Add to that, the necessary precautions to decrease the environmental, economic and social losses were not taken (Tahmiscioglu et al., 2011). This is the result of the

uneven distribution of benefits and the lack of equity which question the value of dams in meeting energy and water development needs (World Commission on Dams, 2001).

"The International Commission on Large Dams" (ICOLD) defines large dams "as dams with height of 15 meters or more. If dams between 10 and 15 meters high have a crest length over 500 meters or a reservoir volume of more than 1 million cubic meters, they are also classified as large dams" (Liagre, 2008, p. ; IUCN, 1997). Large dams are partial symbols of a larger paradigm, nation-building and economic power (Cabalion, 2012). However, small dams built near highly sensitive ecosystems may also have significant impacts (Department of Water and Environmental Regulation, 2019). As for the role of dams, it is concerned with the management, as time and quantity of the releases, and not limited to the storage of water (Lukman et al., 2010). Maximizing the storage capacities of the built dams is one of the measures developed by the governments in the MENA countries to increase water supply. This is due to the fact that the dams have benefits that can be taken into consideration in order to limit the problem of water scarcity. The benefits of dams include controlling stream regimes, consequently preventing floods, obtaining domestic and irrigation water from the stored water and generating energy (Tahmiscioglu et al., 2011).

Many alternatives to dam projects were highlighted to identify the appropriate strategy for water supply with the least costs. Other measures than dam construction for water supply include enhancing the capacities of water harvesting and deploying groundwater recharge techniques (Zyadin, 2013). Besides, additional methods to meet human water needs are: designing less water demand, encouraging solutions which are not structural in flood control, finding better methods to process wastes and purifying waste water (Tahmiscioglu et al., 2011). Large dams act as a main source for water supply in addition to generating energy. Such cost-effective and feasible alternatives for sustainable energy sources of the required loads are the construction of large

photovoltaic systems, concentrated solar power systems, wind energy and sustainable biomass (Dutch Sustainability Unit, 2016). Scholars found that dams might reduce carbon dioxide emissions in comparison with other means of producing energy. However, large dams might emit methane from the organic decomposition occurring in the reservoir leading to question whether large dams should be included in climate change mitigation programs (Liagre, 2008). Defenders of large dams note that they are often the economically least-cost source of electric power available because most other power generation technologies also imply significant adverse environmental impacts (Ledec and Quintero, 2003).

The sustainable approaches to water planning are required to avoid further large-scale biodiversity loss and socio-economic impacts (Kraljevic, Meng, and Schelle, 2013). On one side, dams are important in economic development. They played a key role in the development of the underdeveloped regions in many developed countries (Tahmiscioglu et al., 2011). ICID (2000) considered that dams have solved many problems of communities and provided basis for economic development that has sustained itself. On the other side, Tahmiscioglu et al. (2011) suggested that dams affect the social and economic structure of the region considerably by forcing people, whose settlement areas and lands remain under water, to migrate; thus, affecting them psychologically. Accordingly, the World Commission on Dams (2001) mentioned that benefits and impacts of the dam and its context which are not static over time may be transformed. Such transformation is related to changes in priorities for water use, land use changes in the river basin, changes in public policy, and technological developments expressed in environmental, safety, economic and technical regulations. That means the land use change that follows any large developmental projects, such as the construction of a dam, is inevitably accompanied by different changes (Hosayni, Mirakzadeh, and Lioutas, 2017).

No dam is without an impact and sometimes a dam has been built on the wrong river. It is possible to identify locations that, if not good, are at least less wrong than others because the eco-friendly design and operation cannot fully heal a flawed choice of location (Kraljevic, Meng, and Schelle, 2013). According to Vanclay (2003), some effects of such projects could be generally divided into sub-groups: health and social well-being impacts; cultural impacts; livability impacts; legal, political, and equity impacts; family and community impacts; and economic and material well-being impacts (Hosayni, Mirakzadeh, and Lioutas, 2017). Analyzing the economic pillar, large dams have reinstated itself in a context of radical changes in economic policies raising crucial questions about the state's treatment of rural areas (Cabalion, 2012). In this manner, economic developments have been generated, such as local stabilization of rural population, employment opportunities, and migration of rural unemployed population to urban centers. These developments have been reversed with significant reduction in poverty (ICID, 2000). While rural dams can have economic benefits, they can also have significant social and environmental costs (Department of Water and Environmental Regulation, 2019).

The dam projects in rural areas are one of the solutions for water scarcity in the MENA region, discussing its environmental and cultural impacts because no dam is without an impact. This can be entitled as rural transformative projects.

2.6.2 Social and Environmental Impact Assessment: Dam Projects

One of the main objectives of impact assessments is to study the effects of a proposed dam project (Ogola, 2009). On the one hand, the assessments include the social impact assessment, which is an overarching term for concepts, processes, methods and tools to analyze, evaluate and manage the positive and negative social consequences of a project, thus understanding the social sustainability aspects of the intervention (Terrapon-Pfaf et al, 2017; Vanclay, 2003 and 2006). On

the other hand, another field of research includes environmental impact assessment which considers the physical, ecological, cultural, economic and operational problems (Pandey and Sinha, 2013).

The social impact assessment (SIA) is the process of identifying and managing the social impacts of the projects, policies, plans and programs. It mitigates the negative impacts and identifies opportunities to enhance benefits for local communities and broader society (Wilson, 2017). SIA encompasses all human impacts including landscape analysis, archaeology, heritage, community, culture, demography, economy, health, politics, development, resource issues, impacts of tourism and other impacts on societies (Wong, 2014). Accordingly, UNEP (2002) mentioned the characteristics that are correlated with the social impact assessment from the three pillars of sustainability. These characteristics include environmental changes such as alterations to land use, natural habitat and hydrological regime; economic changes concerned with the employments; and social impacts related to the demographic changes. However, Ronza and Ferretti (2018) only emphasized, in this assessment, the socio-cultural analysis at appropriate times during the project cycle in order to maximize values and minimize the costs of an intervention. Any failure to consider the cultural and social factors of projects can lead to situations where mitigation does not effectively address the impacts they were intended to alleviate (Hanna et al., 2016). The cultural values of a site exceed the social impact assessments, to be interrelated with the environmental analysis as well. This is due to the fact that the social impact assessment is limited to the environmentally related changes (UNEP, 2002).

The environmental impact assessment is an environmental study comprising collection of data and prediction of qualitative and quantitative impact. It also comprises evaluation compensatory measures and comparison of alternatives on the physical, biological, cultural and

socioeconomic attributes of a particular geographical area (Fischer and Nadeem, 2013). On one hand, a new approach to the planning process of dams in compatibility with the environmental impact assessment process has been strongly recommended. Such approach includes the multiple uses of water and other natural resources, the maximization of economic and energy efficiency, and the minimization of environmental impacts (Verocai, 2009). On the other hand, this assessment has been criticized for its subjective judgments and lack of transparency (Pandey and Sinha, 2013), in addition to its effects on the natural environment and the negative socioeconomic impacts (Verocai, 2009). The social life in communities is disrupted, the income opportunities are lost (Petersson and Ostrowski, 2003), and the local communities are resettled, leading to social costs and putting the sustainability issue of these dams into question (Parlak, n.d.). Égré and Senécal (2003) extended their studies to include other social issues such as issues related to cultural heritage preservation, a fair compensation for lost assets, effects on the health of well-being, challenge of economic development on a long-term, and minority rights. There is a growing concern that the transformation of landscapes for the dam projects causes irreversible environment change. Essentially, that change is negatively affecting the flora and fauna, pollution from increased human activity, and disruption of habitats (Manatunge et al., n.d.). It is also important not to neglect the loss of historic and cultural sites that arise as a direct impact of the dam construction influencing the cultural values of the place (Tahmiscioglu et al, n.d.). Once a dam project is approved, promoters tend to neglect the cultural and environmental protection measures that have been identified in the environmental impact assessment studies because those concerns are not fully incorporated in the dam project cycle (Verocai, 2009).

Besides the socioeconomic effects, the large dams have great potential for an adverse environmental impact with long estimated implementation schedule (Department of Water and

Environmental Regulation, 2019). Within the environmental measures, the dam construction disturbs the landscape around the dam (Stephens, 2010) and destructs flora and fauna diversity (Parlak, n.d.). As part of the fauna analysis, the project leads to the extinction of endangered species, such as the valuable fisheries which are a vital component of people's livelihoods (Kraljevic, Meng, and Schelle, 2013); thus, making the fish passage facilities inadequate to restore the pre-dam ecological balance of a river (Ledec and Quintero, 2003). In addition to the destruction of the riparian and wetland vegetation and fauna habitat, the dam construction has environmental impacts on water resources. Those impacts include changes in waterway flow regimes and water quality, in the release of contaminated water during the operation of the dam, and in the formation of a waterway barrier that obstructs the movement of aquatic fauna (Department of Water and Environmental Regulation, 2019).

The location and design of a dam should ensure that there are no harmful effects on upstream or downstream properties. Such properties encompass a reduction of the seasonal stream flow and flooding of neighboring properties (Department of Water and Environmental Regulation, 2019). Accordingly, the Brundtland Commission found that all reservoirs increase the humidity and emit greenhouse gases, due to the rotting of vegetation and carbon inflows from the catchment. The scale of such emissions is highly variable (World Commission on Dams, 2000). Within the environmental impact assessments, archeology should be studied when developmental projects have been implemented, leading to alterations in the land use. In this case, the archeological treasures and historical areas are impacted and its assessments are changed according to the policies of countries to protect their own cultural inheritance (Parlak, n.d.). Some project sites include cultural values such as sacred properties which cannot be salvaged prior to reservoir inundation (Ledec and Quintero, 2003). The environmental impacts of dams on archeology, water,

fauna and flora, along with the socioeconomic impacts, should be assessed to apply the mitigation measures. Dwivedi, Gupta, and Pandey (2010) mentioned that the effects of the dam can be minimized through careful planning and design that incorporate the public involvement in the early stage of this process. This leads to an effective and efficient implementation of the design, construction and operation of the project.

The social and environmental impact assessments for dam projects were analyzed. The analysis encompasses historical areas to minimize greenhouse gases emission, preserve the cultural properties, archeology, natural environment and think of compensatory measures.

2.6.3 Fourth Pillar: Rural Cultural Heritage

The dam projects often offer disappointing results, mainly due to the persistent focus on the economic dimension of rural development and overlook social, ecological, and especially cultural consequences. Thus, the four dimensions of sustainability and the externalities of developmental interventions are underestimated in many cases (Hosayni, Mirakzadeh, and Lioutas, 2017). In this essence, it is essential to set a model for sustainable rural development in a culturally rich area (Feiner, Mi, and Schmid, 2002). The presence of diversified forms of culture has been incorporated into the official discourse, transforming villages into precious archives of cultural, social and biological differences (Pola, 2019). In rural areas, archives contribute to shaping community identity and resilience as they preserve the collective memories and maintain the connection to the past (Matusiak et al., 2019; Beel et al., 2017).

UNESCO promoted the ‘Ruritage’ programme that creates models for cultural and natural heritage and looks for indicators to consolidate the role of culture as the fourth pillar of sustainable development. This contributes to economic growth, social inclusion, and environmental sustainability in rural areas (Pola, 2019; Ruritage 2019). The ultimate scope in rural areas is ‘not

the preservation of their material forms, but the inheritance of the culture that in those forms and places is expressed' (Pola, 2019). UNESCO recognized the need to incorporate cultural heritage into development in a holistic way when it launched the Historic Urban Landscape approach in 2011 (Breznik, 2014). River basins are renowned as cultural heritage and considered a main source for livelihood, commerce, and habitat that provide sustaining ecological functions. Throughout history, the alterations to rivers as a result of dam constructions have affected riverine communities in one way or another (Liagre, 2008; WCD, 2000).

The externalities of the dam projects should be highlighted, accompanied with developing a sustainable rural model to preserve the cultural heritage defined as the collective memory.

2.6.4 Mitigation Measures

The mitigation measures, to restrict the negative impacts, are inherently unsatisfactory even if they are properly implemented (Ledec and Quintero, 2003).

> 'Structures of cultural interest should undergo salvage wherever feasible through scientific inventory, careful physical relocation, and documentation and storage in museums or other appropriate facilities. However, it is often not possible to replace the loss of, or damage to, unique or sacred sites which may have great religious or ceremonial significance to indigenous or other local people' (Ledec and Quintero, 2003).

In practice, many dam projects over-estimate the benefits, while externalizing the environmental and social costs (Kraljevic, Meng, and Schelle, 2013). Assessments to the changing circumstances of the management practices should be done, in order to optimize the benefits, improve measures to limit and restore damage to the environment and address social issues (World Commission on Dams, 2001). Sometimes large dams may be a good option to meet a developing countries' societal demands for water, energy or food supply, but takes up to 15 years to meet these

demands (Dutch Sustainability Unit, 2016). Add to that, each dweller of the social structures is differently impacted by the changes of the dam (Hosayni et al., 2017; Williams and Schirmer, 2012). Even though new rural development policies emphasize partnership and participation, there is a considerable doubt whether the developmental projects are socially grounded (Hosayni, Mirakzadeh, and Lioutas, 2017). This emphasizes the importance of participation of poor consultation in the decision making associated with dams (Stephens, 2010), because a poor consultation and failure to address resettlement and downstream livelihood issues result in conflict (Kraljevic, Meng, and Schelle, 2013).

One of the conflicts dwellers face is the displacement of local residents. However, many of the displaced people were not recognized and neither resettled nor compensated, and the compensation provided was inadequate (Altinbilek and Cakmak, 2001). The World Commission on Dams (2001) investigated the importance of negotiation with affected groups, based on recognition of rights and assessment of risks. As such, it is essential to promote equitable human development and the welfare of all species. It is also crucial to minimize the negative impact and mitigate harm to the health and integrity of the river system, thus protecting the ecosystems at river basin level (World Commission on Dams, 2001). For the safety of lives and properties, urgent solutions for non-potable water must be provided in the case of silting or the collapsing of the embankment due to the presence of big trees. Such mitigations include the removal of trees from embankment and desilting and seepage control (Lukman et al., 2010).

Water pollution control measures may also be needed, such as sewage treatment plants or enforcement of industrial regulations to improve reservoir water quality (Ledec and Quintero, 2003). Management of water releases may be needed for the survival of certain fish species. Mitigation measures are needed for the fish survival including fish passage facilities, example fish

ladders, to help migratory fish move upriver past a dam of limited effectiveness. These measures help fish hatcheries to maintain populations of native species survive but not successfully reproduce within the reservoir (Ledec and Quintero, 2003). Kraljevic, Meng, and Schelle (2013, p. 12) proposed the 'mitigation measures for survival of fish species, including the proper fish bypasses and fish-friendly turbines, but the effectiveness of these is often limited to certain species of fish'.

It is important to minimize the negative effects of dams on the environment from the lens of sustainable development (Tahmiscioglu et al., 2011). Deforestation, which is common in many dam projects, should be minimized and discouraged throughout the catchment of establishing gardens close to the river for irrigation (Stephens, 2010). Even the construction site of a dam project is a rural area with lots of trees, so the fume and dust which are dispersed outside the construction site in a narrow scope, are easily diluted. Its impacts can be limited if mitigation measures are applied well (Dong, 2018). As a way to deal with externalities, the most appropriate way to minimize greenhouse gas releases from reservoirs is to choose dam sites that minimize the flooding of land in general and forests in particular. Another appropriate way can be done through salvage of commercial timber and fuelwood which frequently does not happen because of high transportation costs or political and economic pressures not to delay reservoir filling (Ledec and Quintero, 2003). According to Earthtime Inc. (2009), the recommended mitigation measures, used for the increase in greenhouse effect, are to introduce the plantation of windbreakers at the borders of the cleared areas and replant rubber trees at ratio 1:1. It is a must to ensure a proper maintenance of engines and any machine used off-site and not to exceed a tool's life expectancy in order to reduce the gaseous emissions from transportation.

As for the dust emissions from cutting, sawing and chipping of wood, it requires workers to use personal protective equipment during operations and introduce the use of a dust collector directly after operations take place. Therefore, all procedures in selecting, designing, and building dams must be followed to the highest standards possible because a failed dam is not only a matter of a lost structure but also can result in loss of life and considerable expenses (Stephens, 2010). Lukman et al. (2010) arranged in order, from the most to the least, the causes leading to dam failures, starting with leakage and piping, overtopping, spillway erosion, excessive deformation, sliding, gate failure, faulty construction, and earthquake instability. Dam failures may result in its removal. Poff and Hart (2002) addressed the reasons behind dams removal in case it meets human needs, thinking that this removal is due to a change in society's needs and the effect of dams which impair river ecosystems.

The compensatory measures are highly recommended in order to internalize the externalities, including the greenhouse gas house effect and the damage or loss of cultural properties.

2.6.5 Case Studies: Dam Failure and Success Projects

Different case studies of dam projects are analyzed to show the failure and success aspects of each. The case studies are presented having similar climatic conditions, and cultural and natural heritage as that of Bisri Dam project. Discussing European dams as an example, Luino et al. (2014) stated that Italy has 541 large dams and 10,000 small dams, including 1000 dams failures in the 20th century, due to errors in the poor foundation ground and errors in both planning and construction phases. In the American studies, St. Francis dam was considered as the worst American civil engineering disaster of the 20th century, which resulted in the deaths of over 400 civilians and of poor engineering judgment (Association of State Dam Safety Officials, 2020). As

for the African development projects, Bui Hydroelectric Project, located on the Volta River Basin in Ghana, is one of the large dams which historically examines the large dam debate (Alhassan, 2008). The communities next to Bui project lack social, economic, and political power to press their case for mitigation and development (Abrampah et al., 2015). Politics played a role in the decisions taken for the Bui Dam, involving matters relating to the establishment of the Bui Power Authority, funding arrangements and compensation for affected communities (Darko et al., 2019). Alhassan (2008) considers that this dam acts as a hydropower, irrigation development and aims to enhance the tourism potential. Abrampah et al. (2015) assumes that this project was executed to salvage remains affected by Volta floods following the construction of another dam. As a consequence, the project resulted in the flooding of nearly a quarter of the Bui National Park, destruction of community assets including important plant and animal species which affected the biodiversity and the displacement of seven communities (Arthur, 2018). Even though most of the affected people have been resettled, compensated and rehabilitated in line with preservation and restoration of historic and heritage sites, there are still cultural crises impinging on the history and culture of Bui communities today (Abrampah et al., 2015). The case is worse for the relocated since they have lost the cultural support from part of the community that did not relocate, showing inequality (Arthur, 2018). Thus, the communities have lost access to natural resources and cultural heritage distorting the social memory (Abrampah et al., 2015).

Another dam project analysis located in the MENA region, in Eastern Turkey, is the Keban dam which is Turkey's second biggest dam and the fourth biggest dam lake among all natural and artificial lakes in Turkey (Tiryakioğlu, 2015). It is a hydroelectric dam built on porous limestone cliffs full of caves, in the Eastern Anatolia region of Turkey. It aims at modernizing the Eastern Anatolia region into a major economic asset (Garner and Smith, 2019). However, Garner

and Smith (2019) restated that the dam costs twice as much as originally expected because of safety concerns and use of millions of tons to stabilize the foundation. The dam forms an artificial lake as the water collects, immersing 212 settlements by this lake, forcing over 30,000 inhabitants to leave, and altering the ecology of the region, which appears to have been quite constant for centuries (Erder, 1973). The dam divides the two landscapes Elazig of Turkish speaking inhabitants and Tunceli of mountainous region of Kurdish population. Due to economic inequality, dam flooded many valleys and destroyed the livelihoods of Kurdish population, making Tuncel the least developed (Garner and Smith, 2019). The river network of Keban Lake has determined the course of life throughout the whole Mesopotamian valley (Erder, 1973).

Around 300 dams have been constructed in Turkey and only about 3000 archaeological sites are registered in the whole country, giving the false impression that dams are being constructed in areas that do not impact the cultural heritage (Brandt and Hassan, 2000). Keban Project demonstrated the importance of the region for the cultural history, established its archaeological sequence from the Paleolithic Age to the end of Middle Ages. It also led to the excavation of the ancient sites in the South-East Anatolia (Centre for Research of Historical Environment, 2011). Dismantling was one of the least costly procedures used which does not require advanced tools for salvage of historical monuments. However, the only disadvantage is that the system is limited to structures which have separate pieces that may be lifted without damage. Dismantling of structures was implemented but its re-use is still a question mark (Erder, 1973). In comparison to the regional average of the MENA region, the water storage capacity is very low in Lebanon with only 6 percent of total resources being stored (The World Bank, 2020).

The failure and success stories of dam projects were studied to showcase the measures taken in different countries having the same conditions of Bisri dam in Lebanon. The selected

projects are in rural areas with cultural heritage. Despite the effect of dam constructions on the cultural value, natural resources and social memory, dismantling of structures is one of the measures used for preservation of historical structures.

2.9 Conclusion of Chapter Two

This final section of chapter two aims to present the approaches that will frame the conceptual work of the chapter and guide the empirical work of chapter three, the methodology chapter. The fourth section of chapter two aims to tackle the environmental impact assessment. This will show the significance of studying the cultural heritage in historic sites prior to the implementation of dam projects. Additionally, this will draw a better understanding to calculate the life cycle assessment of historic structures, including the embodied energy and carbon emissions which are the main focus in the methodology chapter. During the archeology relocation or removal as a consequence of this dam proposal, it is important to identify the dataset needed and the methods used to calculate the embodied energy and thus assessing the carbon emissions. The dataset used for the embodied energy is the quantitative measurement which accounts for the energy stored in the historic building as a tangible structure. The assessment of the embodied energy and carbon emissions will present an essential framework to the vitality of historic preservation and energy conservation of historic properties.

Chapter Three

DAM PROJECTS IN LEBANON: BISRI DAM

3.1 Introduction

The issue of water scarcity in Lebanon is a matter of discourse with various political viewpoints. This chapter aims to answer the second objective which discusses the dam projects in Lebanon to contextualize and introduce the case study: Bisri Dam. In Section 3.2, the problem of water shortage is highlighted, and the dam projects are one out of the different solutions for water harvesting and preservation. This section addresses the success and failure stories of the dam projects in Lebanon. Finally, Section 3.3 includes the analysis of Bisri Dam which investigates the history of Bisri Valley, and the impact of Bisri Dam project on the valley from a sustainable viewpoint.

3.2 Dams in Lebanon: Failures and Successes

Lebanon has many rivers and water sources compared to Jordan, Palestine or much of Syria (Walnycki and Husseiki, 2017). Among Middle Eastern countries, Lebanon is considered as the richer in water (Walnycki and Husseiki, 2017). According to Mahfouz (2010), the chronic water shortages were due to failure of institutions to ensure reliable supply water to users and due to poor infrastructure resulted from financial constraints. Whereas, the Federal Institute for Geoscience and Natural Resources, which collaborated with Council for Development and Reconstruction (CDR), considered the failed investments and wrong water infrastructure planning was a result of unmonitored water balance in Lebanon (World Bank's Inspection Panel, 2019). The infrastructure

and services related to the water sector in Lebanon were already negatively impacted by years of conflict and instability, resulting in poor overall management of these services and resources (Ministry of Energy and Water et al., 2018). The mentioned challenges played a partial role in reducing the amount of renewable water available in the country to more than 1,000 cubic meters a year per person, which is considered the threshold of water poverty (Walnycki and Husseiki, 2017). This means, Lebanon must rethink its water strategies and proposals to protect water resources and use them more judiciously (Ministry of Environment, 2000).

Different proposals were analyzed to increase water availability in Lebanon. First, desalination is one of the strategies capable of sustaining long term water supplies to Greater Beirut. However, the high cost and the limitations in the current Lebanese energy sector impede the development of this strategy (Council for Development and Reconstruction, August 2014). Second, groundwater is another strategy suggested. According to the Ministry of Energy and Water (MoEW), the total ground and surface water are

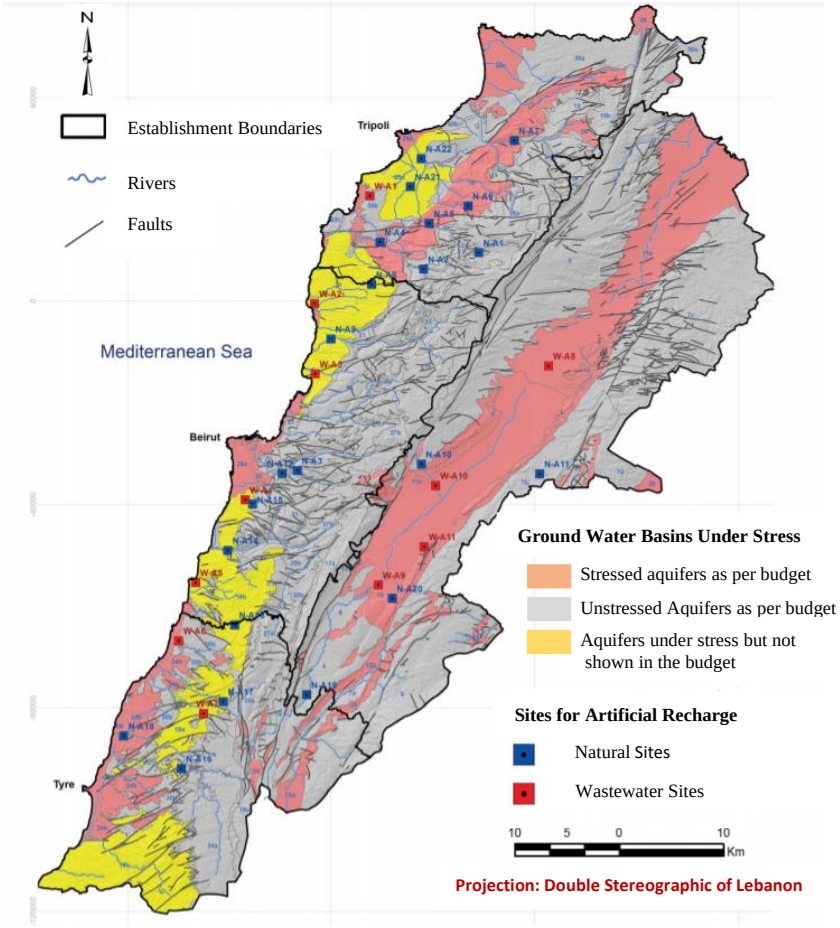


Figure 3.1 Location of the proposed areas for artificial recharge from natural sources and from wastewater effluent overlaid over the GW-basins under stress, Source: MoEW et al., 2014 Accessed 11-4-2021

around 2,700 million cubic meter, the total losses of groundwater is approximately 700 million cubic meter (Preliminary National Water Strategy et al., 2012), and the groundwater assessment study dates back to 1970. Hence, the study is considered outdated (World Bank's Inspection Panel, 2019). In Lebanon, this source of water accounts for 50 per cent of irrigation water and 80 per cent of potable water (Walnycki and Husseiki, 2017). Its regulation results in increasing the storage capacity to capture seasonal surface water runoff (Kfouri, 2013). For this purpose, the third suggested strategy is to manage the losses of surface water storage, which accounts for more than 40 percent (Kfouri, 2013).

Figure 3.1 indicated that there is no physical scarcity in the availability of water in most of the regions of Lebanon while analyzing the ground water basins. Thus, having a sustainable management and monitoring plan for the ground water sector, which is the second mentioned approach, may be a solution for the long term. As mentioned by MoEW et al. (2014), Lebanon is one of the few countries worldwide without a network of monitoring systems for private and public wells. Those systems quantify the groundwater that is being extracted from wells (MoEW et al., 2014). Accordingly, Jihan Seoud, a UNDP environmental specialist, addressed this issue and thought that a large portion of water is not viable for various usages such as drinking or irrigation, and thus needs to be treated (Daou and Mikhael, 2017). The fourth suggested strategy is related to the management of irrigation, which is the largest water consumer in Lebanon. Around two thirds of irrigation water is lost due to the poor conditions of networks (Ministry of Energy and Water et al., 2018). Consequently, implementing recycling plants for irrigation, updating the infrastructure for less water leakage, and installing efficient wastewater treatment are suggested solutions for water availability (Mahfouz, 2010). The fifth strategy is the efficient wastewater strategy that has been suggested by the Ministry of Environment (2000) in order to improve water quality. This

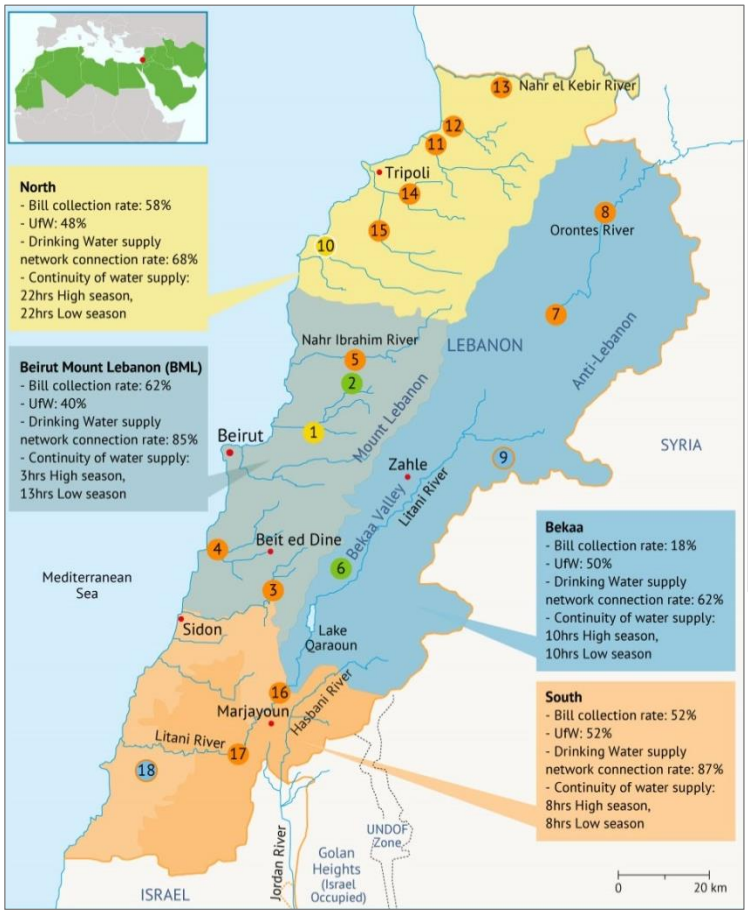
suggestion emerged as a result of disposing untreated wastewaters on land into streams and rivers stops. Only eight percent of the wastewater is treated and most of it is discharged into watercourses, valleys and the sea (Ministry of Energy and Water et al., 2018). The last proposed method is rainwater harvesting, which meets domestic needs (Council for Development and Reconstruction, 2014).

Many investments are made for the availability of water resources and very little is done to preserve it. Such investments include dams, along other activities such as deforestation, irrigation, and drainage canals, which impact the water cycle and alter the conditions for water replenishment (Ministry of Environment, 2000). Though, Mahfouz (2010) mentioned the importance of the buillding of dams and reservoirs, in order to effectively store rainwater and river water that otherwise would be dumped in the sea, allow the water to be used in summer, and create the storage capacity necessary if an exporting project is implemented.

> ‘The building of dams for water storage is a disputed solution amongst water specialists. Opponents to damming claim that dams are dangerous given the seismic activity of Lebanon and are expensive for a country with limited fiscal space. Meanwhile, advocates of building dams claim that it is a reliable solution if the choice of the dam’s location is thoroughly studied and in line with international best practices’ (Daou and Mikhael, 2017, p. 3).

In Lebanon, the dam projects are a matter of debate and conflict between two opposing viewpoints: the first composed of considering a dam project as an effective strategy for the future water availability, while others believe that the implementation of these large investments has subjective analysis and results in an excessive debt-servicing burdens. Both parties are driven by their political affiliations. In Lebanon, part of the conflicts in the implementation of dams is related to

the engagement of the political structure in the decision making. Riachi (2010) believed that water mirrors the political system and the economic structures of the country.



	No.	Dam/Lake	Storage capacity (MCM)	Purpose
BML	1	Boqata	6	Drinking
	2	Chabrouh	8	Drinking+Irrigation
	3	Bisri	120	Drinking
	4	Damour	42	
	5	Janneh	30	Drinking+Irrigation+Hydropower
Bekaa	6	Qaraoun	220	Irrigation+Hydropower
	7	Younine	5.7	Drinking
	8	Assi Phase II	37	Hydropower+Flow Regulation
	9	Massa Lake	8	Drinking
North	10	Mseilha	6	Drinking+Irrigation
	11	Bared	37	Drinking
	12	Qarqaf	20	Irrigation
	13	Noura el tahta	35	Drinking+Irrigation
	14	Iaal	12	Drinking
	15	Dar Boochtar	55	Drinking+Irrigation
South	16	Ibl al Saqi	50	Drinking+Irrigation
	17	Khardali	120	Drinking+Irrigation
	18	Kfarsir Lake	15	Drinking

6 Completed dam
1 Dam under construction
3 Planned dam
9 Planned lakes
Town
River and Wadi
National border
UFW Unaccounted For Water

Figure 3.2 Planned major dams and lakes (>5 MCM) and status of water supply by establishment. Source: Fanack after MEW, 2010, updated based on personal communication with MEW, 2015 Accessed 13-4-2021

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Afif (2019) stated that building more dams without exploring their impact on the environment and whether it is suitable for the lands it is being built on, is wasteful. Riachi (2010) as well thought that there is a severe overestimation of the feasibility of dams. In Mount Lebanon and Greater Beirut, it is estimated that there are 20,000 largely illegal boreholes to provide water to households (Walnycki and Husseiki, 2017). As shown in Figure 3.2, the drinking water supply network connection rate in Beirut Mount Lebanon (BML) is 85%, which is significantly high with respect to other regions. However, the continuity in water supply is not high and shows the lowest

duration in high season (3 hours). For this reson, the table below the map addresses the capacity of water storage in the case of dam projects.

Meanwhile, the mismanagement and poor infrastructure affected the consideration of various alternatives such as the ones previously addressed. The dam project is one of the proposed strategies by the Council for Development and Reconstruction, for the problem of water shortage in Lebanon. For this purpose, different case studies of the dam projects will be discussed, in order to highlight the failures and successes and its controversy of implementation.

Every dam project needs to be well planned with a considerable attention to the compensatory meaures from the lens of sustainability, in order to minimize the costs and maximize the benefits. Daou and Mikhael (2017) indicated that Lebanon benefits from only two dams: Qaraoun Dam and Chabrouh Dam. First, Qaraoun Dam on the Litani River is the largest dam in Lebanon that captures 220 million cubic meters and is used for electricity generation, excluding 30 million cubic meter of this storage capacity for water and irrigation. Second, Chabrouh Dam in Faraya captures 8 million cubic meter water from rain and the Laban Spring for electricity generation. However, the World Bank's Inspection Panel (2019) indicates that Qaraoun Dam is contaminated; making its water unsuitable for domestic use or even irrigation, and Chabrouh Dam leaks more than 30,000 m3 per day. Figure 3.3 shows the location of Qaraoun and Chabrouh dam with respect to the map of Lebanon. Figure 3.5 presents the mass plan of each of the mentioned dams while Figures 3.4 and 3.6 show the pictures of Chabrouh dam and that of the Qaraoun, respectively.

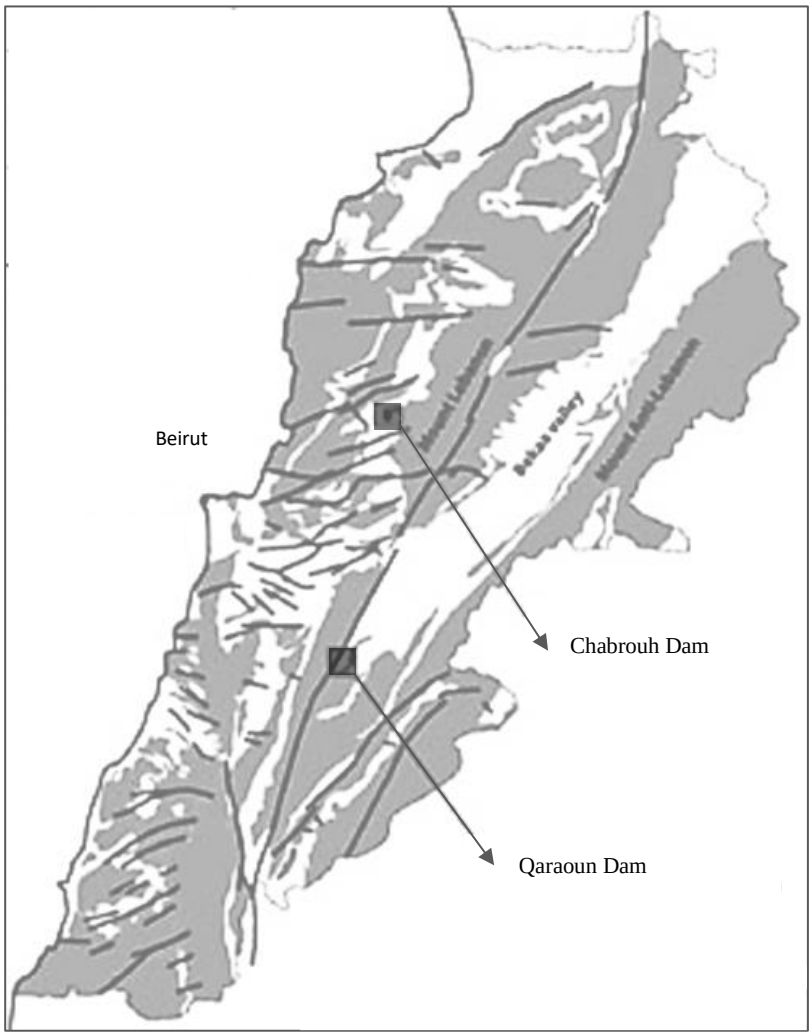


Figure 3.4- Chabrouh Dam

Figure 3.6- Qaraoun Dam

Figure 3.3 Left Side: Map of Lebanon showing the Dam of Qaraoun and that of Chabrouh. Source: Bou Jaoude et al., 2010 Accessed 13-4-2021
Figure 3.4 Chabrouh Dam. Source: lebanoninapicture, 2015 Accessed 13-4-2021
Figure 3.5 Massplan of Chabrouh and Qaraoun Dam. Source: Google Map Accessed 13-4-2021
Figure 3.6 Qaraoun Dam. Source: lebtivity Accessed 13-4-2021

The Inspection Panel (2018) argued that the previous dams in Lebanon have not been successful and the strategies used were not sustainable. Several examples were presented to show water leakage and mismanagement including Mseilha dam on Nahr EL-Jawz river and Janna dam on Nahr Ibrahim, which show infiltration reaching another Basin, Jeita spring (Riachi, 2010). There are other examples such as Balaa Dam, Qaisamani Dam and Brissa Dam (The Inspection Panel, 2018). Brissa Dam in Donniyye, North Lebanon, has been completed in 2013 and failed to collect water, due to its location on karstic limestone surface allowing the infiltration of water (The Inspection Panel, 2018). As for Qaisamani dam, Falougha- South Metn, it has not exceeded 25% of its capacity until the heaviest rain season and resulted in the pollution of Shaghour Spring in Hammana (World Bank's Inspection Panel, 2019).

Despite the investments in the infrastructure, the Government of Lebanon (GoL) has not been able to deliver an improved water service and sustainable water resources management (Kfouri, 2013). However,

Figure 3.7
Mseilha Dam

Source: The961
Accessed 14-4-2021

Figure 3.8
Janna Dam

Source: takepart
Accessed 14-4-2021

Figure 3.9
Balaa Dam

Source: saudi24news
Accessed 14-4-2021

Figure 3.10
Qaisamani Dam

Source: Khoury Engineering and General Contracting
Accessed 14-4-2021

Figure 3.11
Brissa Dam

Source: lebanoninapicture
Accessed 14-4-2021

‘the Federal Institute for Geoscience and Natural Resources (BGR) stated that the Jeita catchment can provide enough water for the Greater Beirut and Mount Lebanon area in case it is managed well, because it has an excellent water quality at its source and is potable (World Bank’s Inspection Panel, 2019, p. 10). Another planned dam that provides water to Mount Lebanon and Greater Beirut is Bisri Dam that has raised debates and claims whether it will be one of the least successful stories. This dam would supply Beirut with water, after it is mixed with water from Qaraoun dam and Litani River. Thus, the adequate measures must be taken into consideration in order to treat the water from pollution (The Inspection Panel, 2018).

The case studies of dam projects were discussed to show the reasons of dams’ failure in Lebanon, ending the analysis with Besri dam which will be further elaborated in the Section 3.3.

3.3 Case Study: The Bisri Dam

This section presents the case study of the thesis. It introduces the project and the controversies of its implementation. Then, a historical overview of Bisri valley is reviewed, showing the impact of the project on the valley from the lens of sustainability: cultural, environmental, social, and economic dimensions.

3.3.1 The Project Vagaries

The planned Bisri dam would be the second largest, after Qaraoun dam, which was built in 1959 (Ayoub and Maroun, 2020), and the loan amounting $617 million ($474 million loan from the World bank, alongside $128 million from the Islamic Development Bank and $15 million from the government of Lebanon) is considered one of the largest projects in Lebanon (Chehayeb, 2020). This rural dam is set to provide water for 1.6 million people living in Greater Beirut and Mount Lebanon, to cover 6 million square meters of land, and provide 11.2 MW of hydroelectric

power and contain 125 million cubic meters of water (Afif, 2019). The proposed dam construction works will be a center core rock fill dam, 73 m in height, 790 m in crest length, around 4.5 million square meter inundated area expected, including an access road, small hydropower plant and transmission line (Kfouri, 2013). The project was introduced in the 1957 but was put in action in 2015, to be cancelled afterwards in 2020 (Abdelbaki, 2020).

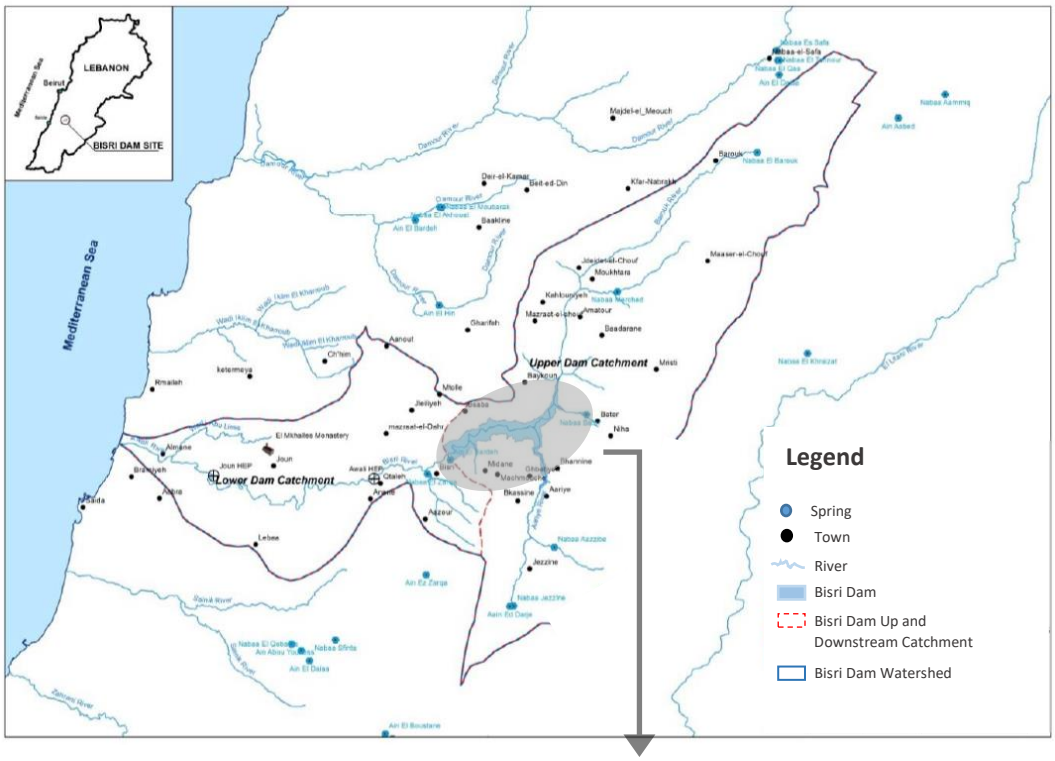


Figure 3.12 Bisri Dam on map of Lebanon and showing the Upper and lower dam catchment,
Source: (Council for Development and Reconstruction, 2014), Edited: By Author, Accessed 14-4-2021

Figure 3.13 Bisri Dam, Reservoir and Expropriation Limits,
Source: (Council for Development and Reconstruction, 2014), Edited: By Author, Accessed 15-11-2020

On the one hand, the Environmental Justice Atlas (2019) considered that Bisri Dam is being advertised as the solution to Beirut's water shortages, and as an economic and touristic boom to the region. Accordingly, the Ministry of Energy and Water justified the need for Bisri Dam on the basis of water scarcity in Lebanon, despite the absence of monitoring water from precipitation, springs, groundwater basins, and wells, since the late 1960s (Afif, 2019). On the other hand, other studies justify the reason behind the refusal of this developmental project, which was advertised to provide water for Mount Lebanon and Beirut. The National Centre for Scientific Research in Lebanon (CNRS) and Strategic Environmental Assessment for the New Water Sector in Lebanon, conducted qualitative and quantitative analysis of some of the springs in Lebanon, which have been estimated to yield 650 cubic meters/year of fresh water, and thus accounts for six (6) times the capacity of Bisri Dam. This will help ensure water security for many years (change.org, 2021). In addition to that, Mount-Lebanon area is dominated with the karstic rock formations and the big volume of alluviums all along the valley and river, which will result in water infiltration, in addition to the fact that Beirut loses 40% of its water due to uncontrolled leakage (change.org, 2021; the Federal Institute for Geosciences and Natural Resources, 2014). Dr. Zaatiti, a hydro-geologist, also questions why other alternatives are not taken into account, thinking that the source of the water that the dam would be bringing to Beirut will be polluted (Environmental Justice Atlas, 2019).

The World Bank's Inspection Panel (2019) investigated the different aspects that were not assessed in this project, such as the variation of water availability with climate change, the future demand with the increasing urbanization, mitigation measures to decrease daily consumption per capita and evaluation of alternatives to limit water shortage. Afterwards, Ayoub and Maroun (2020) proposed alternatives for Bisri dam project that are based on harnessing Lebanon's natural

and geological advantages. This is achieved through the following: desalination; groundwater aquifers with rainfall in the presence of limestone karst formation which already creates aquifers all along its territory; rainfall collection of unused sources of water and reusing wastewater; and constructing small to medium-sized urban collective storage ponds, combined by the monitored springs and groundwater that are more cost-effective and environmentally friendly. For the purpose of having limited impacts on Bisri Valley, the Two International Panels of Experts on Dam Safety are in charge of monitoring the different aspects of the Project's design. They are also in charge of construction and operation to ensure due diligence on technical, social, environmental, and archeological dimensions, according to international best practices and the World Bank policies (The World Bank, 2020).

In case the suggested sustainable alternatives for water availability are not taken into account, then Bisri's natural and geological features should be studied to apply the mitigation measures, before the dam's implementation. Those measures reduce the environmental impacts on the natural and cultural heritage of the valley.

3.3.2 Historical Importance of the Bisri Valley

Bisri valley is one of the outstanding natural environments in Lebanon, known for its cultural significance. The valley of Bisri is one of the major valleys that cut through the Mount Lebanon mountain chain and the district of Jezzine (World Bank's Inspection Panel, 2019), with a strategic ecological zone that needs to be preserved (The Inspection Panel, 2018). The name, Bisri, is a derivative of Bostrenos, which is the river's name in Hellenistic times and the Asclepios is the name in the Greek times equivalent to Ashmoun (World Bank's Inspection Panel, 2019). This valley was named as cultural landscape of the sacred valley of Ashmoun, to show a clear balance between a natural environment and human activities that shaped and developed this

landscape (World Bank's Inspection Panel, 2019). Bisri valley represents almost a full span of human history, from Paleolithic times prior to 8,300 years BCE to the present day (Council for Development and Reconstruction, 2014). It was located directly on historical communication routes of Beqaa and Syria between the coasts. It has been known for human occupation since the Bronze Age (World Bank's Inspection Panel, 2019) and has prospered during Roman times when the valley became a major route between Tyr and Sidon, which is recently known as the Lebanese coast and Damascus (Council for Development and Reconstruction, 2014).

During the Lebanese Civil War (1975-1990), the valley was a demarcation line between the two communities in conflict, considering that the dam project may ignite old rivalry between the two sides of the valley (World Bank's Inspection Panel, 2019). It displays distinct geological and ecological features which fostered agricultural practices, archaeological remains and was used for places of worship since the 13th century with religious, historical, and cultural significance (World Bank's Inspection Panel, 2019). Studies conducted by the local and international survey teams, mainly in the University of Warsaw and Lebanese University, confirmed the exceptional historic value of the valley. It has sites that date back to the Bronze Age, Persian, Hellenistic, Roman, Byzantine, Mameluke and Ottoman Periods (change.org, 2021).

Figure 4.14 Mar Moussa Church, Source: lebanonlawreview, Accessed: 10-11-2020

Figure 3.15 Historic Bridge, Source: lebanoninapicture, Accessed: 10-11-2020

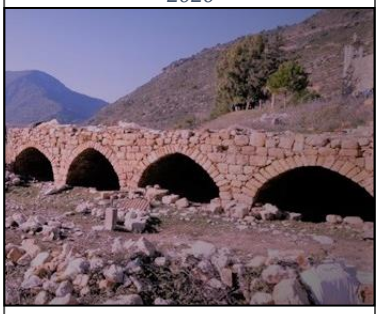


Figure 3.16 St. Sophia Monastery Source: dailystar, Accessed: 10-11-2020

Figure 3.17 Roman Columns, Source: everipedia, Accessed: 10-11-2020

The Bisri project has around 10 sites within 100 m of the expropriation boundary, 30 sites are less than 1km and 10 sites are further than 1 km, from the proposed reservoir (Council for Development and Reconstruction, 2014). Within the project's boundaries, there are around 70 identified archaeological sites in the valley; settlements, tombs, fortresses, ruined convents, bridges, roads, stairs and temples (The World Bank's Inspection Panel, 2019). As an example, the famous Ashmoun temple, located North of Saida, has a symbolic connection on the same pilgrimage route, and was considered as the Roman period temple of the Bisri Valley (World Bank's Inspection Panel, 2019). The Ashmoun Temple was also believed to be connected with the temple of Marj Bisri, which was located in the Lower Awali Valley and dated back to the 7th Century BC (Council for Development and Reconstruction, August 2014).

Accordingly, the Inspection Panel (2018) affirmed the presence of more than fifty archeological remains in the boundaries of the dam project, including historic trails, houses, a village, roman bridge, a convent, and other structures. Other historic structures include Mar Moussa Church and Saint Sophia Monastery, which have socio-cultural importance. The dismantling of the valley's church, monastery, temples, bridges, houses, and all other remains do not protect the historical sites but at least protect pieces and parts of these physical remains. The cultural significance of the physical remains had a role in framing the name of the valley throughout history. Those historical properties of cultural significance such as Saint Sophia Monastery was Byzantine and located 30 meters far from Mar Moussa (Council for Development and Reconstruction, 2014).

The assessments of Besri Valley's cultural heritage will set down the needed procedures during the implementation of the dam project. There are around 70 archeological sites, and dismantling is one of the mitigation measures to minimize the environmental and cultural costs.

However, this measure is not the most effective strategy for the tangible and the intangible historic preservation.

3.3.3 Impacts of the Dam Project on Bisri Valley

The following Table 3.1 discusses the advantages and disadvantages of the dam project on the three pillars of sustainability (environmental, social, economic), and the cultural heritage which is the fourth dimension. This table is further elaborated in the sub-sections 3.3.3.1, 3.3.3.2, 3.3.3.3, and 3.3.3.4 to show the impacts of the dam project on the valley from the four sustainable aspects.

Advantages	Disadvantages
Cultural Heritage Pillar / Environmental Pillar	Social Pillar / Economic Pillar
- Production of approximately 11.2 MW hydroelectric power (Council for Development and Reconstruction, August 2014)	- Loss of historic and cultural heritage (Council for Development and Reconstruction, August 2014)
	- Too high cost to yield positive return (World Bank's Inspection Panel, 2019)
	- Loss of natural landscape (Council for Development and Reconstruction, August 2014)
	- Irreversible damage on the biodiversity (Council for Development and Reconstruction, August 2014)
- 80% of the dam construction material will be sourced from within the reservoir area reducing reliance on external Quarries (The Inspection Panel, 2018)	- Effect on the freshwater prior to the reduction of water flow downstream (Council for Development and Reconstruction, August 2014)
	- Loss of natural vegetation. Most land take, 570 ha, for the project is productive land (Council for Development and Reconstruction, August 2014)
	- Significant erosion and sedimentation is that it imparts a progressive decrease in reservoir storage (Council for Development and Reconstruction, August 2014)
- Bank's goal of poverty reduction by providing improved access to water supply for more than 1.6 million residents in the GBML (The Inspection Panel, 2018)	- Block size and rock quality specifications to be sourced externally (Council for Development and Reconstruction, August 2014)
	- Dam breach flood by either seismic loading or flood failures (Council for Development and Reconstruction, August 2014)
	- Increase in local temperature and thereby Relative Humidity (Council for Development and Reconstruction, August 2014)
- As part of the Greater Beirut Water Supply Project (GBWSP), Bisri reservoir funnels water to Beirut and its suburbs (World Bank's Inspection Panel, 2019)	- Emissions from plants and power generators- GHGs having uncleared vegetation (Council for Development and Reconstruction, August 2014)
	- Increase in water-related diseases (Council for Development and Reconstruction, August 2014)
	- Affected communities not fairly compensated (Council for Development and Reconstruction, August 2014)

Table 3.5 Showing Advantages and Disadvantages of Bisri Dam Project, Source: By Author

3.3.3.1 Cultural Aspect

After defining the evolution of the history of Bisri Valley, this paragraph addresses the cultural impact of the dam project on the valley. The dam affects the archeological, historic, and cultural heritage throughout the project area which will be demolishing Roman ruins, such as Mar Mousa church, and nearly 75 other archeological sites within its premises. Around 200 ancient sites have been registered in this valley and there were efforts to make a UNESCO-protected site. However, most of the sites have been neither studied in the project area nor protected under the Protection of the World Cultural and Natural Heritage or the Lebanese Law No. 37 for Cultural Properties (The Inspection Panel, 2018). For this purpose, the Council for Development and Reconstruction (CDR) (2014) mentioned that the period available to rescue some historic sites with archaeology is likely to be insufficient for extensive and carefully documented excavations.

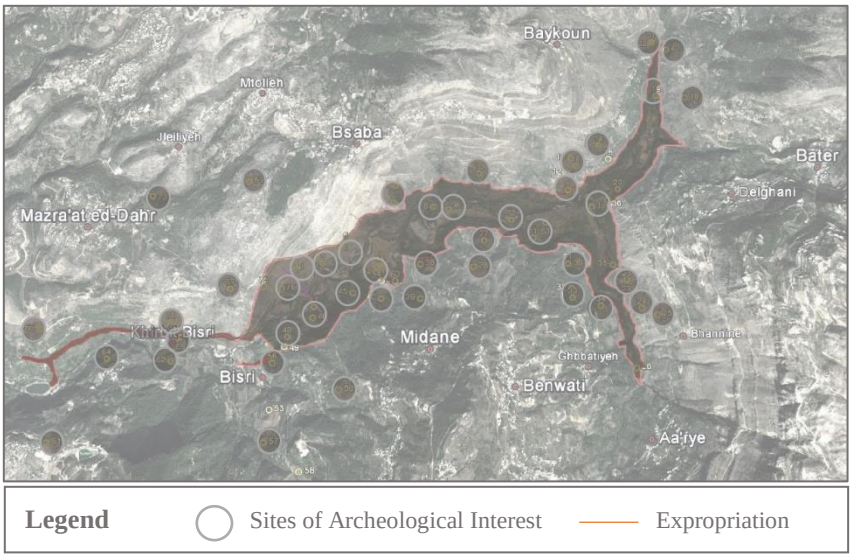


Figure 3.68 Map showing the location of archeological sites within the boundaries of the Bisri Dam Project and outside it. Source: (Council for Development and Reconstruction, 2014), Edited: By Author, Accessed 17-4-2021

The CDR claims that measures have been taken to preserve the archeological and cultural components. This will be funded by the project and thus included in the cost of dam construction (Environmental Justice Atlas, 2019). Different mitigation measures were proposed to preserve the historical remains from destruction. Dismantling and reassembling the removed historic structures

is one of the proposed measures and should be implemented in the case of Mar Moussa church and Saint Sophia monastery, adding to it the old building materials from the ruins of 19-20th century houses (Council for Development and Reconstruction, August 2014). According to the World Bank (2020), those measures for the relocation procedures are done with the oversight of Maronite church authorities and parishioners for preservation purposes. Regardless of those procedures to preserve the historic sites in the location some of the main weaknesses that the Council for Development and Reconstruction (2014) listed are: 1) risking historic and cultural remains, 2) taking productive land, and 3) the high seismic risk.

3.3.3.2 Environmental Aspect

After the discussion of the fourth pillar of sustainability, cultural heritage, this paragraph discusses the limitations of the dam project on the environmental dimension. For this purpose, three factors will be addressed to show the environmental significance and the impacts of this project on nature. Those factors are: natural lands, carbon emissions and seismic risks. First, in 1997, the National Physical Master Plan of the Lebanese Territory considered the Bisri Valley as a protected site by a decision of the Ministry of Environment (Afif, 2019). With the implementation of the project, Bisri River will be the main source of this change by obstructing the river flow. The Environmental Justice Atlas (2019) addressed how this developmental project will be interfering with the natural flow of the river at a site considered a

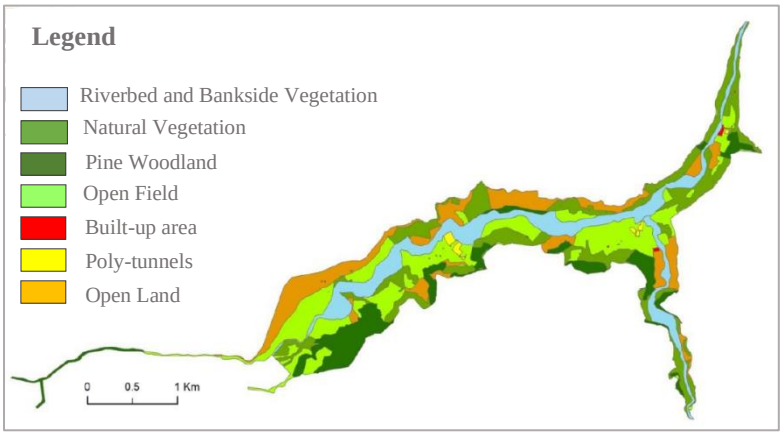


Figure 3.79 Current Land use within Bisri Dam project, Source:: (Council for Development and Reconstruction, 2014), Edited: By Author, Accessed 17-4-2021

natural protected area in Bisri; especially that it is the only one in Mount Lebanon having this expansive agricultural plane (Afif, 2019). As estimation, the project could take up to 500,000 trees, including an approximation of 570 hectares of agricultural land, natural vegetation and pine woodland that will be expropriated and inundated for the implementation of the project (Ayoub and Maroun, 2020). The project is classified under environmental category "A" in the World Bank due to the adverse environmental impacts, mentioning that mitigation measures could be discussed (Kfouri, 2013). However, those impacts are sensitive, diverse, and affect areas broader than the sites (Kfouri, 2013). Second, while analyzing the carbon emissions affecting the environmental balance, around 80% of the dam construction material will be sourced from within the reservoir area, reducing the reliance on external quarries (The Inspection Panel, 2018). However, the Council for Development and Reconstruction (2014) indicated that the block size and the rock quality specifications of the dam project are externally sourced, thus more carbon emissions will be emitted from transportation. In addition, carbon is also sequestrated in the soil, plants and trees as those components decompose (Council for Development and Reconstruction, 2014). Third, the Inspection Panel (2018) mentioned the reasons behind considering the area unsuitable for a dam, such as the sandstone and porous limestone affected by regular landslides. Other reasons are related to the seven major earthquakes in the history of Lebanon which had its epicenter in close proximity to the Bisri dam site. In 2010, scientists at the American University of Beirut's Department of Geology warned of a major earthquake in Lebanon because the country is bisected by two fault lines known as the Yammouneh and Mount Lebanon Thrust fault lines (Ayoub and Maroun, 2020). Out of the 36 released reports, only two reports, which were conducted by the CDR Representatives, offer a counter-explanation regarding the seismic nature of the valley (Afif, 2019). This developed two viewpoints regarding the seismic nature of the site with respect to the

dam construction. From one side, the international panel of experts on dam safety confirmed that Bisri Dam will be equipped with seismic instruments that will continuously monitor the structure of the dam (The World Bank, 2020). Even the International Commission on Large Dams concluded that Reservoir Triggered Seismicity appears to occur on dams which are higher than 100 meters and that contain over a billion cubic meters of water which is ten times that of Bisri dam (Afif, 2019). From the other side, Dr. Zaatiti warns against the project in its specified location, since it is located near a highly seismic area and the geology of the region is highly karstic, making it nearly impossible to store water (Environmental Justice Atlas, 2019). Professor Antonio Gens of the Technical University of Catalonia also states that the location of Bisri Dam is in a highly seismic area, which made the area subjected to earthquakes in 1201, 1759 and 1956. The last earthquake was of 6.0 magnitude and four kilometers east of the proposed site, causing 136 deaths and destroying 6,000 homes (Afif, 2019). The World Bank's Inspection Panel (2019) proposed a similar casestudy to that of Bisri but it is a smaller dam in Greece named as the Marathon dam, which is 60m depth and 41 million cubic meter volume. This dam has triggered an earthquake of 5.75 on the Richter scale, causing destructive impacts to buildings and structures. Such earthquakes bring a noteworthy change to the social structure as well (Gokhale et al., 2004).

Figure 3.20 Bisri Fault, Source: sciencedirect, Edited: By Author, Accessed 14-4-2021

3.3.3.3 Social Aspect

This paragraph continues to identify the third pillar of sustainability and thus shows the impact of the dam construction on the social structure. According to the World Bank's Inspection Panel (2019), the Environmental and Social Impact Assessment (ESIA) is valid for only two years in case the project's works have not started, based on Principles of Environmental Impact Assessment and the Ministry of Environment's approval. The ESIA in Bisri is considered invalid and illegal because it exceeded the 5-year span. Despite the socio-environmental assessments of the project, the dam finds support across the country's political elite in the national water strategy (Ayoub and Maroun, 2020). The support from Lebanon's ruling political parties received rejection from the local residents and environmentalists who feared irreversible damages to the region's rich ecosystem (Chehayeb, 2020). In Besri dam project, the CDR is not providing alternate housing in accordance with the resettlement action plan. This plan is highly recommended in order to monitor whether the displaced residents are able to relocate to comparable living conditions (Kranz, 2019). Not only the farmers on expropriated land will be losing their livelihoods, but also they are not being compensated fairly, claiming that the

Figure 3.21 River bed and bankside vegetation

Figure 3.22 River bed and bankside vegetation

Figure 3.23 Poly- tunnels growing strawberries

Examples of current land utilization within Bisri reservoir, Source: (Council for Development and Reconstruction, 2014), Accessed 17-4-2021

compensation received only covers one or two seasons of what they make off their agricultural lands (Environmental Justice Atlas, 2019). As an example, around 50 percent of all strawberries in Lebanon come from the valley, and local villages still utilize historic aqueducts using river water for gravity irrigation (The Inspection Panel, 2018). Contrary to claims by the CDR and the World Bank, campaigners and some politicians believed that the Bisri Dam would threaten the valley's unique natural environment and poses a serious risk to locals' livelihoods (Kranz, 2019). As such, the Inspection Panel (2018) have warned the affected communities to alleviate their serious concerns, due to the weak dam safety measures.

3.3.3.4 Economic Aspect

The social impacts are also associated with the economic ones. While highlighting the economic pillar in the case of the dam project, the CDR claimed that water will flow to Beirut entirely by gravity, undermining the option of groundwater extraction that requires pumping, thus not assessing its costs in the feasibility reports (World Bank's Inspection Panel, 2019). Accordingly, an amount of 23 million dollars for sanitation projects of the upper catchment area may be needed to minimize the greenhouse gas emissions from the reservoir, and similarly for the mechanical mixing of water to prevent stratification and clearance of vegetation and organic soil, before filling

Category	Value (USD)
Trees losses	$24,659,727
Expropriation Area	$120,751,312
Structures to be demolished	$1,054,590
Other Lands attachment losses	$3,763,058
Mar Moussa Church and Saint Sophia Monastery Relocation	$2,000,000

Table 3.2 Value Estimates of Bisri Dam Expropriation Area adding to it the Relocation of Mar Moussa, Saint Sophia and Architectural Salvage, Source: (Council for Development and Reconstruction, 2014), Edited: By Author, Accessed 17-4-2021

the reservoir (The Inspection Panel, 2018). As shown in Table 3.2, the land acquisition is 5.7 square kilometers (km^2), which includes the dam site, the area inundated by the impounded reservoir, and a 15 m buffer zone around the periphery. The expected cost reaches $150 million. Within this table, other costs are added such as the relocation of Mar Moussa church, Saint Sophia monastery and other architectural salvage, which account for 2 million dollars. On this account, researchers at Oxford University have found that the costs required to implement large dam project is underestimated and too high to yield a positive return (World Bank's Inspection Panel, 2019).

The advantages and disadvantages of the project were highlighted to cover the impacts of the dam project on the cultural heritage, environmental, social and economic pillars. The analysis emphasizes the importance of studying the archeological remains, which indirectly affects the three pillars of sustainability.

3.4 Conclusion

Despite the fact that the United Nations World Water Development Report (2018) made it clear that nature-based solutions are essential to meet the Goal 6 of 2030 Agenda for Sustainable Development (change.org, 2021), this chapter discussed the dam construction as solution of water shortage, at least from the vision of political elite. Hence, chapter three addressed the studied Bisri site with detailed analysis to the climatic, geological, morphological and historical viewpoints. This overview resulted in defining the impacts of the dam construction on Bisri Valley from the lens of sustainability; cultural heritage, environmental, social and economic dimensions. The historic sites were also investigated in order to identify the tools to assess two of those sites (Mar Moussa church and Saint Sophia Monastery) in the following methodology chapter.

Chapter Four

METHODOLOGY

4.1 Introduction

This chapter investigates the appropriateness of tools with regards to the problematic issue at hand and addresses the third objective of the thesis. It reviews methods from literature to address the quantitative tools of assessment to compute the embodied energy and carbon emissions. Building Information Modeling (BIM) and Tally Life Cycle Assessment (LCA) software have shown more specificity and completeness to compute the environmental impacts associated with relocating historic structures than other quantitative tools. This methodology chapter includes six sections. The second and third sections review the case studies from the literature review similar to the one studied in this thesis. Thus, the second section shows a chronological overview of all the approaches used and the quantitative tools needed to assess embodied energy, ending up in the third section with a discussion of the life cycle assessment tools in line with this thesis. The fourth section focuses on the uncertainties whenever the empirical work is implemented. The fifth section is the implemented methodology which is the outcome of previous studies and indicates the limitations of the tools. Finally, the sixth section provides a conclusion and a summary of the adopted LCA tool which will be used in the following chapter.

4.2 Models: Impact Assessment of Built Environment on Natural Environment

This section acknowledges previous studies about tools and techniques in order to focus after that on life cycle assessment as the adopted technique. The tools to assess the embodied energy and the techniques to evaluate environmental impact will be presented to address the impact

of the built environment on the natural environment. The sub-section 3.2.1 presents a historical overview on the tools to compute the embodied energy. The sub-section 3.2.2 discusses the strengths and limitations of the environmental techniques to define the appropriate one for the studied case.

4.2.1 Historical Overview: Approaches for Embodied Energy Assessment

Energy is one of the assessed parameters to identify environmental impacts of any construction. Embodied energy used to be the least assessed component of the whole building life cycle; however, it contributes to significant impacts. Dixit (2016) considers that the total embodied energy accounts for the sum of the initial embodied energy (IEE), recurrent embodied energy (REE), operating energy (OE) and the demolition energy (DE). However, Dixit (2015) considered that the mentioned stages contribute to the assessment of the whole life cycle of embodied energy,

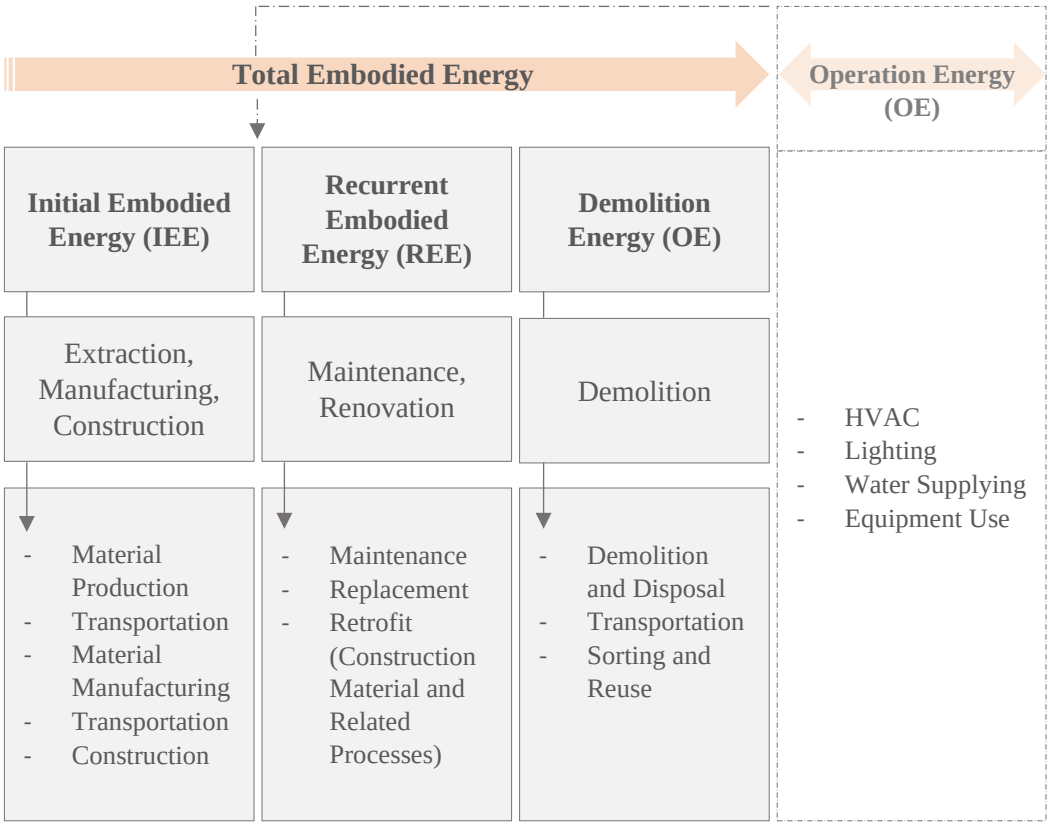


Figure 4.1 Life Cycle of Embodied Energy Stages. Source: Author

excluding the operating energy (OE). The initial embodied energy (Figure 4.1) constitutes the indirect and direct energy.

The indirect energy is the non-renewable energy (natural gas, diesel fuel, and gasoline) required to extract, process, and manufacture the raw materials. While the direct energy is the energy used to transport the finished product to the job site and install it (Abanda et al., 2015; Harries 2007; Shrivastava and Chini 2012). The recurring embodied energy can be defined as the non-renewable energy consumed for maintenance and replacement, ending up with the disposal and recycling phase which is known as the demolition energy (Abanda et al., 2015; Harries 2007; Shrivastava and Chini 2012). This implies that the life cycle of energy (LCE) is distributed within two phases: the embodied energy, and the operating energy (Shadram et al., 2014).

After the 20th century, the studies about the initial, recurrent and demolition embodied energy have been further elaborated to provide database and foster data exchange, despite the scarcity of the reliable data, uncertainty estimates and lack of unsuitability in construction projects (Menzies et al., 2007). To reduce and overcome previous problems, the deterministic approaches which are the oldest major embodied energy calculation methods have been developed (Dixit, 2013; Fay and Treloar, 1998; Lenzen, 2000; Crawford and Treloar, 2003; Ding, 2004; Plank, 2008; Khasreen et al., 2009; Optis and Wild, 2010). The three major accounting methods are: process-based, input-output-based, and hybrid method (Lu et al. 2019). The following (Table 4.1) categorizes the three methods, showing the weaknesses and strengths each has in the assessment phase. The three methods will be analyzed below.

First, the process-based method is the oldest and common-used method that is known for its subjectivity. It models the input and output diagram flow showing the environmental impact (Abanda et al., 2017). As mentioned by Crawford (2004), the results of studies by Bullard, Penner and Pilati (1978), Miller and Blair (1985), Peet and Baines (1986), Lenzen (1999) and Lenzen and Treloar (2003), have proved that the process-based inventories do not achieve sufficient system completeness. The level of incompleteness may reach more than 50%. Similarly, Nill (2002) used this approach to study the power in photovoltaic systems which pointed out to underestimate the burdens by about 40% (Menzies et al., 2007).

Second, the input-output method (I-O) was originally developed by Wassily Leontief around 70 years ago (Wixted et al., 2006). This method computes the prices of materials in order to assess the embodied energy and is applied in the cases when the material data are unavailable. However, this method lacks specificity and transparency (Abanda et al., 2017). As an example, all products would have the same energy intensity which may not be the case (Abdagiri, 2017). While input-output analysis is systemically complete, Crawford (2004; Miller and Blair, 1985; Lenzen, 2001) considered that some I-O models have the following limitations: the age of the data, the conversion of economic data to energy data, the use of national averages, and sector classification and aggregation.

The aforementioned methods (process and input output) are traditional approaches to quantify embodied energy. However, they seemed to have significant limitations such as neglecting the quantification of inputs to a specific product and thus making the system boundary incomplete (Crawford, 2004). Crawford (2004) indicated that the gaps may reach up to 80% for process analysis methods. Later, Nassen et al. (2007) found that the results of an input-output-based analysis could be 90% higher than a process-based analysis (Dixit, 2013). Furthermore,

Menzies et al. (2007) found that the main disadvantages of these approaches are the following: risk of double- counting, subjective data of input, and time consuming.

Third, due to the limitations of the process and input-output methods, the hybrid method was developed by Bullard et al. in the late 1970s in order to restrict the limitations and have considerable results. The hybrid method combines the process- based and input-output methods (Abanda et al., 2017). Dixit (2013) considered the hybrid process-based analysis to be specific to the study but lacks completeness, while the hybrid input-output-based analysis is complete but lacks specificity (Dixit, 2013; Dixit et al., 2012). Crawford (2004; Interalia Leontief, 1966; Lave et al., 1995; Treloar, 1997, 1998; Lenzen, 2000, 2001) viewed the hybrid method to be more comprehensive and to have superior level of completeness. Accordingly, it optimizes the embodied energy associated with buildings and products, and may improve energy efficiency (Crawford, 2004).

Methods	Strengths	Weaknesses
Process- Based Gather energy use data from manufacturers, construction sites, vendors to assess EE for construction materials and processes in first phase	- Detailed process - More Accurate and reliable results - Easy to understand and project specific - Compare environmental impact of different schemes	- Method criticized for its subjectivity - Incomplete analysis due to boundary truncation resulted from exclusion of certain inputs

Input Output- Based (I-O) Study the flow of money from energy sectors to an industry sector manufacturing the material to assess the EE	- Consideration of the system boundary to be complete and comprehensive - Ability to account for all indirect impacts involved in the supply chain of a product or service	- Lacking transparency and specificity - I-O data tables are often too old and outdated - Errors due to conversion of prices to embodied energy - I-O tables of the estimation of material's physical flows through the economy are highly aggregated
Hybrid Unifies the benefits of process-based or IO-based methods for more complete, accurate, and material specific results	- Completeness and Specificity - Remaining inputs to be counted using IO analysis when the upstream energy inputs are truncated within process-based framework	- Relying heavily on the user's input in defining processes, causing truncation errors - Onsite and offsite processes are not completely covered, when using a process-based hybrid method - Excluding the EE in labor and capital inputs in I-O data and cannot assess the whole life cycle

Table 4.1 Methods to assess the embodied energy of buildings. Source: Author

Following the three traditional deterministic approaches, the U.S Congress passed laws to establish a framework to assess the embodied energy in the case of historic preservation. One of the comprehensive acts to preserve historic properties is the National Historic Preservation Act of 1966 which established the Advisory Council on Historic Preservation (DeSantis, 2020). The Advisory Council on Historic Preservation (ACHP) developed tools to calculate the embodied energy. While these models were not updated, they are still useful. ACHP mentioned three different models that are still applicable to assess the embodied energy in different case studies; in

demolition energy for existing building, in the material and construction for existing, and in rehabilitated and new construction. The three models to calculate the embodied energy are the following: the concept model, the survey model, and the inventory model.

The concept model measures the building type and gross square footage (Advisory Council on Historic Preservation, 1979). It is a quick estimation of the embodied energy and shows a lower value than the inventory model (Jackson, 2005). The concept model as a formula is expressed as:

Embodied Energy Investment = Gross floor area of historic building x invested energy per Square foot specific to the building type (Hasenfus, 2013)

The survey model is an intermediate model compared to the concept and is deemed to be useful because it provides more refined results with additional information than that needed in the concept model (Hasenfus, 2013). This model considers that 50% of the embodied energy is contained in the material. The material quantity is based on the seven-primary materials which are the following: wood products, paint products, asphalt products, glass products, stone and clay products, primary iron and steel products, and primary non- ferrous products (Advisory Council on Historic Preservation, 1979). In the case of historic buildings, Jackson (2005) mentioned that the use of a great amount of masonry and metal framing might produce an overestimate of embodied energy. The survey model as a formula is expressed as:

Embodied Energy Investment = Energy used in construction + Energy invested in materials (Hasenfus, 2013)

The inventory model has the most precise results but is considered a bit complicated for historic buildings without construction documents. The AutoCAD Application is making it easier to calculate material quantities (Jackson, 2005). The inventory model formula is expressed as:

Embodied Energy Investment = Energy used in construction + Energy Invested in Materials (Hasenfus, 2013)

An advanced study, with respect to the previous methods discussed, has been conducted by Bassett et al. (2013) to show the importance of calculating the embodied energy values while addressing urban scale projects. Within this study, the VIRVIL software is a recent tool which was highlighted to estimate the impact of the embodied energy at the design stage. The VIRVIL database of embodied energy for materials is populated with average and cradle-to-gate values were taken from Inventory of Carbon and Energy database (Waldron et al., 2013). This software allows regional scale building modelling and considers the impact of the urban surrounding on the operating and embodied energy calculations.

Each of the previous studies has weaknesses that are not suitable in the case of this thesis. As an example, the hybrid method is more useful than the process-based and input-output method even if the hybrid approach lacks specificity and completeness, which is not preferred in this case. Similarly, the Advisory Council on Historic Preservation is not updated and does not show accurate results, thus other precise tools may be used. As for the VIRVIL software, it assesses wider context than a building scale. Meanwhile, other techniques and tools to assess environmental impacts may be addressed to be in line with the studied context, in order to justify the appropriateness of Life Cycle Assessment technique.

4.2.2 Techniques to Assess Environmental Impacts

There are different techniques and tools of assessments that exist in order to analyze the impact of construction on the natural environment. The environmental impact is evaluated and identified through the following techniques: environmental cost accounting, environmental compliance audits, emission inventory, pollution prevention or waste minimization audits, design for environment, environmental property assessment, environmental impact assessment and life cycle assessment (NSF International, 1996). The researched strengths and limitations of the

mentioned environmental techniques are compared in accordance to the scope of this thesis (refer to table 2.2).

The Environmental Cost Accounting is a financial paradigm, and that of the Environmental Compliance Audits is an environmental regulatory paradigm. Those first two environmental techniques are not related to the scope of the thesis because both fall under economic-related categories. As a definition, the Environmental Cost Accounting is an aspect of the environmental management accounting which points at designing environmentally-friendly cost accounting systems or products (Okafor et al., 2013). Whereas the Environmental Compliance Audits is used to assess compliance with the official environmental regulations of the state without any direct relation with environmental impact of a product (NSF International, 1996).

The third and fourth techniques are Pollution Prevention and the Design for Environment. Those two techniques are entitled green technologies and meant to avoid pollution rather than just treating it. However, each signifies different functions in the construction sector. The Pollution Prevention is the green process while the Design for Environment is the green design (Cushman-Roisin, 2021). On the one hand, the Pollution Prevention or what is called Waste Minimization Audits considers the use of materials, processes, or practices that reduce the creation of pollutants or wastes such as hazardous material and energy (Petraru and Gavrilescu, 2010). The wastes are associated with the industrial branch of any building product (Jacobs Engineering Group Inc., 1986). Different practices were acknowledged by Petraru and Gavrilescu (2010) in order to prevent pollution including the substitution of materials for environmental purposes, modification of product characteristics, modification of production equipment at higher efficiencies, reuse of wasted materials, the control of operational procedures, and transformation of waste to a useful by-product to be sold for companies. On the other hand, the Design for Environment technique

aims to help designers for greener products during the early stages of the design in case the life cycle analysis is not feasible (Telenko et al., 2009). From a life cycle viewpoint, Hauschild et al. (2017) discussed the extent of optimization from environmental perspective of Design for Environment and claimed that this technique sometimes failed to optimize the performance of a product and thus contribute for lesser environmental impacts.

The fifth technique which is the Environmental Property Assessment includes two phases. The first phase is a historical evaluation for an industrial standard to determine whether the material used has petroleum products and is hazardous or has a threat on the property in any development proposal, as an example (U. S. Department of Housing and Urban Development, 2003). The second phase tests and analyzes the soil and groundwater to determine the extent of contamination on a property (Edmonton, 2016). This technique does not assess the whole life cycle of a product but rather analyzes the composition of this material and the threat it has on its surroundings.

As for the Emission Inventory technique, it quantifies the emission estimates provided by an inventory (Ministry of the Environment of Japan et al., 2007). This inventory bases its results on fuel combustion used in different stages of the residential and the industrial sectors, such as that of the manufacturing, transportation and construction stages. However, this technique is restricted to those two sectors without any consideration to the energy calculation of the whole building materials (Shrestha et al., 2013).

The environmental impact assessment is a technique used to analyze the physical, social, and biological impacts of a project (Lohani et al., 1997). This technique studies the parameters needed in this thesis including the assessment of energy consumption and emissions of transportation (Jose C. et al., 2018); however, it only deals with huge projects or what is called

developmental projects. The limitations of this technique are the following: usage of a broad scale of analysis (dam projects as an example) and its difficulty to contribute to environmentally building design (Ragheb, 2011). The last technique known as the life cycle assessment follows all the phases of building life cycle from manufacturing to disposal. It narrows the spectrum of analysis to a building scale and is considered the best perceived tool for achieving the sustainability and reducing the adverse environmental impacts. This technique computes the energy consumed and greenhouse gases emitted in the first phase of the building life cycle till the demolition phase. However, some of its tools have missing indicators (Curran, 2014).

Tools	Strengths	Limitations
Emission Inventory	- Calculation of Carbon Emission	- Only Emission estimation in the energy industry, manufacturing and construction stage, transport - Building Type: Residential and Commercial Sectors
Life Cycle Assessment	- Assessing all stages of building life cycle - Addressing the environmental impact of product systems - Assessing the energy consumption and carbon emissions	- Some life cycle assessment tools have missing impact indicators
Design for Environment	- Aiming to minimize energy and material consumption	- Only end-of-life stage of the product - Often failed to address environmental impacts - Generally failed to optimize environmental performance
Waste Minimization Audits	- Energy consumption assessment as an aim to be reduced	- Mainly Industrial Sector - Depending on the wastes leaving the production process

Environmental Cost Accounting	-	- Restricting to assessing the environmental cost
Environmental Compliance Audits	-	- Excluding environmental impacts of any product
Environmental Impact Assessment	- Assessing energy consumption - Assessing use of fossil fuel - Transportation Emissions	- Usage of broad scale of analysis - Difficulty in contributing to environmentally building design
Environmental Property Assessment	-	- Only evaluating the threat of a product on surrounding

Table 4.2 Techniques to Evaluate and Assess Environmental Impacts. Source: Author

When using a technique, it is essential to study and understand its strengths and limitations. According to the table 4.2, each technique is used for a targeted reason. However, the life cycle assessment (LCA) is the most used technique in the literature for a building scale and provides the most applicable tools to the purpose of this thesis.

4.3 Life Cycle Assessment Measures (LCA)

The life cycle assessment is a technique which allows to understand to what extent construction is sustainable, amplifying its preservation and assessing its environmental impacts. Being in the form of historical structures or new buildings, the impacts are manifested through the following categories: Acidification Potential AP, Eutrophication Potential EP, Smog, Human Health Respiratory Effect, Ozone Depletion Potential ODP, Resources Use RU, Fossil Fuel Consumption FFC, and Global Warming Potential GWP. The impact categories are selected depending on the nature of the study when the goal and scope of LCA are defined (Mohan, 2018). These categories are very broad but the reason behind choosing only these is its importance in

literature and from an environmental viewpoint set by US EPA (Ragheb, 2011; US EPA, 2006). In addition, these impact categories are listed within the environmental themes where most environmental experts agree to be of utmost importance in all countries (Ragheb, 2011; Schmidt and Sullivan, 2002). Each of these impacts will be described in the following paragraph.

The Acidification Potential contributes to acid deposition (Pelletier et al., 2007). Acidification also named acid rain pollutes nature and buildings. Its resulting characterization factor is the hydrogen ion which increases the acidity (Mohan, 2018). When fossil fuels are combusted, the released substances are sulfur dioxide, nitrogen oxides and other respective acids and thus contribute to AP (Ragheb, 2011). The acid deposition has a direct and indirect harmful impact on buildings, monuments, and historical artifacts (Ragheb, 2011). The next impact category is the Eutrophication Potential. It refers to natural or artificial addition to water bodies and the provision of nutrients such as the phosphates and nitrates which contribute to biological oxygen demand (Pelletier et al., 2007). This is a form of pollution and it is expressed on an equivalent mass in kg of nitrogen ion basis (Mohan, 2018). The third impact is the Smog which is also known as Photochemical Ozone Creation Potential POCP. It is the reaction resulted between nitrogen oxides and volatile organic compounds (VOC) under UV radiation (Mohan, 2018). This is due to air emissions at the ground level from industries and transportation (Ragheb, 2011). As for Human Health Respiratory Effect, it is the result of diesel fuel combustion which is one of the main causes for human health diseases especially that related to the respiratory system (Ragheb, 2011). The fifth impact category is the Ozone Depletion Potential. The latter contributes to the depletion of stratospheric ozone (Pelletier et al., 2007). The ozone absorbs large portion of UV sun rays and the reduced concentration of ozone causes negative impacts on the natural environment due to the increased UV sun rays (Mohan, 2018). The Ozone Depletion Potential is expressed in terms of

mass equivalence of Trichlorofluoromethane in order to assess the effect associated by various gases (Ragheb, 2011). The Resource Use contributes to the depletion of the renewable and non-renewable resources (Pelletier et al., 2007). This impact category addresses the resource extraction activity in the manufacturing phase of each building material (Mohan, 2018). The seventh impact category is the primary energy consumption or depletion of the non-renewable energy resources (Pelletier et al., 2007). It includes the inherent energy present in the raw material and the indirect ones in the processing and delivery phases. This implies that this impact category is from cradle to construction which means from transport of raw material up to the manufacturing and construction phases of a product (Ragheb, 2011). The last impact category to be analyzed is the Global Warming Potential. It is also called greenhouse effect which contributes to atmospheric absorption of infrared radiation (Pelletier et al., 2007). The greenhouse effect, which is resulted from temperature increase, is due to burning of fossil fuel or any other form of energy (Mohan, 2018). This affects the result of having higher concentration of carbon dioxide, in addition to methane and nitrous oxide (Ragheb, 2011).

Meanwhile, the global warming is the result of greenhouse gases (CO_2, CH_4) and the emission of these gases is due to environmentally harmful human activities such as the burning of fossil fuels (Khasreen et al., 2009). The fossil fuel depletion is identified by measuring the amount of energy consumed and that of global warming by the amounts of carbon emissions outlaid. Section 4.3.1 will present the phases of LCA including a historical overview of LCA technique with case studies. Then, this section will investigate a comparative analysis of eleven tools of LCA to assess those two indicators: energy and carbon emissions. The sub-section 4.3.2 will then discuss the appropriate adopted tool which is BIM and Tally software.

4.3.1 Phases of Life Cycle Assessment

According to Guinee (n.d), the life cycle assessment studies were introduced by the US Department of Energy in the late 1960s and early 1970s, and limited to energy analysis. The scope of studies was broadened to resource requirement, emission loadings and wastes generated (Guinee, n.d). One of the earliest studies conducted was to identify the life cycle of a product, investigating the issues related to energy requirement and energy efficiency, in addition to other environmental releases (Menoufi, 2011). In 1969, Coca Cola Company also adopted studies concerned with the environmental impacts of beverage containers (Menoufi, 2011). After a number of unpublished studies, there has been a growing concern in this subject from the early 1980s (Guinee et al., 2010). This period between 1970 till 1990 was named Decades of Conception which aimed to conceptualize the LCA as approaches, terminologies and results (Guinee, n.d.). Within this period between 1970s and 1980s, the LCA was performed without any theoretical framework (Guinee et al., 2010). In 1979, an inventory analysis was done to compute the total energy of beverage containers in the production phase (Menoufi, 2011). Afterwards, when the solid waste became a global problem in 1988, LCA studies were identified to create an inventory for environmental releases until the establishment of impact assessment (Menoufi, 2011). Starting 1993, the number of articles mentioning LCA were less than 5 and this number increased substantially after 2001 (Figure 4.2) (Guinee et al., 2010). As Guinee et al.

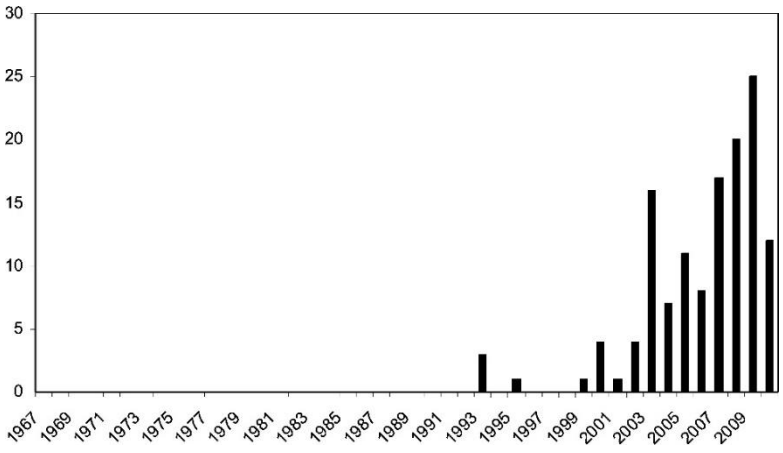


Figure 4.2 Histogram of the number of articles mentioning LCA. Source: (Guinee et al., 2010) Accessed 17-3-2021

(2010) mentioned, LCA gained ground in the first decade of the 21st century. From 1990 till 2000, this period was known as decade of standardization (Guinee et al., 2010). The first decade of the 21st century has been named as decade of elaboration because it showed an increased attention to LCA (Guinee, n.d.). The research conducted by Guinee et al. (2010) is one of the comprehensive studies which has considered that the decade 2010 till 2020 will be named as decade of life cycle sustainability analysis and will aim to broaden the scope of the study from the environmental pillar to cover all the pillars of sustainability.

In 1994, the International Organization for Standardization (ISO) has been involved in LCA (Guinee, n.d.). ISO 14040 defines LCA as 'a technique for assessing the environmental aspects and potential impacts associated with a product, by: compiling an inventory of relevant inputs and outputs of a product system; evaluating the potential environmental impacts; and interpreting the results of the inventory analysis and impact assessment phases' (Khasreen et al., 2009, p.3). According to Mohan (2018), the ISO 14040 series on LCA provides principles, framework, and methodological standards for conducting LCA studies and is illustrated into four distinct phase systems which are:

- ISO 14040 Environmental management, LCA, Principles and framework (1997)
- ISO 14041 Environmental management, LCA, Goal definition and inventory analysis (1998)
- ISO 14042 Environmental management, LCA, Life-cycle impact assessment (2000)
- ISO 14043 Environmental management, LCA, Life-cycle interpretation (2000)

The analysis of this figure is described below, to elaborately explain each step in the LCA phase (refer to Figure 4.3).

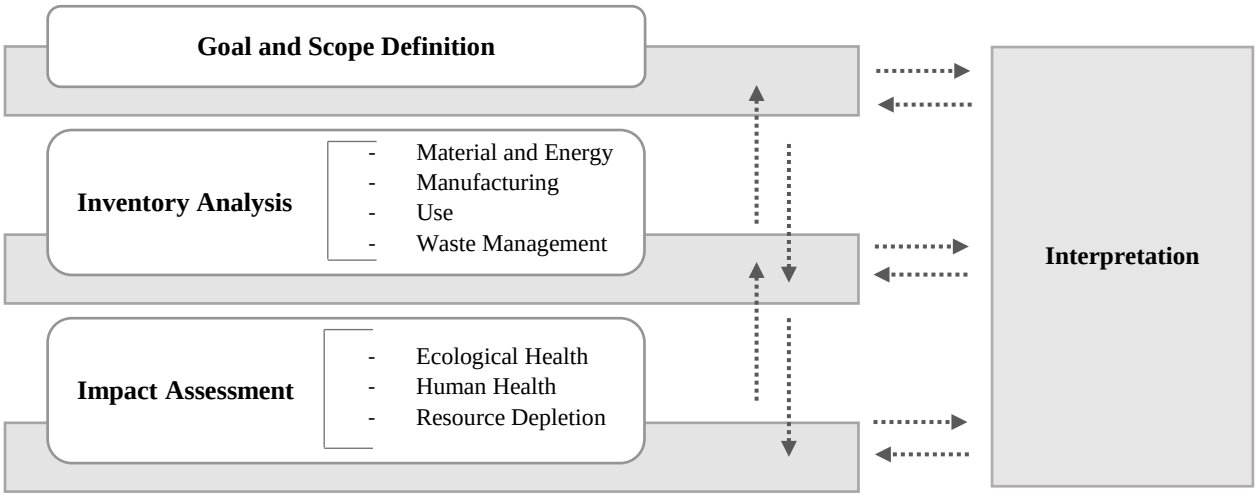


Figure 4.3 Framework for Life Cycle Assessment. Source: Author

The first step is to define the goal and scope. This preliminary step includes different stages. The first stage is related to the functional units that measure the usefulness of a product and actual function of the system in a quantitative way. The second one is related to the system boundaries to define the system under assessment and identify whether the processes are included or excluded. The third stage is related to the data quality goals that establish a defined goal along with justified assumptions, and fourth stage is the critical review process (Çakmakli, 2007). Those details associated with the project guide the further process (Singh et al., 2016). Even the choice of elements of the physical system should be dependent on the definition of the goal and scope of the study (Çakmakli, 2007). The number of phases differs according to the goal of the study, because each phase includes sub-phases. As an example, some researchers such as Khasreen et al. (2009) considered the life cycle assessment as three phases: 1) pre-construction, 2) usage, and 3) demolition. The pre-construction phase includes the extraction, manufacturing, transportation to the start of occupation. Other authors such as Dixit (2016) identified four stages for the life cycle assessment: 1) extraction, manufacturing, and construction, 2) operating, 3) maintenance and

renovation, and 4) demolition. Hence, the goal of the study is the main driver to define what is not included and should be clearly set in the scope.

The second step is the inventory analysis which is concerned with the data collection and calculation procedures. It is highly dependent on the goal of the research. The inventory data is related to reference flows for each unit process in order to quantify the input and output then to investigate the functional unit (Çakmakli, 2007). The inputs are the water, energy, and air, whereas the outputs are in the form of emissions (Singh et al., 2016).

In order to determine the impact assessment, which is the third step, the results of the life cycle inventory should be examined, in collaboration with the impact categories and the category indicators (Çakmakli, 2007). This step aims to better understand the environmental impact of the system. The various impacts are categorized and classified followed by impact measurement. The categories define the environmental categories while the classification is a qualitative step; both are used to assign inventory input and output data to the pre-defined impact categories (Çakmakli, 2007).

The final step is the interpretation. The interpretation of data is synthesized by identifying, quantifying, checking, and evaluating the impacts. The outcome of this phase is to set up recommendations, suggest alternatives to minimize the negative impacts on the natural resources and summarize a conclusion for the study (Singh et al., 2016).

4.3.2 LCA Approaches for Preservation

The life cycle assessment signifies the environment impacts after the inputs and outputs are identified.

The following figure (Figure 4.4) indicates the outputs as environmental impacts resulted from the inputs of natural resources. The energy is quantified in the input of all the phases of construction from material production, manufacturing, construction, use and demolition. The carbon emission is the dominant factor in the output of life cycle phases, in addition to other greenhouse gases and wastes.

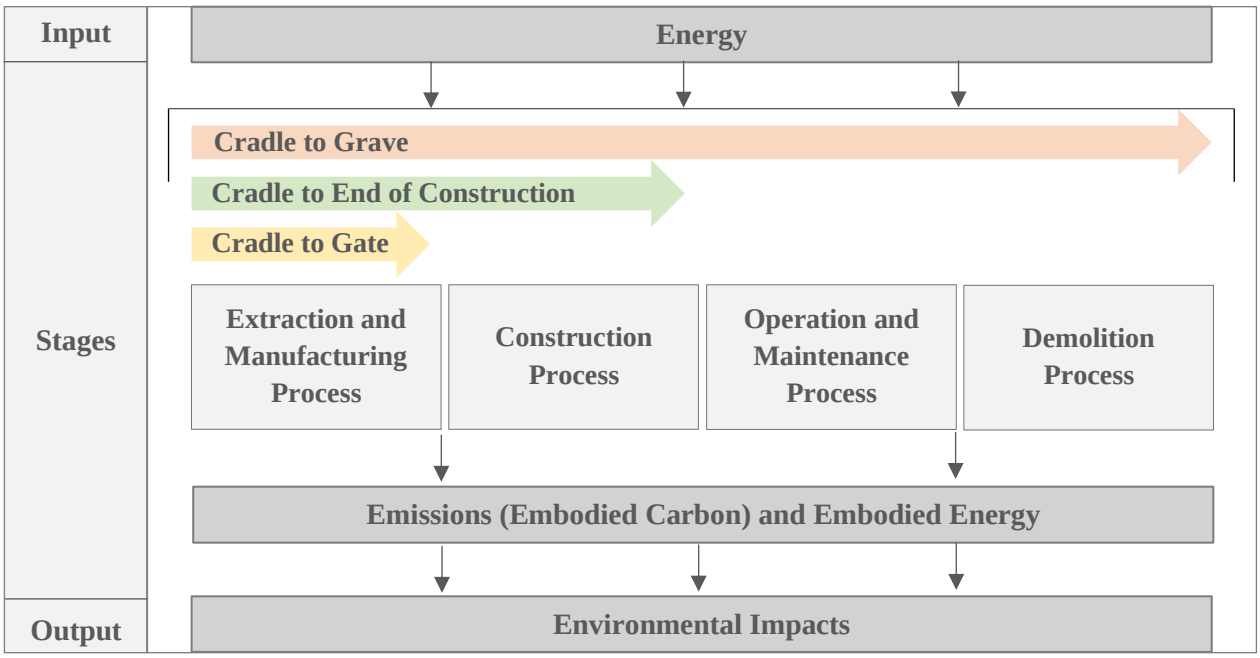


Figure 4.4 Flow Diagram of a Building: Inputs and Outputs of the LCA Stages. Source: Author

The quantitative and qualitative methods to assess the whole life cycle of a building have to define its properties prior to LCA results. Three main LCA tools for building systems are identified (Figure 4.5); building product, building assembly and whole building. The building product is the smallest element of the building which detects the material data. The building assemblies are intermediate building products. The whole building covers all the systems and assemblies (Joshi, 2009).

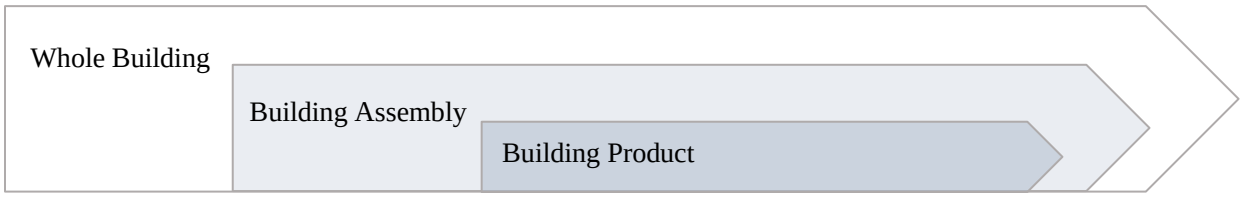


Figure 4.5 Classification of Tools in Building Systems. Source: Author

The life cycle assessment includes qualitative and quantitative tools. The selection of a specific tool depends on the scope of the thesis, limitations of the tools, and the chosen indicators to be analyzed.

The qualitative tools of LCA such as BREAM[1], LEED[2], GBTool[3] and EcoProfile[4] (Çakmakli, 2007) are not needed in this research. Those tools use subjective data and depend on the quantitative methods of assessment to be objective.

The following paragraph discusses a comparative analysis of the eleven quantitative tools in table 4.4 in order to afterwards to define the adopted tool. The quantitative tools that are proposed by Çakmakli (2007) are the BEES (US), BEAT 2000 (Denmark), Invest (UK) and EcoEffect (Sweden). These software assess the whole building; however; the Invest software is used only in the preliminary design phase of the life cycle assessment. Invest is one of the set of tools such as ATHENA and Eco-Quantum, which is recognized to be building design decision, compatible with

[1] The Building Research Environmental Assessment Method (BREEAM) was created in 1990 in UK. Some authors such as Çakmakli (2007) and (Khasreen et al. (2009) define BREEAM as a qualitative tool of LCA, while Vigovskaya et al. (2016) considers BREEAM as a certification technique. This tool assesses the whole building process.

[2] In 1998, the US Green Building Council introduced the Leadership in Energy and Environmental Design (LEED) which is a consensus-based tool that serves as a guideline and assessment mechanism in order to maximize the positive consequences of the construction industry and promote regenerative and restorative strategies, in addition to optimization of indoor environment and solutions for the use of natural resources (Vigovskaya et al., 2016).

[3] The GBTool is the tool used to assess the potential energy and environmental performance of the case-study projects (Gu et al., 2014).

[4] The EcoProfile is a whole building assessment tool to understand the relevant environmental processes and allows comparison of several designs (Reiter, 2010).

known standards (ISO, ASHRAE) and highly objective (Çakmakli, 2007). Those tools are suitable for a detailed design phase to know the impact of the form (Georgia Institute of Technology et al., 2010). ATHENA Impact Estimator and Eco-Quantum assess the extent to which a building is sustainable. ATHENA only evaluates the final building design and is region specific to North America and Canada (Michalski, 2015), while Eco-Quantum is not region specific and evaluates from the design phase (Georgia Institute of Technology et al., 2010).

Adding other quantitative tools, all those assessments adhere to the rigors of LCA (Tables 4.3 and 4.4). Not all tools conduct the cradle-to-grave LCA; most of it account for the cradle-to-gate for construction and material manufacturing phase. The cradle-to-grave tools, which assess all the stages of the building life cycle, are Athena Impact Estimator, Building for Environmental and Economic Sustainability BEES (Georgia Institute of Technology et al., 2010), in addition to SimaPro, TEAM, GaBi and Umberto (Diakoumakou, 2016). The LCA-based software such as BEES database develops the infrastructure that allows comparative assessments to be made (Ragheb, 2011). It assesses the building product based on underlying material data individually but cannot be used to make the whole building design decisions, besides other tools such as SimaPro and TEAM. One of the features SimaPro provides is its adaptability to different databases and thus is not region-specific (Georgia Institute of Technology et al., 2010). This tool is a product design oriented in the post construction phase, makes complex products to be easily analyzed (Michalski, 2015). Similar to SimaPro, Umberto and GaBi are generally used by LCA professionals and take time to learn how to use it. However, the latter allows for flexible inputs and outputs and is applicable for industrial product (Sandanayake, 2016). The other non-region specific software for the life cycle assessment are the following; TEAM, LCAit, and EQUER. TEAM is a powerful and flexible tool for environmental and economic performances of a product

(Diakoumakou, 2016). As for EQUER, it provides quantitative analysis to the environmental impacts, allows a comparison with a reference building and suggests on how to improve (Peuportier, 2004). The LCAiT tool is more complex than EQUER in which the primary product of the process, such as resources, cannot be defined unless links have been established between different processes (Josh, 2009).

Tools	LCA Type		LCA Stages	Impact Categories	Building Type
SimaPro	3	Commercial	Cradle-to-Grave	- Fossil fuels - Ozone layer - Climate change	- Complex products with complex life cycles
ATHENA Impact Estimator	1	Commercial	- Material Extraction and Manufacturing - Related Transport - On-site Construction - Maintenance and Replacement - Demolition and Transport to Landfill (Impact Estimator in On-site phase: energy use + related emissions) (Eco-Calculator in On-site: of Assemblies)	- Global Warming - Ozone Depletion - Total Fossil Energy	- Industrial - Institutional - Commercial - Residential for both New Construction and Major Renovation (ATHENA Eco-Calculator Includes Retrofits)
ATHENA Eco-Calculator	2	Academic		- Global Warming Potential - Embodied Primary Energy - Pollution to Air	
BEES	3	Commercial	- Material Extraction and Manufacturing - Transportation - Installation - Maintenance - Recycling	- Global Warming - Fossil Fuel Depletion - Criteria Air Pollutants - Ozone Depletion	- All Building Product Types
LCAid	1	Academic	- Material Extraction and manufacturing - Construction - Operation (Energy) and Maintenance - Demolition and Waste Management	- Life Cycle Greenhouse gas emissions - Life Cycle embodied energy	- All Types
Eco-Quantum	1	Academic		- Greenhouse effect (GHG)	- Residential
EQUER	1	Commercial		- Primary energy consumption - Global warming	- Similar to Building Types of Athena
LCAit	3	Commercial	Flexible to Include or Exclude any LCA Stage	- Emissions - Wastes - Co-products	- All Types
TEAM	3	Commercial		- Carbon Emissions - Energy Consumption	- All Types
Umberto	3	Commercial		- Material and Energy flow	- Material and Energy Flow
EcoEffect	1	Academic	- Raw material extraction and transformation impacts	- Global Warming - Ozone Depletion - Construction Waste - Energy and GHG	- All Types

1. Environmental LCA Tool for Whole Building
2. Environmental LCA Tool for Building Assembly
3. Environmental LCA Tool for Building Product

Table 4.3 Detailed Properties of the Tools of Assessment. Source: Author

Tools	Performance	
	Strengths	Weakness
SimaPro (Indonesia)	- Data protection - Not region-specific - Widely Used Tool - Ability to Trace the Origin of Results - Professional Software Tool - More Adaptive - Complex Life Cycles Easily Analyzed - Editing Inventory databases and impact Assessment Methods Without Limitations	- Time Consuming - Individual materials to be analyzed - Parameters of the project should be extremely large - More time investment for the users to learn to use the software - No assumptions and exact information or else incomplete results - No Suggestions on how to improve the project - Expensive Software (Fees depend on License-including educational version)
ATHENA Impact Estimator (Canada)	- High Quality - Detailed Results - Whole Building LCA - Conventional Wall Created more than high performance	- Expensive Software (750 $) - Region-specific to North America - Not every aspect of construction stage is covered - Limited options of designing wall assembly - No consideration of floor and ceiling finishes
ATHENA EcoCalculator (Canada)	- Available for free - Easy to compare assemblies	- Fixed Column and Beams Size - Only Assemblies Are Evaluated
BEES (U.S.A)	- Free Software - Single value Performance - Easy Comparison of Products - Transparent in Documentation - Fittings and furnishing included - Assess environmental and Economic Performance	- Lot of Uncertainty in data - Region-specific to America - Only includes data for 200 building products covering 23 building elements
Eco-Quantum (Netherlands)	- Easy to use - Whole Building LCA - Usage During Design Phase - Wide Variety of Assessment Methods - Policy tool to Define for a House-building Program	- Subjective Weighting in Assessment - Only applicable to single residential buildings - User cannot Extend Extensive Database with new Products or materials

LCAid (Australia)	- Easy to use - Can import data from other database like SimaPRo - Evaluating environmental performance of designs and options over the whole life cycle of a building, object, or system	- Lack of Transparency - Region specific to Australia - Output format is not flexible - Needed other environmental tools to incorporate LCA data into the design tool - Operation phase as the main focus without construction phase consideration - Limited building material/ assembly options
LCAit (Sweden)	- Ease of data entry - Inputs and Outputs Easily Edited - Highly complex life cycle system to be simplified	- Complex tool - Lack of comparison of results - Links to be Defined for Product of a Process - Only one inflow and outflow can be assigned to transportation block
TEAM (France)	- Flexible Tool - Data protection - Accessed Online - Use Large Database - Cost Information can be entered	- Expensive Tool - Limited Comparison of Results - Lack of support for factors for impact assessment
EcoEffect (Sweden)	- Easy to understand results - All measurable impacts have been included - Target the field of designing, planning and management of the built environment	- Details can be difficult to understand for an inexperienced user
Umberto (Germany)	- Advanced Software - Transparent Results - Costs can be modelled as well - Determine all Material and Energy Flows - Excel based tool can be provided for sensitivity analysis	- Expensive Tool - Time consuming - Advanced tools applicable for LCA experts
EQUER (France)	- Suggestions on how to improve - Use of a chart to compare different - Comparison with a reference building - Scenarios with large number of environmental indicators - More global assessment is allowed through its link to energy simulation tool	- Expensive Software - Main Focus on the Impacts due to Activities of Occupants

Table 4.4 Performance of the Tools of Assessment. Source: Author

4.3.3 Building Modeling Tool: Energy and Carbon Simulation

Building Information Modeling (BIM) is more than just 3D model-based; it stores additional information about the design, is used for the life cycle analysis and provides a platform for assessing sustainability aspects (Ariyaratne and Moncaster, 2014). 'BIM is a digital representation of physical and functional characteristics of a facility. A BIM is 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' (Shadram et al., 2014; NBIM-US, 2014, p. 3). Similar to the data input method of doing the field measurements then drafting it cad, BIM has the same criteria with Revit. This process, if adopted by preservationists, will be a groundwork to apply historic preservation strategies and model every element of the building separately, to be further analyzed. As Van Wagenen and West (2012, p. 28) mentioned, 'one of the promising aspects of BIM for historic buildings is its ability to detect clashes between old and new parts of the building and between building systems and structure'. Therefore, BIM is being adopted for cultural heritage preservation and management of historic buildings (Megahed, 2015; Fai and Rafeiro, 2014; Garagnani and Manferdini, 2013).

On one hand, BIM is increasingly used to facilitate establishing a bill of quantities of materials throughout the phases of LCA (Marrero et al., 2020) because it eliminates the need for manual data input (Lu et al., 2019) and any material can be isolated for further analysis (Alwan and Jones, 2015). It also offers the opportunity to superimpose different types of information within a powerful federated project model (Abanda et al., 2017). On the other hand, Abanda et al. (2015) are one of the authors who claimed that BIM implementation do not overweigh its costs, in addition to the risky features from liability standpoint to warrant its use (Figure 4.6). In the

literature review, there are different approaches linking LCA to BIM. When searching for life cycle assessment and BIM, around 271 research papers were identified as relevant (Obrecht et al., 2020).

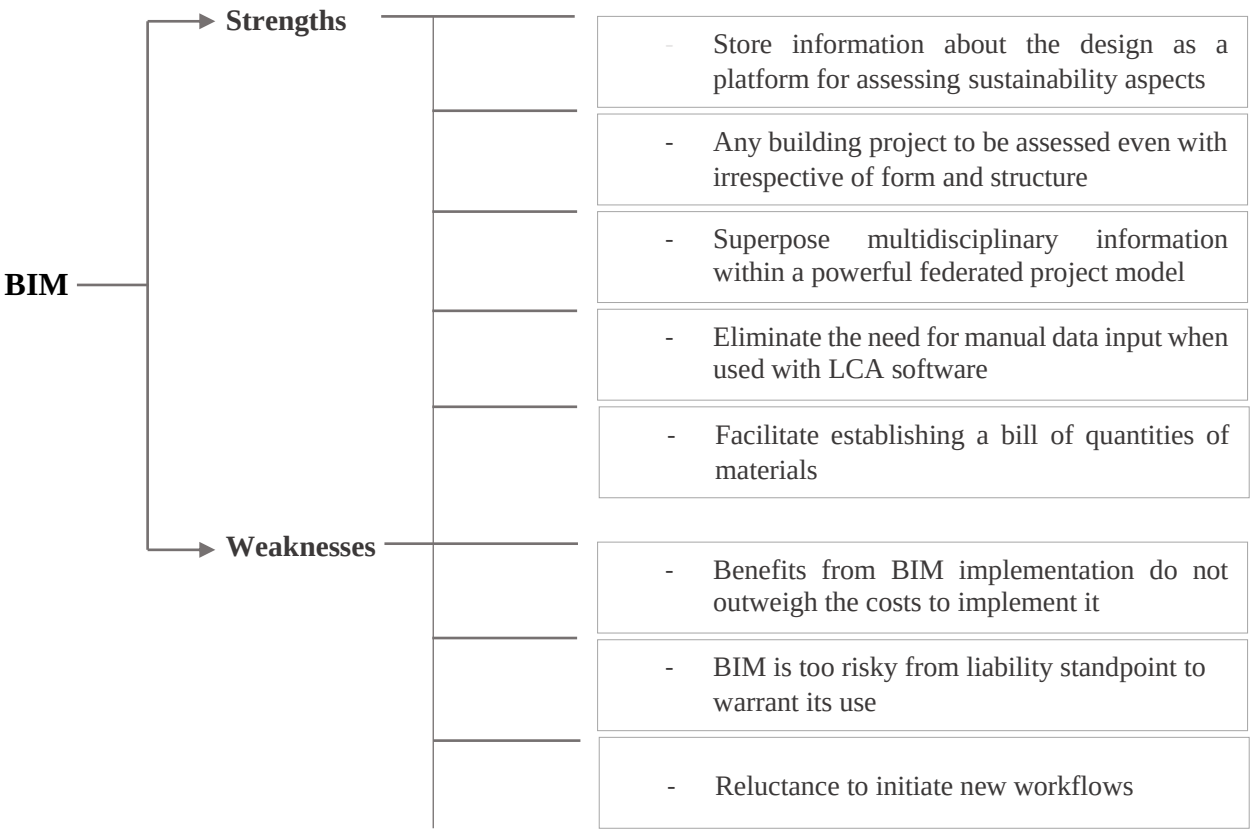


Figure 4.6 Strengths and Weaknesses of BIM. Source: Author

After narrowing the scope of the research and the abstracts, the final sample provided was 60 studies to review (Obrecht et al., 2020). As shown in Figure 4.7, the number of research papers discussing BIM and LCA has increased exponentially between years 2011 and 2019 from

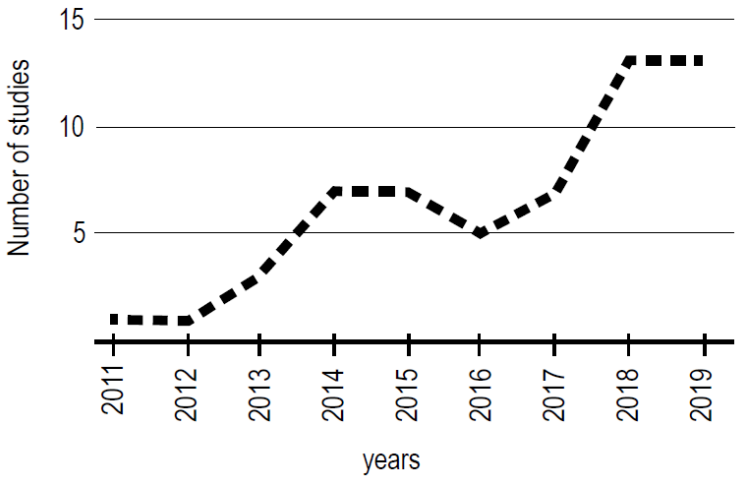


Figure 4.7 The yearly distribution of the papers identified during the literature review. Source: (Obrecht et al., 2020) Accessed: 24-3-2021

range less than 5 to approximately 13 studies respectively.

The building information modeling is combined with life cycle assessment to develop frameworks for a building's embodied energy and carbon emissions. The inventory of materials and energy consumed over the sampled building's life cycle is assessed to calculate the associated indicators (Yim et al., 2018). Around 23 samples focused on the embodied energy in which the number of papers varies in accordance to the studied phase of the life cycle assessment (Obrecht et al., 2020). As shown in Figure 4.8, the cradle to gate phases from A1 (Raw material supply) to A4 (transport to building site) are assessed more frequently (Obrecht et al., 2020). However, B1 (use), B3 (repair), B5 (refurbishment), B7 (operational water use), and D (reuse, recovery, or recycle), have been addressed in few studies (Obrecht et al., 2020). Dixit (2016) in one of the studies named 'A BIM-based Embodied Energy Calculation Prototype for Life Cycle Energy Analysis of Buildings', suggested that the framework of an Application Programming Interface (API) is integrated into BIM for the embodied energy calculation associated with each material in Revit Material Library. It finds the right value from a spreadsheet which includes embodied energy and carbon dioxide emission values for commonly used construction materials.

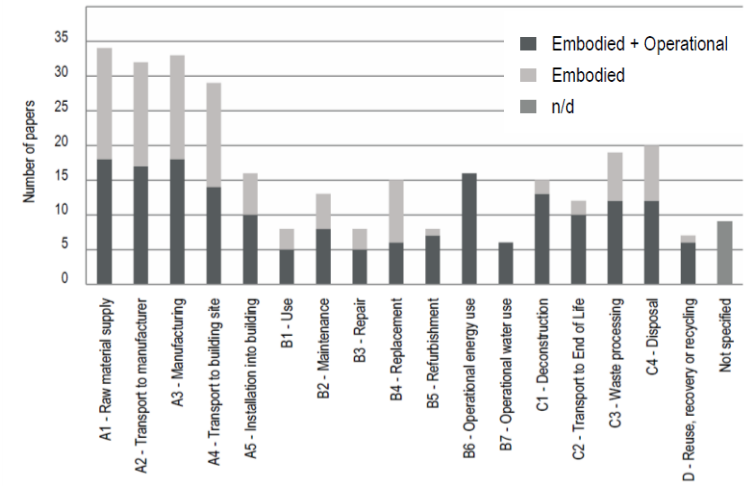


*Figure 4.8 Life Cycle Stages Assessed. Source: (*Obrecht et al., 2020) Accessed: 24-3-2021

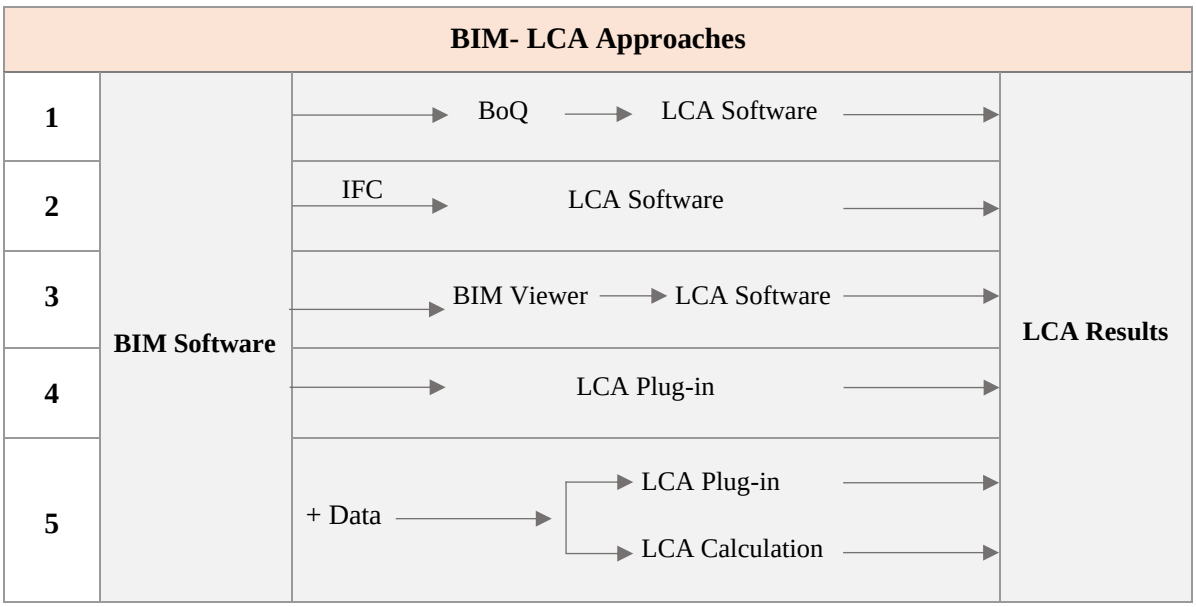


Figure 4.9 Integration Types for the BIM- LCA Approaches. Source: Author

Wastiels and Decuypere (2019) classified five integration types for the BIM- LCA approach (Figure 4.9) (Obrecht et al., 2020).

BIM and LCA tools in the first approach of integration are the exchange of information via Bill of Quantities (BoQ). The data from the BIM model are exported constituting all the materials used and their quantities. These data are then imported into an LCA tool manually, semi-automatically or automatically. The manual approach is the most adopted approach; however, it is very time-consuming and has more risk of errors (Obrecht et al., 2020). In addition, the BoQ export is not suitable to iterative design process (Atik et al., 2020; Wastiels and Decuypere, 2019). Atik et al. (2020) investigated the gaps by proposing an evaluation framework for the current integration practices between LCA and BIM due to inaccuracies that may occur in the modeling and calculation tools. It points out that this approach is traditional and thus highly susceptible to mistakes when manual data exchange is used. The workflow of this study started with inventory of building material and manual data input based on the BoQ (Atik et al., 2020).

The second approach is the use of Industry Foundation Classes (IFC) for the data exchange between BIM and LCA tools. The IFC data determines the building properties. It is a semi-

automatic procedure which needs programming skills and aims to link the LCA data to the building geometry (Obrecht et al., 2020). Through an optimized calculation process, the semi-automatic calculation becomes faster, more consistent, and more accurate than that of manual data-entry (K Forth et al., 2019). Despite the advantages of this approach such as assessing the environmental impact with error free results, the IFC data is not viewed in all LCA software (Koseci, 2018). Antón and Díaz in Koseci (2018) elaborated the direct access approach for the integration through extracting data via IFC file format. This approach 'lacks open standards and the level of interoperability diminishes the quality of data extraction and even may hinder the process itself for some incomputable tools' (Koseci, 2018, p. 17). Sometimes the designer needs to run another LCA process whenever the BIM model is subjected to any change (Koseci, 2018).

The third procedure is a plug-in which acts as a link between geometric data and LCA profiles in a BIM viewer tool prior to its transfer to LCA software. The LCA profile is assigned to the geometry in the 3D environment (Obrecht et al., 2020; Jalalei et al.,2019). This link between LCA and 3D model can be maintained for further reference during an iterative optimization process (Wastiels and Decuypere, 2019).

Atik et al. (2020) indicated that the above-mentioned approaches (1, 2 and 3) have weaknesses which limit its future applicability. The weaknesses are the following: interoperability issues between different programs, license costs and time requirement for the whole process.

An important advantage of the fourth approach compared to the previous ones is that 'the LCA results potentially can be visualized in the geometric model providing an instant view on the hot spots or most important impacts' (Wastiels and Decuypere, 2019, p.7). This LCA plug-in tool is the most adopted approach. This procedure is mostly used in the early stages of the design to assess environmental impacts associated with the different indicators. The plug-in has fast results

(Obrecht et al., 2020) and is considered as automatic link, time-efficient and provides instant results (Atik et al., 2020; Wastiels and Decuypere, 2019). However, the plug-in sometimes uses generic data (Obrecht et al., 2020). Consequently, the dedicated LCA software is replaced by the use of a plugin in order to do calculation, result visualization and analysis (Wastiels and Decuypere, 2019).

The last approach, which is the approach of integration number five, integrates the LCA data into BIM model using a generic or product- specific data Obrecht et al., 2020). Some merge the environmental data into BIM in order to determine the environmental impacts which have the risk of creating an unresponsive file, while others use the Excel-based tools. The calculation and analysis of this approach are done via plug-in or are exported to LCA software (Obrecht et al., 2020). This approach maximizes the potential of BIM through providing useful information for assessments (Atik et al., 2020). Nevertheless, in a context where the design changes continuously, this approach is less effective because users have to change BIM objects in a model rather than changing LCA profile in the LCA software (Atik et al., 2020).

Atik et al. (2020) identified the fourth and fifth approaches to be more promising for future applicability for open development. However, the dependency of LCA data in plug-in/ software may result in some uncertainties and variation in the results.

Therefore, the BIM-based tools for environmental impact assessment showed that most of them need to combine the BIM with other software to obtain the quantification of environmental indicators (Marrero et al., 2020). The BIM model contains mostly information regarding the quantity and quality of the materials. These inputs are essential to be transferred into tools that enable for the calculation of embodied environmental impacts (Obrecht et al., 2020). One of the adopted LCA calculation tool is ‘Tally’. ‘Tally’ is a plug-in package, integration approach type

four, allows who work in Revit to facilitate the quantification of the life cycle environmental impact of the whole building design with a comparative analysis (Diakoumakou, 2016). Najjar et al. (2017) evaluated the performance of Tally, indicating the importance of using automated data extraction process to limit the need of defining the materials again in each phase of analysis (Atik et al., 2020). Table 4.5 shows the properties of the Tally Tool for Life Cycle Assessment. Tally stands out for its technical support, and the fast results will be presented in a useful format (Marrero et al., 2020). It is an easy-to-learn tool and available with the non-commercial licenses (Amany, 2019), although it uses generic data which utilizes a tabular format for inputting and interpreting data (Shreve, 2018).

Alecrim et al. (2020) conducted a study in order to study the current state of implementing LCA in BIM process. A residential building case study was modeled in Revit BIM platform, and then exported to Tally LCA software. This will provide further analysis of the strengths and weaknesses of Tally software with respect to other LCA tools (refer to Table 4.5). Alecrim et al. (2020) mentioned that Tally software was chosen for the study due to its interoperability capabilities, user-friendly interface and different available locations, with a building life span that reaches 60 years. This case study ended up showing that it is important to develop country-specific life cycle inventory data to limit the possibility of uncertainties related to building materials, transportation, and energy.

Tool	**TALLY** (U.S)
LCA Type	- Environmental LCA Tool for Whole Building, Commercial Software
LCA Stages	- Cradle to Grave
Strengths	- Fast Results - Useful format - Available tutorials - Easy to Learn and Use - Available non- commercial licenses - Reliable Results which depend on the details of the 3D model - Facilitate the quantification of the life cycle environmental impact
Weaknesses	- Generic Data - Expensive (1,200 $) - Material Region- Specific to North America - Does not consider the impact of HVAC or either electrical equipment
Impact Categories	- Global Warming Potential - Ozone Depletion Potential - Embodied Impact Calculation (Embodied Energy)

Table 4.5 Properties of the Tally Tool for Life Cycle Assessment. Source: Author

As the previous types are direct approaches, the indirect integration approach relies on linking the building model and environmental properties of the products in the BIM model, which are based on environmental product declarations (EPD) (Koseci, 2018). Databases and EPDs provide data on the various environmental impacts of building materials (Obrecht et al., 2020). From this standpoint, BIM model in Revit and a Microsoft Excel sheet representing the EPDs were used in which the quantity take-off of the BIM materials and building parts are utilized. The

quantities with the constituents EPDs are then mapped to assess the specific environmental impact of the design (Shadram et al., 2014).

According to Lu et.al (2019), there are two stages associated with the building to assess the outputs, carbon emission and embodied energy, before the interpretation of results. The first stage is the BIM modeling software, which reveals information about a building including climate conditions, comfort requirements, and operational schedules. This results in quantities calculation sheet. Then the Green Building Studio, another plug-in tool built by Revit like that of Tally, enables an energy calculation of the operating phase before making use of the BIM model. The BIM model includes graphic information, materials data, and building components with the identification of the Level of Detail. As for the second stage, it is the environmental impact assessment which defines the environmental impacts in the construction, operation, and demolition stage. This tool is not within the scope of the study because this method focuses on operating energy rather than embodied energy.

4.4 Uncertainties

Within the LCA study, it is proficient to assess the reliability and credibility of the data and know if they are affected by uncertainties. This section identifies the uncertainties that this thesis may encounter during the implementation of methodology and the process of data collection.

In much research of the LCA studies, the so-called sensitivity analysis is used as a quantitative method to assess the impact of data uncertainty. This method aims to focus on key data, choices of input parameters, outside conditions of any system and assumptions that have most influenced the results without compromising its robustness (Ragheb, 2011). In the case of relocating buildings, the allocation procedures related to inputs and outputs of the system should be fully detailed. These procedures should reflect the physical behavior of the system since

allocation of building materials is complicated by the large time spans encountered in the lifetime of buildings (Çakmakli, 2007). The uncertainties of a study differ depending on the factors associated with the context and the difficulties of data collection, site analysis and the limitations of assessment tools. The data on energy intensities and carbon coefficients in each country are likely to be different due to dissimilar production processes and fuel sources, but they are used as proxies in some research to calculate the inputs and outputs for materials (Ding and Ying, 2019). The input data required for the energy, which was needed to manufacture building materials a century or more ago, may not represent the calculated values temporally, making it difficult to account and will be taken as average (Frey, 2007). One of the accurately suggested procedures is the translation of the calculated energy values into carbon dioxide emissions rather than using an average embodied energy values which are aggregated for all energy sources (Dixit, 2016). As mentioned by Çakmakli (2007), the data from any of the sources would vary in accuracy depending on how they were collected and compiled and how current they were. It may be impossible at times to ensure that the inventories of inputs and outputs are compiled consistently (Çakmakli, 2007).

4.5 Implemented Methodology

The Bisri valley has witnessed a long history of worship, evidenced in archeological remains such as pottery, rock- cut tombs, dressed stones, stone tools, arches, adding to it houses dating from 19th and 20th century (Advisory Council on Historic Preservation, 1979). This valley presents two of the cultural heritage: Mar Moussa El Habchi Church and the remains of Saint Sophia Monastery. The archeological structures will be out of scope in this thesis because there is not availability of sufficient and updated data to perform an appropriate simulation, or implement the methodology appropriately. However, the church and the monastery will be studied. Taking different case studies on the existence of monasteries in Lebanon, the churches and monasteries

form a system of architectural composition which is significantly related. As an example, the Valley of Qadisha has a religious historical significance and combines two smaller valleys named as Qannounbine Valley located to the South and Qozhaya Valley to the North (Charaf and Chaaya, 2002). The site of Mar Aboun, to the South of Qannoubine Valley, has a church located in a cave with a monastery that occupies a cave near the church (Charaf and Chaaya, 2002). In the case of Bisri Valley, the monastery is located near the church. However, the former predates the latter; the monastery is Byzantine (dates back to 13th century), and the church has been rebuilt few decades ago. The objective of this chapter is to unfold the implemented methodology of this thesis. The empirical work includes the assessment of the embodied energy and carbon emission in the case of relocation (deconstruction then reconstruction) of the Mar Moussa Church and Saint Sophia Monastery.

The scenario that was running is to use a tool which evaluates the embodied energy of relocating the historical church with the monastery in Bisri Valley. Then the carbon emissions will be assessed by conversion or using another tool. The second scenario was to include the carbon emissions within the energy analysis, which means the study of the life cycle assessment of the historical structures to analyze both factors at once.

Figure 4.10 Mar Moussa EL Habachi Church. Source: Author

Figure 4.11 Saint Sophia Monastery. Source: Author

Figure 4.12 Saint Sophia Monastery with the Church located 30 meters far. Source: The Arab Weekly Accessed: 23-2-2021

An integration of BIM and LCA tools proved to be an ideal setup to streamline the process of LCA. The Tally software that plugs into BIM software, assesses the energy impact of a building, and would support to maintain the existing historic buildings rather than demolishing it to construct new one (Van Wagenen and West, 2012). As Shreve (2018) demonstrated (refer to Figure 4.13),

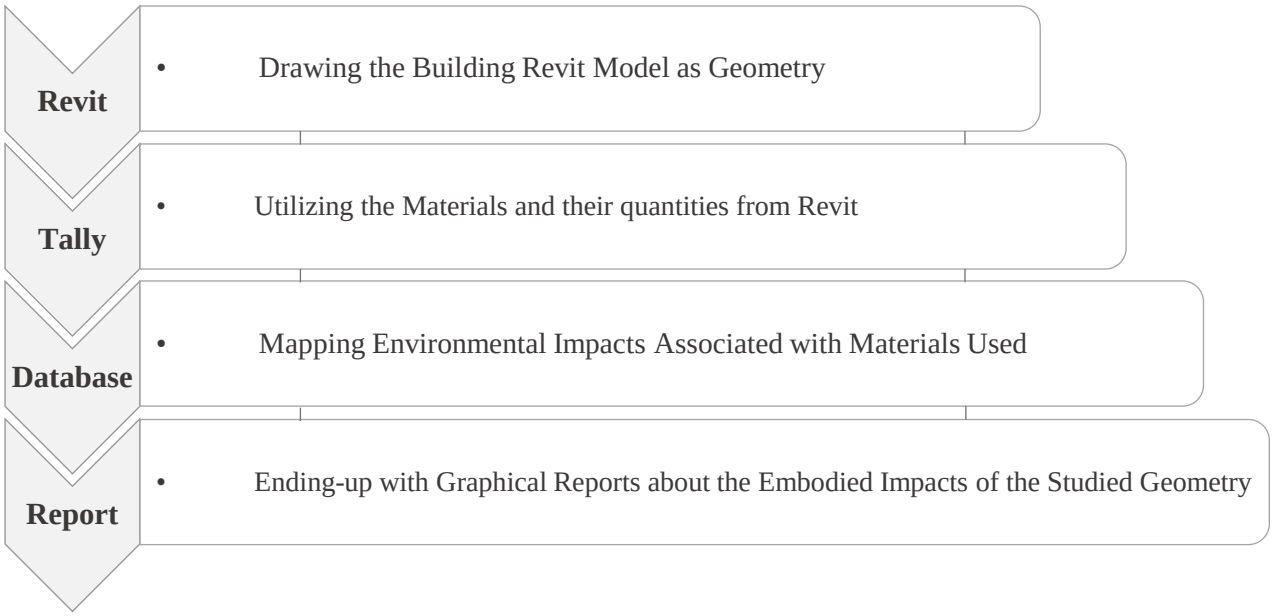


Figure 4.13 Tally Workflow from Development of 3D model on Revit to Reports Generation. Source: Author

the process of work will be introduced with a 3D model in Revit of the geometry of Mar Moussa Church and and Saint Sophia Monastery. The materials and its quanities will be uploaded to Tally software in order to study the environmental impacts aggregated with the existing buildng fabric and its properties throughout the life cycle of the building (Shreve, 2018). The impacts are then mapped from the early stages of design process to demolition stage; from production, transportation, manufacturing, transporation, construction, operation, maintenance and demolition. In this study, the operation phase is considered negligable as this stage is affected by the number of occupants and use of HVAC, to reach comfort values. Saint Sophia Monastery is an outdoor structure while Mar Moussa has an indoor space, visited annually on 28th of August

and using passive systems. Finally, a graphic respresentation in the form of figures will be generated to analyze the impacts of the studied geometry on the environment, as embodied energy and carbon emissions (Shreve, 2018).

The life cycle assessment will be illustrated in this thesis with respect to the four distinct phase system: goal and scope, inventory analysis, environmental impact assessment and interpretation. Each of the indicated phases will be extensively described below.

In the first step, the goal and scope are defined as the life cycle of embodied energy and carbon emissions (LC-EECE). The second step is the inventory analysis, which introduces the 3D model in Revit then BIM plays a role in quantifying the materials in a spreadsheet, prior to its transfer to Tally plug- in tool. This phase has a semi-automatic working process, where the data models are imported to Revit then calculated using the LCA tool, Tally. In this phase, the embodied impacts will be categorized as initial, recurrent and demolition energy, including detailed analysis regarding the stages of the material from cradle to grave. The initial embodied energy and carbon emissions include the raw material supply, transport to manufacturer, manufacturing, transport to building site and construction installation processes (Obrecht et al., 2020). The recurrent embodied energy and carbon emissions encompass the use, maintenance, repair, replacement, replacement, and refurbishment (Obrecht et al., 2020). The demolition energy and carbon emissions include the deconstruction phase and the transportation (Obrecht et al., 2020). The third step will be the environmental impact assessment to deduce the results of the global warming potential and embodied impacts. The global warming potential signifies the carbon emissions while the embodied impacts are meant to be the embodied energy of the building assessed. In Tally, the embodied impact is signified by the embodied non- renewable energy. Finally, the interpretation of results is the fourth step which focuses on the environmental impacts of the construction and

demolition stages, in order to be able to analyze the carbon emission and embodied energy associated with relocation (deconstruction and reconstruction) of the building assemblies. Meanwhile, this step is to analyze, describe the problem in order to formulate general and specific findings, and finally derive to recommendations related to the studied context (Figure 4.14).

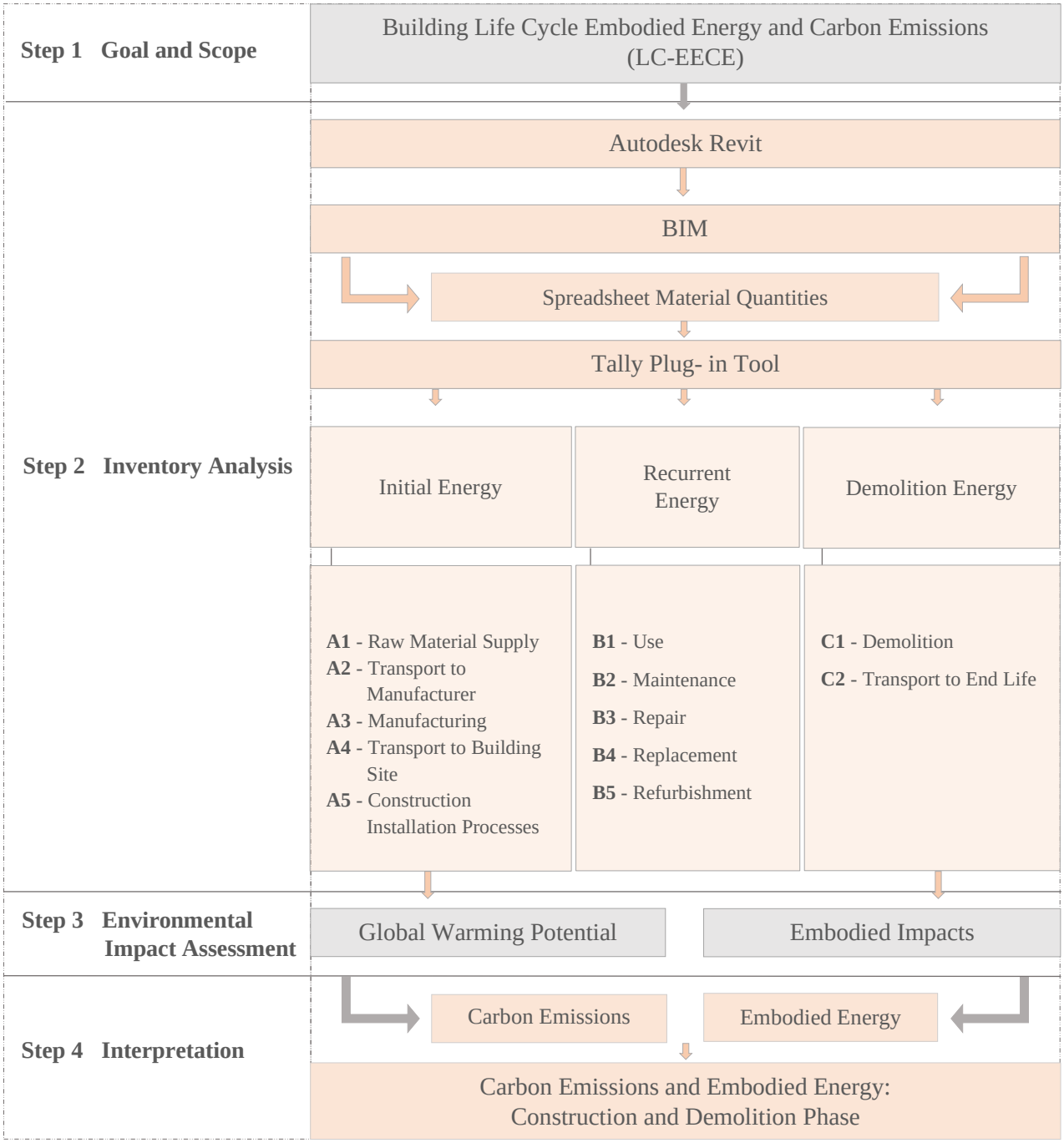


Figure 4.14 Diagram of Implemented phases of Life Cycle Assessment as Embodied Energy and Carbon Emissions. Source: Author

4.5 Conclusion

This chapter presents the methodology and highlights the limitations as well, which is to evaluate the environmental impacts of the relocation of Mar Moussa Church and Saint Sophia Monastery. The tools of assessment were compared in order to select an adequate one to be used in the empirical work which most suits the case of Bisri Valley in accordance to climatic conditions, location, topography, electricity grid and building assemblies. The observation is an introductory phase to take the measures of the studied structures. Then, it inserts that information as bill of quantities and reaches the expected outcome of analysis via Tally software. This chapter fulfills the second objective of the thesis and acts as a basis to construct the implementation framework in the following chapter.

Chapter Five

MODELING, ANALYSIS AND DISCUSSION: ASSESSMENT OF EMBODIED ENERGY AND CARBON EMISSION

5.1 Introduction

This chapter presents the implementation phase to answer the fourth and fifth objectives of this thesis. Those objectives analyze the assessment of the embodied energy and carbon emissions to indicate whether relocation of the church and the monastery is sustainable. Section 5.2 analyzes the existing site of Mar Moussa Church and Saint Sophia Monastery, as orientation, use of material, interior space, exiting conditions and the added structures with respect to the original construction. As for Section 5.3, it shows the steps needed to firstly model each of those historic structures in Revit using the recorded data gathered in the site visits. It also forms a spreadsheet using BIM and finally performs the simulation after defining the input for Tally Software. The input for the Tally Software refers to the literature review discussed in the previous chapter for the process of work prior to the simulation. Then, Section 5.4 investigates the results of the assessment which will be presented in the form of charts, figures and tables, for further analysis, discussion and projections. Finally, Section 5.4 provides a summary of this chapter.

5.2 Analysis: Mar Moussa Church and Saint Sophia Monastery

This section contextualizes the two historic structures in Bisri Valley: Mar Moussa Church and Saint Sophia Monastery. Those two structures are individually analyzed, accompanied by an elaborate synthesis to the transformations occurred in the past decade up till this time. Beirut Water Supply Augmentation Project Report presented by the Council for Development and

Reconstruction (2014) is the main reference in this section. It comprises detailed documentation of the site, including archeological salvage, excavation procedures, and relocation processes of historic structures, before the execution phase of the dam project.

The nature of Bisri dam project requires historic preservation strategies such as excavate, dismantle, relocate, and construct, rather than conserve, preserve, restore, and maintain in-situ (Council for Development and Reconstruction, 2014). The following Figure 5.1 shows the mass plan of the church and the monastery within the sloped valley of Bisri.

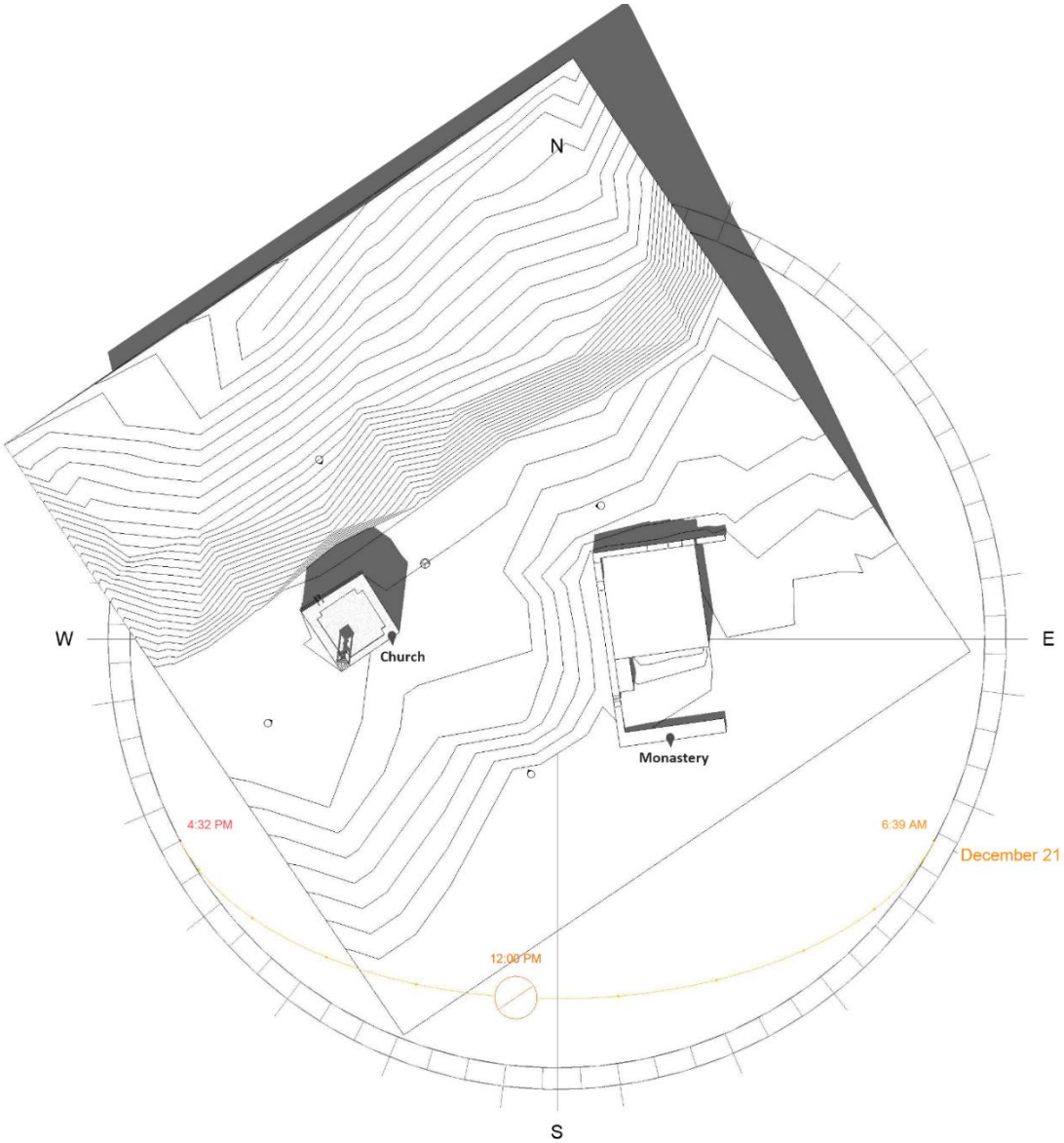


Figure 5.5 Mass Plan of Mar Moussa El Habchi Church and Saint Sophia Monastery, Source: Author

Mar Moussa church is one of the historic religious sites visited annually only on Mar Moussa Day, 28th of August. This is limited to the unpaved track which makes it hard to access the location easily, and the nearest asphalt paved public road is 1,400 meters far from the church (Council for Development and Reconstruction, 2014).

> 'The site is believed to have been used for worship since the 13th century, but the church may have been rebuilt a few decades or more ago as evidenced by the anomaly of a particular cross-engraved stone, broken prior to rebuilding. While a major part of the block has been reused, the missing part was probably lost' (Council for Development and Reconstruction, 2014, p. 198).

According to Alweh (2020), the church dates back to around 150 years which means that its date of construction was in 1871. However, it looks older, and this can be signified throughout the materials used with respect to the ways of reconstruction, and the concrete and metallic additions. Sadaka (2018) in the book of The Virgin Mary in Lebanon of Shouf District has indicated that Mar Moussa El Habachi Church was originally built in the 13th century (approximately in 1280). The residents of Mazraat Al Daher mentioned that the church was destroyed due to an earthquake that occurred in the 1700s. This is emphasized in the report of the Council for Development and Reconstruction (2014), which highlighted those two noticeable earthquakes, of 8.3 magnitudes, were recorded in the 1201 and 1759. This means that the first life cycle phase was from 1280 till 1759, while the second one was from 1871 till now.

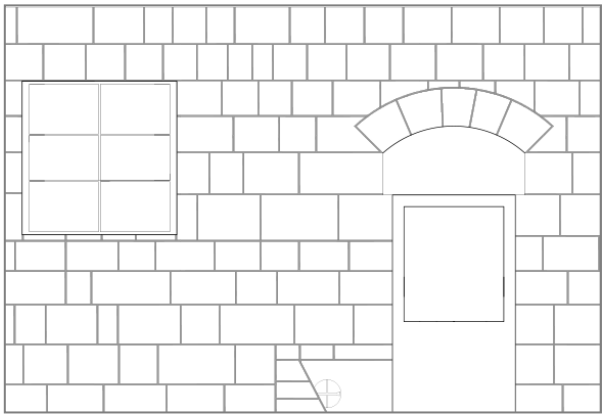


Figure 5.2 Broken Engraved Stone Next to the Door in West Elevation Indicating the Church was Rebuilt, Source: Author

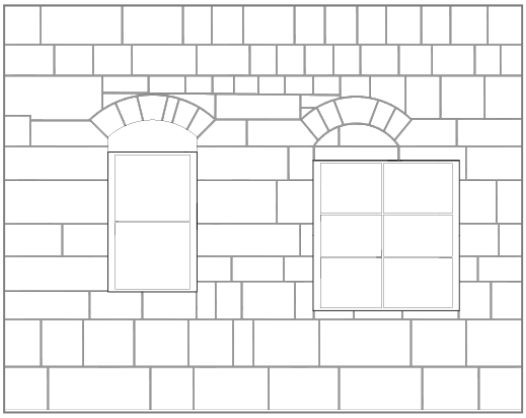


Figure 5.3 Segmental Arch above the Right Window Indicating the Church was Rebuilt, Source: Author

The previous Figures 5.2 and 5.3 show the interior walls of the church. Those two segments of the walls assure that the church was destroyed and then rebuilt. The figure 5.2 shows the broken engraved stone next to the door on the west elevation which was used as a lintel. In the south elevation (Figure 5.3), two windows having segmental arches were present and after reconstruction the right window was replaced by a wider metal one, leaving the segmental arch.

As indicated by the Council for Development and Reconstruction (2014), the strategies required to preserve the church are the dismantling and reassembly of main walls, and the demolition and replacement of church interior vaulting. Besides, architectural salvage from the old houses in the valley will be undertaken to collect old building stones (stone lintels as an example). This could be used to construct other buildings on the new Mar Moussa site. The preservation strategies will require an average of five months to finish the relocation of the church. Four locations were suggested by the Council for Development and Reconstruction (2014) for the relocation of the church, indicating the advantageous and disadvantageous of each option.

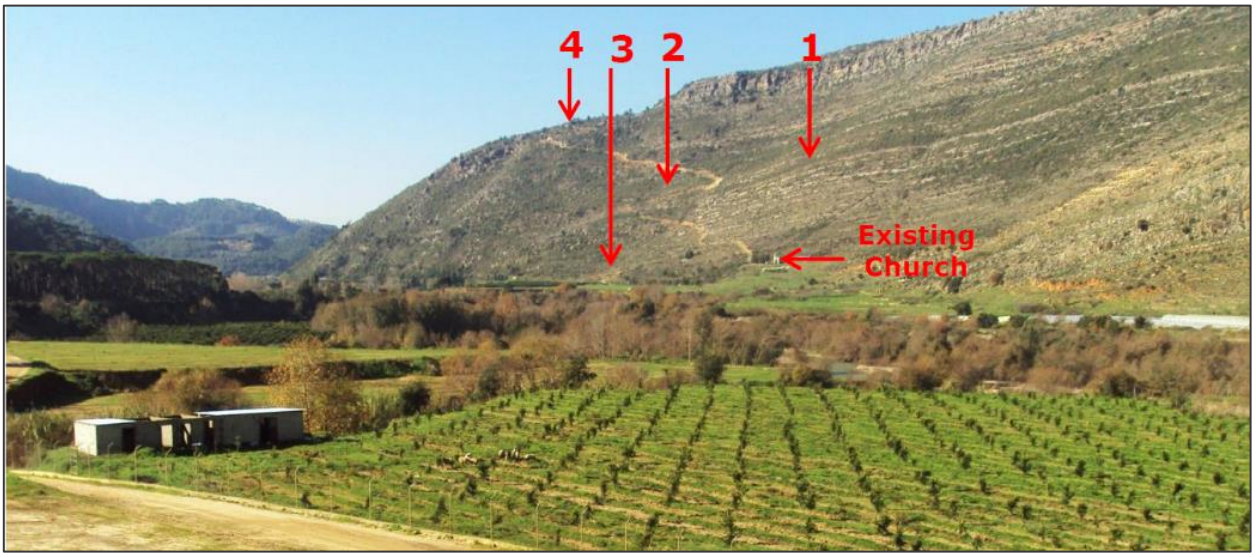


Figure 5.4 Ground View of the Four Site Options for the Relocation of Mar Moussa, Source: Council for Development and Reconstruction, 2014) Accessed: 5-6-2021

The following Table 5.1 addresses the advantages and the disadvantages of the four options of the church relocation. The first option is the most secure with low expropriation cost; however, the site has unattractive views. It needs new access route making the reconstruction phase costly, has steep slopes which results in costly site preparation, and is least expected to provide services and facilities for the future. The second and third option do not need additional land for expropriation because it is partially taken, have space for future facilities, and are less steep than option 1 but still considered steep. The second option is in need of reinforced concrete to stabilize the long sides thus high-cost construction will be charged, has limited view and is difficult to access. As for the third option, it is considered convenient as cost for reconstruction is of similar elevation to the present site. Its location is adjacent to the existing access road and its site clearance is easy. Though, this option has a high risk of dam break risk resulting in structural failure and thus of the church destruction. This means that there is an extensive need for reinforced concrete

retaining walls for stability. Additionally, option three is insecure and has limited vista. The last option (option 4) is not steep and easy to access, has pleasant views, is available for future services, has possibility to attract larger congregation than in the present site. Despite this site requires limited structure: limited retaining walls, it still needs this structure, so additional cost and wastes will be charged. The limitations of this option are as follow: it needs additional expropriated lands, site clearance may be difficult due to in-situ rock, the cost of land is very expensive, and there is no area to accommodate the monastery and the church. While comparing all the options with the most advantages each one has, option four which is 900 meters west southwest and 700 meters away from the river, seemed to be the most recommended.

	Advantages	Disadvantages
Option 1 300 m NNW of present site, 500 m from river	▪ Lower expropriation costs due to steepness of slope ▪ As near vertically above the old site as is possible ▪ Good view upstream over the reservoir	▪ Cost of reconstruction will increase due limited working space and difficult access ▪ The new access track will increase expropriation to 6 plots ▪ Plots are not within present expropriation Decree ▪ Steep slopes (>50%) make site preparation costly ▪ A new access route 400 m in length is needed ▪ No provision to expand current facilities ▪ Site will look unattractive
Option 2 600 m WSW of present site, 500 m from river	▪ The topography is less steep and site clearance will be easier ▪ A larger area is available for the future development of church facilities	▪ Limited view from the site which will primarily be the dam and its concrete apron (300 m downstream of the dam and 30-40 m higher than the crest) ▪ Site is outside the present expropriation, although the plots needed are being partially taken ▪ Reinforced concrete walls will be needed along the site's long sides to provide stability
Option 3 750 m SW of present site, 200 m from river	▪ Available land provides for additional facilities in the future ▪ Site is adjacent to the existing access road ▪ Site is at a similar elevation to present site ▪ The site is already to be expropriated ▪ Most convenient for reconstruction	▪ The site is in the highest dam break risk area, i.e. the church will be totally destroyed if the dam suffers structural failure ▪ The existing access track will be heavily used by construction traffic for a period of 5 years from commencement ▪ The vista from the site will be overwhelmed by the height of the dam and its downstream apron ▪ The site may be more susceptible to vandalism than the other sites
Option 4 900 m WSW of present site, 700 m from river	▪ The highest of the site options, giving long vistas up and down stream without being overwhelmed by the dam structure ▪ Being relatively close to the village, the church may attract larger congregations than is possible at the present site ▪ The existing track from Mazraat El Dahr contains no very steep sections ▪ Land available for the future expansion ▪ Site may require limited retaining walls	▪ Less available area to accommodate for both church and monastery ▪ Very expensive cost of land for land reclamation and terracing part of the site is outside the present expropriation area ▪ Site clearance may be difficult due to in-situ rock

Table 5.8 Advantages and Disadvantages of the Relocation Sites of the Mar Moussa Church, Source: Council for Development and Reconstruction, 2014), Edited by Author, Accessed: 1-6-2021

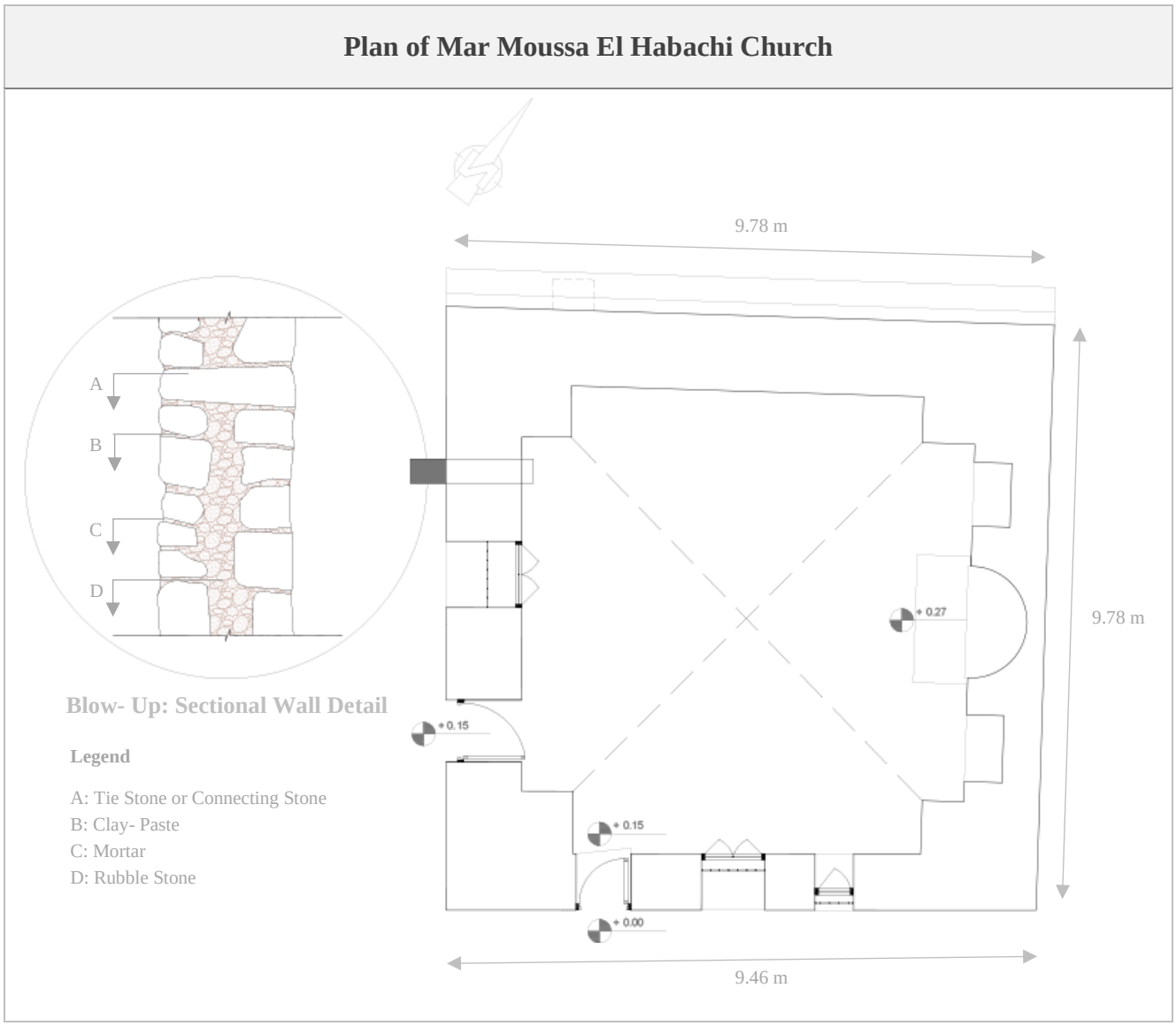
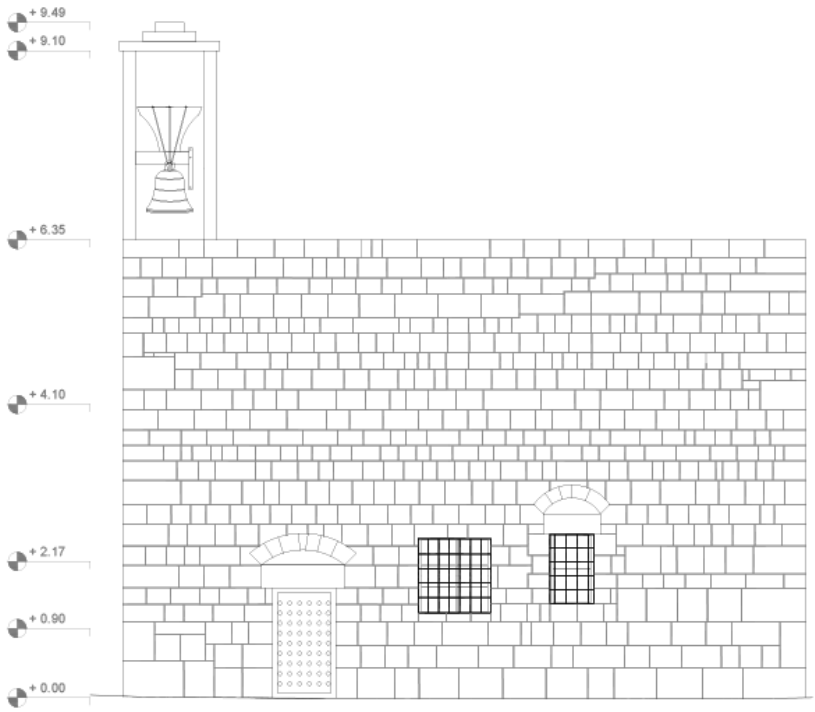
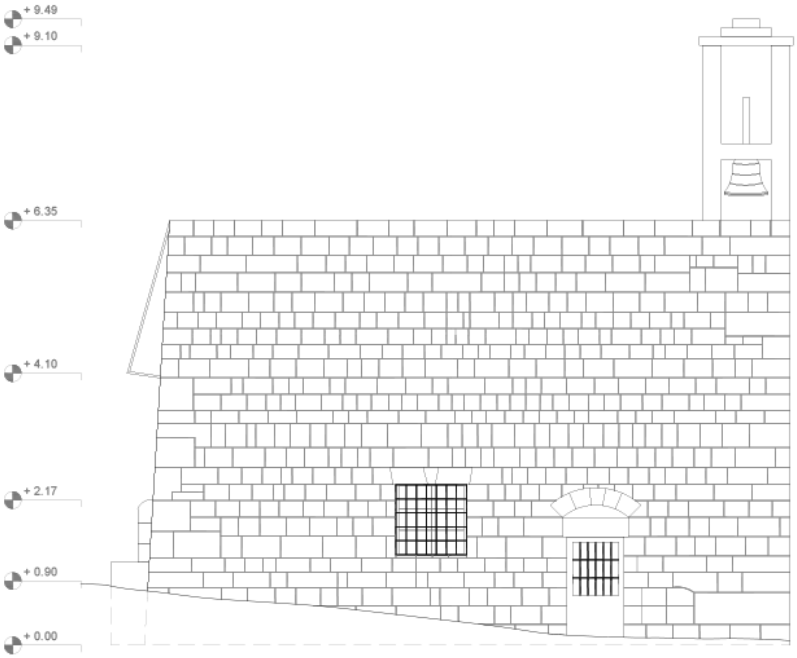
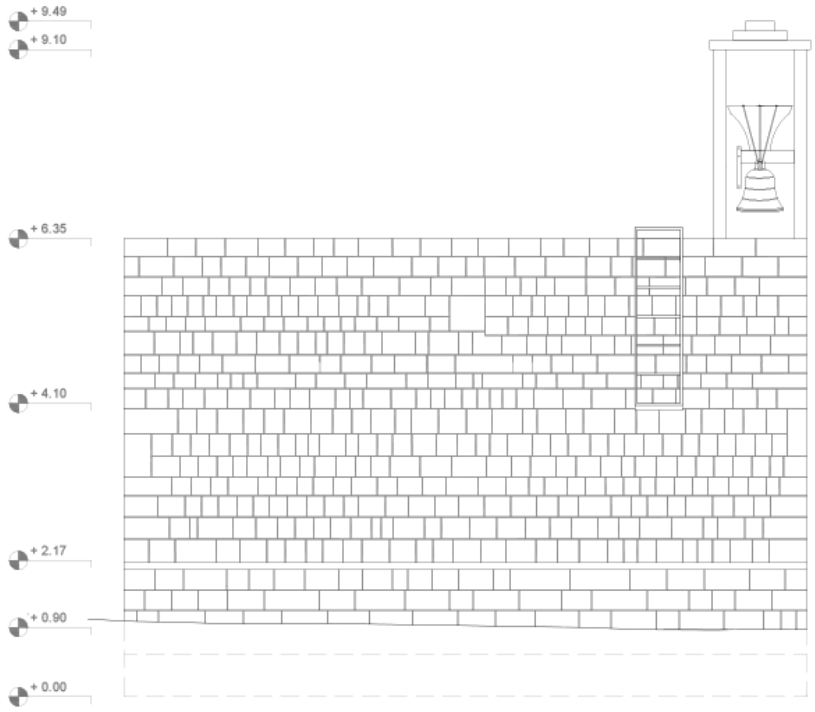
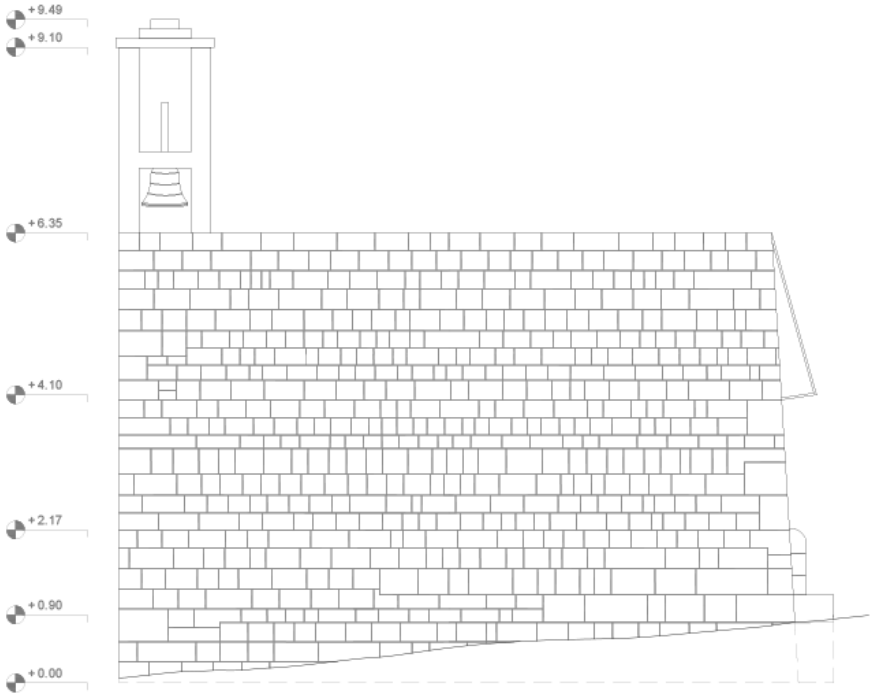


Figure 5.5 Plan of Mar Moussa Church with Blow-up of its Wall Section, Source: By Author

According to Figure 5.5, the height of the church is approximately 6.35 meters and the material used is the masonry unit walls. To the south, there is a metal door with a 15 cm slab to access the interior floor of the church. This side has two windows with metal frames. With the sloped terrain, the west elevation has a recessed metal window with a metal door which allows a direct access to the interior floor of the church. The north elevation has stairs to access the roof while the east elevation is plain. The concrete roof seemed to be added afterwards with a metal bell having concrete structure.

Technical Drawings	Mar Moussa El Habachi Church
South Elevation	 *Figure 5.6 Technical South Elevation of Mar Moussa Church, Source: By Author*
West Elevation	 *Figure 5.7 Technical West Elevation of Mar Moussa Church, Source: By Author*

Technical Drawings	Mar Moussa El Habachi Church
North Elevation	 *Figure 5.8 Technical North Elevation of Mar Moussa Church, Source: By Author*
East Elevation	 *Figure 5.9 Technical East Elevation of Mar Moussa Church, Source: By Author*

Saint Sophia monastery is located 30 meters from the church which is a very close distance. According to the Environmental and Social Impact Assessment, the type of construction seen in the remaining part of the monastery, such as the walls and arches of the stables, indicated that the monastery is considerably older than the church (Council for Development and Reconstruction, 2014). Although there is not an accurate investigation to the date of the monastery, the thick remaining stone wall next to the stables has been reported as a Byzantine wall. This wall was once a boundary wall of the monastery, thus signifying that the monastery as whole dates to the Byzantine period (Council for Development and Reconstruction, 2014).

Plan of Saint Sophia Monastery

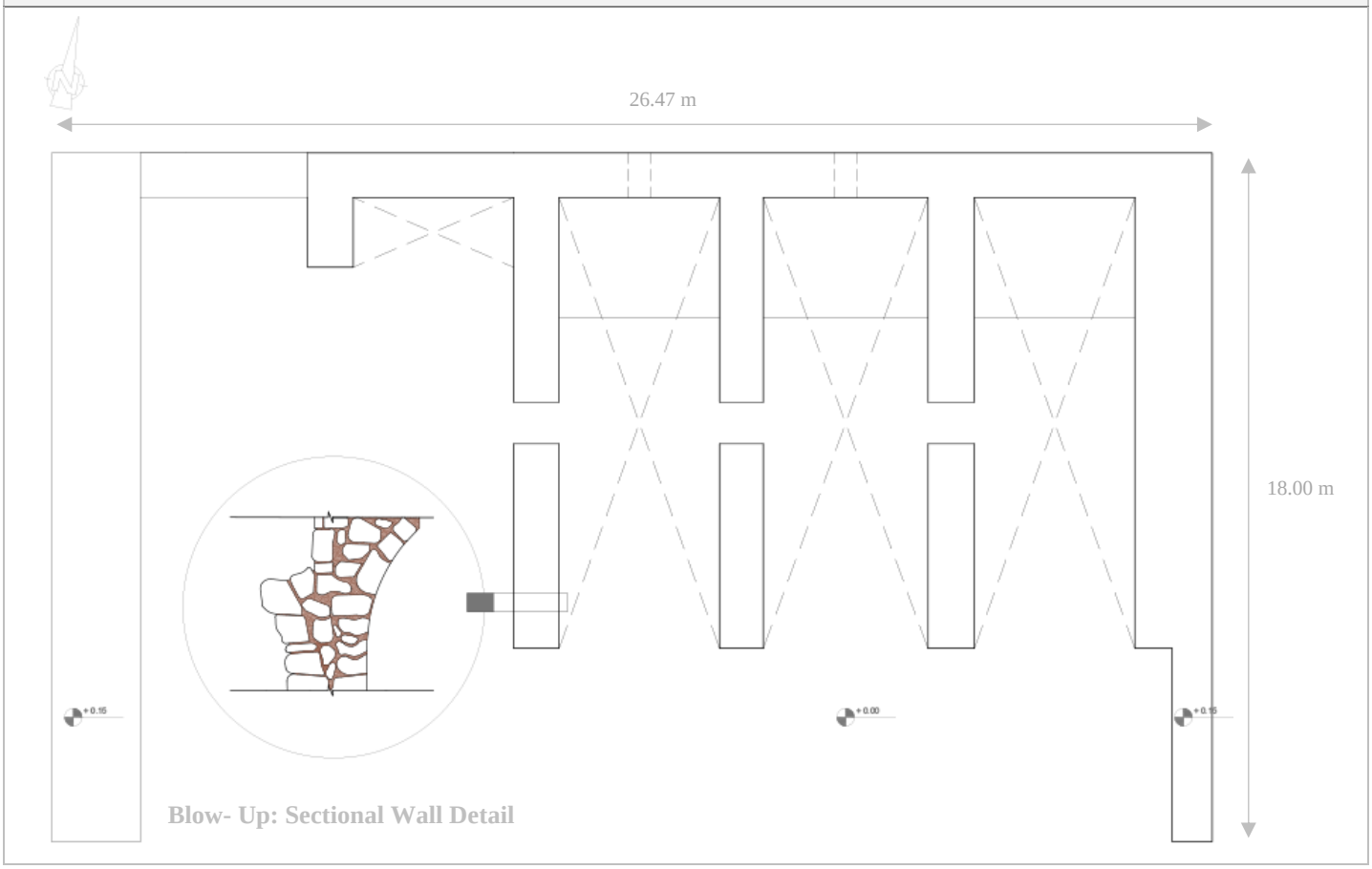
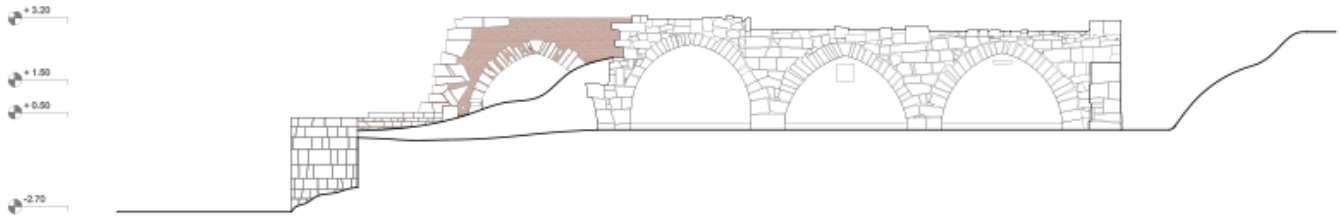
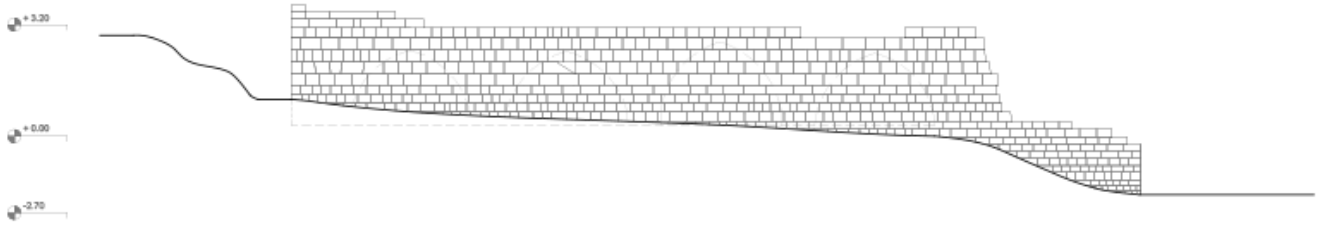
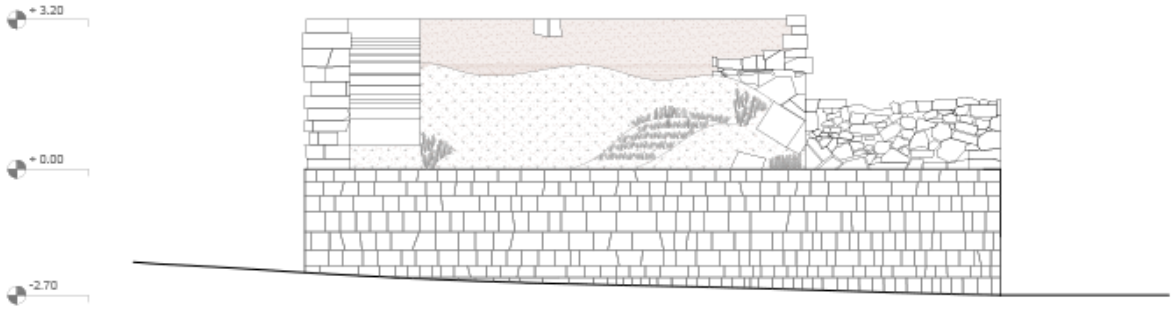
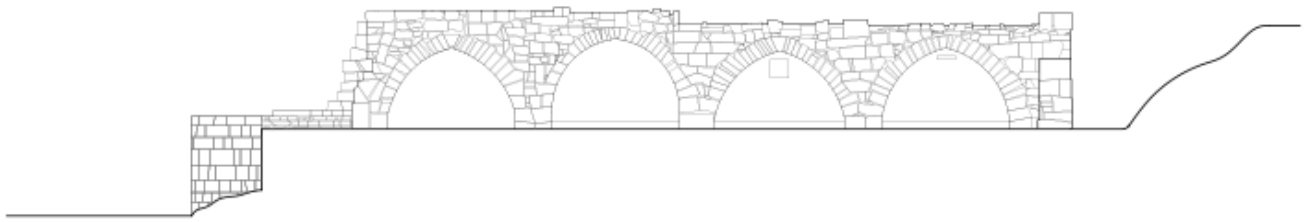
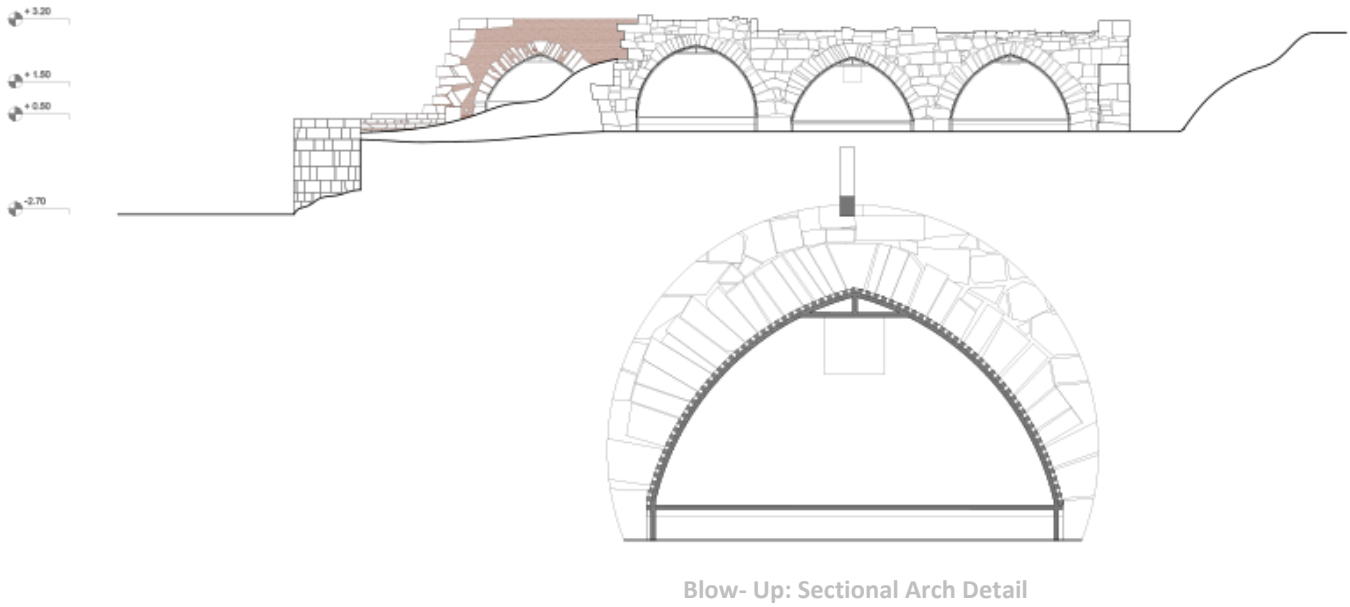


Figure 5.10 Plan of Saint Sophia Monastery with Blow-up of its Wall Section, Source: By Author

Technical Drawings	Saint Sophia Monastery
East Elevation	 *Figure 5.11 Technical East Elevation of Saint Sophia Monastery in Recent Conditions Prior to Structural Additions, Source: Author*
West Elevation	 *Figure 5.12 Technical West Elevation of Saint Sophia Monastery, Source: Author*
South Elevation	 *Figure 5.13 Technical South Elevation of Saint Sophia Monastery, Source: Author*

As shown in the previous Figures 5.11 and 5.12, the monastery is 5.9 meters in height from the lower level of the monastery to the arches of the stables. The monastery is formed of stone material. It has four arches adjacent to each other with a continuous west wall below the level of the arches and facing the valley. There is an interior opening linking each of the arches together. Lately, one the arches fell and resulted in the decomposition of some of the blocks (refer to the

east elevation). It seems that due to the date of the monastery and its failure to sustain the load of the roof on the base, it has resulted in disassembly of one of the arches located on the south side. The structure of the wall in the monastery is mainly large stones attached by soil and rubble, making the structure unstable in the case of any earthquake or pressure exerted. Figures 5.14 and 5.15 below show the original condition of the monastery and the existing condition after the deconstruction of one of the arches. After the deconstruction, a bearing metal and wooden structure was added below each of the arches.

Technical Drawings	Saint Sophia Monastery
Original Condition	 *Figure 5.14 Technical Elevation of the Original Conditions of Saint Sophia Monastery, Source: Author*
Present Phase (Post-Deconstruction)	 *Figure 5.15 Technical Elevation of the Saint Sophia Monastery with Structure After Deconstruction of the Fourth Arch, Source: Author*

As mentioned by Kaplan et al. (2008), a building construction with a tie stone (or connecting stone) acts as an earthquake resistant strategy, especially in the case of Bisri Valley. In chapter four, an extensive analysis was reviewed, through literature, about Bisri Valley and its subjectivity to a seismic risk. Thus, the ways of construction in this region play a role in resisting earthquakes. The church has a tie stone and its construction resists earthquakes because it supports the lateral force of the stone masonry walls (Kaplan et al., 2008). Since the walls of the church were broken and there was no documentation on how it previously looked, this means that the tie stones may be added after its reconstruction (refer to Figure 5.5). However, the monastery is older than the church and its structure is more subjected to fall because it is constructed by pilling loose fieldstones into a dry stone wall, without having tie stones which help in the stability of the structure. For this reason, metal and wooden structures were lately added to the arches of the monastery.

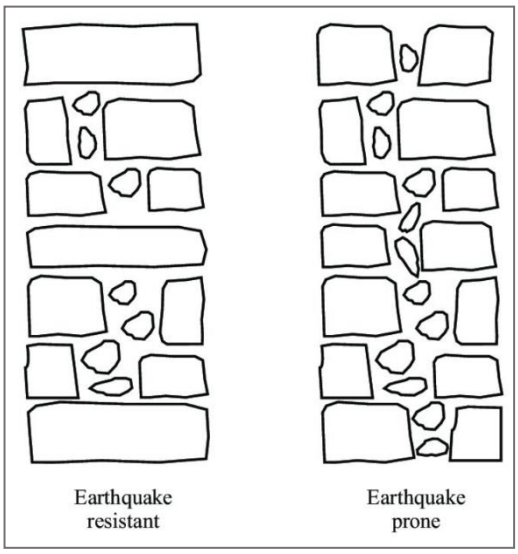


Figure 5.16 Ways of Building Construction as Earthquake Resistance and Earthquake Prone, Source: (Kaplan et al., 2008) Accessed: 9-6-2021

5.3 Applied Modeling and Simulation

As indicated in the methodology chapter, to calculate the embodied energy and carbon emissions of Mar Moussa church and Saint Sophia Monastery, the Revit model was used to simulate the mentioned indicators in Tally Software. In this case, a set of gathered input data such as measures, building location and orientation, was inserted in the Revit model. Section 5.3.1 identifies the data sets which are gathered from site visits and defines the input for Tally software to calculate the embodied energy and carbon emissions.

5.3.1 Revit Model and Input in Tally Software: Calculation of EE and CE

The input data for Tally software is extensively elaborated, including the details and the information needed in each category of the monastery and the church.

- **Mar Moussa Church**

The free trial of Tally version 2020.06.09.01 was downloaded. The models are drawn in Revit then inserted to Tally. The type of study selected is full building study, which is a whole building assessment, including all the categories, phases, work sets and linked models. The categories of the church are the following: floors, roofs, walls, doors, and windows. The green color indicates that all the information of each of these categories was inserted.

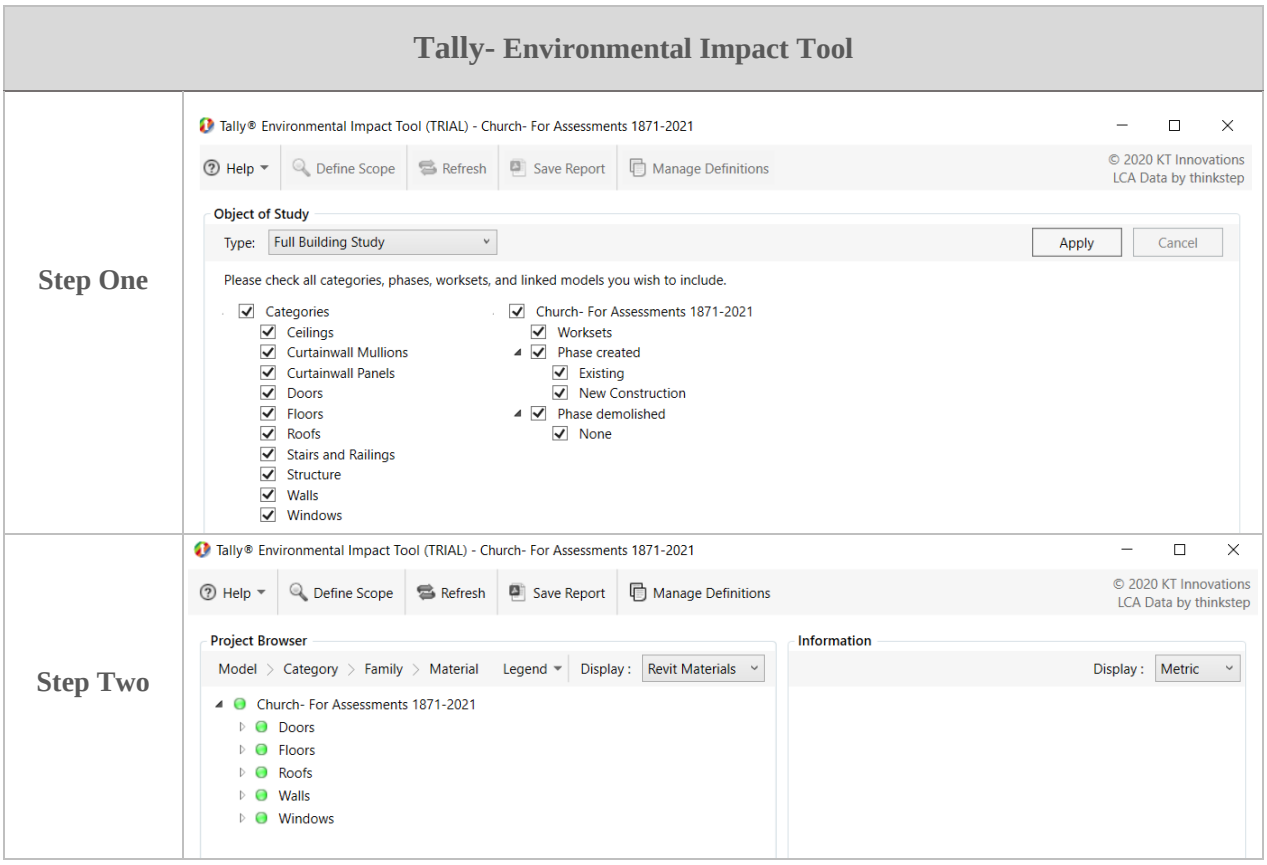


Figure 5.17 The Steps Before Data Input in Tally Software, Source: Author

The two doors of the church are currently of metal structure. The west door is made up of steel with glass intrusions while the south one is purely steel (Figure 5.18). As for the floor category, the main floor of the church is concrete which is shown before entering the church and the interior space has stone tiles. After the period of the church construction, the materials used for the concrete mixture was the following: water, cement, sand, and aggregate. This mixture has no additional materials, and its values were inserted based on the ratio 0.5:1:2:2 respectively. This indicated that each of the sand and aggregate materials are selected equal in quantity, with half its amount for cement and quarter for water. The stone tiles were not recognized as existing or salvaged because its finishing is so clean and seems to be manufactured (as Figure 5.20).

Door of New Church (Figure 5.18)

Total Door Area: 1.53 m²
Door Frame Perimeter: 4.450 m

Door frame, aluminum

Anodized aluminum door frame inclusive of jamb. Entry excludes caulk and attachment method.

Components

- 4.539 kg of Door frame, aluminum, powder-coated, no door
- Service life: manually defined as 80 years
- Takeoff method: by modeled length, using a default value of 1.02 kg/m

0.06622 kg of Fasteners, aluminum (anodized)

- Service life: manually defined as 80 years
- Takeoff method: by modeled length, using a default value of 0.01 lbs/ft

Glazing, monolithic sheet

Components

- 11.48 kg of Glazing, monolithic sheet, safety glass
- Service life: manually defined as 80 years
- Takeoff method: by modeled area, using a predefined value for '3 mm' of 3.00 mm and a density of 2500 kg/m³

Door, exterior, steel

Components

- 26.78 kg of Hollow door, exterior, steel, galvanized, large vision panel
- Service life: manually defined as 80 years
- Takeoff method: by modeled area, using a fixed value of 17.5 kg/m²

1.530 kg of Hardware, aluminum

- Service life: manually defined as 80 years
- Takeoff method: by modeled area, using a default value of 1 kg/m²

1.427 kg of Steel door hinge

- Service life: manually defined as 80 years
- Takeoff method: by modeled area, using a fixed value of 0.933 kg/m²

Figure 5.18 The Details of Doors of Mar Moussa Church in Tally Software, Source: Author

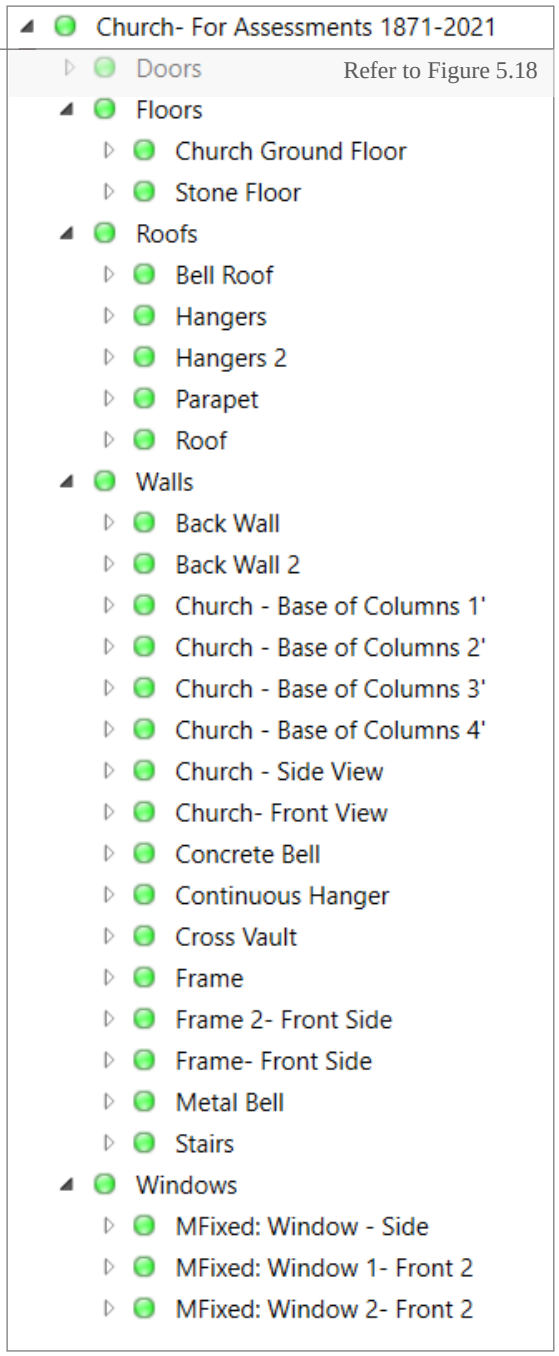


Figure 5.19 The List of Materials for Mar Moussa Church in Tally Software Highlighting the Door Category, Source: Author, Retrieved from Tally

Concrete Ground Floor
(Figure 5.20)

Total Instance Count: 1
Total Floor Area: 96.10 m²
Total Floor Perimeter: 39.21 m
Layer Thickness: 200 m

Cast-in-place concrete, custom mix

Custom concrete mix from ingredients, based on weight of each ingredient per cubic meter of finished concrete.

Component

8,476 kg of Portland cement, PCA – EPD

- Service life: manually defined as 90 years
- Takeoff method: by modeled volume, using a manually entered value of 14.0% by volume and a density of 3150 kg/m³

20,757 kg of Coarse aggregate

- Service life: default to building life
- Takeoff method: by modeled volume, using a manually entered value of 40.0% by volume and a density of 2700 kg/m³

20,013 kg of Sand

- Service life: default to building life
- Takeoff method: by modeled volume, using a manually entered value of 39.0% by volume and a density of 2670 kg/m³

1,345 kg of Water

- Service life: default to building life
- Takeoff method: by modeled volume, using a manually entered value of 7.00% by volume and a density of 1000 kg/m³

Stone Floor Tiles
(Figure 5.20)

Total Instance Count: 1
Total Floor Area: 53.40 m²
Total Floor Perimeter: 29.34 m
Layer Thickness: 30.00 mm

Stone tile

Stone tile inclusive of mortar, grout (if any), and finish (if any). User to specify stone type and tile thickness.

Component

- 4,165 kg of Stone tile
- Service life: manually defined as building life
- Takeoff method: by modeled area, using a manually entered value of 0.03 m and a density of 2600 kg/m³

577.3 kg of Thickset mortar

- Service life: manually defined as building life
- Takeoff method: by modeled area, using a manually entered value of 0.005 m and a density of 2162 kg/m³
- Grout type: None selected

Figure 5.20 The Details of Concrete Floor and Stone Tiles of Mar Moussa Church in Tally Software, Source: Author

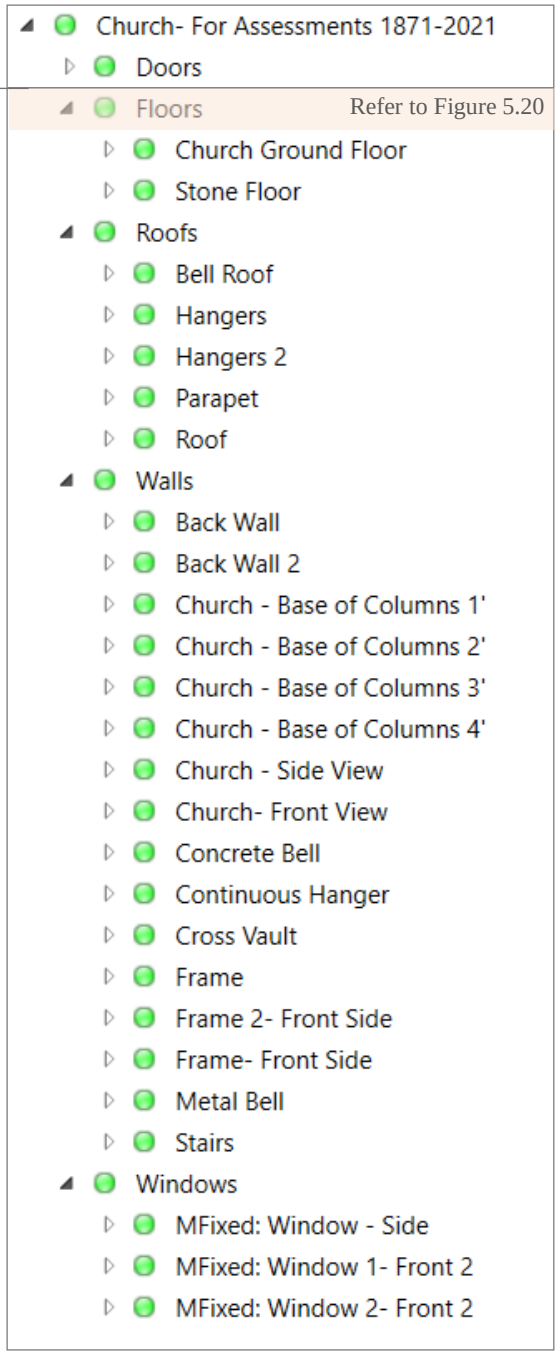


Figure 5.21 The List of Materials for Mar Moussa Church in Tally Software Highlighting the Floor Category, Source: Author, Retrieved from Tally

Roof

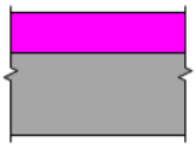
Total Instance Count: 1
Total Floor Area: 91.78 m²
Total Floor Perimeter: 38.33 m

Concrete Upper Part

Layer Thickness: 100 mm (Figure 5.22)

Cast-in-place concrete, custom mix

Custom concrete mix from ingredients, based on weight of each ingredient per cubic meter of finished concrete.



Component

4,047 kg of Portland cement, PCA – EPD

- Service life: manually defined as 90 years
- Takeoff method: by modeled volume, using a manually entered value of 14.0% by volume and a density of 3150 kg/m³

9,912 kg of Coarse aggregate

- Service life: default to building life
- Takeoff method: by modeled volume, using a manually entered value of 40.0% by volume and a density of 2700 kg/m³

9,557 kg of Sand

- Service life: default to building life
- Takeoff method: by modeled volume, using a manually entered value of 39.0% by volume and a density of 2670 kg/m³

642.4 kg of Water

- Service life: default to building life
- Takeoff method: by modeled volume, using a manually entered value of 7.00% by volume and a density of 1000 kg/m³

Earth Lower Part

Layer Thickness: 200 mm (Figure 5.22)

Flooring, underlayment, cementitious

Self-leveling cementitious underlayment or fiber cement underlayment board.

Component

- 45,581 kg of Self-leveling underlayment
- Service life: manually defined as building life
- Existing or salvaged material
- Takeoff method: by modeled area, using a manually entered value of 0.2 m and a density of 2483.25 kg/m³

Figure 5.22 The Details of Upper and Lower Roof Materials of Mar Moussa Church in Tally Software, Source: Author

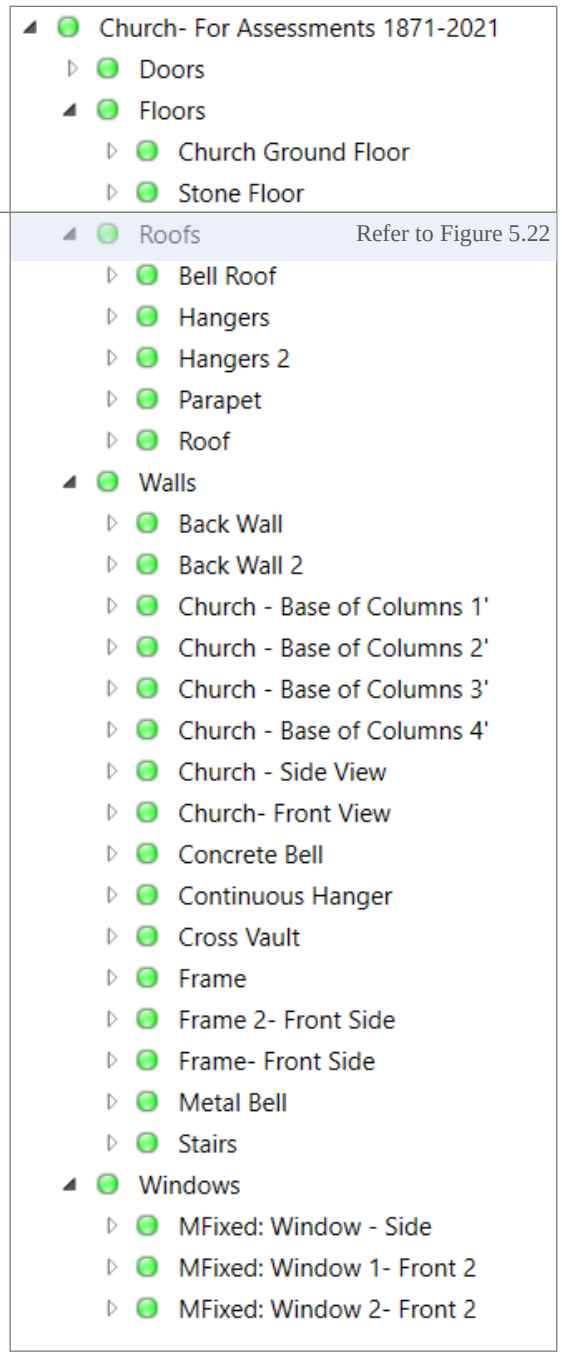


Figure 5.23 The List of Materials for Mar Moussa Church in Tally Software Highlighting the Roof Category, Source: Author, Retrieved from Tally

Metal Bell (Figure 5.24)

Total Instance Count:	1
Total Wall Area:	1.23 m²
Total Wall Perimeter:	6.274 m
Layer Thickness :	100 m

Copper, cast or drawn (Cast or drawn copper member)

Components

- 1,100 kg of Copper, cast
- Service life: manually defined as building life
- Takeoff method: by modeled volume, using a default value of 100% by volume and a density of 8940 kg/m³

Stairs (Figure 5.25)

Total Instance Count:	7
Total Wall Area:	1.332 m²
Total Wall Perimeter:	44.36 m
Total Wall Length:	2.943 m
Layer Thickness:	100 mm

Stair, steel plate

Steel stair riser made from 1/4" steel plate inclusive of forming

Components

- 106.5 kg of Steel, sheet
- Service life: manually defined as 80 years
- Takeoff method: by modeled area, using a default value of 80.0 kg/m²

Windows- Side (Figure 5.26)

Total Instance Count:	1
Total Window Area:	1.134 m²
Total Frame Perimeter:	4.260 m

Curtain wall System (including glazing)

Components

- 40.38 kg of Curtain wall system, Kawneer, 1600 Wall System – EPD
- Service life: manually defined as 80 years
- Takeoff method: by modeled area, using a fixed value of 35.6 kg/m²

Window frame, steel

Components

- 12.65 kg of Window frame, steel, galvanized, divided operable
- Service life: manually defined as 80 years
- Takeoff method: by modeled length, using a fixed value of 2.97 kg/m

1.134 kg of Hardware, stainless steel

- Service life: manually defined as 80 years
- Takeoff method : by modeled area, using a default value of 1 kg/m²

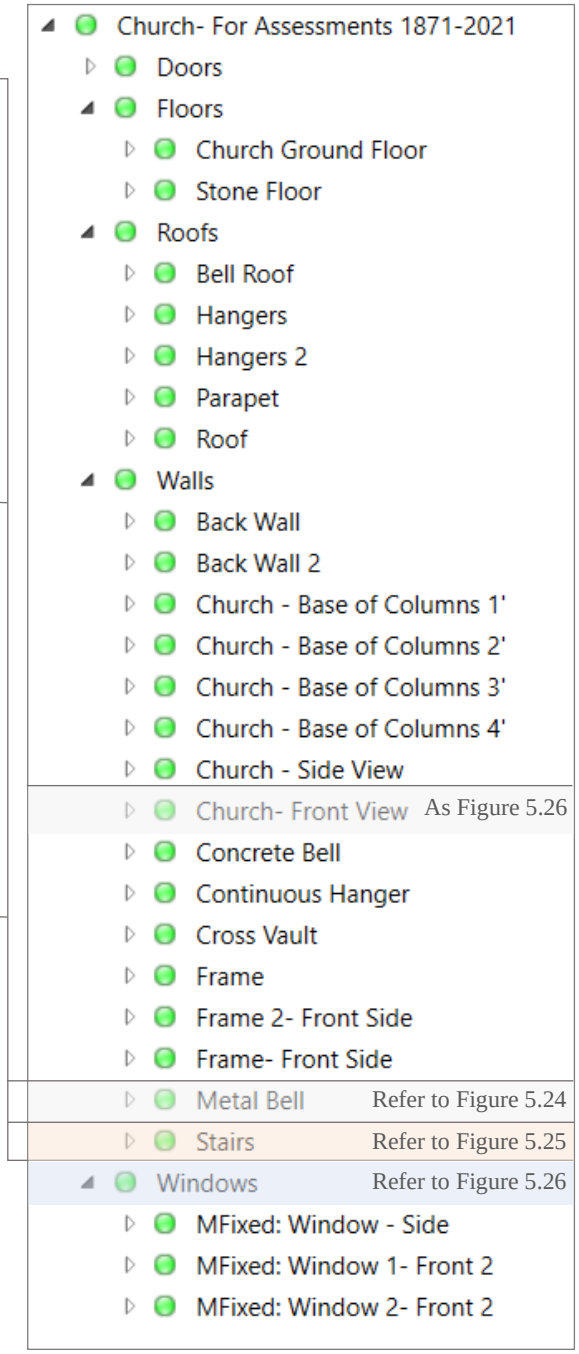
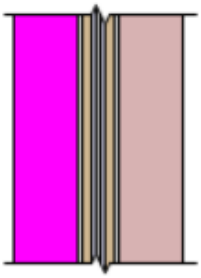
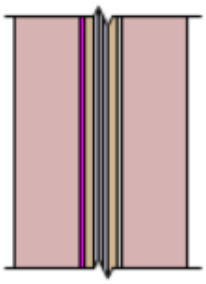
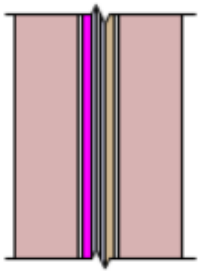


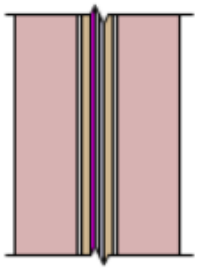
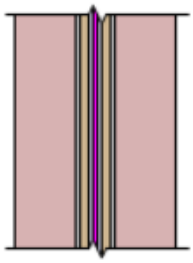
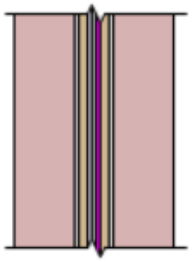
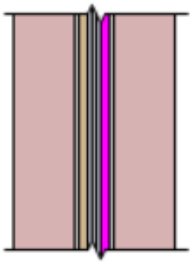
Figure 5.27 The List of Materials for Mar Moussa Church in Tally Software Highlighting Some of Walls Category and the Window Category, Source: Author, Retrieved from Tally

Figure 5.24 Details of Metal Bell Materials of Mar Moussa Church in Tally Software, Source: Author

Figure 5.25 Details of Stair-Roof of Mar Moussa Church in Tally Software, Source: Author

Figure 5.26 Details of Side Window Materials of Mar Moussa Church in Tally Software, Source: Author

Materials of Monastery Front Wall	Total Instance Count: 1 Total Wall Area: 57.10 m² Total Wall Perimeter: 29.29 m Total Wall Length: 8.297 m
Masonry Wall (Finish 1) Layer Thickness: 0.35m	**Stone veneer wall, limestone, grouted** Limestone stone veneer with type S mortar **Components** - 47,961 kg of Stone wall, limestone - Service life: manually defined as building life - Existing or salvaged material - Takeoff method: by modeled area, using a manually entered value of 0.35 m and a density of 2400 kg/m³ 551.3 kg of Mortar type - Service life: manually defined as 1 year - Existing or salvaged material - Takeoff method: by modeled volume, using a predefined value for '6mm joint for 600mm stone' of 1.97% by volume and a density of 1400 kg/m³ 
Mortar (Finish 1) Layer Thickness: 0.01m	**Cast-in-place concrete, custom mix** Custom concrete mix from ingredients **Components** 290.2 kg of Lime - Service life: default to building life - Takeoff method: by modeled volume, using a manually entered value of 23.0% by volume and a density of 2210 kg/m³ 1,067 kg of Sand - Service life: default to building life - Takeoff method: by modeled volume, using a manually entered value of 70.0% by volume and a density of 2670 kg/m³ 39.97 kg of Water - Service life: default to building life - Takeoff method: by modeled volume, using a manually entered value of 7.00% by volume and a density of 1000 kg/m³ 
Clay- Paste Layer Thickness: 0.05m	**Cast-in-place concrete, custom mix** Custom concrete mix from ingredients **Components** 1,451 kg of Lime - Service life: default to building life - Takeoff method: by modeled volume, using a manually entered value of 23.0% by volume and a density of 2210 kg/m³ 5,336 kg of Sand - Service life: default to building life - Takeoff method: by modeled volume, using a manually entered value of 70.0% by volume and a density of 2670 kg/m³ 199.8 kg of Water - Service life: default to building life - Takeoff method : by modeled volume, using a manually entered value of 7.00% by volume and a density of 1000 kg/m³ 

Rubble Layer Thickness: 0.03m	**Trim, stone** Stone trim, by profile. User to select attachment type (if any). **Components** - 4,454 kg of Trim, stone - Service life: manually defined as building life - Existing or salvaged material - Takeoff method: by modeled area, using a manually entered value of 0.03 m and a density of 2600 kg/m³ Attachment: None selected Grout: None selected	
Earth Layer Thickness: 0.03m	**Flooring, underlayment, cementitious** Self-leveling cementitious underlayment or fiber cement underlayment board. **Components** - 4,254 kg of Self-leveling underlayment - Service life: manually defined as building life - Existing or salvaged material - Takeoff method: by modeled area, using a manually entered value of 0.03 m and a density of 2483.25 kg/m³	
Rubble Layer Thickness: 0.03m	**Trim, stone** Stone trim, by profile. User to select attachment type (if any). **Components** - 4,454 kg of Trim, stone - Service life: manually defined as building life - Existing or salvaged material - Takeoff method: by modeled area, using a manually entered value of 0.03 m and a density of 2600 kg/m³ Attachment: None selected Grout: None selected	
Clay- Paste Layer Thickness: 0.05m	**Cast-in-place concrete, custom mix** Custom concrete mix from ingredients, **Components** 1,451 kg of Lime - Service life: default to building life - Takeoff method: by modeled volume, using a manually entered value of 23.0% by volume and a density of 2210 kg/m³ 5,336 kg of Sand - Service life: default to building life - Takeoff method: by modeled volume, using a manually entered value of 70.0% by volume and a density of 2670 kg/m³ 199.8 kg of Water - Service life: default to building life - Takeoff method: by modeled volume, using a manually entered value of 7.00% by volume and a density of 1000 kg/m³	

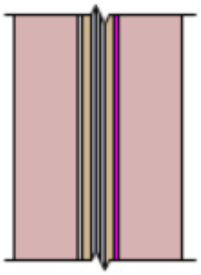
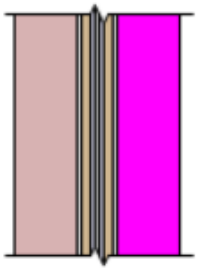
Mortar (Finish 2) Layer Thickness: 0.01m	**Cast-in-place concrete, custom mix** Custom concrete mix from ingredients **Components** 290.2 kg of Lime - Service life: default to building life - Takeoff method: by modeled volume, using a manually entered value of 23.0% by volume and a density of 2210 kg/m³ 1,067 kg of Sand - Service life: default to building life - Takeoff method: by modeled volume, using a manually entered value of 70.0% by volume and a density of 2670 kg/m³ 39.97 kg of Water - Service life: default to building life - Takeoff method : by modeled volume, using a manually entered value of 7.00% by volume and a density of 1000 kg/m³ 
Masonry Wall (Finish 2) Layer Thickness: 0.35m	**Stone veneer wall, limestone, grouted** Limestone stone veneer with type S mortar **Components** - 47,961 kg of Stone wall, limestone - Service life: manually defined as building life - Existing or salvaged material - Takeoff method: by modeled area, using a manually - entered value of 0.35 m and a density of 2400 kg/m³ 551.3 kg of Mortar type - Service life: manually defined as 1 year - Existing or salvaged material - Takeoff method: by modeled volume, using a predefined value for '6mm joint for 600mm stone' of 1.97% by volume and a density of 1400 kg/m³ 

Figure 5.28 Details of Wall Composition of Mar Moussa Church in Tally Software, Source: Author

The previous figures highlighted each of the categories briefly. The roof details of the church in Figure 5.22 have two layers: concrete under the parapet, and the earth layer above the cross-vault. The same ratio of the concrete mixture was used as that of the floor (0.5:1:2:2). The earth layer was substituted by cementitious underlayment because Tally lacks this material. Accordingly, the metal bell on the roof was manufactured from 1,100 kg of copper (refer to Figure 5.24) and the stairs to reach the roof was also made of metal risers (shown in Figure 5.25). As for the window category in Figure 5.26, there are three windows in the church, and all are made of glass with metal frames (weighing around 12.6kg each). Additionally, in front of the windows

there are cold-formed steel frames which are painted white. Finally, the wall category was defined in Figure 5.28. The wall composition was identified into different layers. The thickness of the wall is approximately 0.9m to 1.22m. The exterior finishing is masonry with a clay-paste mixture to combine each stone in the construction phase. Similarly, another finishing from the interior façade is also masonry and clay-paste. The space in between both finishes is a combination of earth and rubble (stones leftovers which are small-sized). The masonry finishing from both facades has mortar between one stone and the other to prevent any infiltration. Prior to saving the report of results and analysis, the transportation factor was selected as zero kilometers for masonry stone walls and 30 kilometers for the added materials to its original construction. The additional materials are manufactured in Jezzine, which is the nearest location to Bisri Valley, thus 30 kilometers represents this distance.

- **The Monastery**

The monastery has a one floor masonry slab of 20cm with a soil floor ground and masonry walls.

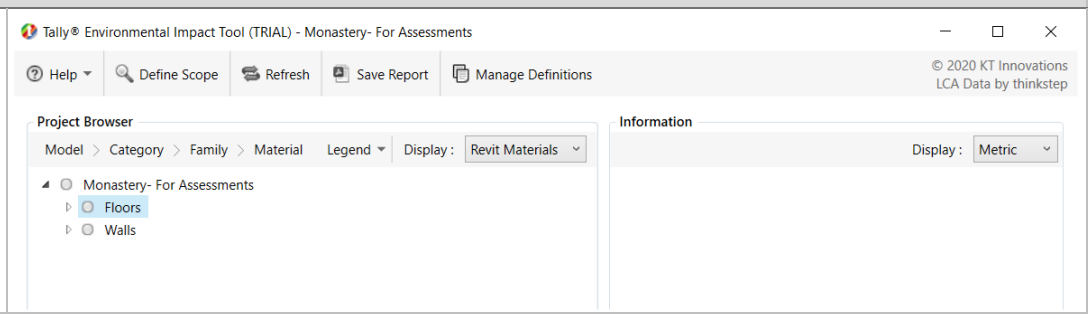
Tally- Environmental Impact Tool	
Monastery- Categories	

Figure 5.29 Categories of Monastery in Tally Software, Source: Author

The details of each of the floor and wall categories were afterwards inserted, such as the materials used and its thickness. Figure 5.29 shows all the materials used for the assessment of the monastery. To make it clearer, the following Figure 5.33 gives an example of the information needed to end up the assessment of the monastery floor, metal elements, wooden elements, and the back wall. Those categories are further elaborated because there is only one floor in the monastery, and within the wall category there are two main structures (metal and wooden elements) under the arches of the monastery stables shown in Figure 5.31 and 5.32. As for the back wall, it represents an example of the composition of the walls which are the same among all walls and differ by the thickness of each of the masonry (finish 1), earth, rubble, and masonry (finish 2). Before conducting the report of analysis, the transportation factor was selected as zero kilometers because all materials are local.

Monastery Floor
(Figure 5.30)

Total Instance Count:	1
Total Wall Area:	27.43 m²
Total Wall Perimeter:	36.70 m
Layer Thickness:	200 m

Stone veneer wall, limestone, grouted

Components

13,168 kg of Stone wall, limestone

- Service life: manually defined as building life
- Existing or salvaged material
- Takeoff method: by modeled area, using a manually entered value of 0.2 m and a density of 2400 kg/m³

151.3 kg of Mortar type

- Service life: manually defined as 1 year
- Existing or salvaged material
- Takeoff method: by modeled volume, using a predefined value for '6mm joint for 600mm stone' of 1.97% by volume and a density of 1400 kg/m³

Metal Elements
(Figure 5.31)

Total Instance Cunt:	58
Total Wall Area:	11.89 m²
Total Wall Perimeter:	1,727 m
Total Wall Length:	263.5 m
Layer Thickness:	35 mm

Steel, rectangular tubing

Structural, cold-formed steel tube. Used for columns, posts, beams, trusses, and miscellaneous framing. User to select steel type and factory or field finish (if any).

Components

- 2.458E+007 kg of Cold formed structural steel
- Service life: manually defined as 4 years
- Existing or salvaged material
- Takeoff method: by modeled length, using a manually entered value of 11.9 m² and a density of 7850 kg/m³

Finish: None selected

Wooden Elements
(Figure 5.32)

Total Instance Count:	192
Total Wall Area:	67.97 m²
Total Wall Perimeter:	436.1 m
Layer Thickness:	35 mm

Wood framing

Kiln-dried wood framing member for stud wall construction. User to choose from a list of standard stud sections.

Components

- 530.4 kg of Domestic softwood, US, AWC – EPD
- Service life: manually defined as 4 years
- Existing or salvaged material
- Takeoff method: by spacing, using a predefined value for '32mm x 45mm' of 14.4 cm² and a density of 433.57 kg/m³, 1-way spacing at 8 cm

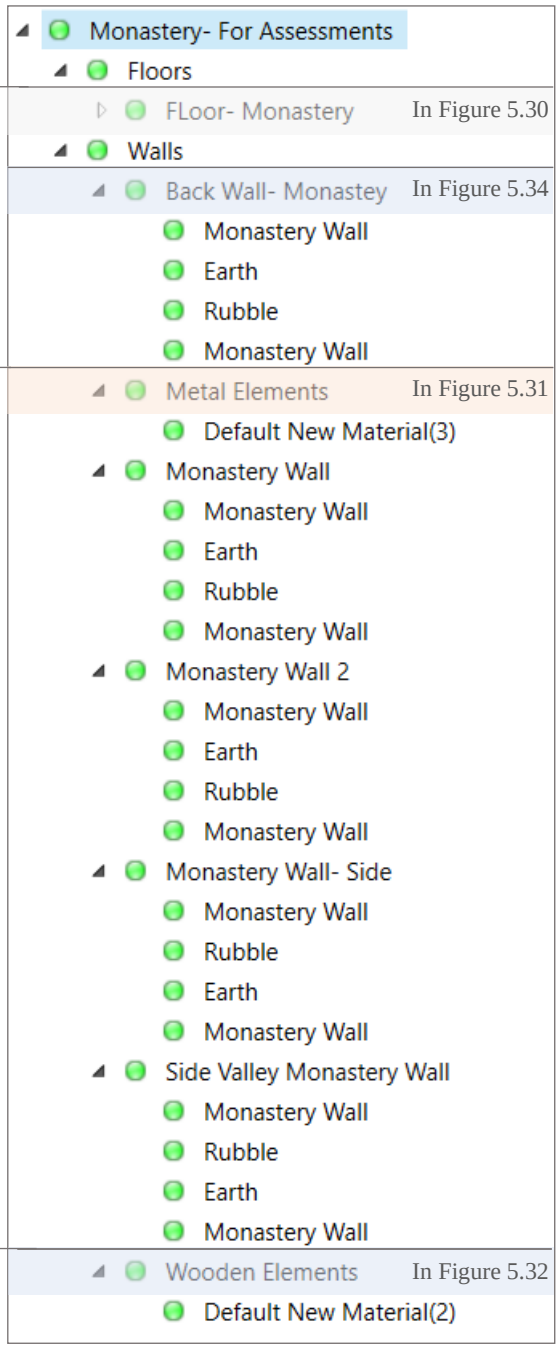
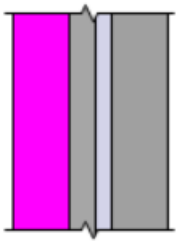
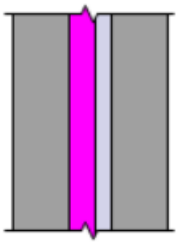
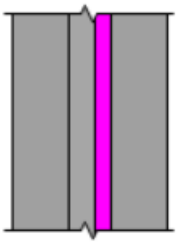


Figure 5.33 The List of Materials for the Monastery in Tally Software Highlighting the Floor and Wall Categories, Source: Author, Retrieved from Tally

Figure 5.30 Details of Monastery Floor in Tally Software, Source: Author
Figure 5.31 Details of Structural Metal Elements of Monastery Stables in Tally Software, Source: Author
Figure 5.32 Details of Structural Wooden Elements of Monastery Stables in Tally Software, Source: Author

Materials of Monastery Back Wall	Total Instance Count: 1 Total Wall Area: 111.9 m² Total Wall Perimeter: 60.61 m Total Wall Length: 25.56 m	
Masonry Wall (Finish 1) Layer Thickness: 0.35m	**Stone veneer wall, limestone, grouted** Limestone stone veneer with type S mortar **Components** - 93,996 kg of Stone wall, limestone - Service life: manually defined as building life - Existing or salvaged material - Takeoff method: by modeled area, using a manually entered value of 0.35 m and a density of 2400 kg/m³ 1,080 kg of Mortar type - Service life: manually defined as 1 year - Existing or salvaged material - Takeoff method: by modeled volume, using a predefined value for '6mm joint for 600mm stone' of 1.97% by volume and a density of 1400 kg/m³	
Earth Layer Thickness: 0.16m	**Flooring, underlayment, cementitious** Self-leveling cementitious underlayment or fiber cement underlayment board. **Components** - 44,460 kg of Self-leveling underlayment - Service life: manually defined as building life - Existing or salvaged material - Takeoff method: by modeled area, using a manually entered value of 0.16 m and a density of 2483.25 kg/m³	
Rubble Layer Thickness: 0.1m	**Trim, stone** Stone trim, by profile. User to select attachment type (if any). **Components** - 29,094 kg of Trim, stone - Service life: manually defined as building life - Existing or salvaged material - Takeoff method: by modeled area, using a manually entered value of 0.1 m and a density of 2600 kg/m³ Attachment: None selected Grout: None selected	

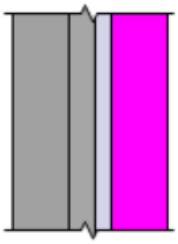
Masonry Wall (Finish 2) Layer Thickness: 0.35m	**Stone veneer wall, limestone, grouted** Limestone stone veneer with type S mortar **Components** - 93,996 kg of Stone wall, limestone - Service life: manually defined as building life - Existing or salvaged material - Takeoff method: by modeled area, using a manually - entered value of 0.35 m and a density of 2400 kg/m³ 1,080 kg of Mortar type - Service life: manually defined as 1 year - Existing or salvaged material - Takeoff method: by modeled volume, using a predefined value for '6mm joint for 600mm stone' of 1.97% by volume and a density of 1400 kg/m³ 

Figure 5.34 Details of Wall Composition of Monastery in Tally Software, Source: Author

5.3.2 Limitations

Tally software uses the American standard and not all the materials of the existing site can be found easily. There was an attempt to choose the materials with minimal differences with respect to the existing conditions. This will not account for significant variations in the results. The materials were selected after an extensive research to better understand the components of each, and which is the most relevant in Tally.

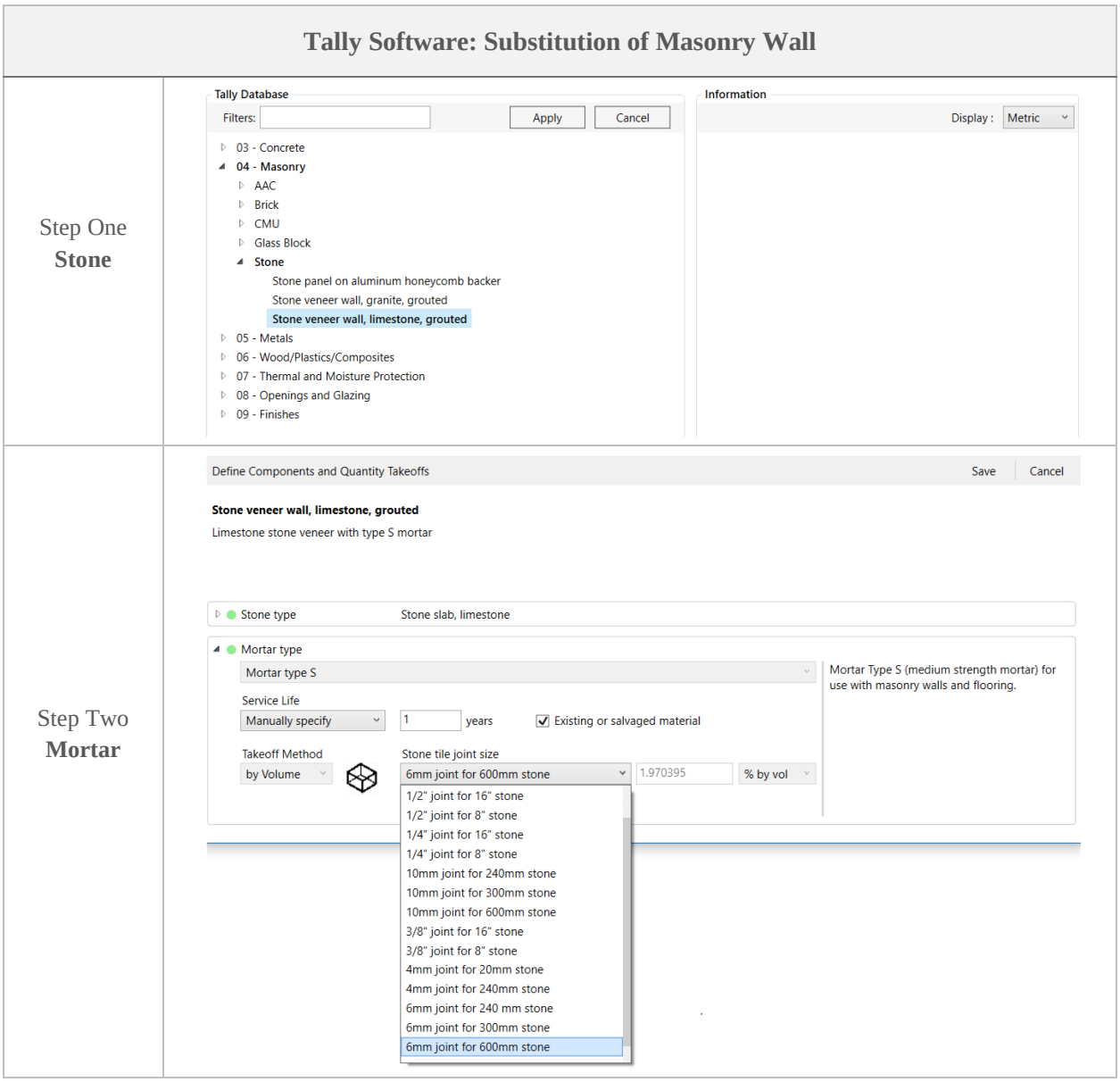


Figure 5.35 Substitution of Masonry Wall to Stone Veneer Wall in Tally Software, Source: Author

First, there is no masonry wall in Tally; thus, there are two options to choose: stone veneer granite wall or stone veneer limestone wall. The most relevant one is the limestone veneer wall (Figure 3.35). In Lebanon, almost all the rocks are of karstic formation and the limestone was used as a building stone (Walley, 1998). During the period of the church construction, local materials were used, so limestone rocks were the existing type in the surrounding of the site. Stones were placed above each other without mortar. Meanwhile, the mortar in Tally was selected with one-year service life as salvaged material, and with elongated joint span to reduce its quantity and thus minimize its environmental impact.

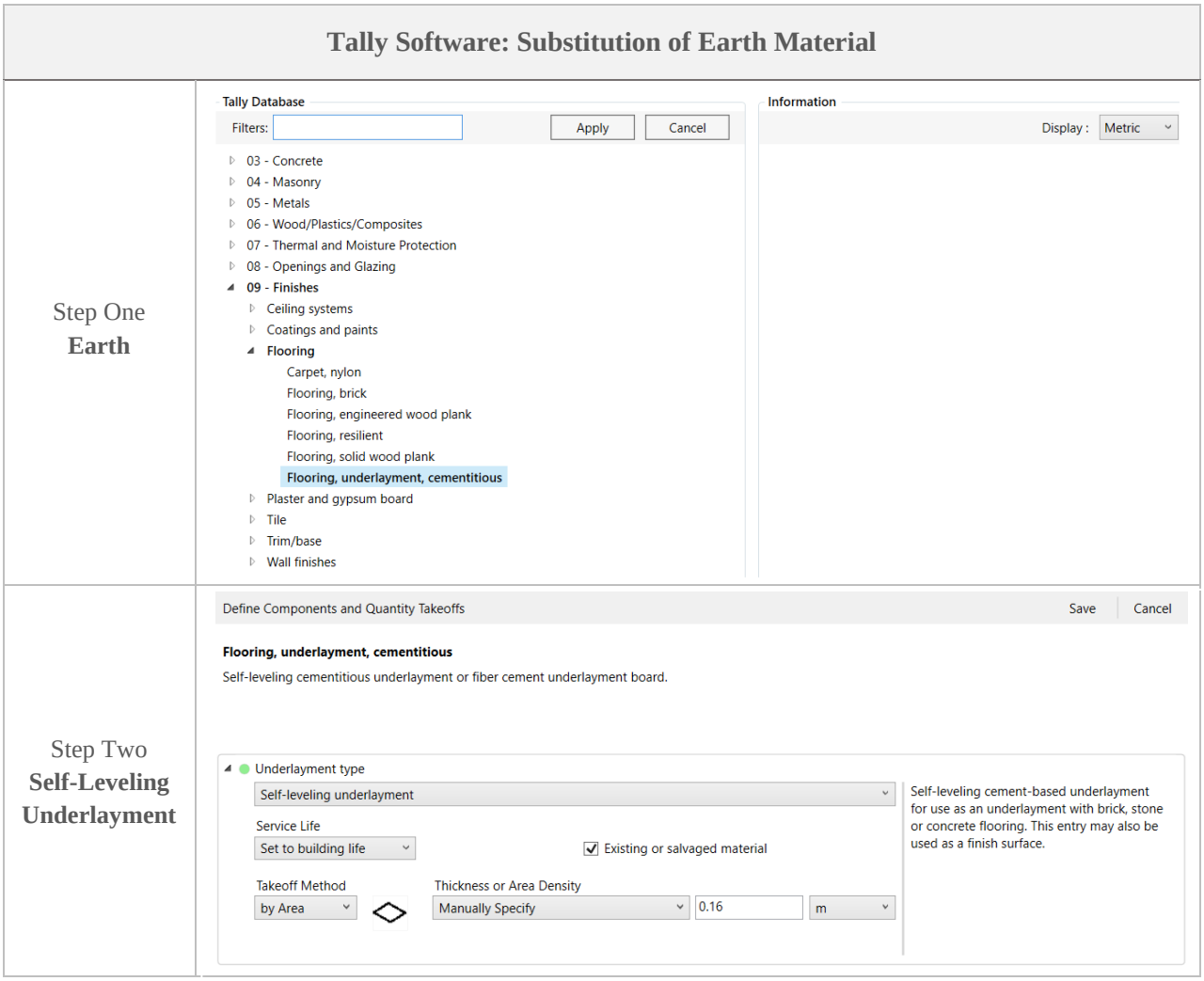


Figure 5.36 Substitution of Earth Material to Underlayment Cementitious Material in Tally Software, Source: Author

Second, the earth material refers to rocks and soils in the existing condition; however, Tally does not include earth. In this case, self-leveling underlayment flooring is used in Tally which includes the stone flooring (Figure 5.36).

Third, the rubble material is a set of small stones on-site which was not used in the finishing phase of construction. In Tally, trim stone material was selected without choosing any attachment and grouting (as in Figure 5.37). This will not carry any environmental impact and will be more relevant to the existing structure.

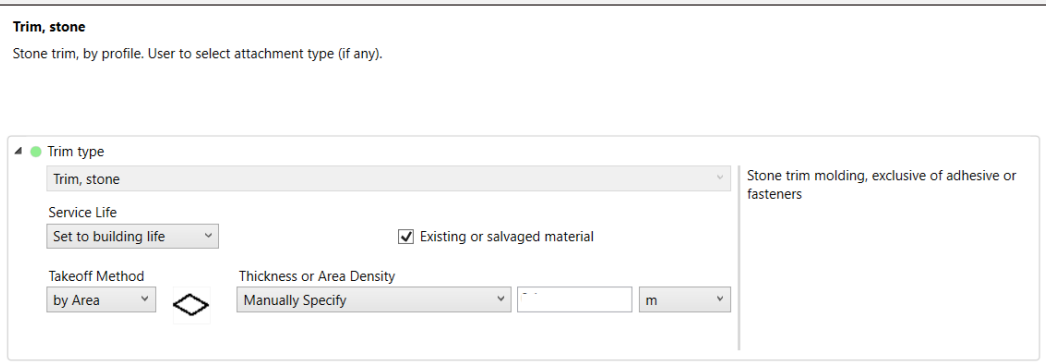
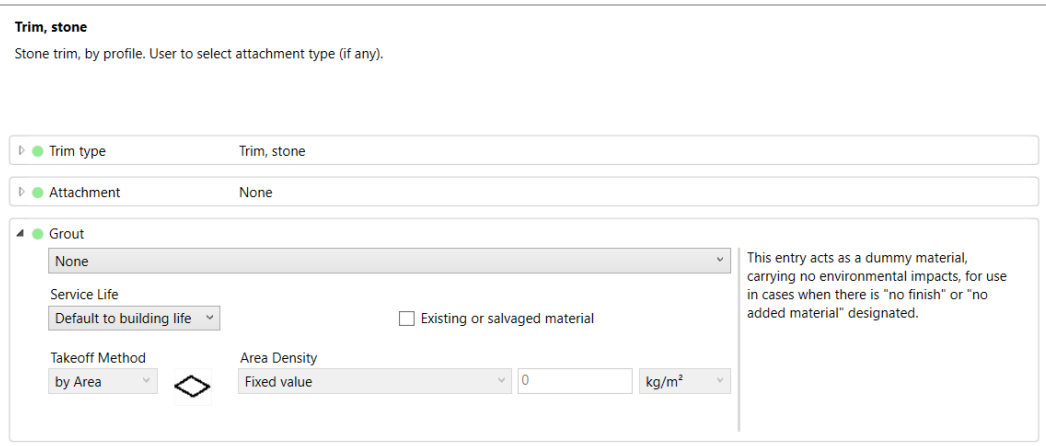
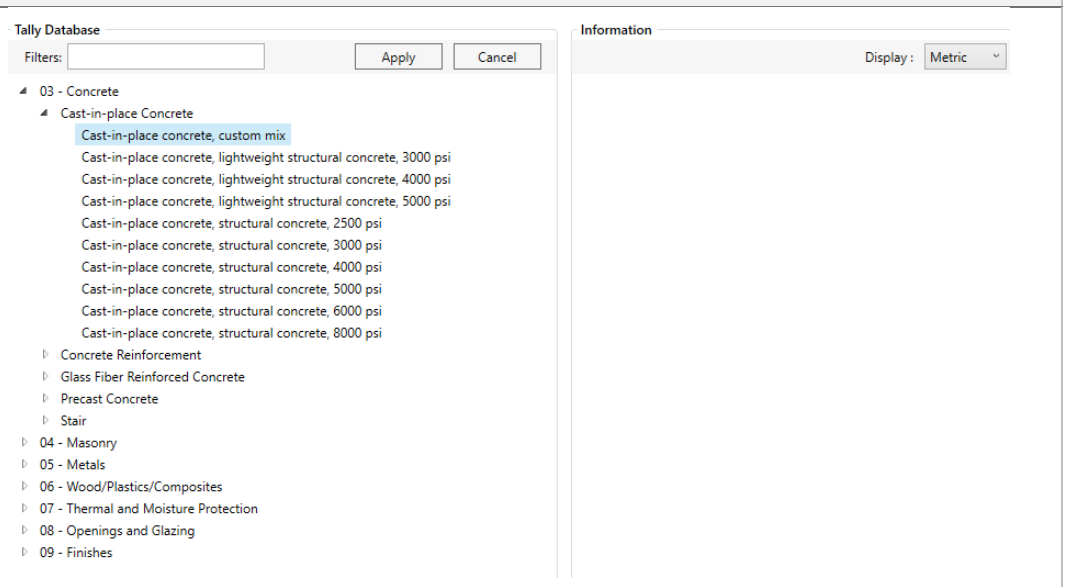
Tally Software: Substitution of Rubble Material	
Step One **Rubble**	
Step Two **Attachment and Grouting**	

Figure 5.37 Substitution of Rubble Material to Trim Stone Material in Tally Software, Source: Author

Finally, the clay-paste material which is used between the masonry stone blocks is not obtained in Tally. The clay-paste in traditional construction methods is a combination of clay, silt, and sometimes lime was added. In Tally, concrete was selected using the following materials: sand, lime, and water. Those materials will make the mixture somehow near to the implemented ones.

Tally Software: Substitution of Rubble Material

Step One
Clay-Paste



Step Two
Sand- Lime-Water

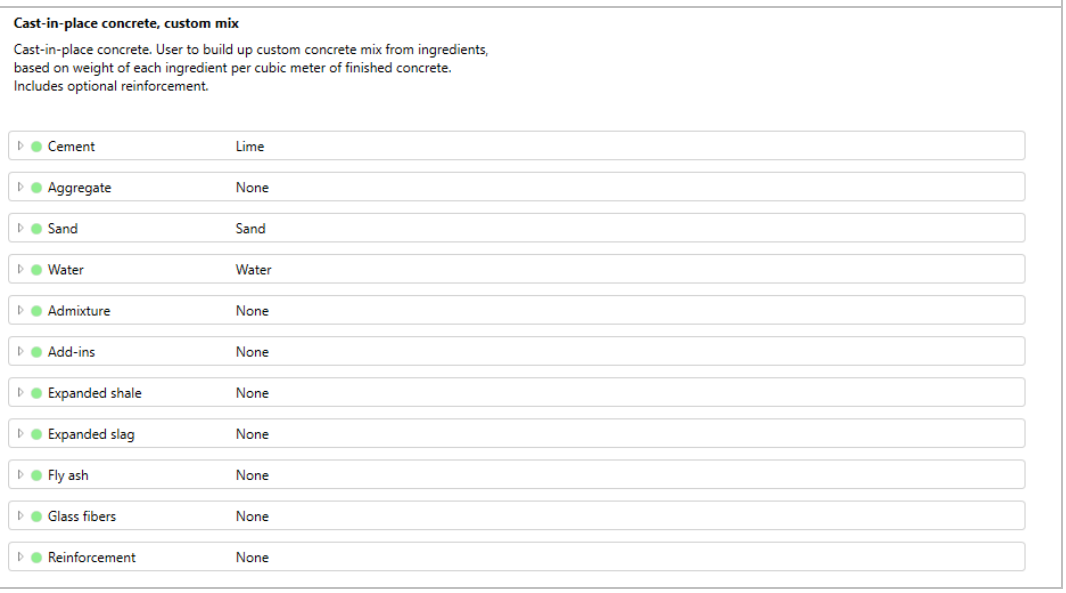


Figure 5.38 Substitution of Clay-Paste Material to Cast-in-place Concrete Material in Tally Software, Source: Author

5.4 Tally Results and Discussion

This section discusses the results which are compared, analyzed, and evaluated referring to the reports conducted by Tally, and based on the aims and objectives of this thesis. The literature review of the previous chapters will be a baseline to further elaborate the findings gathered from Tally.

5.4.1 The Mar Moussa El Habachi Church

Tally was employed to determine the embodied energy and carbon emissions of the church in the case of relocation. As previously mentioned, the reports generated through Tally show different embodied impacts ranging from Global Warming Potential to Renewable Energy. For the purpose of this study, the embodied energy or non-renewable energy, and global warming potential as carbon emissions are the main focus of this discussion to study the environmental impacts of the church. The embodied non-renewable energy is the measure of energy extracted from non-renewable sources such as the natural gas and petroleum while the global warming potential is the measure of greenhouse gas emissions (CO_2). Tally is distinguished by the way the LCA data is organized, categorized, and presented. In Tally, the data is divided according to three categories: the life cycle stage, the division, and the Revit category. To analyze the overall global warming potential and non-renewable energy associated with the demolition phase, the categorization by the life cycle stages is discussed. The division category computes the carbon emissions and embodied energy in regards to the building materials of the church. As for the Revit category, it separately studies the environmental impact of building assemblies which are the following: doors, floor, roof, walls, and windows.

5.4.1.1 Category One: Life Cycle Stage Analysis

According to the end-of-life stage [C2-C4] in Tally, the total global warming potential is 35,355 kg CO2eq which is equivalent to 367.9 kg CO2eq/$m^{2,}$ while the non- renewable energy is 512,038 MJ which equates 5,328 MJ/m^2 (Table 5.2). In comparison to the other life cycle phases,

Environmental Impact Totals	Product Stage [A1-A3]	Construction Stage [A4]	Use Stage [B2-B5]	End of Life Stage [C2-C4]	Module D [D]
Global Warming (kg CO_2eq)	45,309	80.32	235,288	35,355	2,150
Acidification (kg SO_2eq)	146.7	0.3722	499.7	147.8	17.26
Eutrophication (kg Neq)	7.105	0.0303	36.39	7.494	1.005
Smog Formation (kg O_3eq)	2,351	12.30	10,916	2,940	681.7
Ozone Depletion (kg CFC-11eq)	1.205E-005	2.751E-012	1.286E-005	5.880E-009	2.280E-006
Primary Energy (MJ)	413,007	1,168	1,976,719	547,574	21,408
Non-renewable Energy (MJ)	377,837	1,140	1,839,205	512,038	29,939
Renewable Energy (MJ)	35,284	28.24	136,161	36,183	-8,640

Table 5.2 Findings as Summary Highlighting the Studied Indicators, Source: Author, Retrieved from Tally

this end-of-life phase shows the third highest amount of carbon emissions while the second as energy consumption. Figure 5.39 shows the percentages of the all the indicators within the life cycle stages. The maintenance phase accounts for the highest carbon emissions and embodied energy (around 70% each). However, in the case of Mar Moussa there is no refurbishment procedures required. According to the Council for Development and Reconstruction (CDR, 2014), the church will be relocated by demolishing its structure. The demolition phase in the case of relocation [C2-C4] with respect to the initial embodied energy to construct the church [A1- A3] is the focus of discussion. Taking into consideration the overall life cycle analysis, the global warming potential and the non-renewable energy of the product phase are 14% (kg CO_2eq and MJ respectively). Though, the demolition phase has lesser percentage of global warming potential than that in the product stage, which is 11% (MJ), and the renewable energy has higher percentage which is 19% (MJ). This means that the values of energy consumption and carbon emissions in the demolition phase is dependent on the materials used, which may account for higher percentage than that in the product phase.

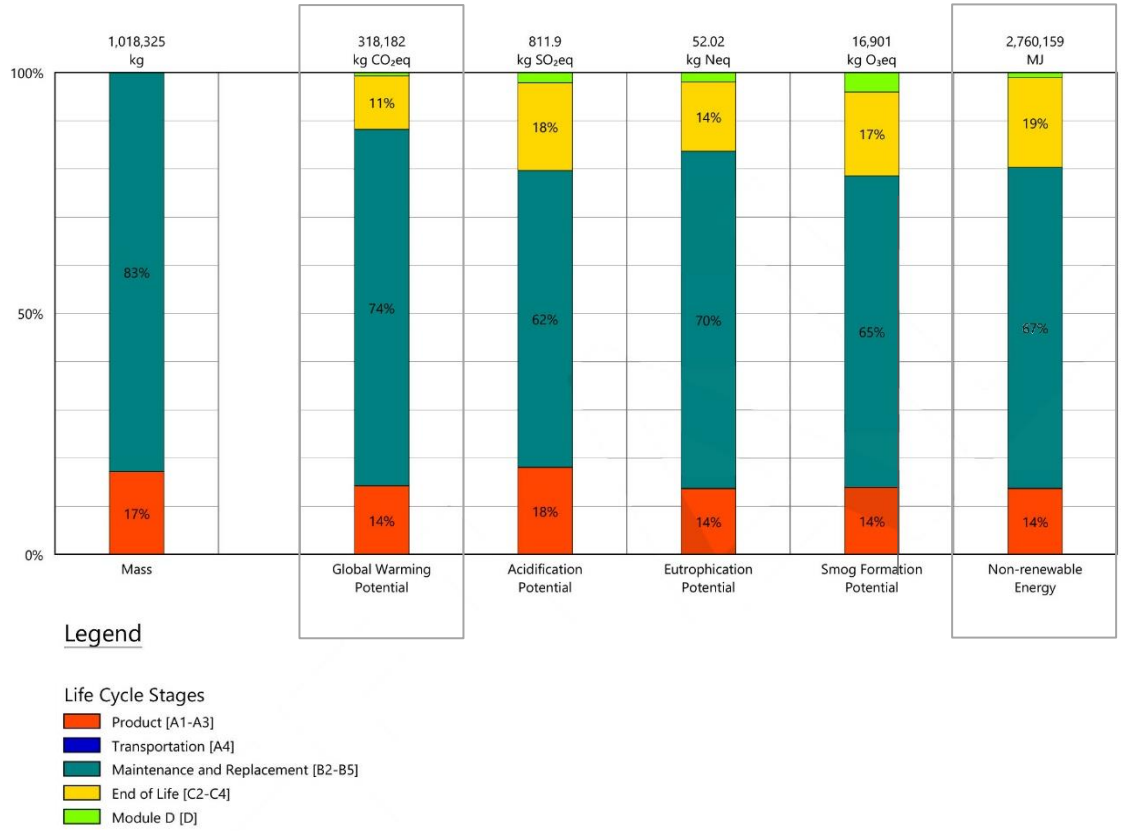


Figure 5.39 Findings as Per Life Cycle Stage, Source: Author, Retrieved from Tally

5.4.1.2 Category Two: Division Analysis

Through further examination, the findings as per division and as per Revit category provide more information in terms of distribution of embodied energy and carbon emissions by Revit families. Each of the materials and categories are separately discussed to know which accounts for the highest embodied energy and carbon emissions. Tables 5.3 and 5.4 outline the impact of the life cycle stage in terms of global warming potential and non-renewable energy. Based on the data, the masonry walls account for zero carbon emissions and embodied energy in the product and transportation phase because the materials are local and considered in Tally as existing or salvaged materials. However, the masonry in the end life phase is the greatest source of carbon emission (22,748.33 kg CO_2eq) and the greatest consumer of embodied energy (364,203.08 MJ). As for the concrete, it has the highest carbon emissions and embodied energy in the product and transportation phases. In the end of the life phase, concrete is the second largest source for the

global warming potential (6,633.09 kg CO_2eq) and the third highest material as energy consumer (52,175.92 MJ) after the finishes (95,114.22 MJ).

Row Labels	Sum of Acidification Potential Total (kgSO2eq)	Sum of Eutrophication Potential Total (kgNeq)	Sum of Global Warming Potential Total (kgCO2eq)	Sum of Ozone Depletion Potential Total (CFC-11eq)	Sum of Smog Formation Potential Total (kgO3eq)
[A1-A3] Product	**146.71**	**7.10**	**45,308.71**	**1.21E-05**	**2,351.45**
03 – Concrete	45.97	3.42	33,836.00	3.69E-09	1,056.95
04 – Masonry	0.00	0.00	0.00	0.00E+00	0.00
05 – Metals	40.04	1.23	4,247.08	5.23E-06	314.57
08 – Openings and Glazing	5.02	0.28	787.36	6.82E-06	49.10
09 – Finishes	55.68	2.17	6,438.27	7.33E-09	930.83
[A4] Transportation	**0.37**	**0.03**	**80.32**	**2.75E-12**	**12.30**
03 – Concrete	0.27	0.02	58.39	2.00E-12	8.94
04 – Masonry	0.00	0.00	0.00	0.00E+00	0.00
05 – Metals	0.03	0.00	6.25	2.14E-13	0.96
08 – Openings and Glazing	0.00	0.00	0.42	1.44E-14	0.06
09 – Finishes	0.07	0.01	15.25	5.22E-13	2.34
[B2-B5] Maintenance	**499.74**	**36.39**	**235,287.64**	**1.29E-05**	**10,915.86**
03 – Concrete	34.83	2.72	15,930.35	2.93E-09	742.04
04 – Masonry	458.87	33.33	218,288.00	3.74E-08	10,109.04
05 – Metals	1.25	0.18	306.22	8.66E-06	16.14
08 – Openings and Glazing	4.79	0.16	763.07	4.16E-06	48.64
09 – Finishes	0.00	0.00	0.00	0.00E+00	0.00
[C2-C4] End of Life	**147.78**	**7.49**	**35,355.02**	**5.88E-09**	**2,939.77**
03 – Concrete	15.06	0.76	6,633.09	5.99E-10	299.56
04 – Masonry	105.12	5.33	22,748.33	4.18E-09	2,091.01
05 – Metals	0.11	0.01	24.45	4.50E-12	2.24
08 – Openings and Glazing	0.03	0.00	8.26	1.75E-12	0.88
09 – Finishes	27.45	1.39	5,940.89	1.09E-09	546.08
[D] Module D	**17.26**	**1.00**	**2,150.37**	**2.28E-06**	**681.73**
03 – Concrete	1.18	0.07	156.19	-3.49E-10	48.89
04 – Masonry	13.01	0.74	1,717.72	-3.83E-09	537.65
05 – Metals	3.75	0.14	484.23	1.69E-06	35.57
08 – Openings and Glazing	-2.66	-0.05	-468.50	5.92E-07	-21.99
09 – Finishes	1.97	0.11	260.74	-5.82E-10	81.61
Grand Total	**811.86**	**52.02**	**318,182.06**	**2.72E-05**	**16,901.11**

Table 5.3 Findings as Per Life Cycle Stage Highlighting Global Warming Potential in End of Life Phase, Source: Author, Retrieved from Tally

Row Labels	Sum of Primary Energy Demand Total (MJ)	Sum of Non-renewable Energy Demand Total (MJ)	Sum of Renewable Energy Demand Total (MJ)
[A1-A3] Product	**413,006.51**	**377,837.41**	**35,284.39**
03 – Concrete	240,729.38	229,252.85	11,397.89
04 – Masonry	0.00	0.00	0.00
05 – Metals	59,986.70	54,889.17	5,114.22
08 – Openings and Glazing	11,450.03	10,178.86	1,276.04
09 – Finishes	100,840.40	83,516.53	17,496.24
[A4] Transportation	**1,168.03**	**1,140.08**	**28.24**
03 – Concrete	849.15	828.83	20.53
04 – Masonry	0.00	0.00	0.00
05 – Metals	90.93	88.75	2.20
08 – Openings and Glazing	6.11	5.96	0.15
09 – Finishes	221.84	216.53	5.36
[B2-B5] Maintenance	**1,976,719.09**	**1,839,204.87**	**136,161.25**
03 – Concrete	110,169.74	100,439.87	9,690.61
04 – Masonry	1,851,513.24	1,725,144.08	125,050.54
05 – Metals	3,941.75	3,747.04	194.77
08 – Openings and Glazing	11,094.36	9,873.87	1,225.32
09 – Finishes	0.00	0.00	0.00
[C2-C4] End of Life	**547,574.41**	**512,037.54**	**36,183.29**
03 – Concrete	55,796.96	52,175.92	3,686.88
04 – Masonry	389,479.00	364,203.08	25,735.49
05 – Metals	420.02	391.80	27.74
08 – Openings and Glazing	163.23	152.52	12.18
09 – Finishes	101,715.20	95,114.22	6,721.00
[D] Module D	**21,407.55**	**29,938.62**	**-8,640.12**
03 – Concrete	1,346.20	1,941.11	-602.10
04 – Masonry	14,805.19	21,347.93	-6,621.81
05 – Metals	9,566.36	7,853.66	1,712.11
08 – Openings and Glazing	-6,557.52	-4,444.57	-2,123.16
09 – Finishes	2,247.34	3,240.48	-1,005.15
Grand Total	**2,959,875.59**	**2,760,158.51**	**199,017.06**

Table 5.4 Findings as Per Life Cycle Stage Highlighting Embodied Non-Renewable Energy in End of Life Phase, Source: Author, Retrieved from Tally

This means that on average the masonry material has the highest global warming potential values and embodied non-renewable energy which is equal to 76%, with respect to the other building materials (as shown in Figure 5.40). Afterwards, the other materials ranging from highest to lowest global warming potential values are the following: concrete (18%), finishes (4%) and metals (2%). Similarly, the embodied non-renewable energy has the same range with different percentages; 14%, 7%, and 3% respectively (refer to Figure 5.40).

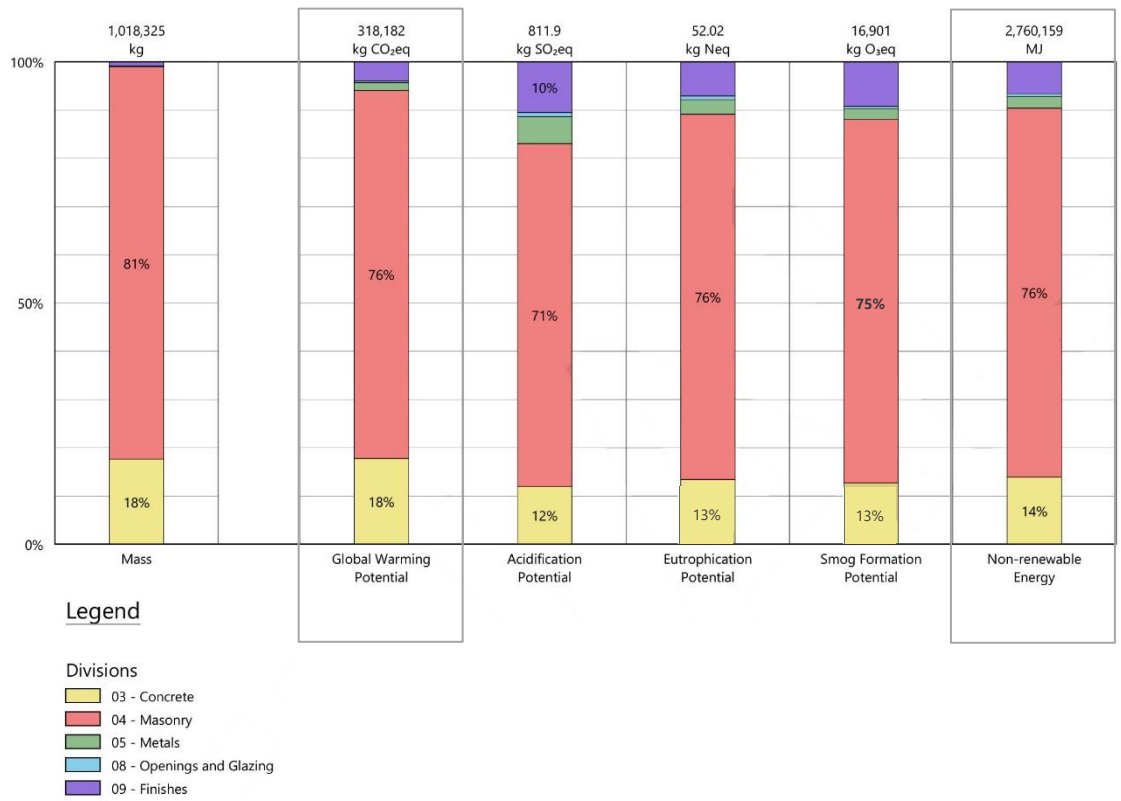


Figure 5.40 Findings as Division, Source: Author, Retrieved from Tally

5.4.1.3 Category Three: Analysis of Revit Families

The average mass of the church is 1,018.325 kg. To filter the impacts of each category, a distribution by Revit families will be examined. This includes the quantity of materials used in the following assemblies: walls, floor, and roof. According to Figure 5.41, the wall assembly has the

highest carbon emission (87%) and energy consumption (88%). then the floor (7% and 6% respectively) and the roof (5% and 4% respectively).

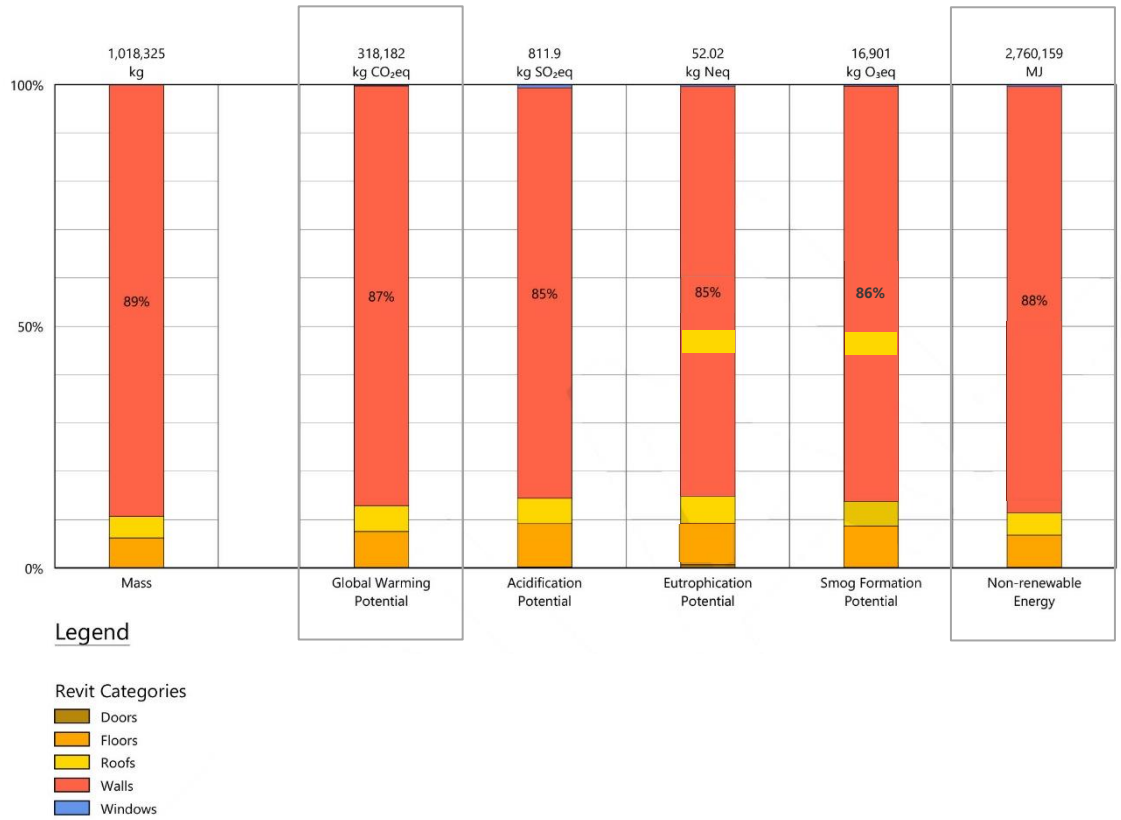


Figure 5.41 Findings as Revit Category, Source: Author, Retrieved from Tally

First, by analyzing the following Tables 5.5, 5.6 and 5.7 by categories, the wall assembly which consists of masonry stone, mortar, clay, rubble and earth, is the main contributor of carbon emission and energy consumption. The values of carbon emissions and energy consumption are directly proportional. The more energy is consumed in the product till the end of life phase, the more carbon will be emitted. Table 5.5 presents the findings of global warming potential and non-renewable energy of the masonry wall components. The average wall global warming potential is 276,345.25 kg CO_2eq (87%) with a total of 2,432,409.38 MJ embodied renewable energy (88%). For instance, the veneer wall which is selected instead of the masonry stone is the largest cause of carbon emission (242,754.05 kg CO_2eq) and energy consumption (2,110,695.09 MJ), then comes

the mortar and clay- paste. Those two materials have different components but detected as the same material in the Tally software because both are identified as concrete custom mix.

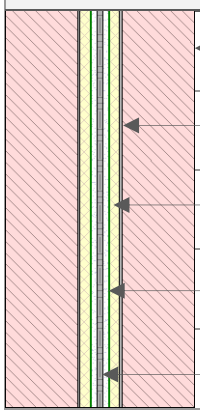
Wall Composition	Global Warming Potential (kgCO2eq)	Non- Renewable Energy (MJ)
 Masonry Wall	242,754.05	2,110,695.09
Mortar	20,442.66	135,164.24
Clay- Paste		
Earth	1,989.05	31,545.29
Rubble	6,506.54	93,571.74

Table 5.5 Findings of Wall Composition as Global Warming Potential and Embodied Non-Renewable Energy in End of Life Phase, Source: Author

Second, the floor assembly follows with an average of 23,714.41 kg CO_2eq and 183,396.99 MJ. Tables 5.6 and 5.7 outline the environmental indicators associated with the categories of the church. The Portland cement shows the highest energy consumption and carbon emissions (17,851.16 kg CO_2eq and 112,640.67 MJ) among other components of the concrete floor materials while the mortar is the lowest (11.93 kg CO_2eq and 189.23 MJ). As for the stone tile above the concrete floor, it is equivalent to 13.5% of the overall carbon emission in the floor assembly and 22.8% of the overall embodied energy.

Third, the roof assembly is the third contributor of the environmental wastes. The roof consists of the concrete parapet which has the highest carbon emissions (15,674.39 kg CO_2eq) and embodied energy (108,106.48 MJ). The lowest energy consumption and carbon emissions are the copper metal bell with 2.28% of the overall roof carbon emission and 3.97% of the energy consumption.

Finally, the windows and doors are the least energy consumers and wastes contributors. The windows account for 0.25% of the total global warming potential and 0.42% of the total embodied non-renewable energy while the doors 0.1% and 0.16% respectively.

Row Labels	Sum of Acidification Potential Total (kgSO2eq)	Sum of Eutrophication Potential Total (kgNeq)	Sum of Global Warming Potential Total (kgCO2eq)	Sum of Ozone Depletion Potential Total (CFC-11eq)	Sum of Smog Formation Potential Total (kgO3eq)
Doors	**1.91**	**0.36**	**319.59**	**1.26E-05**	**23.96**
Door frame, aluminum	0.21	0.02	38.62	6.26E-09	2.39
Door frame, steel galvanized	0.07	0.00	9.05	3.51E-07	0.91
Door hinges	-0.01	0.17	27.49	6.80E-06	-1.14
Door, exterior, steel	1.22	0.15	195.13	5.42E-06	16.80
Glazing, monolithic sheet	0.42	0.02	49.29	2.06E-11	5.00
Floors	**72.64**	**4.47**	**23,714.41**	**7.10E-09**	**1,439.39**
Coarse aggregate	2.34	0.13	899.37	1.11E-10	51.44
Portland cement – EPD	39.11	3.05	17,851.16	3.25E-09	835.44
Sand	3.65	0.20	1,690.48	1.80E-10	88.70
Stone tile	27.35	1.07	3,205.52	3.55E-09	459.78
Thickset mortar	0.06	0.00	11.93	9.81E-13	1.21
Water	0.13	0.01	55.95	2.61E-12	2.83
Roofs	**42.59**	**2.93**	**17,004.30**	**1.20E-08**	**871.80**
Copper, cast or drawn	3.53	0.11	387.78	9.24E-09	28.25
Cast-in-place concrete	34.58	2.59	15,674.39	2.71E-09	748.20
Flooring, underlayment	4.47	0.23	942.12	7.75E-11	95.36
Walls	**689.46**	**44.06**	**276,345.25**	**8.81E-06**	**14,514.37**
Copper, cast or drawn	40.15	1.21	4,405.71	1.05E-07	320.74
Stone veneer wall, limestone	577.00	39.39	242,754.05	3.78E-08	12,737.70
Custom mix concrete	17.50	1.01	20,442.66	6.17E-10	429.78
Underlayment, cementitious	9.44	0.48	1,989.05	1.64E-10	201.32
Trim, stone	43.86	1.89	6,506.54	4.05E-09	803.20
Steel, round tubing	0.10	0.00	16.53	4.60E-07	1.84
Windows	**5.27**	**0.22**	**798.51**	**5.79E-06**	**51.59**
Curtain wall system – EPD	4.27	0.16	666.34	3.77E-07	38.37
Hardware, stainless steel	0.10	0.02	4.26	7.53E-07	0.16
Window frame, steel, divided operable	0.89	0.04	127.91	4.65E-06	13.07

Table 5.6 Findings as Per Revit Category Highlighting Global Warming Potential, Source: Author, Retrieved from Tally

Row Labels	Sum of Primary Energy Demand Total (MJ)	Sum of Non-renewable Energy Demand Total (MJ)	Sum of Renewable Energy Demand Total (MJ)
Doors	**4,986.60**	**4,527.12**	**463.61**
Door frame, aluminum	601.42	523.86	73.96
Door frame, steel, galvanized	139.86	129.88	10.16
Door hinges	602.74	452.62	147.71
Door, exterior, steel	2,978.08	2,792.81	195.15
Glazing, monolithic sheet	664.50	627.95	36.64
Floors	**203,897.64**	**183,396.99**	**20,545.45**
Coarse aggregate	8,032.67	7,493.20	548.19
Portland cement, PCA – EPD	123,478.63	112,640.67	10,793.32
Sand	21,423.73	20,789.52	629.41
Stone tile	50,292.74	41,839.91	8,537.66
Thickset mortar	200.02	189.23	11.00
Water	469.86	444.46	25.88
Roofs	**138,721.52**	**128,132.86**	**10,575.52**
Copper, cast or drawn	5,616.59	5,084.79	533.03
Cast-in-place concrete	117,311.42	108,106.48	9,174.16
Flooring, underlayment	15,793.51	14,941.59	868.33
Walls	**2,600,497.48**	**2,432,409.38**	**167,357.84**
Copper, cast or drawn	63,806.74	57,764.48	6,056.19
Stone veneer wall, limestone	2,255,797.43	2,110,695.09	144,164.22
Cast-in-place concrete	138,175.13	135,164.24	3,022.87
Underlayment, cementitious	33,343.89	31,545.29	1,833.25
Trim, stone	105,394.61	93,571.74	11,967.23
Steel, round tubing	241.64	229.17	12.87
Windows	**11,772.34**	**11,692.14**	**74.63**
Curtain wall system – EPD	9,721.20	9,792.94	-79.63
Hardware, stainless steel	87.09	67.79	19.22
Window frame, steel, divided operable	1,964.06	1,831.42	135.04

Table 5.7 Findings as Per Revit Category Highlighting Embodied Non- Renewable Potential, Source: Author, Retrieved from Tally

5.4.2 The Monastery

As mentioned previously, the monastery is originally Byzantine. The building life span was set as 1621 years with 253 square meter gross area. The results of the assessment of the monastery show negligible values of global warming potential and ozone depletion potential because all the materials are built on-site (selected as existing). This means that the initial construction methods which date back for more than one century did not need tools that account for energy especially with the use of local materials.

Environmental Impact Totals	Product Stage [A1-A3]	Construction Stage [A4]	Use Stage [B2-B5]	End of Life Stage [C2-C4]	Module D [D]
Global Warming (kg CO_2eq)	0	0	0	0	0
Acidification (kg SO_2eq)	0	0	0	0	0
Eutrophication (kg Neq)	0	0	0	0	0
Smog Formation (kg O_3eq)	0	0	0	0	0
Ozone Depletion (kg CFC-11eq)	0	0	0	0	0
Primary Energy (MJ)	0	0	0	0	0
Non-renewable Energy (MJ)	0	0	0	0	0
Renewable Energy (MJ)	0	0	0	0	0

Table 5.8 Findings as Summary Highlighting Global Warming Potential and Embodied Non- Renewable Potential, Source: Author, Retrieved from Tally

5.5 Conclusion

With the completion of the life cycle assessment of the church and the monastery, a better understanding of the embodied energy and carbon emissions have been achieved. All the assemblies contribute to additional consumption of embodied energy and emissions of carbon. The end-of-life phase takes around 11% to 19% of the environmental wastes and the wall assembly represents more than 85% of the mentioned proportion. When local materials are used without any imported substances, then no additional energy consumption and carbon emissions will be charged.

Chapter Six

CONCLUSION

6.1 Introduction

The aim of this thesis was to investigate whether relocating the Mar Moussa El Habachi church and the Saint Sophia monastery in Bisri valley, is a sustainable historic preservation strategy. This was achieved through the assessment of the life cycle assessment to compute the embodied energy and carbon emissions. The study concluded a better understanding to limit the environmental impact of any relocated historic building.

The literature review determined the importance of cultural heritage preservation in historic sites. Firstly, sustainability includes the debate of weak and strong sustainability which is framed by political structure. This debate concluded that natural resources are compensated and substituted which is the weak sustainability, with respect to that preserved known as the strong sustainability. Accordingly, the cultural heritage which is the fourth pillar of sustainability aimed to safeguard the natural and cultural assets. This pillar identifies the importance of preserving the memory as intangible cultural heritage and the physical structure as tangible cultural heritage. Furthermore, historic preservation and energy conservation are two interlinked strategies because sustainability begins with historic preservation strategies to preserve the cultural heritage, and with energy conservation to minimize the embodied energy consumed and carbon emitted.

The context of the case study was located in Bisri Valley, Mount Lebanon. This depicted problem of water scarcity, and the impacts of any transformative rural project, such as the dam projects, on its surrounding. This project is associated with mitigation measures when the

externalities are defined. Firstly, failure and success dam projects in Lebanon were investigated to build viewpoints from previous implemented projects. Afterwards, a transparent discussion of the social and environmental impact assessment is highly suggested in order to deal with the externalities affecting the natural and cultural heritage. The impact assessment analysis of the Bisri valley from the lens of the four pillars of sustainability is needed before the dam's implementation, in case the institutions failed to manage sustainable alternatives.

To review methodologies of studies with similar aims, a chronological overview for the models of assessment was first analyzed to show the advantages and limitations of each. This provided a better understanding of the appropriate tools to assess the embodied energy and carbon emissions. Then, other environmental techniques were evaluated including the life cycle assessment, which is the adopted methodology to assess the mentioned indicators. The first step was to model the case study using Revit. The second step was to identify the materials used of the whole buildings. The third step was to insert the models to Tally plug-in software. Finally, the fourth step was to analyze and compare the Tally results of the following indicators: global warming potential and embodied non-renewable energy.

The analyses of the results were conducted as per whole building scale, material and Revit category. The results show that it takes around 11% to 19% of the environmental wastes at the end-of-life phase, and the wall assembly represents more than 85% of the mentioned proportion. Accordingly, the use of local material accounts for zero emissions and energy consumption in the product and transportation phase; however, it shows high value in the end-of-life phase. This is highly revealed in the wall masonry material which has the highest global warming potential and the embodied non- renewable energy. It is an indication that the relocation or demolishing a building has the same environmental impact, despite the fact that it was local material.

Finally, in order to assume whether the relocation process is a sustainable strategy, further syntheses were drawn. The strong sustainability deals with preservation of natural resources or built heritage without neither replacing parts nor substituting it because damaging one part is to damage a piece of a whole. Meanwhile, demolishing and relocating historic buildings using the same materials, is a weak sustainable strategy and has additional energy consumed for the relocated building with more CO_2 emitted to the environment. This relocation is a weak sustainable strategy to preserve a historic old building. Though, in the case of a planned relocation, it is important to sustain the memory of historic building (intangible cultural heritage) and its physical value for its traditional form and architectural character (tangible cultural heritage). Therefore, there are some recommendations which can be implemented in the case of demolishing the materials to rebuild the building and reduce the externalities which are the carbon emissions and embodied energy. Those strategies are proposed to help internalizing the externalities and provide a better understanding to limit the mentioned environmental impacts. The proposed recommendations are the following: 1) reduction in the quantity of masonry, concrete and metal materials through the whole building life cycle, and the environmental impacts associated with the construction phase, and 2) substitution of metal and concrete materials having high embodied energy and carbon emissions with lower environmental ones. Those strategies in the case of the monastery and the church relocation include the limited use of metal frames, doors and openings in the relocated site to limit additional embodied energy and carbon emissions, in addition to lowering the height of the building to reduce the use of material in the construction phase. This will provide architects with a streamlined process that can be sustainably integrated with limited environmental impacts, in the case of relocating or demolishing historic buildings. Therefore, as

assessed, the embodied energy and carbon emissions for relocated historic buildings have similar environmental impacts to a demolished structure.

6.2 Limitations

There are some challenges and limitations in this study. The limitations related to the software were discussed in chapter five. The external limitations were related to the situation of the country. This research was conducted in the years 2020-2021 when Lebanon was facing lots of challenges and instabilities. During the demonstration which started on October17, 2019, all protestors went to Biri Valley to show their refusal to the dam construction. This resulted in road closures and violations from people pretended to be protestors. Those violations impacted the Mar Moussa Church which witnessed damages in the furniture. After this period, no one was permitted to access the site. I contacted the municipality of Mazraat El Daher and persons concerned with the dam, to be able to reach the site and take measurements. Prior to the demonstration period, the aim of the study was to map all the Bisri area by GIS. Another plan was to use the Digital Twin Technology to assess the cultural and natural heirtage in order to simulate the dam's effect on flood or earthquakes as an example. Additionally, the emergence of the pandemic COVID-19 has its limitations. It delayed the site visits due to the lockdown, and limited the objectives of this thesis to an architectural scale.

6.3 Recommedations for Further Research

Despite the conscious effort to move forward towards a sustainable future with a reduction in environmental impacts, little has been done to address the embodied energy and carbon emissions in historic sites. As stated, this thesis investigated the environmental impacts of relocating historic structures in a chosen case study. The results analyze the conditions in which the relocation is a

sustainable historic preservation strategy for a historic site. It is recommended to consider embodied energy and carbon emissions of historic buildings in other contexts. This will provide concrete data base on embodied energy and carbon emissions of historic buildings, in Lebanon. Validation is also required for retrofitted historic buildings to identify whether retrofitting minimizes the environmental impacts associated with the building life cycle especially in the operating phase.

Moreover, the current thesis just considered the two historic buildings of the Bisri Valley (Mar Mousa Church and Saint Sophia Monastery) despite its rich natural and cultural heritage. Many dam projects in Lebanon had subjective cultural impact assessment studies to take the necessary mitigation measures. Thus, future research can zoom in to discuss the archeological structures of Bisri Valley (stone arches, caves, stone blocks, potteries, shards, tombs, ceramics, and glass) in the case of dam's implementation. This encompasses the impact of relocation or demolition on the environment and on the physical properties of those structures. The analysis may be expanded to evaluate the environmental impact of historic structures, which will be under water, such as the Roman columns and its temple underneath.

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APPENDICES

Appendix A- Procedure for The Tally Software Simulation of Embodied Energy and Carbon Emissions

The assessment of embodied energy and carbon emissions are performed in Tally software. Firstly, in order to do the assessment, the buildings are modeled in Autodesk Revit as masses. The masses were presented with its materials before it is transferred to Tally.

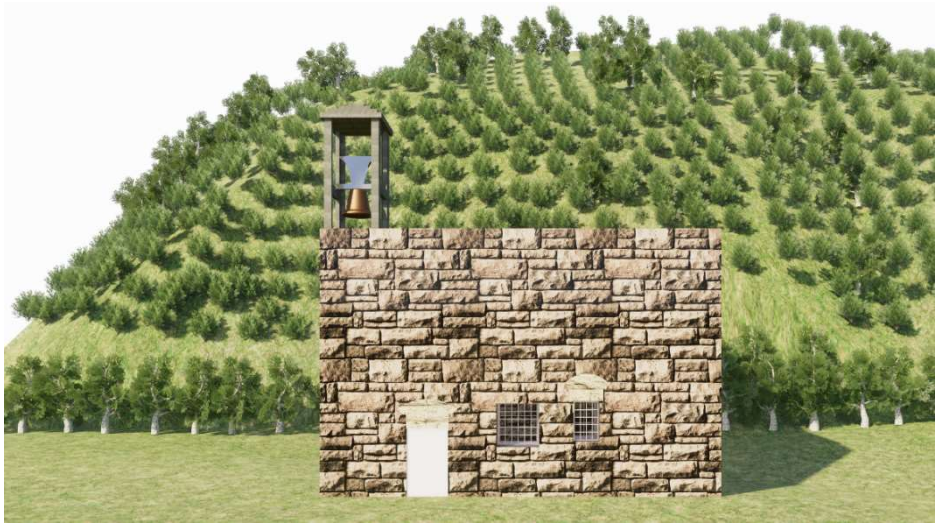
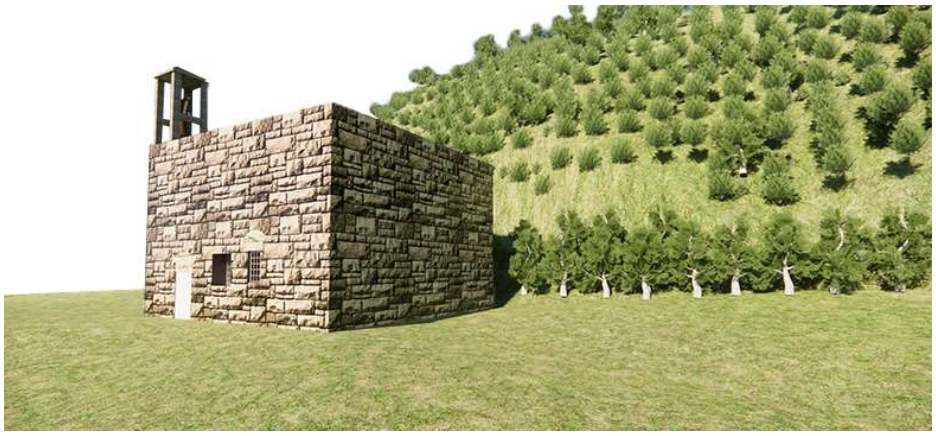
Mar Moussa El Habachi Church	
Mass Modeling	 

Figure A.1 Figure Showing 3D Model of Church in Revit, Source: By Author

Saint Sophia Monastery	
Mass Modeling	

Figure A.2 Figure Showing 3D Model of Monastery in Revit Including Structural Additions, Source: By Author