Developing Strategies of Integrated Whole System Design Approach for Energy Efficient Buildings

by

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Dissertation report submitted in partial fulfilment of the requirements for the
Bachelor of Engineering (Hons) (Civil)

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CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

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Chan Yong Yeah

CERTIFICATION OF APPROVAL

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ABSTRACT

According to Addy et al. (2014) most of our time is spent in buildings i.e. either in the office or at home where buildings actually consume up to 40% of the total global energy. Therefore, energy efficient building is very important to reduce the total energy used and greenhouse gas emissions to prevent climate change. However, the disintegration of multi- participants in construction particularly in the design process is the main barrier to limit the energy efficient building. Hence, whole system design is one such approach that aims to integrate social, economic and environmental phenomena into a comprehensive design solution. This approach encourages the development of partnerships between all project stakeholders from a variety of different backgrounds, disciplines and sectors to develop an energy efficient building at a whole system level.

This research will be focusing on the investigation of the factors of whole system design that able to support the achievement of energy efficient building. While, the ultimate goal of this research is to propose and select the best strategy. Statistical Descriptive Analysis and Descriptive Qualitative Analysis was used to identify the most critical factors and strategies from the results of the surveys. The sampling technique used in this research is Purposive Sampling and Snow Ball Sampling to identify the two main population samples for my research. In order to select the best decision or alternative, Analytic Hierarchy Process (AHP) model is used in the decision making process to analyze the collected data and synthesis through survey, questionnaire from potential respondents. The usage of AHP model was not just to provide the “correct” answer for the decision maker, but to elicit the preference choice of the decision maker towards the alternatives available.

In this study, two respondents are selected as a qualitative approach to identify the most important factors and the best implementation strategy based on their experience and perspective. Thirty respondents were surveyed to get the most important criterias and strategies. The results were then validated by two experienced personnel from the industry to ensure these strategies are applicable in the construction industry.

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CHAPTER 1

INTRODUCTION

1.1 Research Background

As mentioned by Almeida et al. (2018), buildings represent the biggest energy consumption in the use and building sector by means of the emission of incarnated energy and greenhouse gases. Carbon footprint is a way of showing the environmental effects of humans. It is measured by converting our use of fossil fuels in metric tons of carbon dioxide emissions for electricity, heating, transportation and others (Blizzard et al.,2012). Therefore, energy efficient building is very important to reduce the total energy used and greenhouse gas emissions to prevent the climate change and The basic aspect of energy efficiency in buildings is in fact to use much less energy for domestic heating, air conditioning and lighting without compromising the convenience of building users. However, the challenges that often faced in energy efficient building is the disintegration of multi- participants in construction particularly in design process.

According to Charnley et al. (2010), The problems which we are now confronting are complex, with several linked aspects, which often bear most relevant social, economic and environmental significance, due to a rapid and profound change in contemporary society. Therefore, in the absence of whole systems thinking, sustainable management cannot be achieved; the problem can be addressed at the system level. Companies are increasingly entering into partnerships between multiple companies, often in different fields and industries, to achieve a whole system perspective. Therefore, involving multiple participants and disciplines within the design process should build adaptability and flexibility into the design solution to achieve sustainability. Effective integration of sustainability into engineering education calls for system approaches such as the design of whole systems. (Hartungi et al.,2013). Whole System Design is the context and people, processes, structures, technology and other elements and interconnected elements, together with the patterns of interaction, which optimize not only parts but the whole system for a range of benefits. All must be simultaneously taken into account and analyzed to reveal both unwanted and mutually beneficial interactions. The design goal of whole system design is to create a comfortable energy efficient space. Although whole system design does not guarantee on energy efficient design results. But it can provide more opportunity for designers to build sustainable solutions to our most pressing questions than traditional design approaches.

1.2 Problem statement

From the empirical background obtained from previous studies, the impacts and factors that affecting the whole system design are early decisions taken in the design process are highly critical for buildings' energy-efficiency. Furthermore, incorrect decisions and design errors relating to the overall structure of a building will immensely increase the difficulties for whole system design. In addition, disintegration of multi-participants in construction particularly in early design process can have a significant influence on the building's energy efficient performance.

As mentioned in Section 1.1, in the absence of entire systems thinking, sustainability cannot be achieved (Charnley et al.,2010). However, the lack of researches and findings on the collaboration of whole system design shown us the necessity of further research on this topic. As mentioned by Blizzard et al. (2012), the field of whole system design is actually still very young with very limited literature around it. Hence, three (3) questions were formed to set my objectives and goals for this research. The three (3) questions include:

I. What is the factors of Whole System Design that able to support the achievement of energy efficient building?

II. What is the critical factors and strategies for achieving the energy efficient building?

III. What is the best strategy of integrated whole system design approach for energy efficient buildings?

1.3 Research Objectives and Scope of Study

This paper aims to develop the strategies of integrated whole system design approach for energy efficient buildings. To achieve the goal, a total of three (3) objectives have been determined. These objectives were formed based on the problem statements obtained from previous studies. The three (3) objectives are:

1. To investigate factors of Whole System Design that able to support the achievement of energy efficient building.
2. To find and select the critical factors and strategies for achieving the energy efficient building.
3. To propose and select the best strategy of integrated whole system design approach for energy efficient buildings.

1.4 Research Benefits

This research could help the participants or stakeholders to plan and make decision on Developing Strategies of Integrated Whole System Design Approach for Energy Efficient Buildings. The research benefits are stated as below:

1. For pursuit of environmental objectives, not only must renewable energy use be prioritized but also the use of efficiency be improved.
2. A holistic view of the system helps to ensure the most efficient construction performance to help participants or stakeholders to meet the sustainability and environmental goals.

1.5 Limitation of Research

Research limitation is the approach used to gather information from stakeholders by using surveys. The consistency of the result can be affected as the parties involved may have a favourable outcome in answering the questionnaires for their company reputation. Furthermore, it is limited to studying the role of the professional groups during the design stage due to limited research timeframe and the restrictions due to Covid-19.

CHAPTER 2

LITERATURE REVIEW

1.1 Integrated whole system design approach for energy efficient buildings

Energy Efficiency has been incorporated in construction, as it is a critical energy saving factor and contributes to the reduction of global carbon emissions, through these building regulations. Thus, energy efficiency technology has been projected to have the potential of cutting carbon emissions by 60% or more by a billion tonnes of CO2 and thereby conserving conventional energy (Hartungi et al., 2011).

In the whole system approach, the engineering design for radically improved sustainable performance, which aims at optimizing an entire system for several benefits instead of insulated components for single benefit. It is very important to integrate in design stage, by maintaining all system needs and priorities the goal, energy efficient building into consideration. However, there must be more specific definition of the scope of the integrated design process to improve building performance (Blizzard et al., 2011). The differentiation of functionalities and processes often results in a lack of ability to optimise the entire system, leading to inefficient design, delays in construction, excessively large heating systems, greater costs and excessive environmental impacts (Charnley et al., 2010).

According to Anumba et al. (2014) developing accurate parameters is an important step in determining construction performance or efficiency of design processes, it should be built following the concept of target output, on which the decision from a variety of possible design decision options can be made optimally, after they listed out the decision criteria discussed earlier, they will formalize the assessment with the analysis hierarchy (AHP), where priority was based on comparison rules in pairs. They also said that AHP was used as a multi-criteria decision-making strategy that divides the problem into smaller pieces and then uses a comparative judgement on a pair to establish hierarchical priorities to Determine relative weights among the specific system design criteria lists, after that they will also rank the criteria based on the relative weights that had been calculated and the ranking will show the value shift of criteria for different system design decision processes. In prioritizing team values in the evaluation of design options, AHP was found to be very helpful. (Anumba et al., 2014)

2.1.1 Definition and Terminology

There are 5 main importantly terminologies in this research as highlighted below in Table 2.1.

Terminologies	**Definition**
Whole system design	The "whole system" of connected elements, which participate in the design process, impact and influence, includes contexts, persons, processes, structures, technology and patterns of interaction.
Energy efficient	Using less energy to perform the same task
Integrated	Combining or coordinating separate elements so as to provide a harmonious and interrelated whole system.
Qualitative	Collecting and analysing non-numerical data commonly used in the humanities and social sciences
Quantitative	Quantitative information is often called data, involves a measurable quantity—numbers are used but can also be things other than numbers.

Table 2.1 Definition and Terminology

1.2 General overview of previous studies

Through literature review that has been conducted, it can be found 12 related studies. The background and objectives of each studies is discussed in each subsections presented below:

i. Exploring the process of whole system design conducted by Charnley et al. in 2010

The background of this study is the knowledge of factors that influence the entire system design process. The aim of this study is to explore the adoption in a more sustainable and innovative design of a whole system.

ii. Introducing whole systems design to first-year engineering students with case studies conducted by Blizzard et al. in 2011.

The background to this study is the concept of "whole-systems" that optimizes a whole system for several benefits compared to individual components for individual advantages. This study focuses on the efficiency of case studies in the teaching of whole-systems design and thus adds knowledge to entire system design teaching.

iii. Research on energy efficiency and conservation in an office building conducted by Hartungi et al. in 2011

The background of this study is the growing demand of building energy use that brought concerns about rising energy use to such a level that stern measures have been taken in many countries since buildings are responsible for at least 40 per cent of energy use in most countries. The objective of this study is to reviews how a building can be designed to utilize energy efficiently and therefore conserve the energy.

iv. Case study of integrated decision-making for deep energy-efficient retrofits conducted by Anumba et al. in 2014.

The background of this study is the importance of integrating all system requirements and priorities into the design, taking the objective into account. This study focuses on a comprehensive example of the historical retrofitting process, with demonstration characteristics of green technology and high rates of energy efficiency.

v. Research on how energy efficient office buildings challenge and contribute to usability conducted by Meistad.T in 2014

The background to this study is the analysis of high energy efficiency modern office buildings. The objective is to investigate how the interaction between buildings and users affects the overall values created by the structures and long-term sustainability

vi. Research on architect's perception on the challenges of building energy efficiency in Ghana conducted by Addy et al in 2014

Over the years, the population of Ghana has increased, and economic growth rates are steadily increasing too, but the energy supply base has failed to keep pace with growth, while building energy efficiency is an essential part of the sustainable development solution for Africa. The objective of this research is to explore the architects' perceptions regarding Ghana's energy efficiency construction challenges.

vii. Research on technical issues and energy efficient adaptive reuse of heritage listed city halls in Queensland Australia conducted by Mehr et al. in 2018

The study's background is the adaptive reusage of Queensland Australia's classified city halls. The aim of this paper is to identify technical issues in the adaptive reuse of Australian city halls listed as heritage and discuss sustainable strategies for more energy-efficient adaptations.

viii. Research on sustainability in university campus: options for achieving nearly zero energy goals conducted by Almeida et al. in 2018

Historical background of this study is the development of a renovation plan for a DEEC building, which is in line with national legislation on public buildings and a high level of local renewables to guarantee a total reduction in net energy requirements by more than 30 per cent by 2020. It focuses on the measures already taken in the DEEC building and analyzes the improvements to an almost zero energy structure.

ix. Revisiting the role of professionals in designing buildings with low embodied and operational energy conducted by Ekanayake et al. in 2020

The study's background is building energy consumption as a embodied energy and operational energy of two primary forms. This study contributes towards this understanding by reconsidering the roles of the building professionals and proposing how they can harness their strengths to play a significant part in the design of both low OE and EE buildings.

x. Research on integrated design experiences for energy-efficient housing in Chile conducted by Celis-D'Amico et al. in 2019

The background of this study is Chile's national energy policy, which proposes effective building conditions. The aim of this study is to examine the use of integrated design strategies in several housing cases in south-center Chile, in order to see if energy loss and demand is significantly reduced.

xi. A review of integrated applications of BIM and related technologies in whole building life cycle conducted by Li et al. in 2020

The background of the study is BIM because of their potential to support the construction industry, it is important to look less at literature and to systematically integrate new applications throughout the life cycle of building projects at different phases of BIM. The purpose of this study is to review, through three managements, technology and promotional aspects, the existing levels of BIM and the risks and challenges of stakeholders.

xii. A framework for sustainable whole systems design conducted by Blizzard et al. in 2012.

The study is based on an understanding of the interrelationship between problems and solutions of the complete system design. This study aims at defining and unifying the elements of system design in their entirety.

1.3 Previous related case studies

It has been found that the researchers around the world conduct several case studies. Each of the case studies is discussed in the subsections.

Case study 1: At Stanford University, a new department was planning to construct a building with the Maximizing occupant comfort and health as a top priority. Whole system design technique enabled the team to design, without excessive capital costs, one of the nation's most efficient mixed laboratory and office buildings. (Blizzard et al., 2011)

Case study 2: A global leader power group, Delta Group committed to design and develop their new and existing building to recycle waste energy according to green building guidelines. They successfully led to recycle 65-70 percent of waste energy while also reducing the space required by using the design principles of:

think whole-system; think end-use; rethink waste and design for multiple benefits. (Blizzard et al., 2011)

Case study 3: In a suburban district in Chile a house of 300 square meters was built. The experience has been associated with a national research initiative and with the support of a multidisciplinary team from Bio-Bío University. Since the group proposed every initial design decision, it was analyzed with energy simulation software (Ecotect). It shows that initial energy requirements of 75 kWh/m^2 are significantly lower than the home of the Chilean regulations with a minimum of over 130 kWh/m^2 per year. Upon the project was completed a total annual value of 12 kWh/m2, which corresponds to the Passivhaus standard of below 15 kWh/m2 annually and the customers' air quality requirements were met. (Celis-D'Amico et al., 2019)

1.4 Factors found from Previous Study

Based on the previous study that had been conducted there were 4 main criteria had already been found in whole system design for energy efficient building. The listed factors are summarized in Table 2.4.1.

Criteria	Description
Managing Multi-participants	➢ Stakeholder interaction (Blizzard et al., 2011) ➢ Sustainable partnership (Charnley et al., 2010) ➢ Individual characteristic on utilising trans-disclipanry skills (Charnley et al., 2010) ➢ Alignment of interest (Charnley et al., 2010)
Whole system approach	➢ Energy and cost savings using clean sheet approach (Blizzard et al., 2011) ➢ Holistic Approach (Blizzard et al., 2011)

Utilizing integrated design features	➢ Multi-disciplinary collaboration (Celis-D'Amico et al., 2019) ➢ Sustainable building performance goals (Celis-D'Amico et al., 2019) ➢ Features to manage information (Celis-D'Amico et al., 2019) ➢ Availability of building performance assessment (Valiente et al., 2019)
Upskilling knowledge	➢ Financial barriers (Addy et al., 2014) ➢ Policy barrier (Addy et al., 2014) ➢ Production barrier (Addy et al., 2014) ➢ Embodied energy and operational energy reduction strategies (Ekanayake et al., 2019)

Table 2.4.1 Criteria on Whole System Design

1.5 Summary of literature review from previous study

The synthesis of the literature review is summarized in Table 2.5.1, while there are some similarities and differences that had been founded after conducted the literature review and will be present in the Table 2.5.2.

Outcomes	Criterias
The communications and interactions between project stakeholders	Managing Multi-participants
The consideration of alignment of interest between all parties involved in whole system design	Managing Multi-participants
The integration of concept in energy savings of the building particularly until the end-use	Utilizing integrated design features

The opportunity of utilizing holistic approach, which is to consider all facets of the engineering process	Whole system approach
The multidisciplinary collaboration of all professionals	Utilizing integrated design features
Enhancing the awareness of financial matters in the design	Upskilling knowledge
Enhancing the awareness of diverse knowledge about barriers in the concept of energy efficient building	Upskilling knowledge
Enhancing the awareness of barriers in the construction process of energy efficient building	Upskilling knowledge
Enhancing the awareness in developing strategies for reducing the embodied energy and operational energy of the building	Upskilling knowledge
Enhancing the development of integrated system for building utilities	Upskilling knowledge

Table 2.5.1 Synthesis of literature review summary

	Similarities	**Differences**
Background Research	• 5 paper studies about the approach on WSD • 6 paper studies about the sustainability of the building • 2 paper studies about the participants/professionals involved in sustainable building	• 1 paper study about the retrofit process to demonstrate the energy efficient rate • 1 paper study about the BIM application of building life cycle
Methodology	• Most of the studied was conducted based on case	• 1 paper adopt quantitative and

	studies /surveys and questionnaires	qualitative research methods • 1 paper adopt analytical hierarchy processes (AHP) research methods
Results	• 7 paper discusses the benefits and essential of WSD concept • 4 paper discusses the solution for sustainable strategies	• 1 paper discuss about the BIM to develop various functions. • 1 paper discuss about the challenges on energy efficient building

Table 2.5.1 Summary of literature review

CHAPTER 3
METHODOLOGY

3.1 Research Process Flow

In order to achieve the objectives, previous studies have been reviewed to identify the similarities and differences among the papers. Then, the questionnaires will be prepared based on the outcomes from the literature review. Pilot study conducted in preliminary stage is used to evaluate the feasibility of research on the criteria for redevelopment. The data collected will be compile and analyse to achieve the synthesis of finding and developing conclusion. Figure 1 below shows the process flowchart of the research in achieving the objectives, while the research methodology is summarized in Table 3.1.

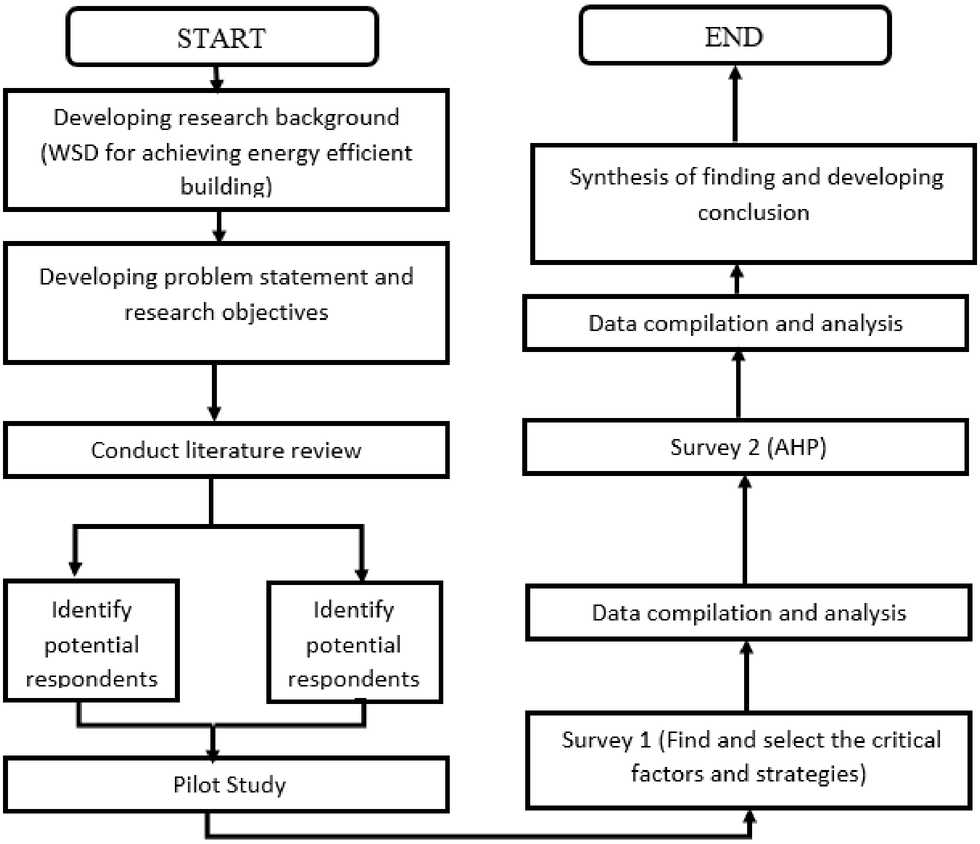

Figure 1 Research process flowchart

OBJECTIVES	APPROACH	DATA				SAMPLE
		TYPE	COLLECTIVE TECHNIQUE	SAMPLING TECHNIQUE	ANALYSIS	
To Investigate factors of Whole System Design that able to support the achievement of energy efficient building	Exploratory	Primary	Survey, questionnaire, interview	Purposive sampling	Qualitative descriptive analysis	-2 respondents from industry (with experience in WSD in project
To find and select the critical factors and strategies for achieving the energy efficient building				Snowball sampling	Statistical descriptive analysis (scatter plot of mean and standard deviation)	Minimum 30 industry practitioners from energy efficient building
To propose and select the best strategy	Confirmatory	Primary	Questionnaire	Purposive sampling	Analytical Hierarchy Process (AHP)	2 potential respondents in energy efficient building

Table 3.1 Research Methodology

3.2 Achieving Objective 1 and Objective 2

In order to achieve first and second objectives, exploratory approach have been used to investigate the factors of whole system design that able to support the achievement of energy efficient building and to find and select the critical factors and strategies for achieving the energy efficient building. Qualitative analysis was used for the first objective and statistical analysis (scatter plot of mean and standard deviation) and the second objective. In order to achieve the first objective, 2 respondents from industry (with experience in WSD in project) were selected to answer the questionnaires and survey. 1 of the respondent are from academia but at the same time he had served in the industry for more than 10 years, while another respondent is the executive of the company that had served in the industry for less than 5 years. Both of them had confirmed and modified the whole system design factor for energy efficient building project that obtained from previous studies and also gave some strategies to achieve the goal. The data are collected through interviews and questionnaire as the data type are primary data. After the data collection is complete, the data are analyzed using Descriptive Qualitative Analysis.

By achieving objective 2 (refer to table 3.1), the exploratory approach has been used. The respondents are identified using Snowball Sampling and once the respondents related to my research are identified, the respondents will identify further respondent which will likely to look for a respondent who will be similar to themselves. The target number of respondents will be around thirty (30). The respondents are project stakeholders from the construction industry. The collection technique is surveyed by distributing the questionnaire. The respondents rated the WSD factors based on a Likert Scale in the questionnaire and provide the suitable implementation strategies based on their experience, hence the data type is also primary. The data collected are then analyzed using Statistical Descriptive Analysis to identify the most critical WSD factors and strategies.

3.3 Achieving Objective 3

For the third objective, confirmatory approach was used to propose and select the best strategy for integrated whole system design to achieve energy efficient building. The data was collected through questionnaire and using purposive sampling form 2 potential respondents (decision maker). Then Analytical

Hierarchy Process (AHP) was used as a multi-criteria decision-making to find the best strategy. As mentioned by Anumba et al. (2014), AHP has been found to be beneficial in determining the relative weightings of the option rating assessments which will lead to the final value of the decision. The sample of AHP model will be shown in the figure below, where level 1 is the goal for selecting the best strategy of Integrated Whole System Design to achieve energy efficient building, level 2 will be the criteria, level 3 is the alternatives.

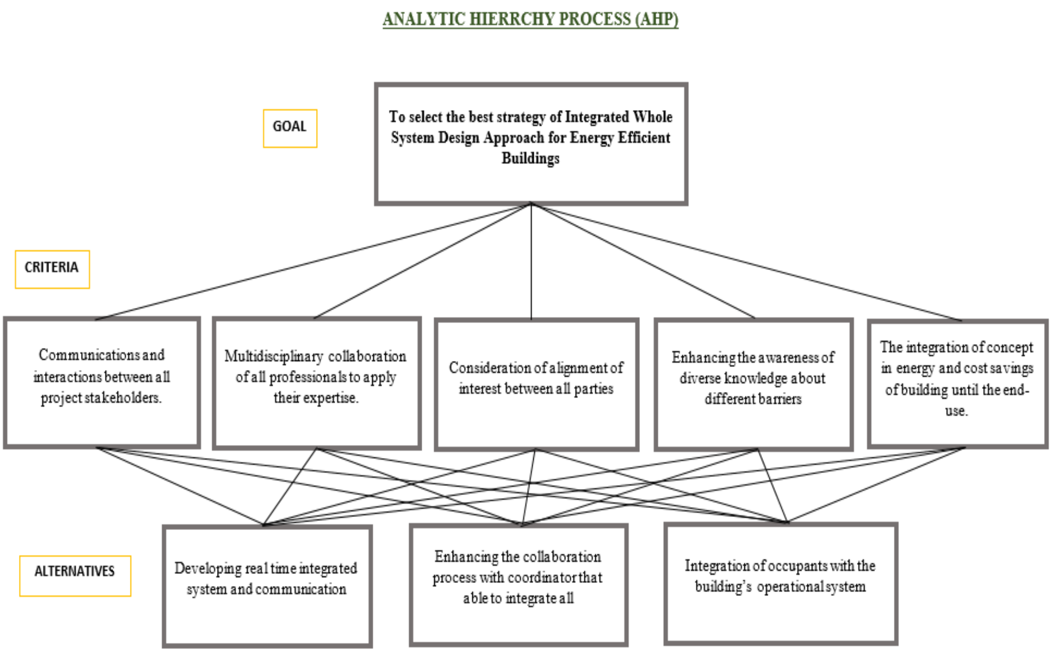

Figure 2 AHP model

3.4 Project Milestone and Gantt Chart

		Timeline								
No.	**Research Activities**	**2019**				**2020**				
		FYP 1				**FYP2**				
		Sept	Oct	Nov	Dec	Jan	Feb	March	April	May
1	Background study									
2	Literature review									
3	Determining Variable									
4	Developing Methodology									
5	Determining samples and populations									
6	Preparing questionnaire									
7	Pilot study									
8	Data collections									
9	Data analysis									
10	Model development									
11	Results and discussions									
12	Dissertation submition									

Figure 3 Project Gantt-Chart and milestone of the research in the Final Year Project 1 and Final Year Project 2

CHAPTER 4
RESULTS AND DISCUSSION

4.1 Pilot study

A pilot study has done on week 7 with an expert from Blue Snow Consulting and Engineering Sdn Bhd, Ir. Bernard Sagaiyaraj, who have industrial experience that more than 10 years and he is also one of the earliest LEED (Leadership in Energy & Environmental Design) Accredited Professional in country that has triple LEED Accreditation under his belt. The another candidate that were chosen for the pilot study is Shia, who is an executive from IJM construction Sdn Bhd. They were chosen as the candidates because they are very experienced in the construction industry.

The main objective of the pilot study is to validate the result from objective 1 which is "the factors of Whole System Design that able to support the achievement of energy efficient building" before finalizing the questionnaire which will be distribute to the industry. Then, the factors were chosen based on the agreement from both candidates whereas if there is any disagreement from any side, the criteria will not be considered. This pilot study also aims to explore and observe the contract model in the industry.

4.1.1 Summary of findings from the pilot study

Based on the pilot study, 14 criteria were nominated as the factors of whole system design for energy efficient building that we found out from the previous studies. From Table 4.1.1.1, we can obtain that both respondents show highly agreement with 12 factors, while there were 2 factors were disagreed from any side which will not be considered. In addition, Ir. Bernard had recommended us to have strong knowledge of HVAC systems, which have similar thoughts with Hartungi et al. (2011), as they mentioned about the improve control and monitoring of mechanical heating and ventilation can helps in energy conversation. systems. Besides, Ms. Shia had recommended her thoughts on the best strategy for whole system design, which have a similar point of view with Charnley et al. (2010) as they mentioned, the role of a facilitator is very important to regard the system from above and also identify gaps or problems between sub-systems. The results from the pilot study is summarized in the table below.

No.	Factors of WSD in supporting Energy Efficient Building	Ir. Bernard	Ms. Shia
1	Communications and interactions between project stakeholders with different background and expertise	Strongly Agree	Agree
2	Sustainability of the partnership between projects stakeholders.	Strongly Agree	Disagree
3	Consideration of alignment of interest between all parties involved in the process of a whole system design	Strongly Agree	Agree
4	The integration of concept in energy and cost savings for the utilization of the building, particularly until	Strongly Agree	Agree

	the end-use (termination) of the building		
5	The opportunity of utilizing holistic approach, which is to consider all facets of the engineering process and improvements	Strongly Agree	Agree
6	Multidisciplinary collaboration of all professionals to apply their expertise for developing the concept of the building (energy efficient building)	Strongly Agree	Agree
7	The opportunity to find new strategies and substantial design modifications to have improvement and achieve significant performance	Strongly Agree	Agree
8	Having frequent meeting between project stakeholders	Neutral	Disagree
9	Availability of various building performance assessments (the opportunity of having variety of advanced tools and systems)	Agree	Agree

10	Enhancing the awareness of financial matters in the design	Strongly Agree	Strongly Agree
11	Enhancing the awareness of diverse knowledge about barriers in the concept of energy efficient building	Strongly Agree	Strongly Agree
12	Enhancing the awareness of barriers in the construction process of energy efficient building	Strongly Agree	Strongly Agree
13	Enhancing the awareness in developing strategies for reducing the embodied energy and operational energy of the building	Strongly Agree	Strongly Agree
14	Enhancing the development of integrated system for building utilities	Strongly Agree	Agree
15	Other factors of WSD that necessary to be considered in achieving energy efficient building.	Strong knowledge of HVAC systems	Cost of energy efficient design will be the main concern of client
16	Best strategy of WSD in achieving the energy efficient building.	Start with the HVAC and Facade Design and use as much	Having a key coordinator that combine

		water via air-water systems and water in embedded systems	all parties together.
17	Suggestion on articles or projects that related to this topic	Active Chilled Beams , Radiant Cooling and Low E Fenestration	-

Table 4.1.1.1 results of pilot study

4.2 Primary Survey

Primary survey aims to collect the data from the stakeholders in order to prioritize the criteria and potential strategies of WSD in achieving the energy efficient building. This is necessary in achieving Objective 1 and Objective 2. This primary survey was conducted through online survey form and the respondents were allowed to give necessary suggestion of the strategies. The online survey form was shared and circulated online through social medias to the project stakeholders and also thorough snowball sampling. A total of 30 respondents were obtained from the primary survey. The demographic profile of the respondents and statistical descriptive analysis were discussed in Section 4.2.1 and 4.2.2.

4.2.1 Demographic Profile of the Respondents

Referring to figure 4.2.1.1, 83% of the respondents have an qualifications level of bachelor's degree and 10% of the respondents are Master's degree. Then, 3% of respondent completed their studies up to diploma level.

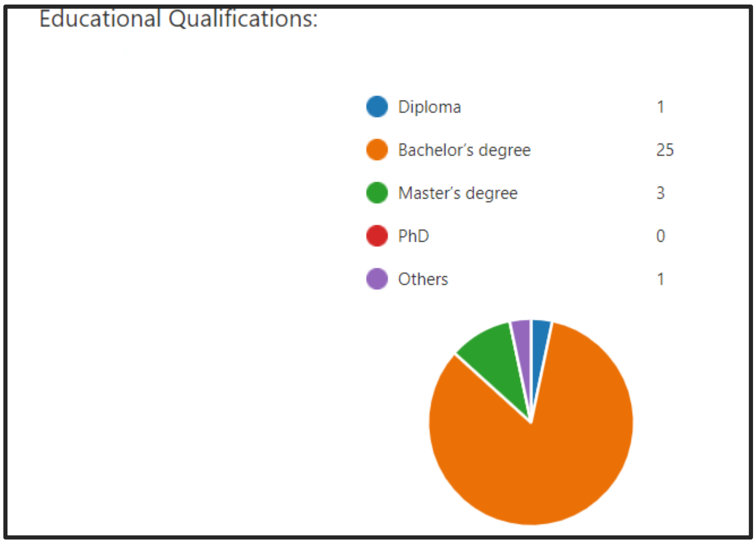

Figure 4.2.1.1educational qualifications of respondents

Besides, based on figure 4.2.1.2, 40% of the respondent are the executive of a company. Then, 7% and 26% of the respondent designations are senior management and junior management respectively, while another 26% of respondent are having different designation in the company.

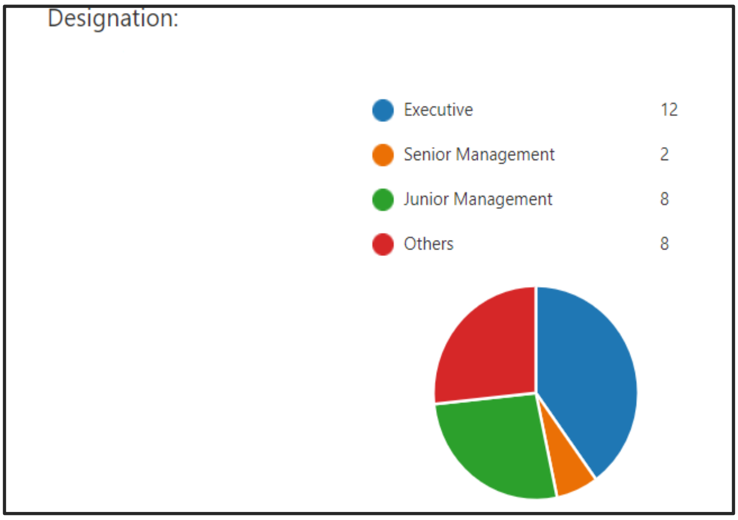

Figure 4.2.1.2 Designation of respondents

Figure 4.2.1.3, shows the nature of business of the respondent. From the figure, we can see that the majority of the respondents' business developer, which consist of 43.3% and 33.3% are engineering consultant. Besides, 3.33% of respondent work as green consultant and architect. 30% of respondent are having others nature of business.

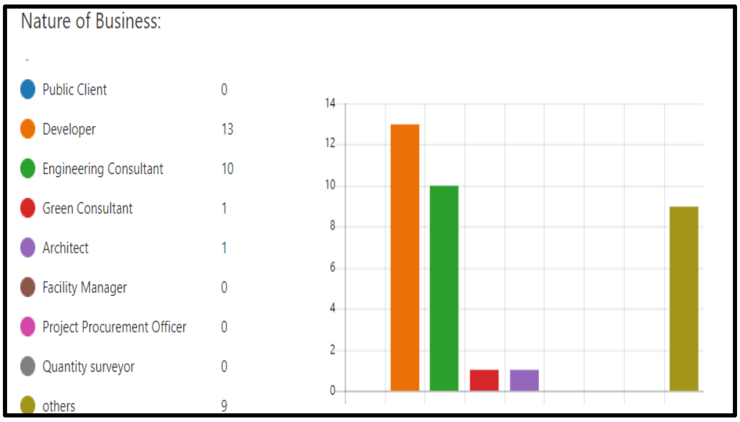

Figure 4.2.1.3 Nature of business of respondents

According to figure 4.2.1.4, 50% of the project size of the respondents are basically RM5 to RM10 million and more than RM10 million. Then, there were 20% of the project size were RM1 to RM5 million, while there were only 3.33% of the project size were less than RM1 million.

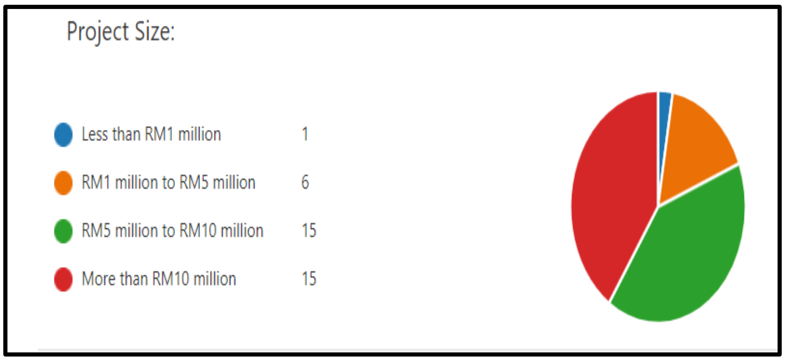

Figure 4.2.1.4 Projects size of respondents

From figure 4.2.1.5, we can know the project types of the respondents were mainly on residential building, which consist of

36.6%. Following by commercial buildings and infrastructure, which are 28.3% and 18.3% respectively. There were also 6.66% of the project types are industrial buildings, whereas for educational building, health building and others types of the project are having same percentage as 3.33%.

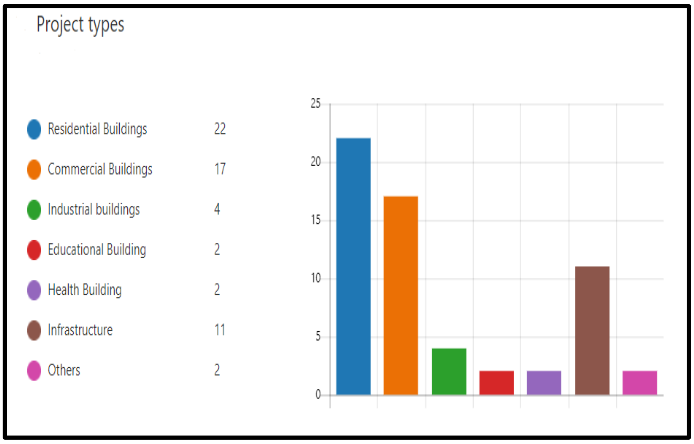

Figure 4.2.1.5 Project types of respondents

4.3 Mean and Standard Deviation Analysis for Statistical Descriptive Analysis

From the primary survey that had been done, the respondents were instructed to rate their agreement on the criteria for project redevelopment decision making through Likert scale which range from strongly disagree to strongly agree. The data were collected from 30 respondents successfully. After that, mean and standard deviation analysis were used to determine the collected data using excel. The analyzed mean and standard deviation result were presented in scatter plot in order to visualized and rank the criterias as shown as the figure below. According to figure 4.3.1, most of the criterias actually falls into high mean high standard deviation and high mean low standard deviation.

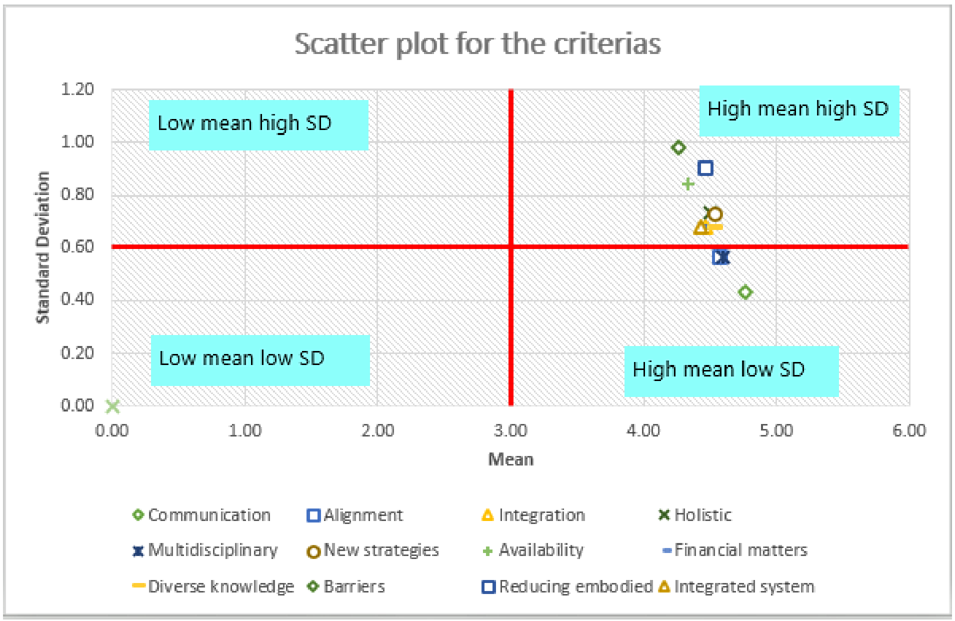

Figure 4.3.1 scatter plot for the criterias

Then, after the criteria had been analysed, the top five ranking of the criteria were chosen as the main criteria for whole system design for energy efficient building. By referring to the Figure 4.3.2, "Communications and interactions between all project stakeholders" having the highest rank with the highest mean and lowest standard deviation, which are 4.77 and 0.43 respectively. Then, the second rank of the criteria is "Multidisciplinary collaboration of all professionals to apply their expertise", which have the mean of 4.6 and standard deviation of 0.56. Next, the criteria that rank at third is "Consideration of alignment of interest between all parties", by having by having mean and standard deviation of 4.57 and 0.57 respectively. The fourth and fifth criteria, will be "Enhancing the awareness of diverse knowledge about different barriers" and "The integration of concept in energy and cost savings of building until the end-use" respectively. These 5 criteria selected were the main criteria for the AHP model.

Factor	Mean	Standard Deviation	Rank
Communication	4.77	0.43	1
Alignment	4.57	0.57	3

Integration	4.47	0.68	5
Holistic	4.50	0.73	8
Multidisciplinary	4.60	0.56	2
New Strategies	4.53	0.73	7
Availability	4.33	0.84	9
Financial Matters	4.46	0.68	6
Diverse Knowledge	4.53	0.68	4
Barriers	4.27	0.98	12
Reducing Embodied	4.47	0.90	10
Integrated System	4.43	0.90	11

Table 4.3.2 analysis of criteria using statistical descriptive analysis

Apart from that, by considering all strategies that recommended by the respondent, there were 3 strategies selected to be as the alternatives of the AHP model. These strategies selected were based on the consideration of the strategies that had been found from the previous study with an empirical validation to validate whether these strategies are applicable in the construction industry. These 3 strategies will be show on the table 4.3.3 below.

Strategies	Related study	Source
Developing real time integrated system and communication	One of the essential component of whole system design is openness to communication, information and participation that is direct, open and effective communication and information sharing	- Blizzard et al. (2012)
Enhancing the collaboration	The integration of design elements leads to synergistic	- Blizzard et al. (2012)

process with coordinator that able to integrate all	solutions that can reduce project costs and negative impacts. In the context of a whole system design, it is suggested that it is important for someone who can look at the system from above and identify gaps or potentially ignored relationships between subsystems.	 - Charnley et al. (2010)
Integration of occupants with the building's operational system	The knowledge and understanding are recognized as key factors in other studies to influence comfort: users are much less satisfied when they cannot understand how things are working or how temperature and ventilation are controlled.	- Judith et al. (2013)

Table 4.3.3 Empirical validation of strategies

4.4 AHP model

A second set of questionnaires has been used to collect data for the Analytic HierarchyModel or known as AHP model. The purpose of the AHP model is to achieve objective 3 which is to propose best strategy of Integrated Whole System Design Approach for Energy Efficient Buildings. In the AHP questionnaire, two criteria are compared to each other with a scale from 1-9 for “more important” and as well as scale from 1-9 for “less important”. There were 2 sections include in the AHP questionnaire, which are section 1 on the main criteria and section 2 on the alternatives. The respondents were instructed to put weightage by comparing two criteria under different perspective. 5 main criteria were prepared in the questionnaire selected from the previous ranking of the scatter plot, while 3 alternatives were prepared by considering the recommended strategies from the respondent of the previous survey.

Main criteria	Alternatives
Communications and interactions between all project stakeholders	Developing real time integrated system and communication
Multidisciplinary collaboration of all professionals to apply their expertise.	Enhancing the collaboration process with coordinator that able to integrate all
Consideration of alignment of interest between all parties	Integration of occupants with the building’s operational system
Enhancing the awareness of diverse knowledge about different barriers	
The integration of concept in energy and cost savings of building until the end-use.	

Table 4.4.1 selected criteria and strategies

4.5 Demographic profile of the respondent for AHP survey

Two respondents were invited to participate in this AHP survey. One of the respondent have experienced in the industry for more than 10 years and another respondent have experienced in the industry for less than 5 years while continuing to study on Master's degree currently. They were chosen as the potential decision makers as they are highly experienced in this sector.

Respondent 1	
Year(s) of work experience	More than 10 years
Name of company	Petronas Refinery & Petrochemical Corporation Sdn. Bhd.
Designation	Executive

Table 4.5.1 Demographic profile for respondent 1

Respondent 2	
Year(s) of work experience	Less than 5 years
Name of company	Setia Runding Sdn. Bhd.
Designation	Junior Management

Table 4.5.2 Demographic profile for respondent 2

**symbol to represent each factors for the discussion*

List of Criteria	List of Alternatives
C1: Communication **C2:** Multidisciplinary **C3**: Alignment **C4**: Diverse Knowledge **C5**: Integration	**A1**: Developing real time **A2**: Integration of occupants **A3**: Collaboration process

4.5.1 Respondent 1

According to Table 4.5.1.1 and Table 4.5.1.2, respondent 1 think that (**C1**) is the most critical criteria when compared to the other factors with the weightage of 2.40. Besides, the second most critical criteria which is **(C4)** then followed by **(C5)**. Next, the weightage of **(C1)** and **(C2)** are 0.45 and 0.23 respectively which ranked at number 4 and 5. When considering from the perspective of **(C1)**, respondent think that **(A1)** is the most critical strategy. When considering from the perspective of **(C2)**, **(A1)** is the most critical strategy**.** When considering from the perspective of **(C3)**, **(A1)** is the most critical strategy. When considering from the perspective of **(C4)**, **(A3)** is the most critical strategy**.** When considering from the perspective of **(C5)**, **(A3)** is the most critical strategy**.** In summary, when considering all criterias respondent actually think that **(A1)** is the most important strategy.

i. **Comparing of criteria of function with respect to each other**

	C1	C2	C3	C4	C5
C1	1.00	3.00	0.20	0.33	0.25
C2	0.33	1.00	0.14	0.20	0.33
C3	5.00	7.00	1.00	5.00	3.00
C4	3.00	5.00	0.20	1.00	3.00
C5	4.00	3.00	0.33	0.33	1.00
Total	13.33	19.00	1.87	6.87	7.58

Table 4.5.1.1AHP matrix on criteria of function from respondent 1

	C1	C2	C3	C4	C5	Weightage	Ranking
C1	0.08	0.16	0.11	0.05	0.03	0.42	4
C2	0.03	0.05	0.08	0.03	0.04	0.23	5
C3	0.38	0.37	0.53	0.73	0.40	2.40	1
C4	0.23	0.26	0.11	0.15	0.40	1.14	2
C5	0.30	0.16	0.18	0.05	0.13	0.81	3
Total	1.00	1.00	1.00	1.00	1.00		

Table 4.5.1.2 Normalization of AHP on criteria of function from respondent 1

ii. Comparing alternatives with respect to each other by considering in Communications and interactions between project stakeholders with different background and expertise

	A1	A2	A3
A1	**1.00**	3.00	5.00
A2	0.33	**1.00**	0.33
A3	0.20	3.00	**1.00**
Total	1.53	7.00	6.33

Table 4.5.1.3 AHP matrix on alternatives (communication)

	A1	A2	A3	Weightage	Ranking
A1	0.65	0.43	0.79	**1.87**	**1**
A2	0.22	0.14	0.05	**0.41**	**3**
A3	0.13	0.43	0.16	**0.72**	**2**
Total	1.00	1.00	1.00		

Table 4.5.1.4 AHP normalization on alternatives (communication)

iii. Comparing alternatives with respect to each other by considering in Multidisciplinary collaboration of all professionals to apply their expertise for developing the concept of the building (energy efficient building)

	A1	A2	A3
A1	**1.00**	3.00	5.00
A2	0.33	**1.00**	0.33
A3	0.20	3.00	**1.00**
Total	1.53	7.00	6.33

Table 4.5.1.5 AHP matrix on alternatives (Multidisciplinary)

	A1	A2	A3	Weightage	Ranking
A1	0.65	0.43	0.79	**1.87**	**1**
A2	0.22	0.14	0.05	**0.41**	**3**
A3	0.13	0.43	0.16	**0.72**	**2**
Total	1.00	1.00	1.00		

Table 4.5.1.6 AHP normalization on alternatives (Multidisciplinary)

iv. Comparing alternatives with respect to each other by considering in Consideration of alignment of interest between all parties involved in the process of a whole system design

	A1	A2	A3
A1	**1.00**	5.00	3.00
A2	0.20	**1.00**	3.00
A3	0.33	0.33	**1.00**
Total	1.53	6.33	7.00

Table 4.5.1.7 AHP matrix on alternatives (Alignment)

	A1	A2	A3	Weightage	Ranking
A1	0.65	0.79	0.43	**1.87**	**1**
A2	0.13	0.16	0.43	**0.72**	**2**
A3	0.22	0.05	0.14	**0.41**	**3**
Total	1.00	1.00	1.00		

Table 4.5.1.8 AHP normalization on alternatives (Alignment)

v. Comparing alternatives with respect to each other by considering in Enhancing the awareness of diverse knowledge about barriers in the concept of energy efficient building

	A1	A2	A3
A1	**1.00**	0.33	0.33
A2	3.03	**1.00**	0.33
A3	3.03	0.33	**1.00**
Total	7.06	1.66	1.66

Table 4.5.1.9 AHP matrix on alternatives (diverse knowledge)

	A1	A2	A3	Weightage	Ranking
A1	0.14	0.20	0.20	**0.539**	**3**
A2	0.43	0.60	0.20	**1.229**	**2**
A3	0.43	0.20	0.60	**1.232**	**1**
Total	1.00	1.00	1.00		

Table 4.5.1.10 AHP normalization on alternatives (diverse knowledge)

vi. Comparing alternatives with respect to each other by considering in The integration of concept in energy and cost

savings for the utilization of the building, particularly until the end-use (termination) of the building

	A1	A2	A3
A1	1.00	0.33	3.00
A2	3.00	1.00	0.33
A3	0.33	3.00	1.00
Total	4.33	4.33	4.33

Table 4.5.1.11 AHP matrix on alternatives (Integration)

	A1	A2	A3	Weightage	Ranking
A1	0.23	0.08	0.69	**1.000**	**2**
A2	0.69	0.23	0.08	**0.999**	**3**
A3	0.08	0.69	0.23	**1.001**	**1**
Total	1.00	1.00	1.00		

Table 4.5.1.12 AHP normalization on alternatives (Integration)

<u>Summary of result for respondent 1</u>

	Weightage	A1		A2		A3	
C1	0.42	1.87	0.7854	0.41	0.1722	0.72	0.3024
C2	0.23	1.87	0.4301	0.41	0.0943	0.72	0.1656
C3	2.40	1.87	4.488	0.72	1.728	0.41	0.984
C4	1.14	0.54	0.6156	1.23	1.4022	1.232	1.40448
C5	0.81	1	6.3191	0.999	3.3967	1.001	2.85648
Sum			12.6382		6.7934		5.71296
Ranking		**1**		**2**		**3**	

Table 4.5.1.13 synthesis results of AHP on alternatives when considering all criteria from respondent 1

From the result, the strategy of Developing real time integrated system and communication **(A1)** is the most important alternatives followed by Integration of occupants with the building's operational system **(A2)** and Enhancing the collaboration process with coordinator that able to integrate all **(A3)**. This strategy was agreed by Blizzard et al. (2012), as it mentioned that there is potential to improve the performance of whole system design when communication and information sharing is in open, direct and effective.

4.5.1 Respondent 2

According to Table 4.5.2.1 and Table 4.5.2.2, respondent 2 think that (**C3**) is the most critical criteria when compared to the other factors with the weightage of 1.75. Besides, the second most critical criteria which is **(C4)** then followed by **(C2)**. Next, the weightage of **(C5)** and **(C2)** are 0.74 and 0.15 respectively which ranked at number 4 and 5. When considering from the perspective of **(C1)**, respondent think that **(A1)** is the most critical strategy. When considering from the perspective of **(C2)**, **(A1)** is the most critical strategy**.** When considering from the perspective of **(C3)**, **(A1)** is the most critical strategy. When considering from the perspective of **(C4)**, **(A1)** is the most critical strategy**.** When considering from the perspective of **(C5)**, **(A1)** is the most critical strategy**.** In summary, when considering all criterias respondent actually think that **(A1)** is the most important strategy.

i. Comparing of criteria of function with respect to each other

	C1	C2	C3	C4	C5
C1	**1.00**	4.00	5.00	0.25	0.33

C2	0.25	**1.00**	0.14	0.20	0.25
C3	0.25	7.00	**1.00**	6.00	4.00
C4	4.00	5.00	0.17	**1.00**	3.00
C5	3.00	4.00	0.25	0.33	**1.00**
Total	**8.50**	**21.00**	**6.56**	**7.78**	**8.58**

Table 4.5.2.1AHP matrix on criteria of function from respondent 2

	C1	C2	C3	C4	C5	Weightage	Ranking
C1	0.12	0.19	0.76	0.03	0.04	**1.14**	**3**
C2	0.03	0.05	0.02	0.03	0.03	**0.15**	**5**
C3	0.03	0.33	0.15	0.77	0.47	**1.75**	**1**
C4	0.47	0.24	0.03	0.13	0.35	**1.21**	**2**
C5	0.35	0.19	0.04	0.04	0.12	**0.74**	**4**
Total	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**		

Table 4.5.2.2 Normalization of AHP on criteria of function from respondent 2

ii. Comparing alternatives with respect to each other by considering in Communications and interactions between project stakeholders with different background and expertise

	A1	A2	A3
A1	**1.00**	4.00	5.00
A2	0.25	**1.00**	4.00
A3	0.20	0.25	**1.00**
Total	1.45	5.25	10.00

Table 4.5.2.3 AHP matrix on alternatives (communication)

	A1	A2	A3	Weightage	Ranking
A1	0.69	0.76	0.50	**1.952**	**1**
A2	0.17	0.19	0.40	**0.763**	**2**
A3	0.14	0.05	0.10	**0.286**	**3**
Total	1.00	1.00	1.00		

Table 4.5.2.4 AHP normalization on alternatives (communication)

iii. Comparing alternatives with respect to each other by considering in Multidisciplinary collaboration of all professionals to apply their expertise for developing the concept of the building (energy efficient building)

	A1	A2	A3
A1	**1.00**	4.00	5.00
A2	0.25	**1.00**	0.25
A3	0.20	4.00	**1.00**
Total	1.45	9.00	6.25

Table 4.5.2.5 AHP matrix on alternatives (Multidisciplinary)

	A1	A2	A3	Weightage	Ranking
A1	0.69	0.44	0.80	**1.934**	**1**
A2	0.17	0.11	0.04	**0.324**	**3**
A3	0.14	0.44	0.16	**0.742**	**2**
Total	1.00	1.00	1.00		

Table 4.5.2.6 AHP normalization on alternatives (Multidisciplinary)

iv. Comparing alternatives with respect to each other by considering in Consideration of alignment of interest between all parties involved in the process of a whole system design

	A1	A2	A3
A1	**1.00**	6.00	5.00
A2	0.17	**1.00**	5.00
A3	0.20	0.20	**1.00**
Total	1.37	7.20	11.00

Table 4.5.2.7 AHP matrix on alternatives (Alignment)

	A1	A2	A3	Weightage	Ranking
A1	0.73	0.83	0.45	2.020	**1**
A2	0.12	0.14	0.45	0.712	**2**
A3	0.15	0.03	0.09	0.265	**3**
Total	1.00	1.00	1.00		

Table 4.5.2.8 AHP normalization on alternatives (Alignment)

v. Comparing alternatives with respect to each other by considering in Enhancing the awareness of diverse knowledge about barriers in the concept of energy efficient building

	A1	A2	A3
A1	**1.00**	4.00	5.00
A2	0.25	**1.00**	4.00
A3	0.20	0.25	**1.00**
Total	1.45	5.25	10.00

Table 4.5.2.9 AHP matrix on alternatives (diverse knowledge)

	A1	A2	A3	Weightage	Ranking
A1	0.69	0.76	0.50	**1.952**	**1**
A2	0.17	0.19	0.40	**0.763**	**2**
A3	0.14	0.05	0.10	**0.286**	**3**
Total	1.00	1.00	1.00		

Table 4.5.2.10 AHP normalization on alternatives (diverse knowledge)

vi. Comparing alternatives with respect to each other by considering in The integration of concept in energy and cost savings for the utilization of the building, particularly until the end-use (termination) of the building

	A1	A2	A3
A1	1.00	0.50	5.00
A2	2.00	1.00	0.33
A3	0.20	3.00	1.00
Total	3.20	4.50	6.33

Table 4.5.2.11 AHP matrix on alternatives (Integration)

	A1	A2	A3	Weightage	Ranking
A1	0.31	0.11	0.79	**1.213**	**1**
A2	0.63	0.22	0.05	**0.900**	**2**
A3	0.06	0.67	0.16	**0.887**	**3**
Total	1.00	1.00	1.00		

Table 4.5.2.12 AHP normalization on alternatives (Integration)

Summary of result for respondent 2

	Weightage	A1		A2		A3	
C1	1.14	1.952	2.22528	0.763	0.86982	0.286	0.32604
C2	0.15	1.934	0.2901	0.324	0.0486	0.742	0.1113
C3	1.75	2.02	3.535	0.715	1.25125	0.265	0.46375
C4	1.12	1.952	2.36192	0.763	0.92323	0.286	0.34606
C5	0.74	1.213	8.4123	0.9	3.0929	0.887	1.24715
Sum			16.8246		6.1858		2.4943
Ranking		**1**		**2**		**3**	

Table 4.5.2.13 synthesis results of AHP on alternatives when considering all criteria from respondent 2

From the result, respondent 2 actually thinks that the strategy of Developing real time integrated system and communication **(A1)** is the most important alternatives followed by Integration of occupants with the building's operational system **(A2)** and Enhancing the collaboration process with coordinator that able to integrate all **(A3)**. In summary, respondent 2 are actually having similar thought with respondent 1.

4.5.3 Synthesis of AHP on alternatives based on criteria of function by all respondents

From Table 4.5.3.1, the synthesis of AHP on alternatives based on criteria of function by both respondents for whole system design for energy efficient building factors of all respondents have been obtained. From the results, the integrated perspective shown that the most valuable strategy for Whole System Design for energy efficient building is Developing real time integrated system and communication **(A1)** among all three strategies. Blizzard et al. (2012) mentioned that one of the most important and essential component in whole system design is the openness to communication which is direct, open and effective. Therefore, we can know that both respondents actually having same thoughts to make the communication between all project stakeholders to be in real-time. Then, the second important strategy is Integration of occupants with the building's operational system **(A2).** According to Judith et al. (2013), occupants need to have high understandingand integrated with the building's operational system to increase the level of comfortable. The third important strategy is Enhancing the collaboration process with coordinator that able to integrate all **(A3)** as claimed by Charnley et al. (2010) and Blizzard et al. (2012), they had agreed that a person that able to integrate all subsystems and look at the system from the above in whole system design process leads to synergistic solutions that can reduce project costs and negative impacts.

	C1	C2	C3	C4	C5	Sum	Ranking
A1	3.822	3.804	3.89	2.491	2.213	16.22	**1**
A2	1.173	0.734	1.435	1.992	1.899	7.233	**2**
A3	1.006	1.462	0.675	1.518	1.888	6.549	**3**

Table 4.5.3.1 Synthesis of AHP on alternatives when considering all the criteria of function from all respondents

4.6 Validation on Criteria through Previous Studies

The five most important criteria identified from statistical descriptive analysis were synthesis with previous study to provide the validation as shown in the Table 4.6.1 below.

Main criteria	Sources	Empirical

Communications and interactions between all project stakeholders	Blizzard et al. (2011)	Interactions between stakeholders largely contributed to the take away of integrative design.
Multidisciplinary collaboration of all professionals to apply their expertise.	Valiente et al. (2019)	With all professionals applying their respective previous knowledge during whole system process will cause less conflicts and positive contribution to the work.
Consideration of alignment of interest between all parties	Charnley et al. (2010)	Participants all agreed that an important aspect of openness and honesty surrounding all parties' interests, expectations and needs was a cohesive and whole system solution that satisfy as many requirements as possible.
Enhancing the awareness of diverse knowledge about different barriers	Micheal et al. (2014)	Many energy efficiency and energy conversation opportunities in building are not taken up by markets despite it is very cost-effectiveness, This is due to various barriers, including behaviour, technology and market characteristics.

The integration of concept in energy and cost savings of building until the end-use.	Blizzard et al. (2019)	The Rocky Mountain Institute suggests that designers should first downstream and then upstream transform those compounding loss to a compounding benefit. That would involve building retrofits to resource efficiency to make the energy and water treatment plants more resource-saving.

Table 4.6.1 Validations of criteria

CHAPTER 5
CONCLUSION AND RECOMMENDATION

5.1 Conclusion

Through the research, this study successfully investigated the factors of whole system design that able to support the achievement of energy efficient building through the previous literature review and able to identify the most relevant factors that relate to the real industry through pilot study conducted with 2 respondents from the industry field. Furthermore, from the total of 14 criterias, we able to select the 12 most critical factors and develop 3 strategies for achieving the energy efficient building through the data collection from the 30 respondents using statistical descriptive analysis. Then, based on the integrated responses from both respondents we successfully propose and select the best strategy of integrated whole system design approach for energy efficient buildings using AHP model. To conclude, communications and interactions between different project stakeholders is the most critical criteria. As for the strategies, developing real time integrated system and communication is the best strategy to be implemented in the integrated whole system design approach for energy efficient buildings by obtaining the integrated perspective of both respondents.

5.2 Recommendations

In order to improve the research, more respondents for the survey should be used to get more accurate results. The respondent is also expected to come from others country, as the project type varies by region, which means the respondent's perspective on the subject will vary considerably.

REFERENCES

[1] Addy, M. N., Adinyira, E., & Korantengz, C. (2014). Architect’s perception on the challenges of building energy efficiency in Ghana. *Structural Survey, 32*(5), 365-376.

[2] Almeida, A., Fonseca, P. and Moura, P. & Jorge, H. (2018). Sustainability in university campus: options for achieving nearly zero energy goals. *International Journal of Sustainability in Higher Education*, *19*(4), 790-816.

[3] Charnley, F., Evans, S., & Lemon, M. (2011). Exploring the process of whole system design. *Design Studies, 32*(2), 156-179.

[4] Hartungi, R., & Jiang, L. (2012). Energy efficiency and conservation in an office building: a case study. *International Journal of Energy Sector Management, 6*(2), 175-188.

[5] Blizzard, J. L. & Klotz, L. E. (2012). A framework for sustainable whole systems design. *Design Studies, 33*, 456-479. doi:10.1016/j.destud.2012.03.001

[6] Blizzard, J. and Klotz, L., Dukes, M. & Pradhan, A. (2011). Introducing whole-systems design to first-year engineering students with case studies. *International Journal of Sustainability in Higher Education*, *13*(2), 177-196.

[7] Anumba, C. J., Anumba, P., & Leicht, R. M. (2014). Case study of integrated decision-making for deep energy-efficient retrofits. *International Journal of Energy Sector Management*, *8*(4), 434-455.

[8] Celis-D’Amico, F., Echeverria-Valiente, E., Garcia-Alvarado, R., & Saelzer-Fuica, G. (2019). Integrated design experiences for energy-efficient housing in Chile. *Construction Innovation, 19* (2), 236-255.

[9] Ekanayake, B. J., Tennakoon, G. A., & Waidyasekara, A. (2020). Revisiting the role of professionals in designing buildings with low embodied and

operational energy. *Built Environment Project and Asset Management, 10*(1), 110-123.

[10] Li, Z., Meng, Q., Shi, W., Sun, Y., Wang, J., Wang, X., Xu, L., & Zhang, Y. (2020). A review of integrated applications of BIM and related technologies in whole building life cycle. *Engineering, Construction and Architectural Management, 27*(8), 1647-1677.

[11] Mehr, S. Y., & Wilkinson, S. (2018). Technical issues and energy efficient adaptive reuse of heritage listed city halls in Queensland Australia. *International Journal of Building Pathology and Adaptation, 36*(5), 529-542.

[12] Meistad, T. (2014). How energy efficient office buildings challenge and contribute to usability. *Smart and Sustainable Built Environment, 3*(2), 110-131.

APPENDIX I

Questionnaire for Statistical Descriptive Analysis

Dear Sir/Madam,

SUBJECT: A questionnaire survey for Developing Strategies of Integrated Whole System Design Approach for Energy Efficient Buildings

I'm conducting a research on Developing Strategies of Integrated Whole System Design Approach for Energy Efficient Buildings in Malaysia throughout the project development which intends to:

1- To investigate factors of Whole System Design that able to support the achievement of energy efficient building.
2- To find and select the critical factors and strategies for achieving the energy efficient building.
3- To propose and select the best strategy of integrated whole system design approach for energy efficient buildings.

Your contribution in this research will play a role in the success of this study. I would really appreciate if you could contribute by answering this questionnaire survey.

Sincerely,
(CHAN YONG YEAH)
Final year student at UTP

E-mail: chan.yong_24502@utp.edu.my
Contact no: +6017-5858689

Name (optional):	____		
Contact (email/phone no):	____		
Educational Qualifications:	(a) Diploma	(b) Bachelor's degree	
	(c) Master's degree	(d) PhD	
	(e) Others,(please Specify): ________________		
Years of Experience:	(a) Less than 5 years	(b) 5 to 10 years	(c) More than
Designation:	(a) Executive	(b) Senior Management	
	(c) Junior Management	(d) Others, (please state): __	

Name of the Company/Organization: ____

Nature of Business: (a) Public Client (b) Developer (c) Engineering Consultant
(d) Green Consultant (e) Architect (f) Facility Manager
(g) Project Procurement Officer (h) Quantity surveyor
(i) others ,(please Specify):________________

Organization Establishment: (a) Public client (b) Private organization

Involvement in green project: (a) First Project (b) More than one Project

Project Location: (a) Peninsular Malaysia (Please specify the state) ______________
(b) Sabah (c) Sarawak

Project Size: (a) Less than RM1 million (b) RM1 million to RM5 milli
(c) RM5 million to RM10 million (d) More than RM10 million

Client for the Project (a) Federal Government (b) State Government
(c) Local Authorities (d) Private Sector
(e) others, (Please state) ______________

Project types (a) Residential Buildings (b) Commercial Buildings
(c) Industrial buildings (d) Educational Building
(e) Health Building (f) Infrastructure
(g) Others (Please state) ______________

(You may choose more than one options)

SECTION 2: Factors of WSD in supporting Energy Efficient Building

Do you agree or disagree that the following factors are supporting in Energy Efficient Building? Please tick (√) based on your perception.

(1)	(2)	(3)	(4)	(5)
Strongly disagree	Disagree	Neither agree or disagree	Agree	Strongly agree

No.	Factors of WSD in supporting Energy Efficient Building	↔ 1 5

1	Communications and interactions between project stakeholders with different background and expertise					
2	Sustainability of the partnership between projects stakeholders.					
3	Consideration of alignment of interest between all parties involved in the process of a whole system design					
4	The integration of concept in energy and cost savings for the utilization of the building, particularly until the end-use (termination) of the building					
5	The opportunity of utilizing holistic approach, which is to consider all facets of the engineering process and improvements					
6	Multidisciplinary collaboration of all professionals to apply their expertise for developing the concept of the building (energy efficient building)					
7	The opportunity to find new strategies and substantial design modifications to have improvement and achieve significant performance					
8	Having frequent meeting between project stakeholders					
9	Availability of various building performance assessments (the opportunity of having variety of advanced tools and systems)					
10	Enhancing the awareness of financial matters in the design					
11	Enhancing the awareness of diverse knowledge about barriers in the concept of energy efficient building					
12	Enhancing the awareness of barriers in the construction process of energy efficient building					
13	Enhancing the awareness in developing strategies for reducing the embodied energy and operational energy of the building					

14	Enhancing the development of integrated system for building utilities					
15	Other factors of WSD that necessary to be considered in achieving energy efficient building.					
16	Best strategy of WSD in achieving the energy efficient building.					
17	Suggestion on articles or projects that related to this topic					

<u>SECTION 3</u>:

Based on your experience as a practitioner, could you please contribute through answering the following questions?

1. Other factors of WSD that necessary to be considered in achieving energy efficient building.
2. Best strategy of WSD in achieving the energy efficient building.
3. Suggestion on articles or projects that related to this topic

Appendix II

AHP Survey Form

Dear Sir/Madam,

SUBJECT: A questionnaire survey for Developing Strategies of Integrated Whole System Design Approach for Energy Efficient Buildings

I'm conducting a research on Developing Strategies of Integrated Whole System Design Approach for
Energy Efficient Buildings in Malaysia throughout the project development which intends to:

1- To investigate factors of Whole System Design that able to support the achievement of energy efficient building.
2- To find and select the critical factors and strategies for achieving the energy efficient building.
3- To propose and select the best strategy of integrated whole system design approach for energy efficient buildings.

Your contribution in this research will play a role in the success of this study. I would really appreciate if you could contribute by answering this questionnaire survey.

Sincerely,

(CHAN YONG YEAH)
Final year student at UTP

E-mail: chan.yong_24502@utp.edu.my
Contact no: +6017-5858689

Section 1: Main Criteria

Criteria	Factor Weighing Score			Criteria
	More important than	Equal	Less important than	
Communications and interactions between all project stakeholders	☐9 ☐8 ☐7 ☐6 ☐5 ☐4 ☐3 ☐2	☐ 1	☐9 ☐8 ☐7 ☐6 ☐5 ☐4 ☐3 ☐2	Multidisciplinary collaboration of all professionals to apply their expertise.
Communications and interactions between all project stakeholders	☐9 ☐8 ☐7 ☐6 ☐5 ☐4 ☐3 ☐2	☐ 1	☐9 ☐8 ☐7 ☐6 ☐5 ☐4 ☐3 ☐2	Consideration of alignment of interest between all parties
Communications and interactions between all project stakeholders	☐9 ☐8 ☐7 ☐6 ☐5 ☐4 ☐3 ☐2	☐ 1	☐9 ☐8 ☐7 ☐6 ☐5 ☐4 ☐3 ☐2	Enhancing the awareness of diverse knowledge about different barriers
Communications and interactions between all project stakeholders	☐9 ☐8 ☐7 ☐6 ☐5 ☐4 ☐3 ☐2	☐ 1	☐9 ☐8 ☐7 ☐6 ☐5 ☐4 ☐3 ☐2	The integration of concept in energy and cost savings of building until the end-use
Multidisciplinary collaboration of all professionals to apply their expertise.	☐9 ☐8 ☐7 ☐6 ☐5 ☐4 ☐3 ☐2	☐ 1	☐9 ☐8 ☐7 ☐6 ☐5 ☐4 ☐3 ☐2	Consideration of alignment of interest between all parties
Multidisciplinary collaboration of all professionals to apply their expertise.	☐9 ☐8 ☐7 ☐6 ☐5 ☐4 ☐3 ☐2	☐ 1	☐9 ☐8 ☐7 ☐6 ☐5 ☐4 ☐3 ☐2	Enhancing the awareness of diverse knowledge about different barriers
Multidisciplinary collaboration of all professionals to apply their expertise.	☐9 ☐8 ☐7 ☐6 ☐5 ☐4 ☐3 ☐2	☐ 1	☐9 ☐8 ☐7 ☐6 ☐5 ☐4 ☐3 ☐2	The integration of concept in energy and cost savings of building until the end-use
Consideration of alignment of interest between all parties	☐9 ☐8 ☐7 ☐6 ☐5 ☐4 ☐3 ☐2	☐ 1	☐9 ☐8 ☐7 ☐6 ☐5 ☐4 ☐3 ☐2	Enhancing the awareness of diverse knowledge about different barriers
Consideration of alignment of interest between all parties	☐9 ☐8 ☐7 ☐6 ☐5 ☐4 ☐3 ☐2	☐ 1	☐9 ☐8 ☐7 ☐6 ☐5 ☐4 ☐3 ☐2	The integration of concept in energy and cost savings of building until the end-use
The integration of concept in energy and cost savings of building until the end-use	☐9 ☐8 ☐7 ☐6 ☐5 ☐4 ☐3 ☐2	☐ 1	☐9 ☐8 ☐7 ☐6 ☐5 ☐4 ☐3 ☐2	Enhancing the awareness of diverse knowledge about different barriers

Section 2: Alternatives

Pair wise comparison of alternative in **<u>Communications and interactions between project stakeholders with different background and expertise</u>**

Criteria	Factor Weighing Score			Criteria
	More important than	Equal	Less important than	
Developing real time integrated system and communication	☐9 ☐8 ☐7 ☐6 ☐5 ☐4 ☐3 ☐2	☐ 1	☐9 ☐8 ☐7 ☐6 ☐5 ☐4 ☐3 ☐2	Integration of occupants with the building's operational system
Enhancing the collaboration process with coordinator that able to integrate all	☐9 ☐8 ☐7 ☐6 ☐5 ☐4 ☐3 ☐2	☐ 1	☐9 ☐8 ☐7 ☐6 ☐5 ☐4 ☐3 ☐2	Integration of occupants with the building's operational system
Developing real time integrated system and communication	☐9 ☐8 ☐7 ☐6 ☐5 ☐4 ☐3 ☐2	☐ 1	☐9 ☐8 ☐7 ☐6 ☐5 ☐4 ☐3 ☐2	Enhancing the collaboration process with coordinator that able to integrate all

Pair wise comparison of alternative in **<u>Multidisciplinary collaboration of all professionals to apply their expertise for developing the concept of the building (energy efficient building)</u>**

Criteria	Factor Weighing Score			Criteria
	More important than	Equal	Less important than	
Developing real time integrated system and communication	☐9 ☐8 ☐7 ☐6 ☐5 ☐4 ☐3 ☐2	☐ 1	☐9 ☐8 ☐7 ☐6 ☐5 ☐4 ☐3 ☐2	Integration of occupants with the building's operational system
Enhancing the collaboration process with coordinator that able to integrate all	☐9 ☐8 ☐7 ☐6 ☐5 ☐4 ☐3 ☐2	☐ 1	☐9 ☐8 ☐7 ☐6 ☐5 ☐4 ☐3 ☐2	Integration of occupants with the building's operational system
Developing real time integrated system and communication	☐9 ☐8 ☐7 ☐6 ☐5 ☐4 ☐3 ☐2	☐ 1	☐9 ☐8 ☐7 ☐6 ☐5 ☐4 ☐3 ☐2	Enhancing the collaboration process with coordinator that able to integrate all

Pair wise comparison of alternative in **Consideration of alignment of interest between all parties involved in the process of a whole system design**

Criteria	Factor Weighing Score			Criteria
	More important than	Equal	Less important than	
Developing real time integrated system and communication	☐9 ☐8 ☐7 ☐6 ☐5 ☐4 ☐3 ☐2	☐ 1	☐9 ☐8 ☐7 ☐6 ☐5 ☐4 ☐3 ☐2	Integration of occupants with the building's operational system
Enhancing the collaboration process with coordinator that able to integrate all	☐9 ☐8 ☐7 ☐6 ☐5 ☐4 ☐3 ☐2	☐ 1	☐9 ☐8 ☐7 ☐6 ☐5 ☐4 ☐3 ☐2	Integration of occupants with the building's operational system
Developing real time integrated system and communication	☐9 ☐8 ☐7 ☐6 ☐5 ☐4 ☐3 ☐2	☐ 1	☐9 ☐8 ☐7 ☐6 ☐5 ☐4 ☐3 ☐2	Enhancing the collaboration process with coordinator that able to integrate all

Pair wise comparison of alternative in **Enhancing the awareness of diverse knowledge about barriers in the concept of energy efficient building**

Criteria	Factor Weighing Score			Criteria
	More important than	Equal	Less important than	
Developing real time integrated system and communication	☐9 ☐8 ☐7 ☐6 ☐5 ☐4 ☐3 ☐2	☐ 1	☐9 ☐8 ☐7 ☐6 ☐5 ☐4 ☐3 ☐2	Integration of occupants with the building's operational system
Enhancing the collaboration process with coordinator that able to integrate all	☐9 ☐8 ☐7 ☐6 ☐5 ☐4 ☐3 ☐2	☐ 1	☐9 ☐8 ☐7 ☐6 ☐5 ☐4 ☐3 ☐2	Integration of occupants with the building's operational system
Developing real time integrated system and communication	☐9 ☐8 ☐7 ☐6 ☐5 ☐4 ☐3 ☐2	☐ 1	☐9 ☐8 ☐7 ☐6 ☐5 ☐4 ☐3 ☐2	Enhancing the collaboration process with coordinator that able to integrate all

Pair wise comparison of alternative in **<u>The integration of concept in energy and cost savings for the utilization of the building, particularly until the end-use (termination) of the building</u>**

Criteria	Factor Weighing Score			Criteria
	More important than	Equal	Less important than	
Developing real time integrated system and communication	☐9 ☐8 ☐7 ☐6 ☐5 ☐4 ☐3 ☐2	☐ 1	☐9 ☐8 ☐7 ☐6 ☐5 ☐4 ☐3 ☐2	Integration of occupants with the building's operational system
Enhancing the collaboration process with coordinator that able to integrate all	☐9 ☐8 ☐7 ☐6 ☐5 ☐4 ☐3 ☐2	☐ 1	☐9 ☐8 ☐7 ☐6 ☐5 ☐4 ☐3 ☐2	Integration of occupants with the building's operational system
Developing real time integrated system and communication	☐9 ☐8 ☐7 ☐6 ☐5 ☐4 ☐3 ☐2	☐ 1	☐9 ☐8 ☐7 ☐6 ☐5 ☐4 ☐3 ☐2	Enhancing the collaboration process with coordinator that able to integrate all

Appendix III

Turnitin Report

FYP 2

ORIGINALITY REPORT

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SIMILARITY INDEX	INTERNET SOURCES	PUBLICATIONS	STUDENT PAPERS

PRIMARY SOURCES

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