DEVELOPING AN INTEGRATED, INTELLIGENT AND INNOVATIVE FRAMEWORK FOR GREEN RETROFIT DESIGN OF COMMERCIAL BUILDINGS

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Developing an Integrated, Intelligent and Innovative Framework for Green Retrofit Design of Commercial Buildings

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Certificate of Originality

I hereby declare that this thesis is my own work and that, to the best of my knowledge and belief, it reproduces no material previously published or written, nor material that has been accepted for the award of any other degree or diploma, except where due acknowledgment has been made in the text.

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Signed

BU Shanshan

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Abstract

The value for retrofitting existing buildings is both been recognized by both the academic field and the industry. Green retrofit design (GRD) in the building stock is worth investigation as it aims to improve energy efficiency and provide a better environment. Building sector takes 40% of overall energy consumption in general. Workflow and process model in the decision support system for integration in the future for existing buildings need to solve multi-disciplinary, multi-objective, multi-constraint problems.

This thesis first reviews the process of green retrofit design (GRD) and parametric tools in the GRD process, then investigates methodologies which provide service for the owner-driven design for GRD as a tool. The approach to be adopted in this thesis is the improvement for BIM-facilitated green retrofit design process comes with a form of framework. In the methodology part, the thesis presents a qualitative approach to green retrofit process development, aiming to analysis the factors and link the significance of the factors in the process. Then the steps of the conjoint analysis take HOQ as a method example are presented in detail with the accompanying hypothetical design.

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The objectives of this research are: (1) to identify the components of a conceptual I3-GRD framework for commercial buildings, (2) to analyse the critical factors in the I3-GRD for commercial buildings, (3) to develop an I3-GRD framework for commercial buildings.

Both empirical and hypothetical studies are included in the thesis. Questionnaires are designed for the empirical study in the industry to get their point of view of the incentives in the GRD process. This is a quantitative study to adjust the framework and also get the results to compare with the current self-validation system in the industry. Factors are analyzed from ANOVA and Pearson test for significance.

These results are collected from both industry and academic institutions for comparison.

The current situation in the GRD research field faced a challenge in the coming economic development especial in China for the 13th Five-year plan. The contributions from this research would be:

1 The typology of approaches and systematic framework can be used as a reference for systematic consideration by all the sectors involved in GRD.

2 The build-up framework and collection of grouped factors can be used as an assessment tool to evaluate the quality of GRD.

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3 The results of the quantitative analysis of the factors can help designers and owners become more aware of their focus.

4 The obtained results are suggestions which could support the future big data of interactive research in GRD

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Publications

1. Bu, S.; Shen, Q.P.; Anumba, C.J.; Wong, K.W.; Liang X. (2015). Literature review of green retrofit design for commercial buildings with BIM implication. Smart and Sustainable Built Environment, Volume 4, Issue 2, 21 September 2015, Pages 188-214

2. Bu, S., & Shen, Q. P & Liang, X. Conjoint Analysis in the I3-E GRD framework of Green Retrofitting commercial buildings. Proceedings of International Conference on Sustainable Development in Building and Environment 27-29 July 2015, Reading, UK

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Chapter 1 Introduction

1.1 Introduction

This introduction chapter provides an overview of the research work, including the research background, research aim and objectives, an overview of research methods and process, academic significance and practical significance, and some implications of research outcomes.

1.2 Background information of Green Retrofit Design

1.2.1 Why green retrofit design

According a report from the American Society of Heating, Refrigeration, and Air-conditioning Engineers (ASHRAE) from the US, existing commercial buildings in the United States consumed 19.4×1015 kJ of primary energy in 2008, which amounts to 18.4% of all energy consumed. Existing commercial buildings use over 70% of all electricity in the United States (DoE, 2011). The U.S. Energy Information Administration’s Commercial Buildings Energy Consumption Survey report (EIA, 2015) indicates that between 1983 and 2003 there was no real improvement in the aggregate commercial building stock. Buildings of less than 100,000 square feet (9,290 square meters) account for 65% of commercial building floor space (EIA, 2015). In the twelfth Five-Year Plan for Energy Conservation of the Building Department in China 2012 (Drafts), the potential building energy conservation market is extremely large. The building energy conservation range is expanding. During the

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twelfth five-year period, 570 million square meters of building area are in need of energy retrofitting. Before the year 2020, project investment for energy conservation for buildings will be at least RMB 1.5 trillion in China (Sina News, 2012). This means that the demand for energy retrofitting is huge. So, as in Hong Kong, with the "ten major infrastructure projects" in the Policy Address 2007/2008 in the government economic promoting strategy, the design process should include planning and control strategies for emissions reduction.

1.2.2 Why green retrofit design of commercial buildings is a challenge

The categories of buildings are defined with their functions, which are shown in the diagram (Figure 1.1). Commercial buildings have the commercial functions of storage, living, market, and private usage, making up half of the total buildings.

The research on design optimization about GRD is relatively scarce compared to what has been done on green building and energy conservation analysis. For research on design optimization in green building using multi-objective genetic algorithms, a multi-objective genetic algorithm is employed to find optimal solutions for green building design (Wang, Rivard, & Zmeureanu, 2005; Wang, Zmeureanu, & Rivard, 2005). Lifecycle analysis methodology is employed for economic and environmental criteria. GRD combines the design process with retrofitting, renovation, and refurbishment in the possible considerations toward the requirement for clients' needs, policies, motivations, and construction behaviors (Kissock, 2003; Wang, Rivard, et al., 2005; Wang, Zmeureanu, et al., 2005).

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In the opinion of many architects and engineers, developing building forms which are sensitive to the environment and energy conscious is what sustainability is about (Ali, 2008). To design a high-performance green building, building systems are required to be specially focused on energy, daylighting, and analysis of materials (Korkmaz, 2010). Buildings should be sustainably designed from the aspects of energy modeling, renewable energy use, sustainable materials use, and water harvesting. Comparing the design of a new green building and the retrofit process for buildings, the discussion in this chapter will focus on the green retrofit design (GRD) process regarding sustainable design aspects and cooperation between different sectors.

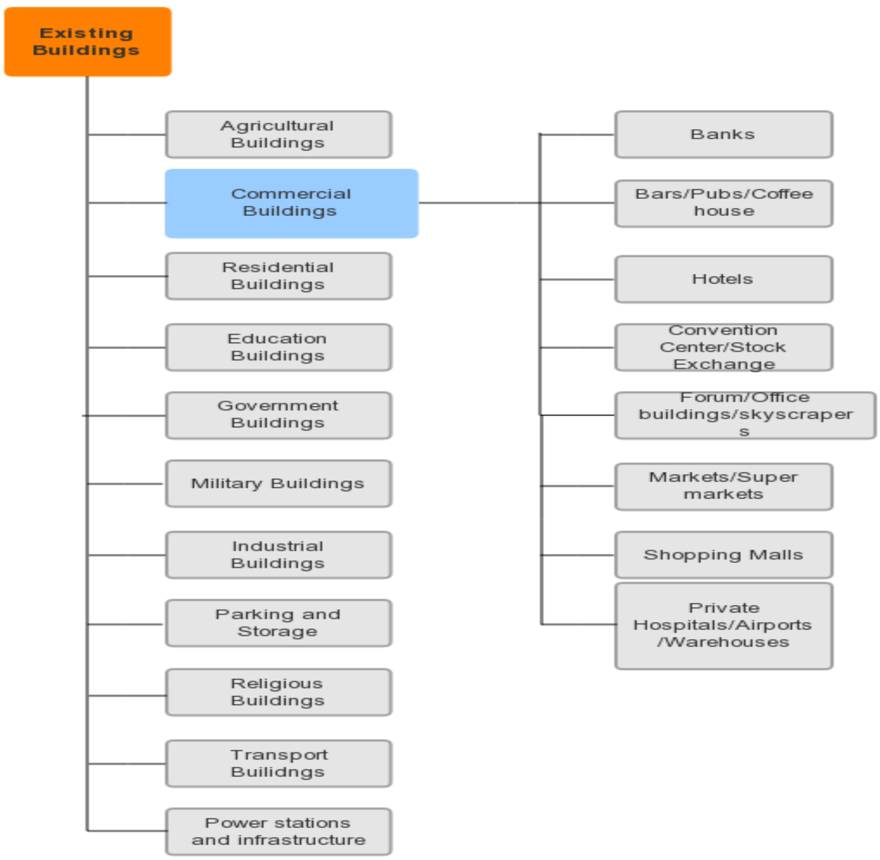

Figure 1 Existing building claasification

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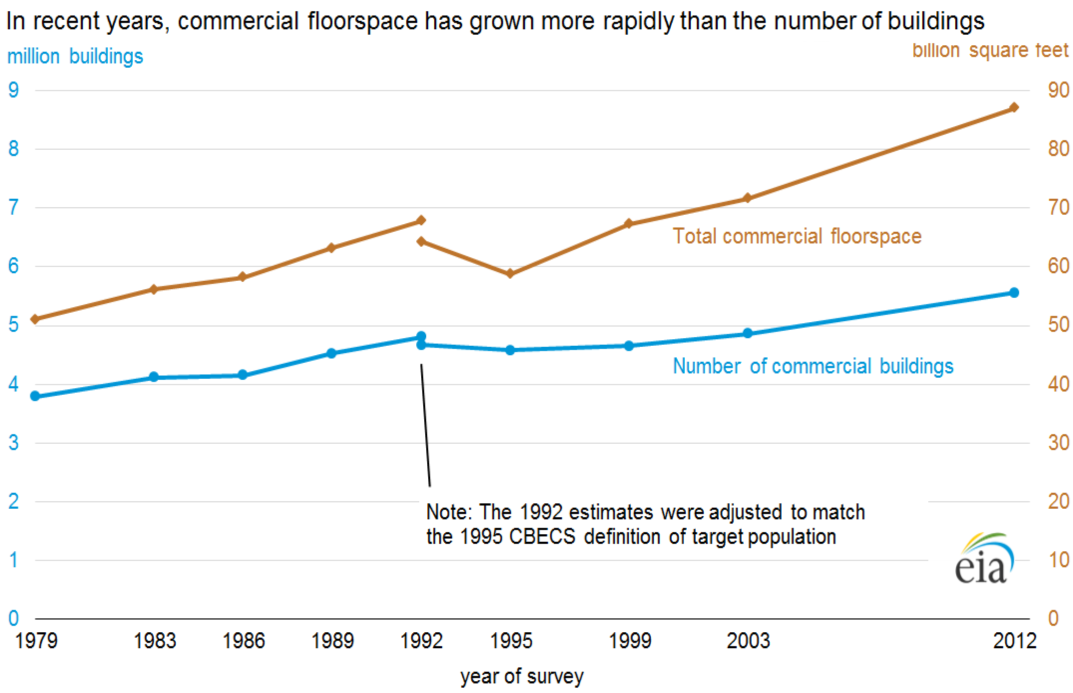

Figure 2 Data of commercial building floorspace

As there is large growth in commercial floor space, investigating the energy savings in commercial buildings would have wider implications.

The map shown above shows the current projects already got the green label for new buildings. The darker color results shown on the map means the areas got more projects with the green label. The current situation is in the Jiangsu and Guangdong Province in mainland China now hold the largest number of green buildings with a green label.

Most of the provinces in the west and north are still under-developed and hold a relatively low number of green label.

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The projects obtained a green label for both green buildings and green retrofitting reached peak time during 2013 and 2014. During this period is 12th Five year plan, when the government led a formal start for green building subsidies in Shanghai and Shenzhen. So during the case study analysis and questionnaire survey, the targets are chosen from mainly Guangdong province and Shanghai Beijing areas.

1.2.3 Why a framework is needed

Green Retrofit (GR) refers to "incremental improvements to building fabric and service systems with the primary intention of improving energy efficiency and reducing carbon emissions" (Rhoads, 2010). It has built up two major aims for GRD, which are reaching energy efficiency and reducing carbon emissions.

In the U.S. Green Building Council's (USGBC) view, according to an interview with Gatlin (vice president, marketplace development, U.S. Green Building Council), Green Retrofit (GR) is considered as

> *any kind of upgrade at an existing building that is wholly or partially occupied to improve energy and environmental performance, reduce water use, and improve the comfort and quality of the space in terms of natural light, air quality, and noise—all done in a way that it is financially beneficial to the owner. (Lockwood, 2009)*

According to UNEP (2011), for "green economies" facing financial, economic, food, and energy crises, GR also aims to create integrated development models that focus

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on poverty and human well-being to avoid costly retrofits. Energy retrofitting, which is the core of GRD, is the improvement, replacement, and substitution of new or modernized equipment, parts, and systems to better their energy efficiency (Autodesk, 2009).

The quantity of existing residential buildings, for instance, is enormous. According to research from the Construction Science and Technology Centre (CSTCMOC) in China in 2012, in the north heating areas in towns alone, residential buildings account for 3.5 billion square meters and are worth being transformed for energy savings. As Ali brought up in his research on energy-efficient architecture and building systems (2008), “no humanly created environment can survive without the contributions of the larger natural environment or ecological systems,” and “sustainable design is a response to awareness and not a prescriptive formula for survival.”

In this research, green retrofit design is defined as a process to not only gain sustainable design for green purpose, but also allocate works with integrated teams in the process of design.

In the paper about early-stage integration of retrofit design, Sweetser (2012) mentioned a team that involves owners, architects, engineers, and others with multi-disciplinary workshops. This integrated team will cooperate across different specialties in contrast to the traditional “solo” approach. However, the information flow between each party seems to cause chaos easily, and for integrating a GRD team, the specialist will need a design framework at a relatively high level, covering each

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role's needs.

1.2.4 Related Research

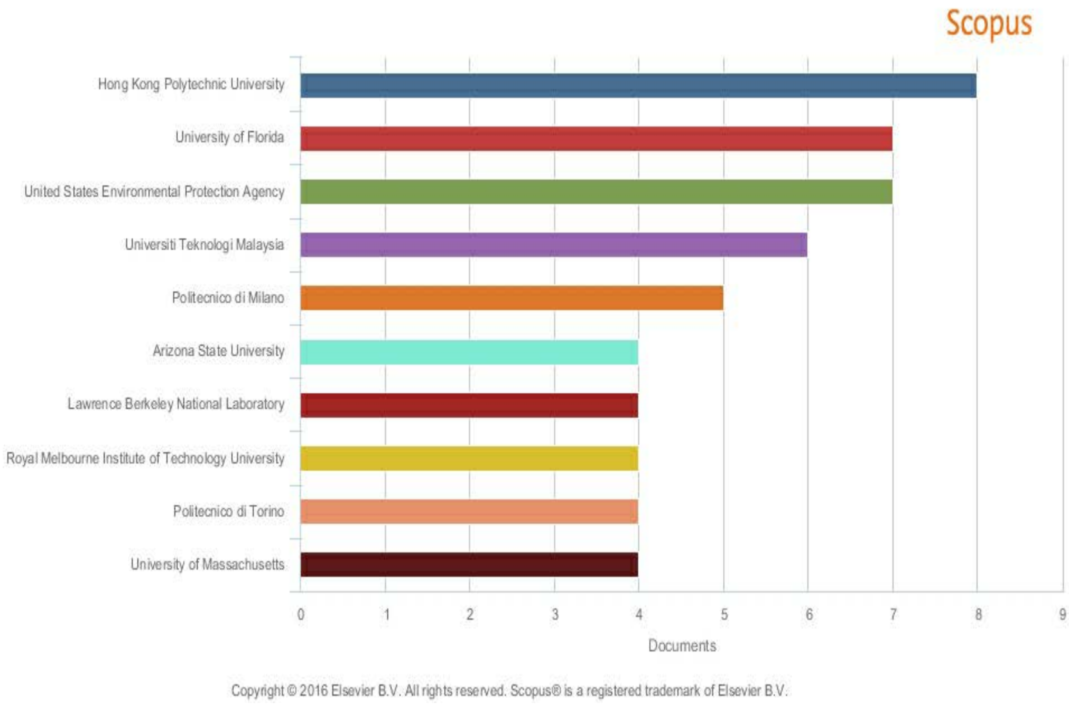

Figure 3 Search results of Scopus with key words 'Green Retrofit'

According to the statistics in Scopus, topics related with Green Retrofit are relatively few and publications present with limited research institutions. The trend shows a growth with sharp rise from 2004.

1.3 Definition of Sustainable Development

The two main objectives of GRD in reaching the goals for sustainability are carbon emissions reduction and environmental improvement. These are concerted actions in sustainable development. To extend the research objectives, the following paragraph examines sustainable development in three sections.

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1.3.1 What do the economists think about sustainability

From an economist's point of view, measuring the needs of human beings has always been a big research topic. Many studies argue that if we consume too much, it will cause nations to fail and worsen the relationship between humans and the natural environment (Acemoglu, 2012; Dasgupta, 2001).

$$d\frac{V(t)}{dt} \geq 0$$

In Dasgupta's article, genuine investment relative to population must be non-negative; genuine investment means four basic things in terms of a society's productive base (Dasgupta, 2001).

Manufactured capital. This includes buildings, bridges, infrastructure, etc.

Human capital. This includes health and education.

Nature capital. This consists of natural resources within the economy (oil, lumber, etc.) and outside (ecosystem services—climate regulation, clean air, etc.).

Institutions. Institutions have the ability to effectively turn the productive base over to human beings. Inclusive wealth in a lot of institutions in institutions would also affect genuine investment.

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National accounting aggregates—savings, depletion and degradation

Gross savings (% of GNI)	25.4
Consumption of fixed capital (% of GNI)	15.2
Education expenditure (% of GNI)	4.3
Energy depletion (% of GNI)	2.0
Mineral depletion (% of GNI)	0.5
Net forest depletion (% of GNI)	0.1
CO_2 damage (% of GNI)	0.5
Air pollution damage (% of GNI)	0.2
Adjusted net savings (% of GNI)	11.1

2 2015 The Little Green Data Book

Figure 4 Adjusted net savings for environment in national accounting aggregates

The number above shows that the genuine investment (adjusted net savings) for the environment is rising, according to the national accounting aggregates in the US (World Bank, 2015). Natural resources are not unlimited. So, increasingly, scholars are discussing nature's role in sustaining economic development.

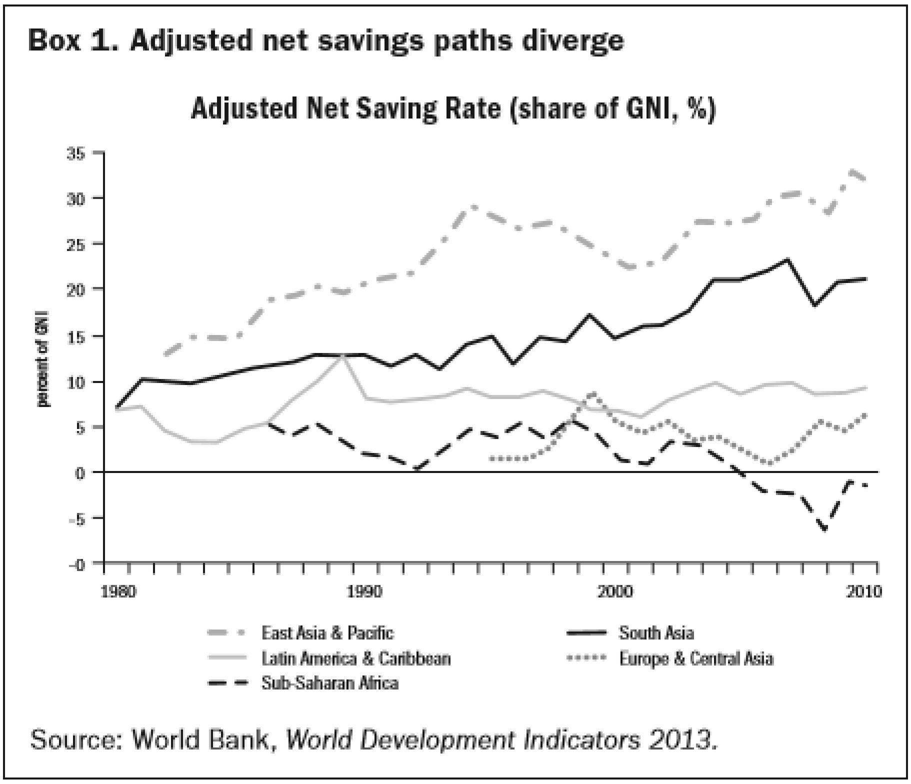

Figure 5 Adjusted net savings rate of different regions in the world

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The data from the World Bank indicate that the Asia and Pacific area still hold the highest savings rate among the developing areas, as the adjusted net savings (ANS) shows the real differences between production and consumption. ANS measures the investment in human resources, education, nature, and the damages caused by pollution.

The strengths and weakness of the valuation scheme of sustainability does not acknowledge any biophysical limits; it only involves the bottom line in the maintenance of a resource base.

In *Our Common Future*, well known as the Brundtland report (WCED, 1987), which was published in 1987, targets for a sustainable development path are established, and environmental concerns are classified as an independent issue. The metrics for human well-being distinguish between constituents and determinants. Determinants are grouped with the basic physical and capital needs of intertemporal like human capital, natural capital, and institutions.

In short, economists mainly agree with the Brundtland report with regard to the indices of human development and eco-efficiency and then draw a neutral conclusion. Their discussion differentiates between current well-being and future well-being and identifies an aggregate stock counted in financial units.

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1.3.2 What do ecologists think about sustainability

In all, the ecologists delimit triple bottom line (TBL) for sustainability, accounting scheme as Social (People), Environment (Planet) and Economic (Profits), which has already been widely used in industry.

1.4 Green Retrofit Design Process

1.4.1 People Involved in GRD

The traditional green design team model and the BIM integrated design team model are shown in the following section (Source: Green BIM).

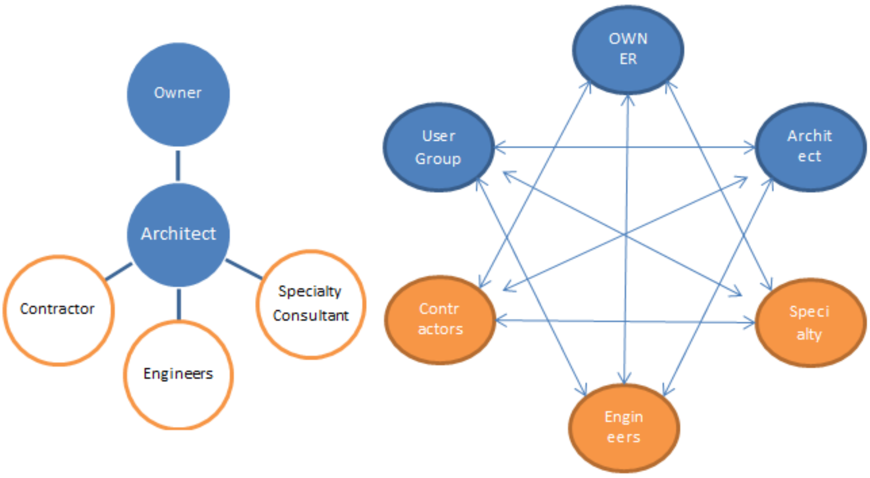

Figure 6 Traditional green design team model and BIM integrated design team model

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Typical energy efficiency consultancy (specialty) offers include

- corporate energy and climate change strategy development;
- voluntary carbon programs (including climate neutral enterprises);
- carbon footprints and supply-chain carbon analyses;
- benchmarking; and
- climate change impacts and adaptation (ECOYFS, 2012).

The existing GRD process in the sustainable design industry is constrained by the reliance on the various levels of workforces and different layers of information delivery. It is relatively easier to obtain stable results in the sustainable assessment using green building design (GBD, new-build). On the contrary, the GRD (existing-build) process faces more challenges from the existing building service systems and various technologies, including methodological, cultural, social, and organizational aspects, which leads to more unexpected final results in terms of energy savings and building performance. GRD requires a multi-disciplinary approach to handle the different requirements from architects, engineers, and clients in terms of design, information about technical design parameters, green technologies, financial status, construction effects, and management factors. The research is workflow-based and has practical research in real-world cases.

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1.4.2 Technical process in GRD

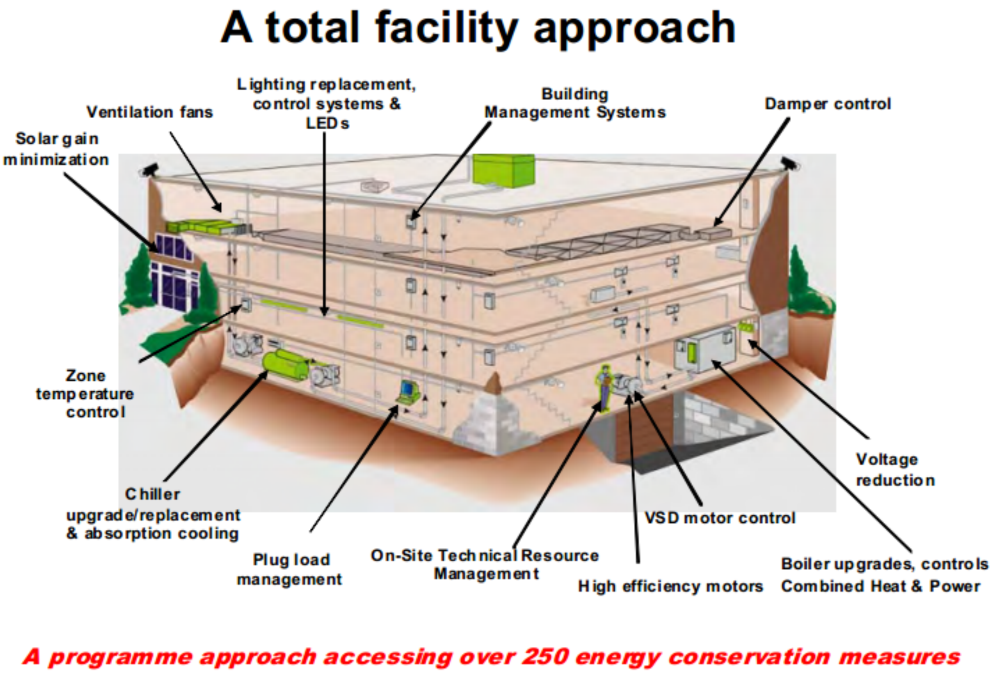

Figure 7 A program approach accessing over 250 energy conservation measures

A typical facility approach for GRD programs, an example of which is shown above in Figure 10, could be complicated to measure since it contains over 250 energy conservation measures.

The roadmap of retrofit design defined by (Rhoads, 2010) concludes the retrofit design process into seven steps as following:

- Define Corporate Retrofit Goals
- Designate Roles & Responsibilities
- Prioritize Building Portfolio

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- Agree on Financing Arrangements
- Select Appropriate Technology
- Delivery
- Evaluate

The process of any reuse, refurbishment renovation projects, is managed to produce heritage of a newer functional need. Usually, the presence of a 20 years-long building would face a cycle of re-composition. This would contain different people involved and in the following section, the focus would be on the design team from both traditional and BIM integrate angle.

In the design process, cost-effectiveness and the energy savings of buildings need to be measured using appropriate design and analysis tools (Federal Energy Management Program, 2001). Data input for energy analysis includes

- building geometry;
- building orientation;
- building construction elements for thermal properties;
- building function usage;
- internal loads and schedules for lighting;
- HVAC system type;
- space conditioning requirements; and
- weather data, etc. (Information Delivery Manual, 2010).

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1.4.3 Comparison on the aim of GBD and GRD

Green building design (GBD) process. To design a high-performance green building, building systems are required to be specially focused on energy, daylight, and analysis of materials (Korkmaz, 2011). Buildings should be sustainably designed in terms of water harvesting, energy modeling, renewable energy use, and sustainable materials use.

Energy-efficient design is seen as the biggest factor in improving the long-term operating costs and the environmental protection methods for part of the GBD process. Prowler (2000) labeled energy-efficient design as “energy-conscious,” “passive,” or “bioclimatic,” providing a design which meets the functional, environmental, and comfort needs of occupants. The service targets defined energy-saving tasks, profiles existing renovation conditions, and conducts energy and economic analyses through the design process and system alternatives. The steps in energy-efficient design that Prowler (2000) described are in three scales of effort: modest effort, intermediate effort, and large effort, taking human effort from person-days to person-months (Prowler, 2000).

In the book “Sustainable Construction: Green Building Design and Delivery,” the process of green design is described as “front loading,” requiring that building design, as well as the surrounding landscape and entire communities, be considered as a whole system.

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Green retrofit design (GRD) process. While designing retrofit plans for existing buildings, primary existing conditions for buildings are differentiated and considered for design, mainly for energy modeling, variations benefits, and legislation considerations.

GRD should be based on a detailed investigation of unit building results combined with the local climate conditions; it should establish a reasonable economy, help save energy, provide comprehensive climate-protection and energy-saving reform plans, and make accommodations for specially designed retrofits. Design goals should be guaranteed to meet indoor thermal comfort needs, under the premise that buildings' energy consumption should satisfy the existing local energy-efficient building design standards for heating and energy consumption in advance.

GRD should provide the rainwater reuse technology, air-conditioning and heating energy-saving technology, shading technology, roof–ground insulation technology, and lighting systems modification technology solutions to the existing building energy issues from a technological point of view. To protect the palisade structure of old buildings and to improve heating systems, air-conditioning systems, lighting equipment, and hot water supply facilities and to implement energy-saving transformations, GRD should also realize energy-efficient designs integrated with legislation, energy codes, and standards. Energy contract management, as a form of energy-saving transformation, such as energy performance contracting (EPC), is essential in GRD.

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Different considerations are contained in the GRD process compared with designing a new green building. Setting up the goals for retrofit design is essential from the start of a design project. Challenges for GRD would be the cost for the retrofit and the benefit trend. The associated opportunities and living comfort would be given to the users, while the budget would be determined by the owners. Improving energy efficiency is one of GRD's contributions to society; at the same time, creating new job opportunities and enhancing social responsibility would accompany the development of GRD.

1.5 Research Propositions and Objectives

This research reviews the literature regarding green retrofit process from generic and project level. Three gaps in the scope of the existing research on green retrofit design are identified. The research gaps are:

Gap 1. a comprehensive literature review on the green retrofit design (GRD) process has not yet been summarized.

Gap 2. a range of practical approaches that can be used for green retrofit design (GRD) need to be consolidated.

Gap 3. a systematic framework for green retrofit design (GRD) needs to be further developed.

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This study begins by examining the generic GRD process and conducting research into and an analysis of internal problems to explore the GRD process from the generic level to the project level. The process is developed in vertical and horizontal directions based on the research participants, influencing factors, and an analysis of the system problems for decision making. Then, the I3-GRD design framework is designed to solve the existing problems in GRD on multi-objective, dynamic, complex, multiple factors and multiple constraints. On this basis, this study builds an integrated, intelligent, and innovative GRD (I3-GRD) network for the growing need for carbon reduction and energy efficiency. This study will help the various stakeholders, particularly owners and designers, better understand the process of dynamic GRD in commercial buildings.

According to these research proposition, the aim of this research is to develop a intelligent, innovative, integrated framework for green retrofit design (I3-GRD), including work contents through stages

The following objectives are designed to achieve the above aim:

- Objective 1. To identify the components of a conceptual I3-GRD framework for commercial buildings.
- Objective 2. To analyze the critical factors in the I3-GRD for commercial buildings
- Objective 3. T develop a I3-GRD framework for commercial buildings.

1.6 Scope of Research

The research is mainly focused on designing a framework for commercial building GRD (green retrofit design). As the existing research topics are mainly focused on detailed green retrofit technology and policy, a gap existed in the GRD process. Although the huge potential of green retrofit projects has been well recognized, the related research is still at an early stage of development. The research objectives of this research are commercial buildings which had or determine to have GRD. The scope of this design is taking insight the buildings both on generic level and project level.

1.7 Summary of the chapters

Chapter 1 presents the overall view of GRD. It provides the information about background of the research, research questions, objectives and research methods and scope.

Chapter 2 and Chapter 3 review the literature about GRD with models in papers and in practical. Starting with an example of typical GRD project, the literature on GRD concepts and major difference between new green building design and GRD models is explored. Following the comprehensive literature review, research gaps are identified. Macroeconomic considerations in GRD are varied according to society, economy, environment, and policy. Microeconomic considerations are discussed in this chapter from users' requirements, technical design parameters, green technologies, financial

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status, construction effects, use, and management factors. A detailed research process is developed followed by the knowledge gained and selected research methods.

Chapter 4 describes and justifies the research design after reviewing the research objectives in Chapter 1, and introduces the methodology used in the following chapters.

Chapter 5 presents the components in the I3-GRD framework. Through the above literature review, finding are summarized and components for the I3-GRD are collected for the preparation in developing I3-GRD framework.

Chapter 6 shows the factors analysis in I3-GRD. Factors that influence the quality of GRD with inter-cooperation factors, and considerations in Chapter 2 have also ben grouped and analyzed. The research result with the findings from questionnaire survey and the empirical studies in both Hong Kong and China mainland. By using the ANOVA test and Pearson analysis, the factors are categorized into groups.

Chapter 7 presents the workflow in I3-GRD. A comparative analysis of the different groups' view on the relevant factors is conducted.

Chapter 8 develops the I3-GRD framework and makes the conceptual framework work in concert with each components and factors analysis.

Chapter 9 reviews the research findings related with the research objectives and summaries the contributions of this work to green retrofit design (GRD). The Chapter then concludes the limitations of this study and gives recommendations for future research and practice.

Figure 8 Overall Research Map

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Chapter 2 Literature Review

2.1 Introduction

This part reviews the existing literature from a broad research territory including retrofitting commercial buildings process, energy modelling and. First, several key definitions related to this research area are described. Second, a comprehensive review of theoretical development on sustainable design review is given and relative theories foundation for the model establishment is also introduced in the literature review part.

In this Chapter, energy analysis process with BIM tools is also reviewed. Based on the existing built energy analysis process from buildingSMART and this is the foundation of the inputs to the CBRES (Commercial Building Retrofitting Energy Simulator) based on BIM. Finally, the research gaps in this research niche are pointed out based on this series of a systematic review.

2.2 GRD process in literature

2.2.1 Building Energy Consumption Simulation

The annual energy consumption in buildings can be estimated from (Essah, 2009):

- Length of the heating season
- Operation hours of heating system

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- Efficiency of heating system
- Mean internal temperature
- Mean (design) external temperature
- Annual degree days

The building energy simulation modelling methods could be divided into two board categories: forward modelling and inverse modelling (ASHRAE, 2005). 'Forward modelling' is using for new building design modelling (classic approach) and 'Inverse modelling' (data driven approach) is using for existing buildings (Pan, 2008). There are three categories of inverse modelling (Pan, 2008):

- **Empirical or 'Black-Box' Approach** Empirical approach is building regression model between actual energy consumption with indicators. This model could be used on any time scale (by days, by months). Single-variate, multi-variate, change-point, Fourier series and artificial neural network (ANN) are all part of this category.
- **Calibrated Simulation Approach** This category insists on using the existing building energy consumption software for model building. Then further adjust and calibrate the model, making the actual building energy consumption and the output of the model results to be better identical. The analyst could use the 'forward modelling' (for instance DOE-2, VE-Pro, Energy Plus) for model building, and use building energy consumption data to calibrate the model. This calibrated simulation approach highly depends on the analyst and consume a lot of time.

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- **Gray-Box Approach** This approach firstly builds a physical model for the building and air conditioning system. Then use statistical methods to determine each physical parameter. For fault detection and diagnosis (FDD) and online control, the application prospect is good. For the whole building energy consumption estimation, limitations exist in the application (Pan, 2008). Gray-box models include deterministic and stochastic time series models and time derivative models

By the increasing complexity, inverse models can be classified as a constant-base degree days (nP) model, VBDD (Variable-based Degree-days) models, Bin methods models (ASHRAE, 1993), Correlation and regression models (Reddy, 1989) and Artificial Intelligence models as ANN and the Fuzzy Logic models.

The new research in the inverse model developed in large commercial buildings in evaluating the energy performance from Abushakra's point of view has been developed from 3 stages layer in the layer.

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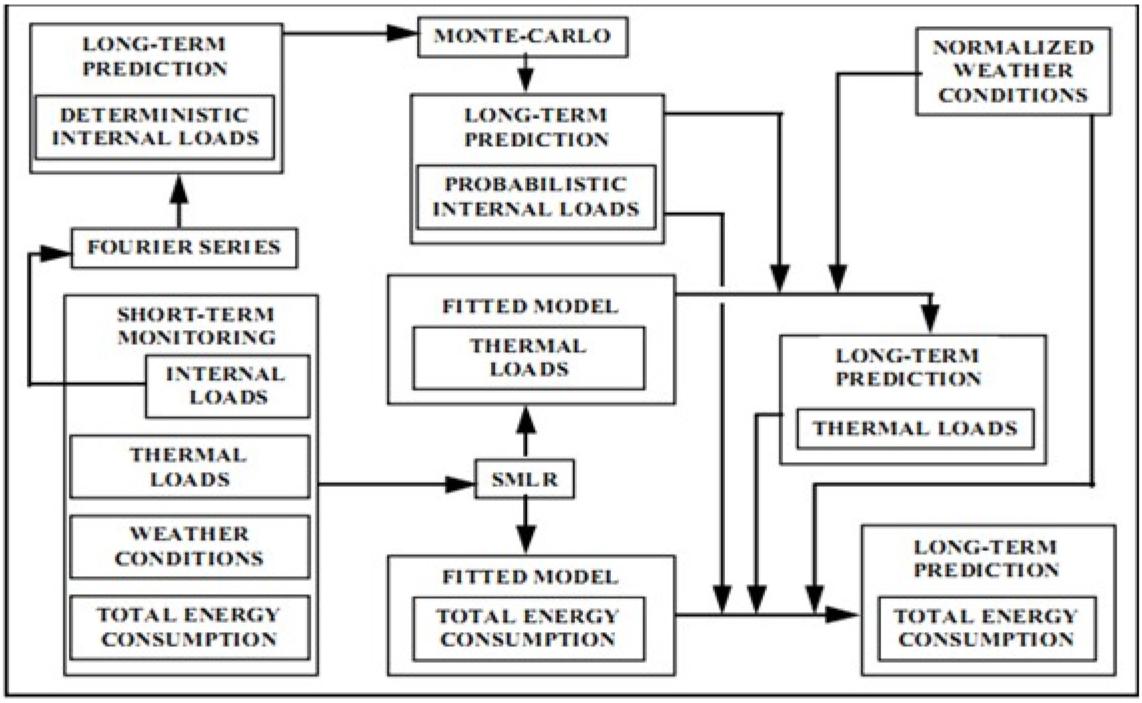

Figure 9 Abushakra's study of inverse model in large commercial buildings

In Abushakra's study in the first stage, compliance of the results is based on the site visit and basic information in the rough disaggregation, the pre-design stage would have rough analysis just to meet the client's need for design. Interviews and site study are used for the pre-retrofit study. Preliminary disaggregation from the interviews and site studies would be focusing on the potentials for energy savings in the building by comparing the results from the similar target building values by the previous study record and energy standards (Abushakra, 1996). Here in GRD, baseline and comparisons considerations are discussed in the section of 2.2.4.7. In the second stage, predictions of the duration began to raise a level as variables for short-term measurements are considered and to compare the pre-retrofit and post-retrofit, analysis for pre-retrofit would be modificated for post-retrofit prediction and put into the assessment for final recommendations.

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For the core of pre-retrofit stage, the third figure on the left shows for the fitted model of the SMLR (Stepwise Multiple Linear Regression) techniques. The fitted model is developed for thermal loads, function of internal loads and weather conditions and the model is assessed with the R^2 value, first developed for total electricity consumption from hourly values with dependent and independent variables then developed for thermal loads, function of internal loads and weather conditions, estimating the standard error of estimation, mean absolute error.

In the 1990s, the size and expenses grew in energy conservation programmes in the last two decades, so did the emphasis on evaluation (Kissock, 2003). In Kissock's paper, procedure to measure savings is the result of Inversing Modelling Toolkit (IMT). ASHRAE began to develop one method for measuring retrofit savings since 1994. Steps of the measuring energy savings are:

- Step 1 measure energy use and influential variables (pre-retrofit)
- Step 2 Develop a regression model as function of influential variables
- Step 3 measure energy use and influential variables (post-retrofit)
- Step 4 use the values of the influential variables from step 3 in the model of step 2

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- Step 5 Subtract the energy use from step 3 and predict step 4 to estimate saving

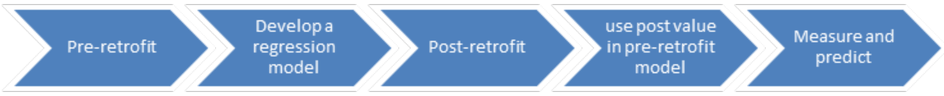

Figure 10 Stages for energy saving measurement in ASHRAE

The models include variable-base degree-day models, change-point models, and multivariable regression models (Kissock et al.) Rapid energy modelling with Autodesk is part of the solution tools, through Client, auditor, assessment, initial sketch process from the design stage, process could be seen as:

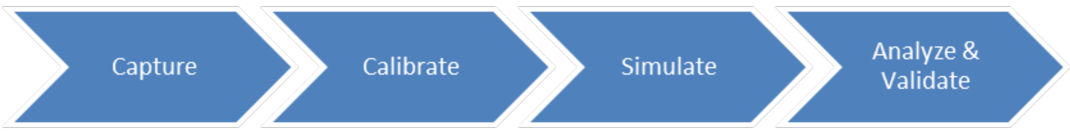

Figure 11Rapid Energy Modeling

1) Capture Stage

Capturing the existing building conditions is the first step of energy modeling. The

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particular workflow could be realized by a series of software and beamers. Software including ImageModeler, Project Photofly, Global Link, Pictometry Online and PKNail, they collect the building conditions by digital photographs, aerial images, satellite images and laser distance meters. The minimal information for collection about the building and its operation (Autodesk, 2008):

- Square footage
- Operating schedule (12/7, 10/5 etc.)
- Information on structural anomalies not visible in pictures (such as atriums,
- Basement, and storage areas)
- Operational idiosyncrasies such as inefficient HVAC, simultaneous heating/cooling
- High server load
- Utility bills (for comparison)

2) Calibrate Stage

Calibrate stage as mentioned in calibrated simulation, is enriching the model stage. After collecting date from the capture stage, a conceptual massing model was built or a more detailed model which include building elements. In advance, a more detailed model for further engineering driven analysis, for design and facility management (FM) is needed.

3) Simulate Stage

Through tools like Autodesk Green Building Studio in the rapid energy modeling,

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simulation stage is the core stage of estimating the on-site building audits and renewable assessments, which are time and resource intensive (Autodesk, 2008).

4) Analyze & Validate Stage

These audits and assessments from the stages above would help the analyst and energy team in prioritizing the energy and carbon reduction efforts. Communication made in this stage will contribute to evaluate the potential financial and environmental values of energy efficiency. Application for solar thermal, day-lighting, natural ventilation and solar photovoltaic for specific green building measures as well as data on utility costs, building performance and building use, would be outputted in this stage (Autodesk, 2008).

2.2.1.1 Enhance building maintenance structure of the thermal insulating properties

Improving the building of the thermal insulation performance can directly and effectively reduce the cold and hot load in the building. According to Heat Transfer Formulae report, palisade structure of the heat transfer coefficient increases each one w/M2 • K, with other conditions unchanged, the air conditioning system design calculation load increase nearly 30%. So as to improve building peripheral protection structure of the heat preservation performance is the first architectural design on energy saving measures, In China *'heating ventilation and air conditioning design standard'* (GBJ42) on the air conditioning building external maintenance of heat

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transfer coefficient for the rules, the comfort air conditioning maximum coefficient of heat transfer rules of 0.9 ~ 1.3, can use glass cotton, polystyrene board, aerated concrete heat preservation material, also can use double glazed window, top aerial insulation and air layer on adiabatic effect.

2.2.1.2 Global studies on efficiency of retrofit methods

A bunch of case studies in sustainable retrofit design are taking worldwide. For instance, as far back in 1979, Freund had a study in some buildings in the UK in the efficiency of common retrofit methods. In his research, suggestions are made that selection of retrofit methods should be made based on ROI (Return on Investment) and the calculation of each energy-saving technology. In Australia, benefits come for GRD as considering making workforce development and joint purchasing with lighting, single stream recycling and wastewater efficiency etc (WARM, 2012). Conducting how to promote energy conservation and sustainability is the aim for GRD. Griffith (2007) in LBNL (Lawrence Berkeley National Laboratory in the US) did a research project chosen 4,820 measured data points based on real investigation and calculated technologies which energy-saving potential through extensive computer simulation. The conclusion suggested that the commercial building could achieve 43 percent energy saving from the code requirements of ASHRAE-90.1 (American Society of Heating, Refrigeration, and Air-conditioning Engineers).

The relatively large amount of retrofit technologies existing in the industry would help to realize building sustainable development for GRD. Key retrofit elements in

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GRD would be steadily considered in stages of assessment and revised in post assessment stage.

According to the Smart Market Report 2009 by McGraw-Hill in the US, the expectation for commercial Green Retrofit market to grow is high. Around 86 percentage of building owners are hoping to see the growth. And 41 percentage of the owners used energy-efficiency savings resulting from the retrofit/renovation. Based on a study made by RICS in 2010, evidence suggested 'only a premium for Energy Star rated buildings, with none found for LEED buildings'.

2.2.1.3 The baseline calculation and components in GRD

Conducting Energy Audit (EA) is necessary to GRD. For some cases, EA is crucial to the whole LCA, as the programmes based on different sophisticated diagnostic tools such as blower doors and infrared scanners, but auditors may not have certification from the main rater certification organization in the US (NHPC, 2010).

As the report of NHPC taken in the US review 126 programmes, around half (52%) of the programmes offer the owners free energy audits. And the majority of the programmes, which mostly sponsored by municipal or investor-owned or utilities were requiring auditing performed by a third party. The report presents a baseline for the field. To understand the GRD process and gain better acceptance, the process faced the challenges from reaching the national GHG reduction goals and limited

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resources using with loan funds, energy modelling, data collection and transfer standards (NHPC, 2010).

The review of Canadian commercial retrofit projects taken by the CBEEDAC sampled 3151 buildings underwent retrofits in 2000 and over 75% of them were privately owned. Over 60% of them involved only one component, and only 17% of the retrofitted buildings involved 3 or more components (CBEEDAC, 2004).

Different components are considered in retrofitting projects. For example, for residential retrofitting projects, mostly considered is insulation (NHPC, 2010). For commercial building retrofitting projects: mostly considered is heating equipment in Canada and while others are lighting systems, ventilation or air conditioning equipment. Other projects like government buildings, mostly considered is heating followed by lighting in Canada (CBEEDAC, 2004)

The selection for GR strategy would be based on the very specific building energy characteristics (Ma, 2012). As the results taken by the research from Hestnes and Kofoed (2002) for existing office buildings, Cooperman (2011) for building envelope and Roulet (2002) for office building have shown that it is possible to evaluate archetype modeling to develop database to formulate sets of mathematical equations for energy consumption estimation (Ma, 2012). Most of the research done for the GRD would only simulate the energy consumption using numerical simulations, however, this is way far from the actual case need. Experience based database through

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systematic incorporation is also needed for building up the confidence for the owners to retrofit their buildings (Ma, 2012).

2.2.1.4 Renewable Energy

There is seven recognized renewable energy, known as solar, wind, biomass, hydrogen, geothermal, ocean, and hydropower (Krygiel, 2008). Using BIM for renewable energy is to use the BIM model for helping the designers to configure the building orientation from the location and availability of the renewable resources for system use. In different design stages, there are potential ways of using renewable energy, take a geothermal system as an example (Krygiel, 2008):

- **In predesign stage**

Speed, direction, and frequency of the wind on the site information is required, as well as the amount of radiation availability and geothermal potential of the project. After that, setting the angel of PV panels for the best annual average capture of solar radiation, and setting the water-based geothermal system according to the distance to the water are all derived from the information above, as the BIM model analysis starts.

- **Schematic design**

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At this stage, roof areas, orientation and slope information is related to use for PV panels and rainwater capture. Information can be tracked to predict annual energy use of the project.

- **Design development**

Collecting some facts for the BIM model analysis, like location and the predicted annual use, then define the area for panel array availability. As early as 2004, the BIM analysis tools are developed to create a geometrically correct, equivalent thermal energy model and provides almost immediate feedback on the energy implications of architectural design scenarios" (Rick, 2004). The designers then could have a dynamical change as they adjust the building and roof shapes during design.

2.3 Energy intensity for commercial sector

The ratio of energy consumed as fuel to economic production as EPA (2002) described in the Energy Trends report. The existing policies and incentives to buildings are mainly calculating the energy consumption by the electricity usage. As the EERE (Energy Efficiency & Renewable Energy) Department in the US mentioned in the building energy data book (2012), the commercial buildings consume around 20% of the total energy with office space and educational facilities representing half of it. Energy efficiency opportunities for manufacturing energy system is relatively less than the facility-related energy requirement for lighting, heating, ventilating and air conditioning (HVAC) and office equipment are the main contents in energy and uses (EPA, 2007). The energy-intensive industries include the commercial sector

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would seek for controlling the energy costs by investing in the energy efficiency that is the common consensus in the research of GRD (EERE, 2012).

Public programmes effect the decision-making for the existing building retrofit as the policy incentives may come from pre-design analysis assumption, government pressure, cooperation cycle, budget execution and construction behaviour etc. factors (Okay & Akman, 2010; Shi & Chew, 2012; Xu & Chan, 2013).

2.4 Barriers to Energy Efficiency in The Commercial Building Sector

UNEP-SBCI mentioned in their report of 2007 that major barriers to energy efficiency in the building sector are categorized into six types as:

- Economic/Financial barriers
- Hidden Costs/Benefits
- Market failures
- Behavioural and Organizational barriers
- Information barriers
- Political and Structural barriers (UNEP, 2007).

Table 2.1 Barriers to energy efficiency in the building sector (Source: UNEP, 2007)

Barrier categories	Definition	Examples	Countries facing the barriers
Economic/Financial barriers	Ratio of investment cost to value of energy savings	The high efficient equipment early cost The lack of energy	Most countries Especially developing, also developed

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		subsidies for the channel Lack of environmental, health and other The internalization of external costs	
Hidden Costs/Benefits	Cost or risks (real or perceive) that are not captured directly in financial flows	Due to the potential incompatibilities cost and risk, performance risk, The transaction cost, etc. Poor power quality, especially in Some developing countries	All the countries
Market failures	Market structures and constraints which prevent a consistent trade-off between specific EE investment and energy saving benefits	Limitation of the typical building design process and fragmented market structure. Landlord/tenant split and misplaced incentives	All the countries
Behavioural and Organizational barriers	Individual and Enterprise behaviour	Tendency to ignore small energy saving opportunities Traditional, behaviour and life style Corruption transition in energy expertise	Developed countries Developing countries
Information barriers	Lack of information provided on energy saving potentials	Lacking of awareness of consumers, building managers, building companies, and politicians	Most countries Especially developing, also developed
Political and Structural barriers	Structural characteristics of political or economic or	Slow process of drafting local legislation Gaps between	Most developing countries, also some of the

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	energy system which bring difficulty to efficiency investment	regions at different economic level Lack of governance leadership/interest Lack of equipment testing/certification Inadequate energy service levels	developed countries

2.5 Considerations Between Designers and Owners on GRD

The relationship between occupiers and designers is the main core for decision-making in selection appropriate technology and delivery. Detailed considerations include (Rhoads, 2010):

- Percentage emissions saving
- Accelerated equipment replacement
- Number of low carbon retrofit projects over a defined period
- Elect board level champion
- Designate senior management roles to implement targets
- Service charge structure
- Carbon saving/payback potential
- Building retention strategy
- Initial engagement to discuss shared project goals
- Agreement of financial evaluation criteria and project limitations
- Agreement of retrofit options including costs, benefits and impacts

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- Choose technologies which minimize disruption
- Select proven technologies where data is freely available in the market
- Where possible use organizations that offer performance guarantees to minimize risk
- Identify ‘best in class’ suppliers
- Manage the process
- Focus on commissioning and handover
- Feedback lessons learnt into internal processes
- Communicate lessons learnt to educate wider market

2.6 Rating Systems on Sustainability Indicators for Energy Efficiency

For green buildings, numerous rating systems are built throughout the world for grading sustainable design, which includes (Bank, 2010):

(1) LEED (Leadership in Energy and Environmental Design program) from the United States Green Building Council

(2) BREEAM from BRE Environmental Assessment Method

(3) Green Globes from Canada

(4) BOMA BESt from Building Environmental Standards

(5) HK-BEAM (The Hong Kong Building Environmental Assessment Method) etc.

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The development overtime for green building assessment as followed:

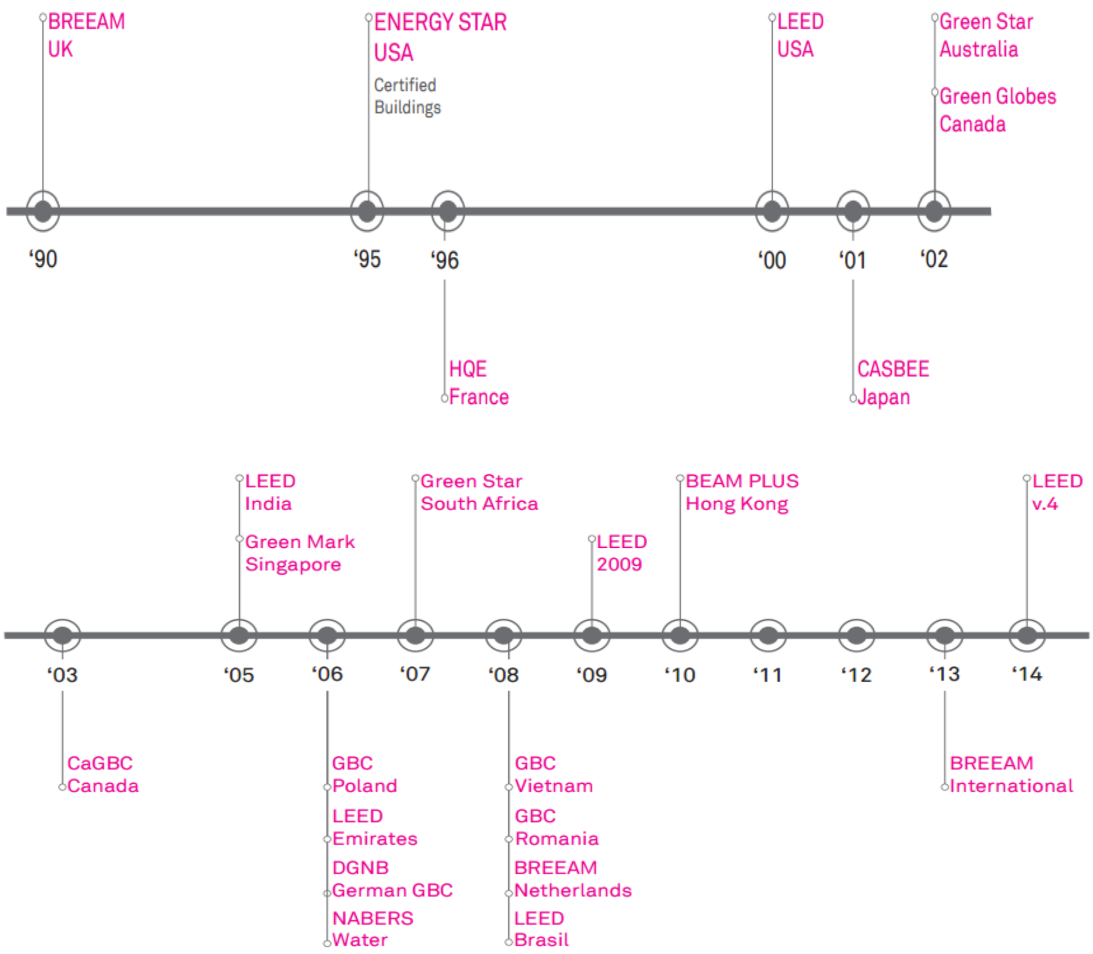

Figure 12 Green Builidng (inclusing GRD) assessment development

Building and Equipment performance data collection are divided in to general building data, building construction data, lighting load data, air-conditioning design load data, systematic design data and equipment performance data six parts from the aspects of HK-BEAM (CET, 1999). The genesis of Green Globes system, HK-BEAM was BREEAM, credit system covering the process from management, health and wellbeing, energy, transport, water, materials, waste, land use and ecology and pollution (BREEAM, 2012). The assessment of these systems would be used in GRD as covering the projects types for major refurbishments for existing buildings and

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existing building service systems. Been adopted by the Building Owners and Managers Association of Canada (BOMA), Continental Association for Building Automation (CANA) and Green Building Initiative (GBI), the Green Globes system for Existing Buildings have developed well in both Canada and US. The existing rating systems for green buildings are designed to categorize the sustainable design levels, the aspects for these grading are of sustainable sites, water efficiency, energy, and atmosphere, materials and resources with indoor environmental quality promotion (LEED, 2012).

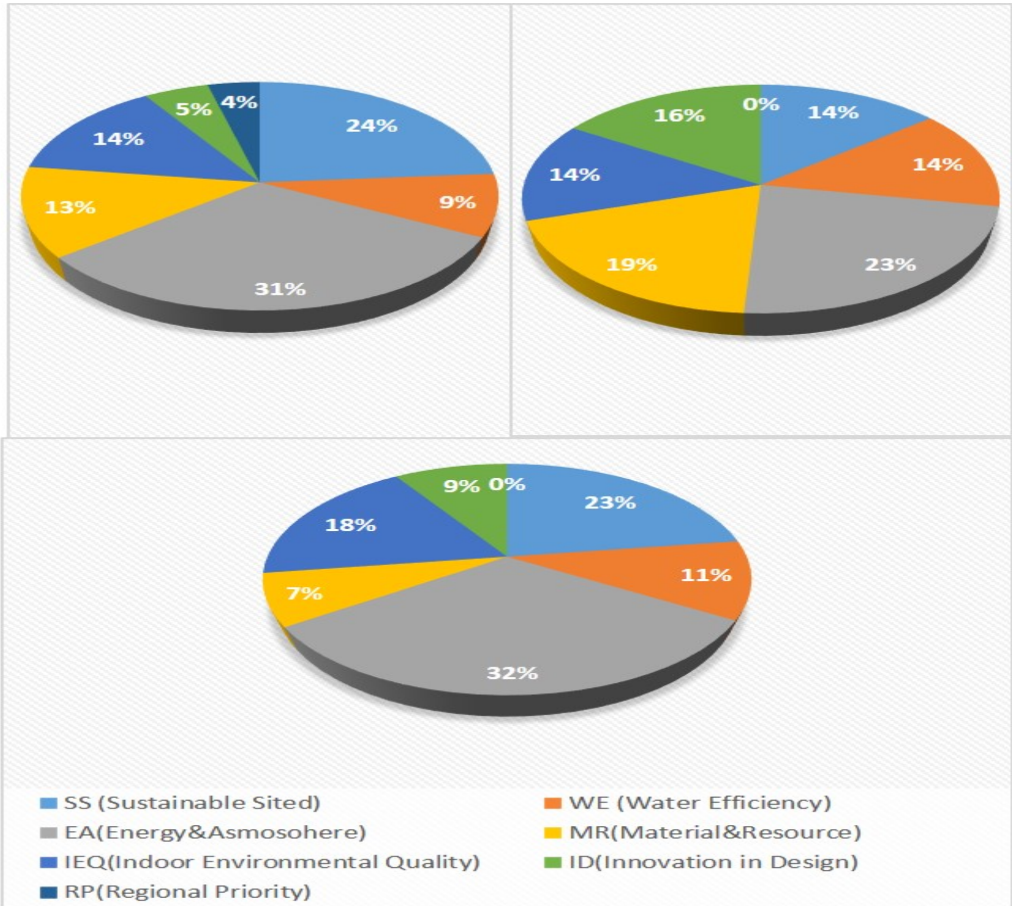

Figure 13 LEED/3 Star/HKBEAM assessment creteria differences

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2.7 BIM and visualization tools

The design of a building could be normally seen as overlapping activities, which contain architecture design, structure design, MEP design (Mechanical, Electrical & Plumbing design) flexibility and furniture systems and so on. In recent years, environmental considerations are becoming important annulus throughout the design process.

In the traditional design process, parametric models are built in the design stage and then generate layers to next stages. These layers of design in models require much more documentations than architecture drawings. Looking back on the history of parametric modeling, technologies are improving the modeling system step by step (Eastman, 2011):

1. From the first level, complex shapes or assemblies are defined by only a few parameters. This is once described as parametric solid modeling.

2. AutoCAD is an example in CAD platform. Many BIM tools are grown upon in CAD platform.

3. As in the next level, automatically changes functions are added when shape's parameters are changed in assembling modeling, which can be called as parametric assemblies.

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4. Further improvement allows the parameters which define one shape, to be linked to the parameters of another shape. Full parametric modeling it is called, or Parametric Object Modeling.

However, in the traditional design process, information about scheduling and cost would hardly be connected to the design changes directly.

Compared with the traditional design process, BIM allows a 3D simulation of buildings and the components taken part in the activities. BIM gives permits to all the project members to make changes during the design or documentation process. ()

The traditional design process is longitudinal and horizontal parallel. As could be seen in Figure 1 that a typical traditional design process in a building project is operation step by step, that prioritized is done in the first stage and then site visit and cost estimation step by step. The one third of the design work to be followed then waiting for the owner's approval for the next half part of work to be reviewed. The process is

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layered overlapping.

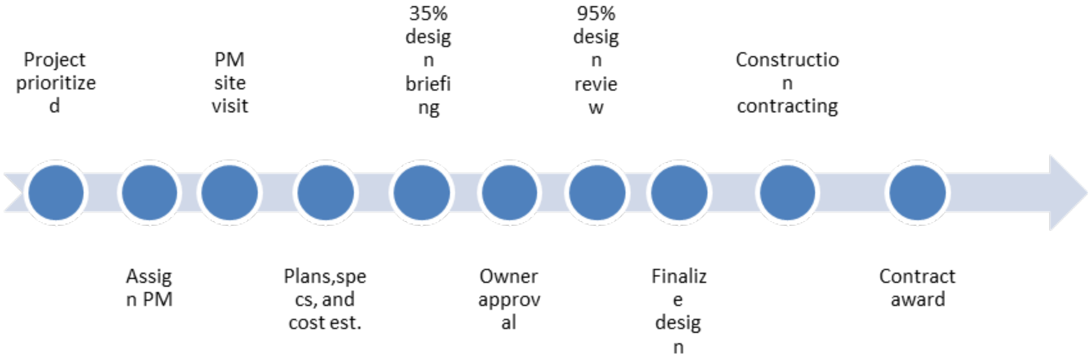

Figure 14 Traditional Design Process

2.8 Using visualization tools in GRD

Using visualization tools in the design process has significant benefits to GRD. According to Maver and Petric (2003), not only did the visualization tools widen the search for solutions, they also improve the design insights, which provide differentiation of objective and theme judgment to each design. For instance, BIM parametric models, they provide visualization, quantification and what-if analysis for the essence of design. And in the design analysis, the parametric models will provide immediate feedback on design alternatives early on the design process. Visualization tools help our subconscious to produce the desired outcome. The tools form in organizing thoughts and ideas then projects, so they are completed more accurately and more efficiently.

`

Autodesk (2007) defines parametric models are those made by *parametric modelling engines that used parameters (numbers or characteristics) to determine the behaviour of a graphical entity and define relationships between model components.*

In the industry, parametric modelling is the design concept in *which the absolute values of a model or part of it, like the height of the structures, the loading at the top surface, the thickness of a web, the grade of the concrete or the time of casting,* are replaced by relative parameters and parametric models are seen as the foundation of BIM modelling (Autodesk, 2007).

Several tools are designed to create parametric architectural models (Katz, 2008):

- **Digital Project**, which is an application based on Catia by Dessault Systems and developed for Architects by Gehry Technologies
- **Generative Components**, which is operating in MicroStation by Bentley System
- **AutoCAD; Revit Architecture (BIM platform)**, which is creating models in a conventional way, and nowadays the models with parameters with numeric values

Decision support tools (DSTs), which can be defined as any tool used as part of a formal or informal decision support process (Kapelan et al. 2005). The criterion for GRD DSTs consideration for analysis of sustainability could study the as-built DSTs for sustainable urban development (Kapelan et al. 2005) and green buildings (Keysar, 2005).

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However in the BIM based integrated design process, the overlapping will not only happen to the layers. The BIM process is naturally sustainable, as in the Validation Phase described by Jernigan (2008), the information flow will all come to a Design Repository Model or Concept Vision Model. The Validation Phase aims to define a good and objective definition of quality and develop solid project controls (Jernigan, 2008). By using BIM technology tools, design considerations of environmental problems will be well adjusted at the beginning of design process.

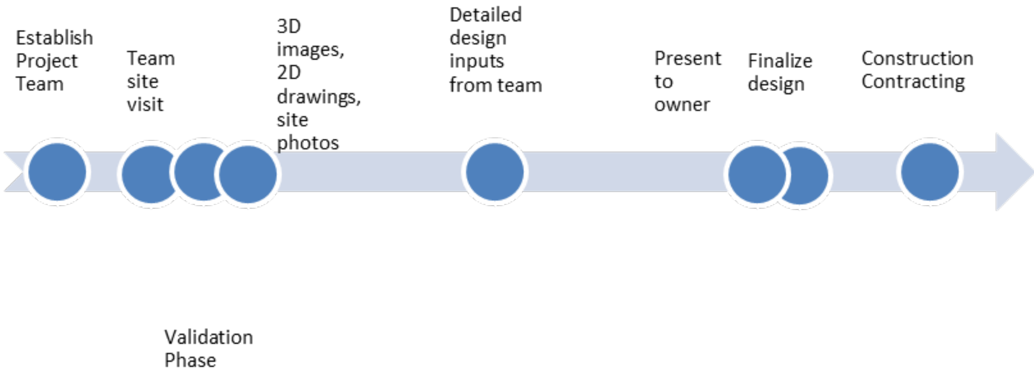

Figure 15 BIM based Integrated Design Process

> *'All of the building design and documentation work can be done concurrently instead of serially because design thinking is captured at the point of creation and embedded in the documentation as the work proceeds. (Autodesk, 2012)'*

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In an ideal BIM-based system, architects work with the consultants in the same model in the first stage, interacted with other engineering parts. While the model is going through its basic shape, it will pass to the contractors and the building team. They will specify the further information by data exchange protocols with engineering analysis. As construction taken place, the BIM model can be modified to the changes happen in the field. Afterwards, the model will be revised and shared with clients and facilities operators. The model is then growing and using for the future maintenance (Krygiel, 2008). Attributes now contributing in the Parametric Object Modelling by changing the properties of specialised components are as needed by different developers.

2.9 Software retained in the process

The software retained in the process would cover the functions of:

- Drawings for wall/body window
- Recognition conversion
- Architectural sustainable design framework
- Index calculation
- Comprehensive evaluation

Building energy efficiency can be divided into two parts: a, building its energy saving, second, air-conditioning system energy saving. Its energy saving mainly from architectural design planning, maintenance structure, shading facilities into consideration. Air-conditioning system energy saving is to reduce heat and cold source energy consumption, conveying system energy consumption and the operation

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of the system management of considering. Structural analysis, energy analysis, lighting and HVAC analysis are all contained in the system analysis.

For BIM platform to be used in GRD process for analysis for example,

- For structural analysis, BIM platform used for drawing and avoiding conflicts by external applications to create analytical models.

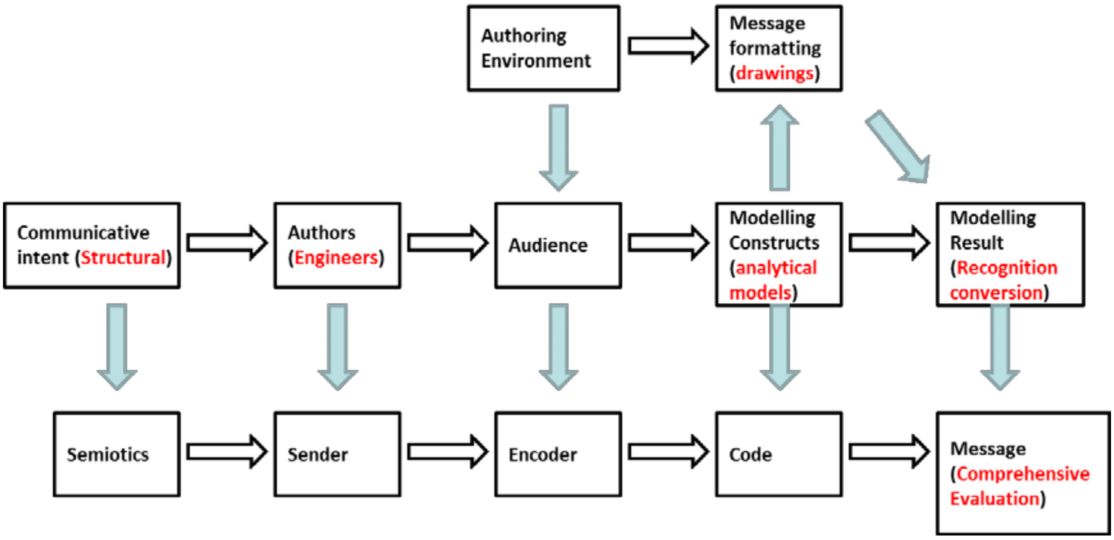

Figure 16 Structural analysis in BIM

- For energy analysis, BIM platform is effective for value engineering and abundance of energy model & analysis software which will help site analysis and sustainability efforts.

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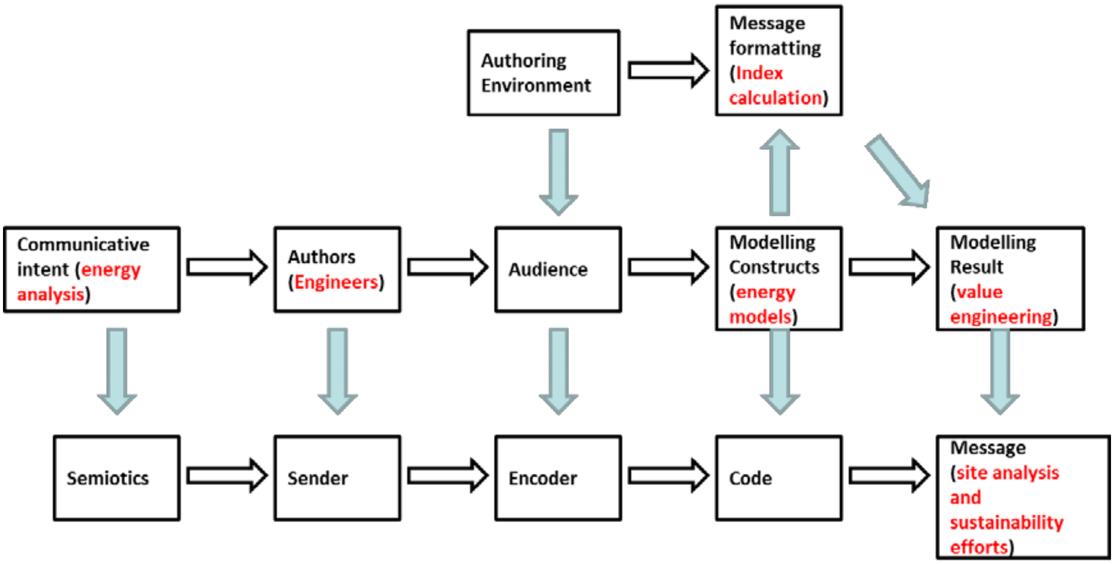

Figure 17 Energy analysis in BIM

- For lighting analysis, BIM platform is helpfully for sustainability analysis integration in one rich database.

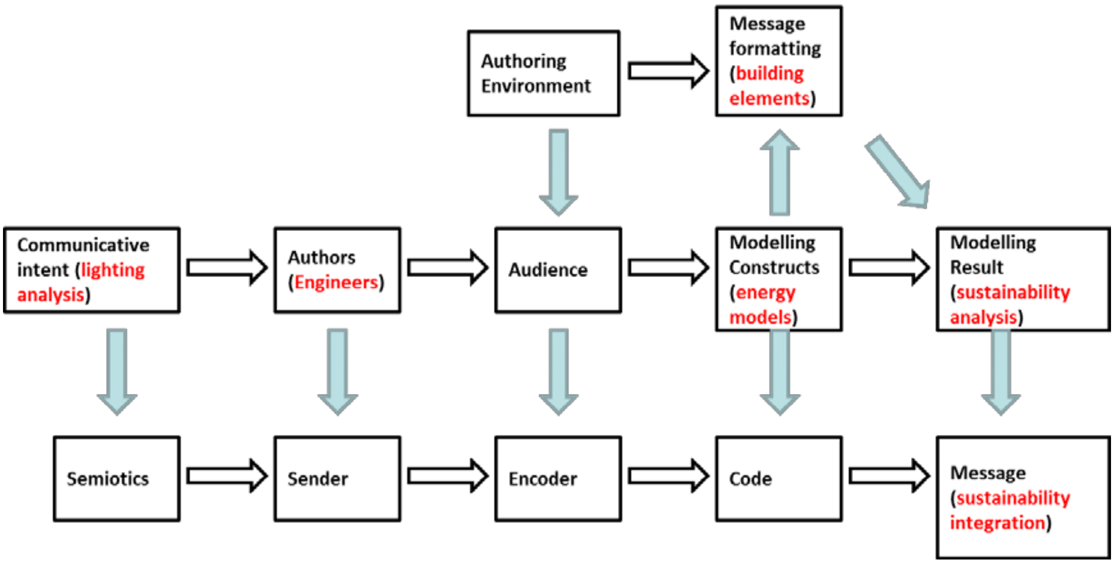

Figure 18 Lighting analysis in BIM

- For HVAC analysis, BIM tools are used for integrating design solutions to emerge.

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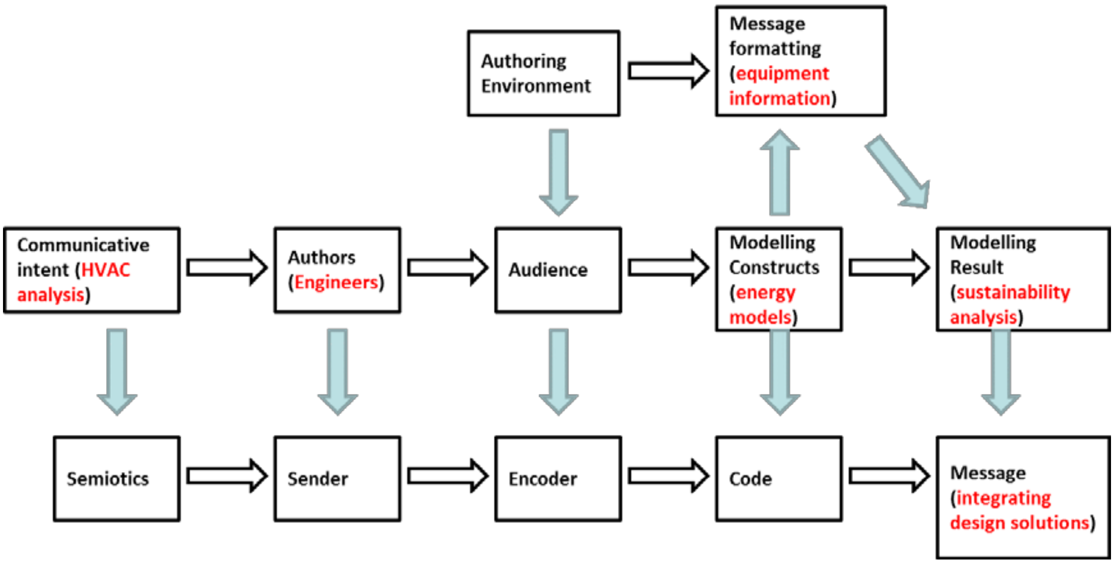

Figure 19 HAVC analysis in BIM

For the building sector, energy consumption is taking 25% of the whole in China. From the aspects of sustainable development, energy consumption is meant to reach 0.8 billion tce (Jiang, 2012) for the energy limitation. For the commercial building and public building sectors, future energy consumption will reach 0.24 billion tce compared to the number now is 0.174 billion tce in the next 20 years.

For the technical main problem, architectural sustainable design concept and HVAC design are the essential to GRD.

2.10 Comparison of energy analysis tools with BIM

High technology now with a definition varies from the context which is being used from industry-based, firm-based, product-based and life-cycled based (Steenhuis, 2006). For defining high technology, a lot of considerations are for economic growth. However, problems existed that not all the energy analysis are designed for the same function.

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Table 3.1 BIM Energy analysis tools

Tools Name	Manufacture	BIM Use	Manufacture's Description	Primary Function
Green Building Studio	Autodesk	**Energy Analysis**	Autodesk Green Building Studio web-based energy analysis service can help the architects and designers perform whole building analysis, optimize energy efficiency, and work toward carbon neutrality earlier in the design process	Measure energy use and carbon footprint
Ecotect	Autodesk	**Energy Analysis**	Autodesk Ecotect Analysis green building software is a comprehensive sustainable analysis tool that delivers a wide range of simulation and analysis functionality through desktop and web-service platform	Weather, energy, water, carbon emission analysis
Project Vasari	Autodesk	**Energy Analysis**	An easy to use tool for expressive design with integrated analysis for energy and carbon, focusing on conceptual building design using both geometric and parametric modelling	Energy & Carbon emission
VE-Pro	Integrated Environmental Solutions (IES)	**Energy & Environ mental Analysis**	IES offers a wide range of energy-related analytical tools for use on 3D models	All aspects of energy analysis and simulation in many areas
Energy Plus (OpenStudio Plugin)	U.S. Department of Energy & LBNL	**Energy Analysis**	EnergyPlus models heating, cooling, lighting, ventilating, and other energy flows as well as water in buildings	Energy Simulation
DOE-2	Lawrence Berkeley National Lab (LBNL)	**Energy Analysis**	DOE-2 is a widely used and accepted freeware building energy analysis program that can predict the energy use and cost for all types of buildings.	Energy Simulation
TRNSYS	Solar Energy Lab/ U of Wisconsin & U of Colorado	**Thermal Energy Analysis**	TRNSYS is a well respected energy simulation tool under continual development by a joint team made up of the Solar Energy Laboratory (SEL) at the University of Wisconsin-Madison, The Centre Scientifique et Technique du Batiment (CSTB) in France and Transsolar	Simulation of performance of thermal energy systems

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	Energietechnik GmbH in Germany and Thermal Energy Systems Specialists (TESS) in Winsconsin

2.11 Separating BIM stages in design

Separating BIM stages for a linear model through object-based modelling to model-based collaboration and then finally the network-based integration for the long-term goal of implementation IPD are described as the BIM organisational hierarchy (Succar, 2010). .

In the pre-BIM status, disjointed and reliant on 2D dimensional documentation, industry would suffer for lacking of interoperability (CWIC, 2004) as collaborative practices between the owner-user group are not in a designed schedule and the workflow is *linear and asynchronous* (NIST, 2004). Moving to the stage of the Object-based stage, the collaborative practices between different sectors are similar and no significant model-based interchanges between different disciplines (Succar, 2010).

3D parametric software tool deployment in the stage of Object-based Modelling in BIM is similar to ArchiCAD, Revit, Digital Project and Telka (Succar, 2010). The modelling deliverables would include not only the architectural design models but also the duct fabrication models. As described in the discussion of GRD, the core for GRD would be architectural sustainable design and air-conditioning optimization. The basic data export from this stage would influence a lot to the quality of GRD,

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including the model collaboration stage. The stages above are described as *transformational*.

BIM Stage 2 of Model-based Collaboration would be considered essential to GRD, as 'collaborative model' like Design-Design (DD) Model, Design-Construction (DC) Model and Design-Operations (DO) Model are instructed to be integrated together and be developed. From the aspect of the AECO industry, research criteria and scope for BIM fields have been discussed. For the technology field, people who specialise in developing sorts of software, hardware, equipment and networking systems are generating software solutions to the design, construction and the facilities management (Succar, 2010).

Milestones for technology development in BIM would consider being taken places in between time of 1970, 1985, 1993-1995, end of the 1990s until now (Moum, 2010).

- As early as 1970, according to Howard and Bjork, as product modelling was once introduced.
- Then since 1985 to mid-1990s, came with ISO (Standard for the Exchange of Product Data) in the application of some European and German research projects.
- From 1993 to 1995, after gaining the experiences of the project from the COMBI, the industry consortium IAI (International Alliance for Interoperability) took over the AEC industry for the product modelling standardization.

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- Finnish research activities including VERA programme in 2006 were in a good effort in developing IAI then the well-know IFC (Industry Foundation Classes).
- AIA introduced the Brand ‘BuildingSMART’ in June 2005 for integrating technologies 3D object-based modelling and BIM in the AEC industry.

The BuildingSMART community shares the building information circle from the open standards (IFC.IDC and IFD) for the practice of architectural design and project in practice. IDM (Information Delivery Manual, 2010) has developed a concept design phase for energy analysis shown as followed:

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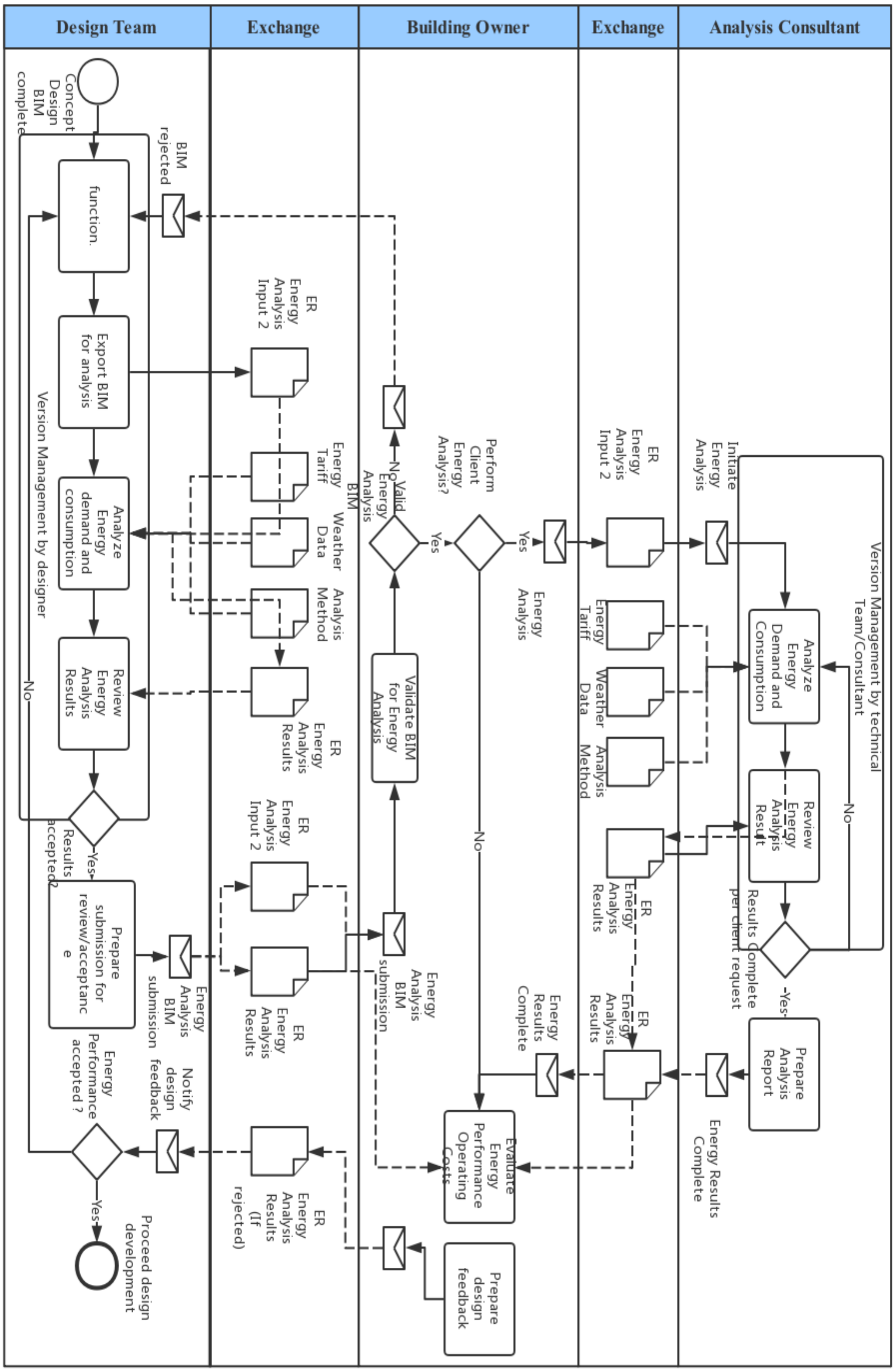

Figure 20 Concept Design BIM analysis process

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2.12 Summary

To sum up, GRD consist the main technical measures of:

- Energy saving building planning and design, enhance maintenance structure of the heat insulation performance,
- Air-conditioning system energy saving technical measures,
- New development of energy-saving technical measures such as cold storage technology and cooling tower cooling technology, etc
- The air conditioning system of the maintenance and management of energy saving technical measures.
- Renewable energy
- Indoor environment enhancement

In the enhancement of GRD, a lot of building information conduct in determining the analysis of energy consumption, for instance, geographic location, building orientation information about the type and size of the building, occupancy schedule, building service system (Ma, 2012). Cooperation of different sectors from the owner-user group and A&E&S in agreement of design would also be the main factors to influence the quality of GRD. Inter-cooperation would be the reflection of cooperation, measuring the effects on the cooperation of different sectors by decision support systems would be discussed in the next chapter.

For the variables for behavior in construction, considerations for energy consumption would mainly for technology and delivery, methods could be concluded for example

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designate senior management roles and managing the organizations that offer minimized risks. Feedbacks from the revise and report from energy modeling and facility management would benefit the retrofit projects in the long run and be studied for the future.

In literature, reviews for state-of-art retrofitting existing buildings could be found for decision support system (Ma, 2012), for technical application with BIM implementation in existing building (Rebekka, 2014) and aspects from a few cross-sectional fields. Functional and maintenance issues are mainly for new buildings, also in the field for renovation and demolishing. Publications also show that environmental, social and technical issues are often examined separately in the decision process of GRD. Papers in the facility management (FM) scale would concentrate more on organization/legal issues. Publications with questionnaire design to devoting on the usage on life-cycle assessment on existing building. However, they have not yet focused on the design process analysis and related optimization issues.

The Concept Design BIM analysis process is a merge process which reflect the best practice in information flow. These activities stacking together as a BIM model which contain physical design model, solar analysis model, digital design model and energy model, can provide vision for the future of the projects for design professionals, construction professionals, manufacturers, software developers and academic sectors

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in GRD especially on the sectors involved in managing minimized risks and choosing appropriate technology for GRD

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Chapter 3 Methodology

3.1 Introduction

This chapter discusses the research methodology employed in this study. It identifies three major research methods, namely literature review, qualitative analysis, model establishment and case study which are used in this research according to the needs of research objectives. And the detailed research process and research plan are also provided to explain how and when to finish this research project.

The overall research idea for green retrofit design process is a dynamic and complex process, involving multiple parties, multiple targets, multiple factors and multiple constraints. In this respect, both local and abroad research has just started, lacking systematic study and research. GRD process as the main line builds multi-phase and multi-level research, by adopting the combination of vertical and horizontal, collecting relevant information from a variety of channels, synthetical analysis, and induction. And on this basis, this research is to further develop on the basis of the theory of workflow I3-GRD, so as to deepen the research of planning and design. This research adopts the specific research methods including comprehensive literature search, depth interview, case investigation, workshop, action research, expert assessment and network show, etc.

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3.2 Review the previous work

To achieve the aim of the objectives, the research use combination of empirical and hypothetical methodology adopting data (energy modelling) and literature (literature reviews, interviews). Details are discussed as followed.

For reviewing the literature, which is an essential stage in the research conducting, will involve reading and appraising content from others' point of view in the subject area (Naoum, 2007). The literature review contained in this research mainly sourced from an extensive range of academic research journals, refereed conferences, dissertation/theses on relevant topics, reports, and government publications.

The aims for the board amount of review are:

- To enrich the background for the research and identify the research issues with different aspects
- To clarify the research problem
- To provide current developments and resources on the topic
- To find the research gap towards future model designing

The literature review focuses on the areas of:

Process Review GRD in built projects and the process each sector is involved in the design stage. To design a process model for GRD, the sustainable design process is the foundation in control the system. Each operating cost-saving will affect the

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performance of design process model. The LCA (life cycle assessment) is the assessment to the GRD inspection. The elements in the process contain the process and stages, roles involved, work content and the information needed in the processing stages (in Chapter 2).

Energy Control Modelling Review Energy saving realization is the core to GRD. For energy controlling application, GRD will be more focused on the control system and certification.

Decision Support Tools Review Decision support tools are designed to help with information control and simulation models regarding information systems. Information systems in the phase of paradigm models are the forms for the complex and sophisticated situation, which is adequate for GRD as macroeconomic and microeconomic considerations are all combined in the model (in Chapter 3).

3.3 Interviews

The type of this research is a combination of pure research and applied research which will be done to develop a decision support model for GRD process and solve specific and practical chaos problem in the GRD process. Sectors from design and contractors and policy party are all involved in GRD, based on the different supporting systems for the DSS, decisions from the different sectors need to be collected and analysed.

Opinions on designers' point of view are essential to the research, energy control model for pre-design stage could be rebuilt to study the decisions forwards and backwards from information workflow point of view. Laboratory experiments with

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inverse modelling will also be involved during the modelling stage. Energy analysis tools are introduced in Chapter 2.

A formal interview is demanded pre-arranged interview. As another category, a semi-structured interview is described as a qualitative study for gathering insight from an informed group of people rather than quantitative data from a sample of research participants. The quantitative study could be the source of a problem solving on a subject, as the objective is gaining the insight view of designing a suitable decision support tool.

Industrial participants from experienced international project managers and design team in international design companies will take part in the interview. Questionnaires will be designed for the managers and designers on the topics from:

- The current retrofitting design process from application situation, factors from the macroeconomic reasons, variations in design
- Major causes for causing the problems for design change in retrofitting
- The process in decision making for GRD

3.4 Questionnaire survey

From the view point of ASHRAE, the building energy simulation modelling methods could be divided into two board categories: forward modelling and inverse modelling. For existing building retrofitting, for example, inverse modelling is more capable and building a physical model for conditioning. OpenStudio as the tool for parametric

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BIM model for design and management will be consequently designed for the inverse modelling process.

3.5 Case studies

Case analysis with semi-structure interviews are chosen to study the workflow and GRD process in differenct stages. Case studies are mainly chosen from Hong Kong and Shenzhen where the leading GRD projects located in China. The workflow study is to analyze the simulation green retrofit design process, and the participants in the different phases in the process of the dynamic factor, the needed information and information flow, problems to be resolved and stage results. On this basis, the process of GRD could be seen as future study template.

The methodology used in this thesis has correspondence to the research objectives as following:

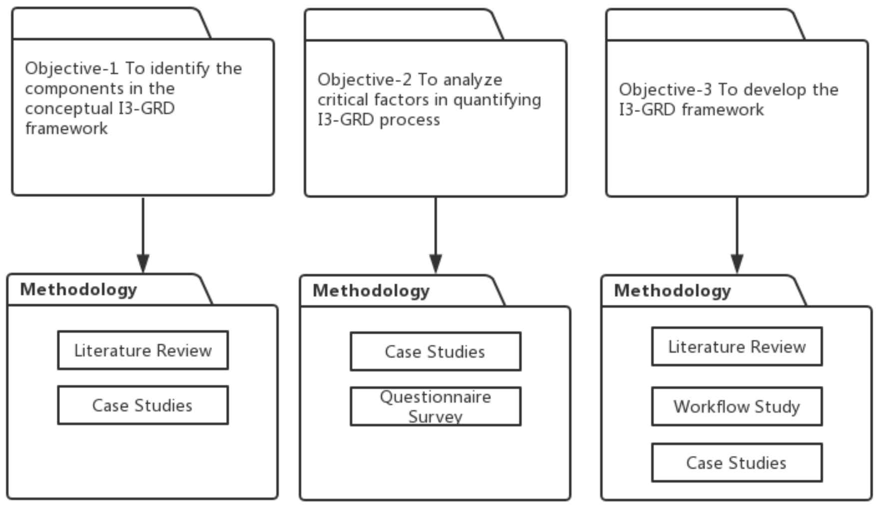

Figure 21 Methodology and objectives

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The overall research idea for green retrofit design process is a dynamic and complex process, involving multiple parties, multiple targets, multiple factors and multiple constraints. In this respect, both local and abroad research has just started, lacking systematic study and research. GRD process as the main line builds multi-phase and multi-level research, by adopting the combination of vertical and horizontal, collecting relevant information from a variety of channels, synthetical analysis, and induction. And on this basis, this research is to further develop on the basis of the theory of workflow I3E-GRD, so as to deepen the research of planning and design. This research adopts the specific research methods including comprehensive literature search, depth interview, case investigation, workshop, action research, expert assessment and network show, etc.

In both industrialized countries and developing countries, modification, retrofits, and rebuild of existing buildings are in demand. Existing Green Retrofit Design (GRD) process in the sustainable design industry is constrained by the reliance on various levels of workforce and different layers of information delivery. Especially for the huge energy consuming (over 40 percent for the building sector), buildings shall be sustainably designed from the aspects of energy modelling, renewable energy using, sustainable materials using and water saving. The Green Building (new-build) design is relevantly easier to have stable results in the sustainable assessment. On contrary,

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the Green Retrofit Design (existed-build) process facing more challenges from the existed building service systems and various technologies include methodological, cultural, social and organizational aspects, will lead to more unexpected results in the final results of the energy saving and building performance. This would require an approach conclude different requirements from architect, engineer and client sectors with design aspects, information of design technical parameters, green technologies, financial status, construction effects and management factors. HOGR is short for House of Green Retrofit, borrowing the idea from the house of quality, which used for defining the relationship from the perspective of customer/owner desires and the firm/product capabilities. Conjoint-HOGR analysis, which refers a combination of HOQ method with green retrofit design (GRD) process and conjoint analysis, is a quantitative method for analyzing owner requirement in the early stage of retrofitting existing buildings. The improvement of this method is based mainly on improving energy efficiency and reducing carbon emissions and analysis of participants' trade-offs, which will reveal the relative importance of component attributes. Research in GRD has been recognized as valuable by both academic and industry.

The types of conjoint analysis have developed from creating Full Profile studies to hybrid conjoint techniques, the attributes of the analysis grow from originally 4 or 5 to 30. In the pioneered research of Jordan Louviere, only one choice task was used and became the basis of choice-based conjoint and discrete choice analysis.

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The requirements from architects, engineers and facility managers based on the existing literature could be categorized from perspectives including social environmental, economic and technical (Menassa, 2014). The owners then would be making decisions based on the attribute input.

Conjoint design, which refers to describe a product or service area, is regarding some attributes like a television with screen size, screen format, brand, price and so on (Green, 1978). Subsequently, conjoint analysis technique is always desired which may refer to as multi-attribute compositional modelling, discrete choice modelling or stated preference research. These statistical techniques used in market research are to determine how people value different features that make up an individual product or service. When it comes to quantitative analysis in design and testing customer acceptance, social sciences and applied sciences including marketing, product management, and operations research have all implemented the conjoint design with the application.

3.6 Summary

The literature review combined with GRD process study and BIM process study is the theoretical background for the research on I3-GRD. On the first half of the literature review, investigation is to define the key problems in GRD with roles of stakeholders, and to study the cooperation, available methods for detailed investigation. After building the initial model for GRD, further methods are reviewed to support the GRD

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process and design solutions for a detailed research in the second half of the literature review with BIM. These studies are designed to identify the advantages and disadvantages in GRD process. In additionally, this research also reviewed the GRD process and decision-making process. The collected information and knowledge in this phase is indispensable.

Case studies with semi-structure interviews are chosen to study the workflow and GRD process in differenct stages. These case studies are mainly chosen from Hong Kong and Shenzhen where the leading GRD projects located in China.

The case studies provide fundamental study for framework building. In the following chapters, the framework would be introduced from three parts. First part is the components of the I3-GRD framework, second is the factors analysis with the influence on I3-GRD. Then in the last part, with workflow in the I3-GRD, the framework would be shown as entirety.

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Chapter 4 Components of I3-GRD framework

4.1 Introduction

This chapter concludes the process in I3-GRD framework and define the components in the I3-GRD framework.

4.2 Stages in I3-GRD framework

For a typical retrofit project, the point of departure is site study and decision making for analyzing contents in the predesign stage. From a normal designer's point of view, how they would consider the site to be retrofit, refurbish, or demolish start here. The Building and Construction Authority in Singapore developed a guide model for existing building retrofits (BCA, 2011). Their steps are fewer and more concise, focusing on the clients' points of view, as follows:

1 Determine the baseline.
2 Review maintenance, purchasing, and energy procurement.
3 Establish targets and goals.
4 Choose between "crunch," "refurbish," or "demolish."
5 Select the optimal upgrade initiatives.
6 Realize the project.

Information requirements in the process after the enrollment stage could be concluded in different stages and from different involvement aspects. Building retrofit process flow was described by FCM (2011) in eight steps, which are as follows:

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1. Designate a contact person (Enrollment).
2. Identify priority areas (Assessment).
3. Create an action plan (Post-assessment review).
4. Summarize the benefits and purposes of the retrofit work (Action plan).
5. Define retrofit's recommended scope and preferred mechanisms for financing and implementation (Project proposal).
6. Determine savings potential and budget based on engineering calculations from detailed auditing and costing (Feasibility study).
7. Supervise the retrofit process (Project implementation).
8. Implement a system to keep operations efficient (Monitoring and verification).

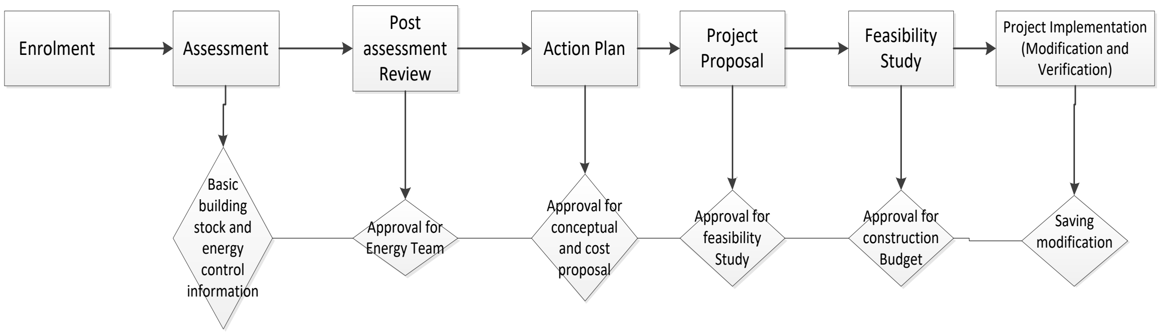

Figure 22 GRD implementation progress in project level

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4.3 Components in stages of I3-GRD framework

When designing for the retrofitting of an existing building, primary existing conditions for buildings are differentiated and considered for design, mainly for energy modeling, variations benefits, and legislation considerations.

GRD should provide rainwater reuse technology, air-conditioning and heating energy-saving technology, shading technology, roof–ground insulation technology, and lighting systems modification technology solutions to the existing building energy issues from a technological point of view (Roahds, 2010). Investigations into unit building results, combined with the local climate conditions, establish a reasonable economy, which would be helpful for comprehensive energy-saving and climate-protection reform plans, and make accommodations for specially designed retrofits. Design goals should be guaranteed to meet indoor thermal comfort needs, under the premise that building energy consumption should satisfy the existing local energy-efficient building design standards for heating and energy consumption in advance.

In the first stage of enrollment, the contact person is essential. The person would normally be a consultant or a technology specialist from the GRD energy team. The systems approach of the existing systems for retrofitting buildings, the functions of the system performance, and the mechanism records need to be analyzed. As the contact person for the coordination, the first step is a study of the site assessment, which should cover the basic information about the building, including the shape, size,

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age, and the existing building service systems. A lot of professionals would involve a design team in this process. Before the project proposal phase, building an energy team is essential. The team should be built with roles in engineering, purchasing, operations and maintenance (O&M), facility management (FM), environmental health and safety, corporate real estate and leasing, construction management (CM), contractors and suppliers, and utilities management (UM) (Energy Star, 2012). Changes in design management would greatly benefit (Tombesi & Whyte, 2011) sustainable design.

In different countries, the case for choosing whether to demolish or rebuild buildings varies due to a lot of reasons. In Singapore and some Asian countries, some buildings are demolished and rebuilt after only 10 to 15 years (BCA, 2010). Uncertain economic times and environmental awareness make the choice of retrofitting and refurbishing more obvious for a sustainable future. From the perspectives of designers and engineers, models for the retrofit process from different levels of high technology and involvement of sectors are worthy of discussion. According to a report by ASHRAE about current energy models (ASHRAE), this is not only a technology topic but also a design topic.

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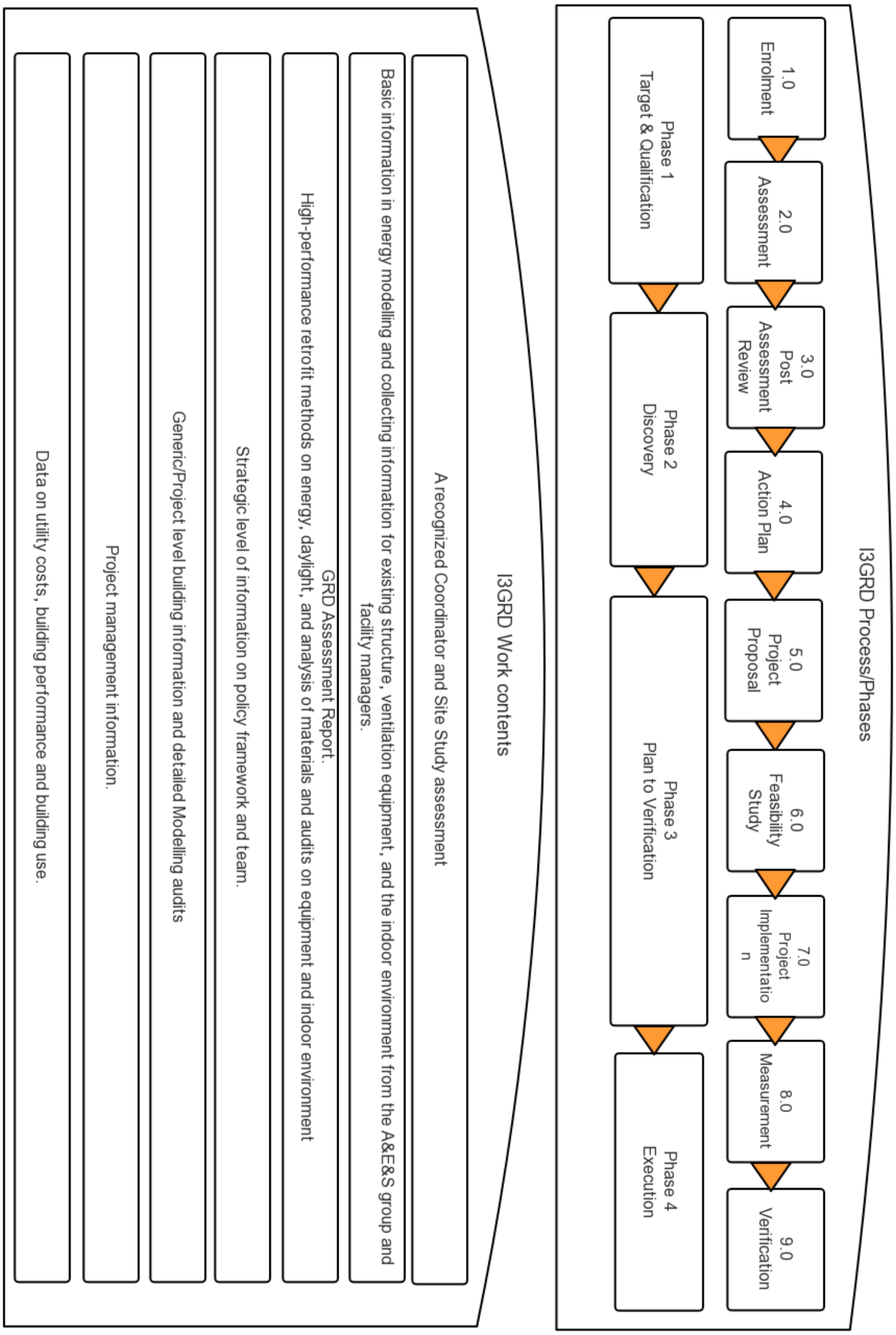

Figure 23 I3-GRD Process and phases with work contents

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The definition of high technology varies from the context of industry-based, firm-based, product-based and life-cycle based techniques (Steemhuis, 2006). Like the US, industry-based high technology is defined by SIC codes. Two indicators include the R&D (research and development) intensity and sales expended on R&D. High technology from firm-based definition would more depend on the company level instead of the entire industry.

Product-based high technology would more be measured by the amount of R&D investment for creating the products, which in the retrofit industry, is the investment in maintenance and plants. Life-cycle based high technology definition has 'an industry's clockspeed. From this point of view, continuously, quickly and keeping update 'cradle-to-grave' approach for assessing industrial systems is the process where high technology is involved in.

For developing a reliable model for the retrofit process, manufacture, use, and maintenance is all called in the design process. For re-design, the building process, determining the optimal engineering for the GRD project be for engaging the Design Excellence Architect is essential in the GRD (AIA, 2012a, 2012b). Another concept to be mentioned is “eco-renovation”, which refers to the retrofitting activities aiming to achieve carbon reduction of over 60% compared with pre-renovation emissions (Fawcett, 2011).

The systematic approach for GRD could be divided from the pre-retrofit section and post-retrofit section (Ma, Cooper, Daly, & Ledo, 2012). The activities in the

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Pre-Retrofit section are mainly managing the Pre-Retrofit energy use baseline and the energy audit report for the client review. In the Post-Retrofit activities, post measurement and verification is for users' survey and the final retrofit report would be monitored and reviewed. In the GRD assessment report, improving energy and environmental performance, reducing water use, and improving the comfort and quality of the space regarding natural light, air quality, and noise.

In the pre-retrofit activities, a pre-retrofit survey to establish targets & goals to reach the client resources and expectation is initiating. After that determine the scope and level of the project whether it counts for a genetic level or a project level is the next step. Then for determining energy performance indicators and performance assessment tools to reach baseline establishment is before the decision making for whether retrofit or demolish the building (Ma et al., 2012). Retrofit measures and energy simulation are then determining for preparing quantifying energy benefits to prioritize for clients' review. If not satisfied, the circle would be retained and reviewed for another round. Cost-benefit analysis and risk management would also consider in the quantify stage. The analysis in the post-retrofit activities would rapidly review for the duration of the retrofit activities, Post assessment and M&V (Monitoring and Verification) stage would be quick for proceeding, as there is much shorter time for procedure change during the final stage.

To protect the palisade structure of the old buildings, improve the heating system, air conditioning system, lighting equipment, and hot water supply facilities and implement energy saving transformation, GRD should also realize energy-efficiency

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design integrated with legislation and energy codes and standards. Managing energy contract management way of energy saving transformation is essential in the GRD, for instance, EPC (Energy Performance Contracting) (Xu & Chan, 2013).

4.4 Workflow in GRD Energy Analysis

For engineers in the GRD process, core for the retrofitting process is energy control. The information grows in smart control in the design process, for instance ‘smart grid’ (Samad, 2011). In power control system, the main source of energy, which is mainly manipulated from the fuel, is not true for renewable energy like solar, wind energy (Samad, 2011). For high performance and reliable operation, renewable energy requires advanced control techniques in GRD. This led to a challenge for the GRD process for energy controlling application.

Relevant research areas for controlling engineering (EPSRC, 2012) in the UK focus more on technology, which is going through design and analysis of controllers for individual systems. As the next generation of smart emerging technologies coming, the transformative potential for more sophisticated control is undergoing. By which means, the smart technologies have a potential controlling need for management modelling. For retrofitting modelling, which may combine more than a hundred energy conservation measures, will have more sophisticated control system modelling considerations. The academic-industry engagement and time-consuming retrofitted control solutions to design problem is suggested to be earlier identified at the current level (EPSRC, 2012).

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Energy control, as well as ventilation and thermal comfort control, are the main parts in the GRD modeling considerations. Previous related studies by integrated simulation which effort the designers for green building design such as Building Design Advisor, ATHENA, Project Vasari and Ecotect which could facilitate the comparison of design alternatives with different performance criteria as daylighting, building massing and thermal energy consumption (Papamicheal,1999). Optimization, which is considered as a trial-to-error process of avoiding and recognizing disadvantages of design, has the capability of distinguishing advantages of optimum or near optimum design alternatives (Wang, 2003).

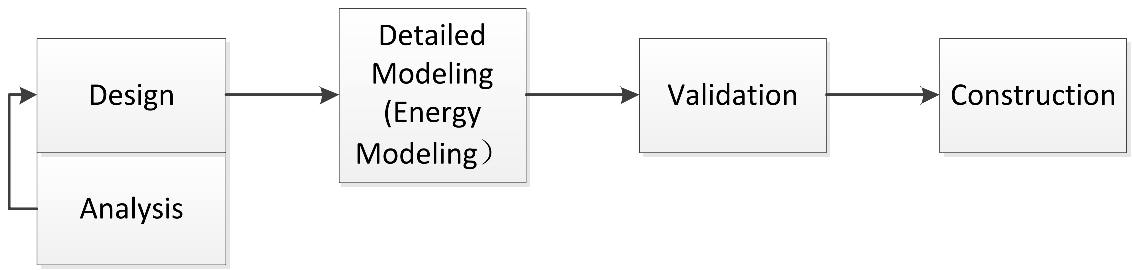

Figure 24 General energy analysis workflow in GRD

As the core of GRD, energy analysis would count for the energy saving as well as carbon emission model. For the energy policy analysis, many papers represent the bottom-up activities analysis (Berglund & Söderholm, 2006; Bohringer, 1998; Kavgic et al., 2010; Koopsmans, 2001; McFarland, Reilly, & Herzog, 2004). Energy simulation models are the practical analysis tools deal with the correlated inputs, the computation of the variations of sensitivity index and software (Tian, 2013). Model parameters in the energy model are calibrated. Take EnergyPlus to be used as retrofit analysis as an example, steps of formation, data evaluation through *physically*

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observable methods (Heo, Choudhary, & Augenbroe, 2012) and energy saving design report as outputs through retrofit analysis. The term of *parameter estimation* describes by Heo to present the process of the process of setting values for *the non-observable* simulation parameters. Uncertain parameters with decisions for architects are often replaced by several parameters as the data limit and a probable and reasonable number of parameters are selected as calibration exercise.

4.5 Decision support models for GRD

Existing decision support tools for office building upgrading such as TOBUS methodology, EPIQR (Energy Performance Indoor Environmental Retrofit) methodology in European energy studies show good examples for GRD strategy for the decision-making process (Balaras, 2002; Caccavelli, 2002; Heo et al., 2012; Jaggs, 2000). The diagnosis as the core, include physical, functional, energy and indoor environmental quality to be distinguished and systematically collected from the database. The auditor to register the construction date for the building HVAC system, equipment and water use for decision making process to promote the greatest energy savings through various retrofit actions.

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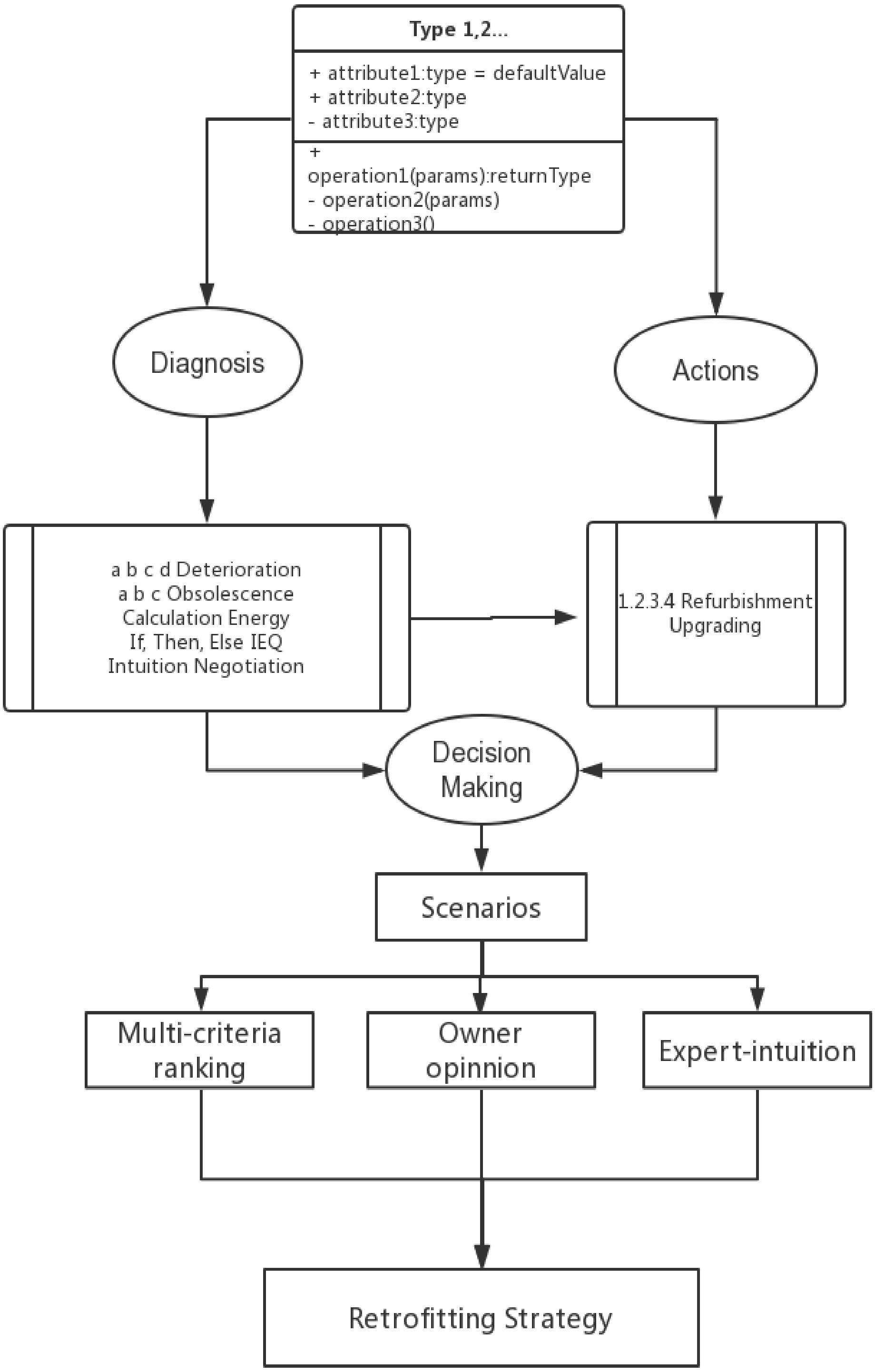

Figure 25 TOBUS methodology as an example for retrofitting existing office buildings

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Many papers on the calibration of energy models and optimal retrofit models and building retrofit strategies (Ascione, de Rossi, & Vanoli, 2011; Gamtessa, 2013; Rysanek & Choudhary, 2013) present the existed retrofit models and suggest sufficient static simulation models for the retrofit analysis. Calibration of building energy models is the core to retrofit analysis (Heo et al., 2012). The split out of the potential efficiency savings between residential, commercial and industrial sectors as Murray (2011) bring out in his research suggests that less time consuming model is adequate means to make retrofitting decisions(Murray, Rocher, & O'Sullivan, 2012).

In the 1990s, the size and expenses grew in energy conservation programmes in the last two decades, so did the emphasis on evaluation of building energy analysis (Kissock, 2002, 2003). In Kissock's paper, the procedure to measure savings is the result of Inversing Modelling Toolkit (IMT). ASHRAE began to develop one method for measuring retrofit savings since 1994.

Kumbaroglu (2011) introduced a techno-economic evaluation method in his study for German office building retrofitting, as the study made a major comparison to the TOBUS software in Switzerland as an interactive aid tools for decision-making (Kumbaroğlu & Madlener, 2012). The seven modules in the TOBUS model conclude the considerations for making assumptions for interest rates, inflation, energy prices and rates of variable changes, enhance high energy efficiency with low total annual cost while no reduce of the human comfort.

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Doukas et al. developed building energy management system (BEMS) to support decision makers for the existing office building in Greece based on the loads, demands and user requirements in the energy auditors and building administration management (Doukas, Nychtis, & Psarras, 2009; Doukas, Patlitzianas, Iatropoulos, & Psarras, 2007). Theodoridou (2012) proposed an integrated assessment tool in Greece using GIS (Geographical Information System) for the existing urban building stock for a special focus on residential buildings(Theodoridou, Karteris, Mallinis, Papadopoulos, & Hegger, 2012). The outcomes from the methodology are designed flexibly for different city structure which is in macro-economic scale considering the evaluation parameters of renewable energy sources, building envelope and carbon emissions.

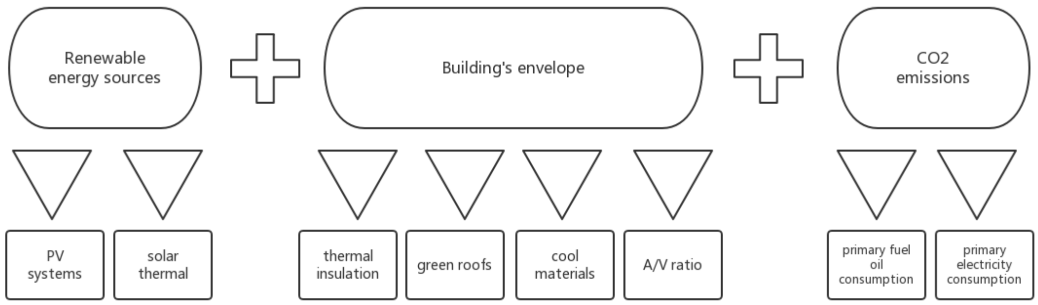

Figure 26 Criteria being revised to the GIS methodology

Kolokotsa et al. (2009), developed energy management system towards decision support methodologies on the energy efficiency, for the group of strategies for building sustainability, are analysed from the considerations on the building codes, passive energy design, policy packages and building certification schemes (Kolokotsa, Diakaki, Grigoroudis, Stavrakakis, & Kalaitzakis, 2009).

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The role of building expert is essential in this decision making model, he/she determines the result for the life of existing building directly with the sensitivity analysis and came with the solution for the data recycling in the database.

4.6 Discussion

In the first stage of enrolment, the contact person is essential, either the person would be a consult or a technical guy from the energy team in the GRD followed. The systems approach of the existing systems for retrofitting buildings, functions of the system performance and mechanisms records would be in the need for analyzing. As the contact person for the coordination, first thing first is the study of the site assessment, what conclude in the site assessment would cover the basic information about the building include the shape, size, age etc. and the existing building service systems. A lot of professionals would involve in a design team. Before the project proposal phase, building an energy team is essential. The team would be built from roles in (Energy Star, 2012):

- Engineering
- Purchasing
- Operations and Maintenance
- Building/Facilities Management
- Environmental Health and Safety
- Corporate Real Estate and Leasing
- Construction Management

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- Contractors and Suppliers
- Utilities

For a typical approach to retrofit project development and execution as in the assessment stage, take the Empire State Building (ESB) as an example, the ESCO process (Energy Service Company) for a retrofit project could be described in four phases (Fluhrer, 2010).

- From Phase 1, the energy service company investigates credit worthiness, capital constraints, energy cost savings potential, building lease structures, client goals, and other basic elements that determine the viability of a retrofit project. These considerations will result in a memorandum of understanding between the energy company and the client in the Enrolment stage.
- In Phase 2, data are collected, including interviews, drawings, and specs, past projects, utility bills, etc. This information will form in a preliminary report in assessment stage. The metrics provided on each measure with capital cost, energy savings, capital cost, energy savings, maintenance savings, simple payback, return on investment, net present value (NPV), internal rate of return (IRR), etc. (Fluhrer, 2010). At the end of Phase 2, a project development agreement should be presented to the client.
- In Phase 3 and 4, verification and execution, detailed engineering capital costs and energy and maintenance savings which would be detailed in cost proposal and feasibility study in Action Plan stage and Project Proposal stage.

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The increasing need for retrofitting lead to a need for decision redesign in GRD process for several reasons, lessons could be learned from retrofitting in production (Westerberg, 1987):

- Increasing the throughput of the current process
- Processing a new feedstock
- Improving the quality of the building
- Improving the economics by improving the life cycle of the existing building
- Reducing the environmental impact of the existing building

The types of modifications using in the GRD may have several implementations compared to the retrofit design in general:

- Possibly altering the operating conditions of the process, changing equipment (mainly for air-conditions systems) is relatively high cost compared to investment in changing process
- Keeping the same equipment but altering the piping which connects to it and used in a new purpose
- Adding new equipment
- Changing materials, for example, exterior wall material for extra materials donated or reused on other projects, purposing on retaining as much original structure as possible

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4.7 Summary

To conclude, steps through the I3-GRD process would vary as projects all have different issues on equipment and budget on retrofitting. However, one and the most important issue in the process is that the decision-makers in GRD would not be single. The speciality of the contact person would be extremely decisive in the design process.

The considerations for the influences and requirement for GRD could be concluded from the research above for environmental, energy, financial and social factors. The issues for the investment from the owner to invest the long term benefits for the building users, whether the building user would accept the retrofit method is a topic to be discussed for sensitivity analysis. The differences between GBD and GRD would come along with the different aspects in decision making towards the technology and methods between different sectors.

The selection for GRD strategy would be based on the very specific building energy characteristics (Menassa, 2011; Zhao & Magoulès, 2012). As the results taken by the research from Hestnes and Kofoed (2002) for existing office buildings, Cooperman (2011) for building envelope and Roulet (2002) for office building have shown that it is possible to evaluate archetype modelling to develop database to formulate sets of mathematical equations for energy consumption estimation (Ma et al., 2012). Most of the research done for the GRD would only simulate the energy consumption using numerical simulations, however, this is way far from the actual case need. Experience

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based database through systematic incorporation is also needed for building up the confidence for the owners to retrofit their buildings.

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Chapter 5 Factors analysis in I3-GRD framework

5.1 Introduction

The content of this chapter is to determine the key factors which are considered when making demolish/retrofit decision in retrofitting of commercial buildings. The design of the research contained three phases, first identifying the potential factors from the literature. The second phase involved discussions with experienced project managers and scholars to confirm and refine the factors which had been found out from the literature. The results of these two phases were listed in the first half and resulted in 9 main factor categories.

5.2 Analysis in this research

In this process study, analysis involved in the questionnaire study include analysis of variance (ANOVA) and Pearson correlation coefficient study, which is used to compare the statistical data.

Analysis of variance (ANOVA) for data analysis in the common statistical model to analyze the relationship between continuous data and dependent variable. When applied in the situation with variable factors equal to or more than three categories, the combination of pooled T-test and Equality variance could be broadly regarded as Equality of variance.

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Based on the basic algorithm concept of variance analysis, in accordance with the number of factors can be divided into the single factor analysis of variance, double and multiple factor variance analysis for different interests. According to the factors of characteristic, there are categorized into three different types. They are called fixed effects analysis of variance, random effects analysis of variance and mixed effect analysis of variance.

In statistics, analysis of variance (ANOVA) is a process of a series of statistical analysis. One variable can be decomposed into different sources. One of the simplest way is that the variance analysis of the statistical tests the average value of several groups of data. The two groups of T test results could be verified. When doing the multiple sets of double variable T test, the probability of error will be much bigger, especially for the type 1 error, so the variance analysis only when two to four group of average is more effective.

5.3 Contents for from national standard

The questionnaire survey has a nationally based range, and could be representative and need for comparison. The listed report contents below are from the self-validation report from the industry according to the national standard in China (See Appendix).

Technical parameters, including the status of the existing buildings, indoor environmental quality (S1);

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The existing technology, including green technology, available maturity and cost (Theodoridou, 2012) (S2);

Influence of construction, including the influence of construction plan and the influence to users (Klotz, 2010 & Manfren, 2013) and also the use of IT technology for uncertainty analysis (Manfren, 2013) (S3);

Conditions of building, including the habits of the users, control system, property management (Kaklauskas, 2005 & 2006) (S4);

Social factors, like the effects to the community, the property unit and heating unit (S5);

Economic factors, including the bank interest, the price of water, electricity and gas, housing rents (Enreop, 2010) (S6);

Environmental factors, including carbon emissions, carbon tax (Fuerst, 2011) (S7);

Financial status, including project budget, operating costs (Gaterrell, 2005) (S8);

Policy factors, including emissions standards, government incentives (Kolokotsa, 2009 & Juan, 2010). The hidden costs and benefit barriers in GRD when considering potential incompatibilities (S9).

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Table 5.1 GRD Operation Management (According to GB/T50378-2006)

	Category	Code	Content	Y/N
GRD Operation Management	**Compulsory**	5.6.1	Formulation and implementation of energy saving, water saving and resource saving and management system. (S1, S4)	—
		5.6.2	All standard waste gas, waste water discharge in construction stage. (S7, S8)	—
		5.6.3	Classified collecting and processing waste, without secondary pollution.(S4)	—
	Added	5.6.4	Good quality of construction earthwork and road facilities in use in the process of operation.(S4)	—
		5.6.5	ISO14001 environment management registered (S9)	—
		5.6.6	Equipment, pipes, set up to facilitate maintenance, renovation, and replacement.(S4)	☐
		5.6.7	Follow the national standard for air conditioning and ventilation system air conditioning ventilation system cleaning standard GB 19210 rules for regular inspection and cleaning. (S8)	—
		5.6.8	Building intelligent systems for functional information network system. (S4)	☐
		5.6.9	Building ventilation, air conditioning and lighting equipment such as automatic monitoring and control system technology for efficient operation.(S5)	☐
		5.6.10	Office, shopping malls with classified building electricity, cold heat metering systems.(S2, S3)	—
	Optimized	5.6.11	Implementation of resource management incentive mechanism, management performance, and saving resources, improve the economic benefit. (S4, S6)	—

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As in the construction industry, communication of retrofitting decisions always depends on the one-way communication status, the prevalence of information model like BIM has not reached the decision process with all the sectors sitting together to make a demolition or retrofit decision. Managing decisions of demolishing or retrofit either refurbishment with purchased mandatory factors from cost time and polices are suggested as the most important constraints and effective use of a firms' resources. This indeed could consider as the key factors in managing information in retrofitting the commercial building. Organisations are increasingly acquiring low-carbon design while at the same time enhancing the indoor environment and the ROI for retrofitting facilities. However, retrofitting of commercial buildings has an effect on users' experience and further rental contract extension which would have commercial and environmental balance issues among the decisions.

This research aims to answer the questions between demolishing and retrofit decisions during green retrofitting process of commercial buildings at the strategic level among users in large organisations with a turnover greater than RMB 40 million in the retrofitting project.

- **What factors are considered in making a retrofit/green retrofitting decision or a green retrofit approach?**
- **Which factors are most important to the retrofit/green retrofitting decision process?**

While the research focus on the binary scenario of retrofit/green retrofitting, the format of the scenario could be more complex with different ownership and different

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function use of the building. The research firstly describe potential factors from the literature review and then discuss the methodology adopted by the research and examples we found in the semi-structure interviews. Interview projects include China Resource Building and Hong Kong Shue Yan University (Wanchai Campus). After that indemnifying the drivers behind the approaches and outline the findings and look forward to the future study. The main technical measures of GRD could be concluded from following aspects (CBEEDAC, 2004):

- Energy saving building planning and design, enhance maintenance structure of the heat insulation performance,
- Air-conditioning system energy saving technical measures,
- New development of energy-saving technical measures such as cold storage technology and cooling tower cooling technology, etc
- The air conditioning system of the maintenance and management of energy saving technical measures.
- Renewable energy
- Indoor environment enhancement

To realize the strategy of sustainable development, in the long run, it is imperative to building energy efficiency (Beheiry, 2006). As long as the combined with national conditions and the actual situation, comprehensive use of various energy saving technical measures to seek advantages and avoid disadvantages, the choice of economically reasonable energy saving the plan, will surely get remarkable energy saving effect in GRD.

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For the roles in GRD, the coordinator would be taking the main chair of the design, while as the architects and engineers may have a technical gap in considering GRD. Because analysis assumptions and numerical algorithms in energy model would be differentiated from different aspects (Menassa, 2011). Even just from the engineers, aspects from energy modeller, facility manager, structural engineer and optimizer would be different for energy saving measures and indoor environment enhancement.

For the variables for behaviour in construction, considerations for energy consumption would mainly for technology and delivery, methods could be concluded for example designate senior management roles and managing the organizations that offer minimized risks (Carvalho, 2010). Feedbacks from the revise and report from energy modelling and facility management would benefit the retrofit projects in the long run and be studied for the future. For green retrofitting considerations could be basically concluded categories in three triangles (See Figure 23) like PM triangle (cost, time and quality); sustainable triangle (people, profit, and planet) and technical triangle (integrated, innovative and intelligent), either to build new or sustainable retrofit the commercial building would consistently depend on the requirements from different stakeholders (Savitz, 2006 & Singer, 2007). The objectives for retrofitting commercial buildings come with the following scale:

- Save the ‘down-time’ of the commercial property
- Expand the life expectancy of the commercial building which is usually around 50 years.

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- Stop the dropping of the rental incomes.
- Arise the prestige commercial office accommodation.
- Increase the period of vacancy by increasing shorter-term rental periods to safeguard against organisational and business changes.

Few papers write about the systematic factors with retrofitting decisions for academic studies. Therefore, the research with experienced senior practitioners in this field to confirm and refine the factors in the literature.

Retrofitting buildings in different regions would have different social, economic and environmental drivers for energy savings (which has been mentioned in Chapter 2 Table 1). These drivers lead to different measures for renovation works. For instance, in the cold regions like Finland and Norway, the considerations are evaluated from minimizing air leakage to improve the thermal losses (Bjorn, 2002). Regions like high density cities like Hong Kong would see facade refurbishment as a key during the retrofit work to reduce the air condition energy waste.

5.4 Factors considered in GRD

5.4.1 Introduction

Driven by the high energy demand for electricity and heating and cooling in building sectors, factors which influncing the GRD decisions are still not well understood and not properly addressed by the current design.

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5.4.2 Data and methods

The data set ananlyzed in this section consists of survey responses of more than 300 participants with roles of owner/designer/tenant on GRD involved projects mainly in China mainland and HK areas. The survey was carried out by a research group in Hong Kong Polytechic University BRE department with help of Beijing University of Civil Engineering and Architecture in two stages: first stage is an introduction seminar in Beijing University of Civil Engineering and Architecture, second stage is the scattered questionnaire survey with the selected participants. This contained mostly closed questions about the attitudes towards factors they considered to be most important considered on design stage. These factors are grouped in different categories and are presented in the following section.

5.4.3 Group the factors

For green retrofitting considerations could be basically concluded categories in three triangles, like PM triangle (cost, time and quality); sustainable triangle (people, profit, and planet) and technical triangle (integrated, innovative and intelligent), either to build new or sustainable retrofit the commercial building would consistently depend on the requirements from different stakeholders (Savitz, 2006 & Singer, 2007).

The benefits for the owners and users will draw main motivations for these factors leading the key issues like letting voids to let the developers have more market opportunity (fitting the sustainable triangle).

The calssifications of the factors from literature are grouped:

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Table 5.2 Interview results for the factors findings from case studies

Key Findings of factors	Study 1	Study 2	Study 3
Main economic (Profit) (S1)			
Financial status including:			
• Project budget	Yes	Yes	Yes
• Operating costs	Yes	Yes	Yes
Macro-economic factors including:			
• The bank interest	Yes	Yes	Yes
• The price of water	Yes	Yes	Yes
• Electricity and gas	Yes	Yes	Yes
• Housing rents	Yes	Yes	Yes
Environmental (Planet) (S2)			
• Carbon emissions	Yes	Yes	Yes
• Carbon tax	Yes	Yes	Yes
Social (People) (S3)			
• Lower mid-cost energy bills for owners	Not found	Not found	Not found
• Lower carbon emissions	Yes	Yes	Yes
• Improving health and comfort of the occupants	Yes	Yes	Yes
• Creating jobs for a wide range of workers	Yes	Yes	Yes
• Positive effects on neighbourhood and community	Yes	Yes	Yes
Intelligent (S4,S5,S7)			
• Technical parameters, including the status of the existing buildings, indoor environmental quality (S4)	Not found	Yes	Yes

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• Existing technology, including green technology, available maturity and cost (S5) • The use of IT technology for uncertainty analysis (S6)	Yes Yes	Not found Not found	Not tested Not tested
Innovative (S7) Policy factors, including: • Emissions standards (S7) • Government incentives (S8)	 Yes Yes	 Yes Yes	 Yes Yes
Engineering (S9) • Conditions of building, including the habits of the users • Control system, property management	 Not tested Yes	 Yes Yes	 Yes Yes
Others: • Subjective expectations from building owners • Influence of construction, including the influence of construction plan and the influence to users	 Not tested Not found	 Yes Yes	 Not tested Yes

After the group meetings, factors are categorized in a form

1) Main economic (Profit) exactly as economic factors, including the bank interest, the price of water, electricity and gas, housing rents Financial status, including project budget, operating costs (Gaterrell, 2005) (Enreop, 2010) (S1);

2) Environmental (Planet), as including carbon emissions, carbon tax (Fuerst, 2011) (S2);

3) Social (People), like the effects to the community, the property unit and

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heating unit (S3)

4) Intelligent as technical parameters, including the status of the existing buildings, indoor environmental quality (S4); The existing technology, including green technology, available maturity and cost (Theodoridou, 2012) (S5); and also the use of IT technology for uncertainty analysis (Manfren, 2013) (S6)

5) Integrated, such as Policy factors, including emissions standards, government incentives (Kolokotsa, 2009 & Juan, 2010). The hidden costs and benefit barriers in GRD when considering potential incompatibilities (S7).

6) Innovative, such as developing the innovative technology and promoting enterprise image (S8)

7) Engineering, such as conditions of building, including the habits of the users, control system, property management (Kaklauskas, 2005 & 2006) (S9);

5.4.4 The analysis using ANOVA test

The analysis for a price-demand using conjoint analysis model in marketing field is very common. To study the short-term promotional pricing for similar brands, market surveys would have questionnaire asking simply ask how much the consumers would pay for different new products in the 1970s (Mahajan, 1982). In the next level, consumers are asked to evaluate sets of combination contained with different fractional factorials. These combinations are designed to choose their preferences. This type of study is now developing as big data is infiltrated into life.

`

In this framework, factors are analyzed and accounted according to a questionnaire survey. After concluding the results from the literature and interviews, another round of questionnaire survey is built and send to expertise from both the industry and academic field for ANOVA test. The questionnaire contents are attached in Appendix G. To analyze the outcome of the questionnaire survey, the ANOVA test is selected to study the significance.

5.4.5 Results and discussion

Before turning to the estimation results, let us first discuss drivers and barriers to GRD, as they were identified by participants in this survey. The participants were provided with lists of possible reasons why they would consider GRD as important in the design stage. Stated drivers for the investigation were improving energy consumption (63%), need in renovation (44%), increasing comfort (36%) and environmental protection (32%). On the other hand, the barriers exist on economic/financial, hidden costs, market failures, behavioural and organizational, information, political and structural. Details are listed in the table following.

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Table 5.3 General reasons for GRD from the overview statistics

Reason	%(N=300)
Improving energy consumption	63.0
Need in renovation	44.0
Increasing comfort	36.0
Environmental protection	32.0
Increasing Market Value	26.0
Expected future legal requirements	20.0
Current legal requirements	18.0
Attraction of the new technology	14.0
Positive attitude of the new technology	10.0
Other reasons	8.0
Not stated	6.0

Table 5.4 Barriers to GRD in the building sector

Barrier categories	Definition	Examples	Countries facing the barriers
Economic/Financial barriers	Ratio of investment cost to value of energy savings	The high efficient equipment early cost The lack of energy subsidies for the channel Lack of environmental, health and other The internalization of external costs	Most countries Especially developing, also developed
Hidden costs/Benefits	Cost or risks (real or perceive) that are not captured	Due to the potential incompatibilities cost and risk,	All the countries

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	directly in financial flows	performance risk, The transaction cost, etc. Poor power quality, especially in Some developing countries	
Market failures	Market structures and constraints which prevent a consistent trade-off between specific EE investment and energy saving benefits	Limitation of the typical building design process and fragmented market structure. Landlord/tenant split and misplaced incentives	All the countries
Behavioural and Organizational barriers	Individual and Enterprise behaviour	Tendency to ignore small energy saving opportunities Traditional, behaviour and life style Corruption transition in energy expertise	Developed countries Developing countries
Information barriers	Lack of information provided on energy saving potentials	Lacking of awareness of consumers, building managers, building companies and politicians	Most countries Especially developing, also developed
Political and Structural barriers	Structural characteristics of political or economic or energy system which bring difficulty to efficiency investment	Slow process of drafting local legislation Gaps between regions at different economic level Lack of governance leadership/interest Lack of equipment testing/certification Inadequate energy service levels	Most developing countries, also some of the developed countries

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The sample size is 300 with 5% of the total unsatisfied response rate. The questionnaire objects are from the industry with experience group with 0,5 to 10 years, 10 to 20 years and over 20 years. This group classification is to compare the subjective opinions towards development of the GRD. Also the objects are separated from designer and non-designer to compare the opinions.

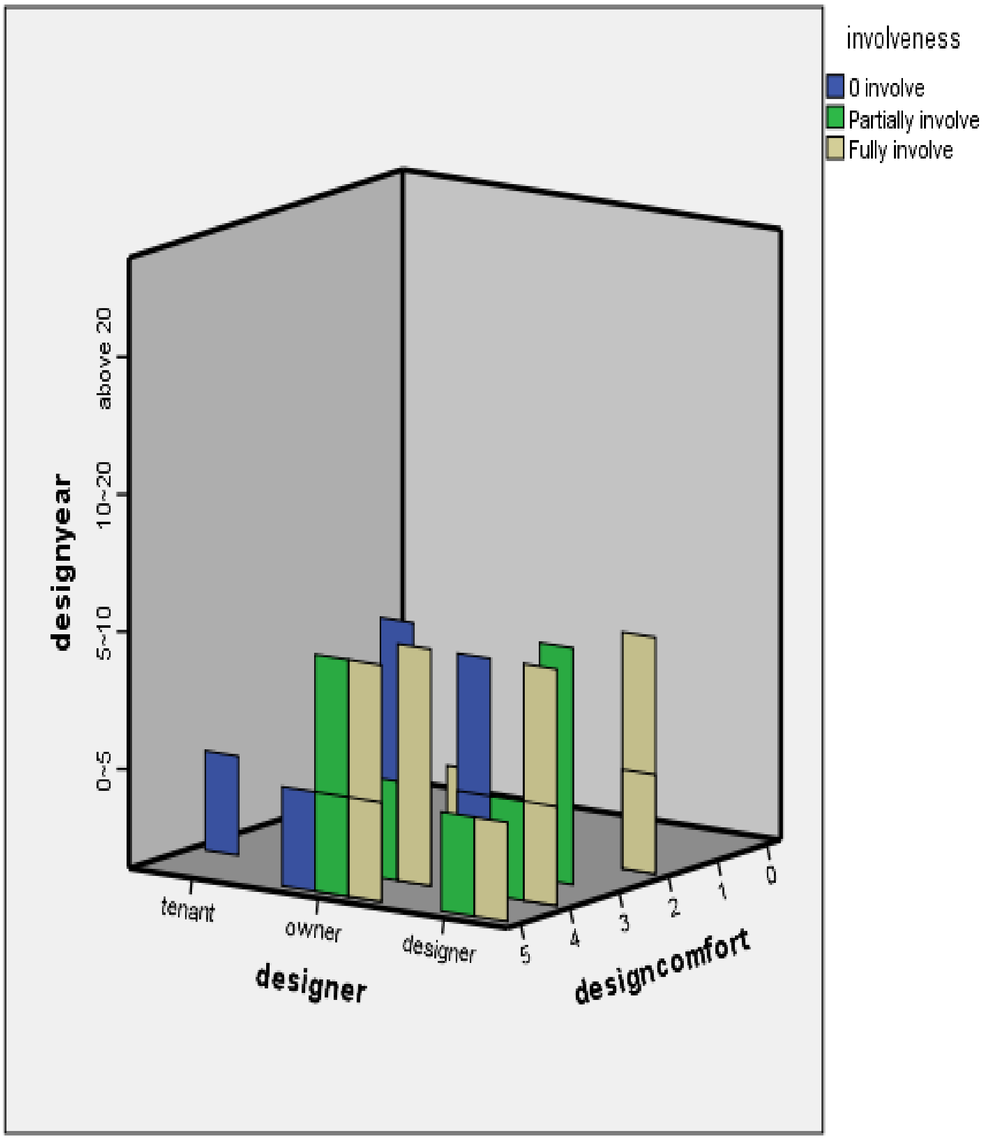

Figure 27 ANOVA test result

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The figure above shows the test result on design comfort for three comparison groups with different involvness and different design experience. From the figure we could conclude that new owners comparisively have preference on design comfort so as the designers. This implies the new modified designs for GRD are carried forward with their frontier designs.

In the following figures, variance test results (group differentiate from design experience, characteristics, involveness) are shown. The factors are presented with these different groups to show the similarity and difference towards experience, involveness and design/non-design point of view.

Results with particular attention:

1) Results show large divergence between different experiences on rent, bank interest floating and policy encouragement.

2) Designer and non-designer shows divergence on energy improvement.

3) Partially design and fully design in GRD groups pay more attention on bank interest floating and have more divergence on operation fee reduce.

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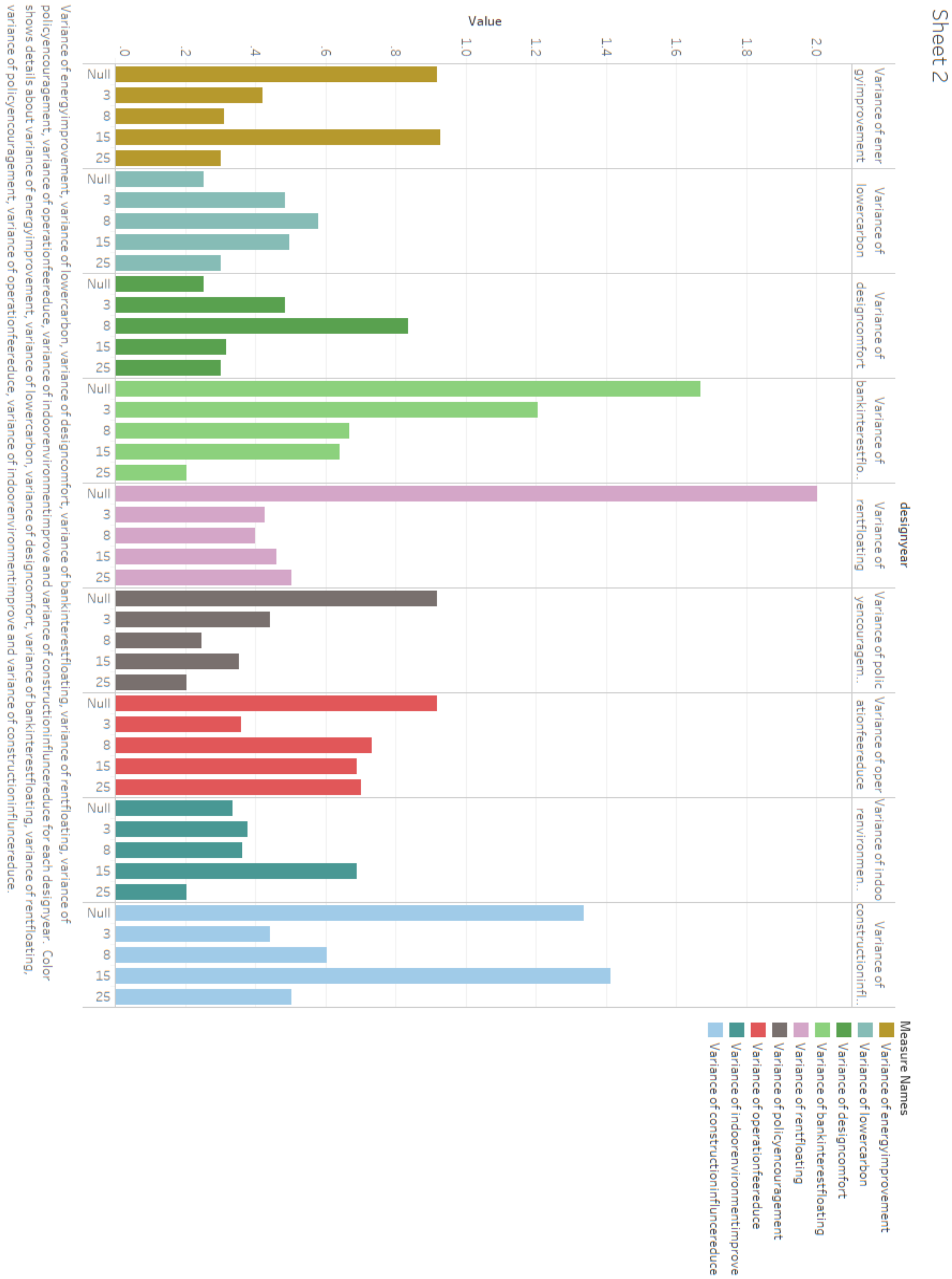

Figure 28 Variance test result (group with different design year)

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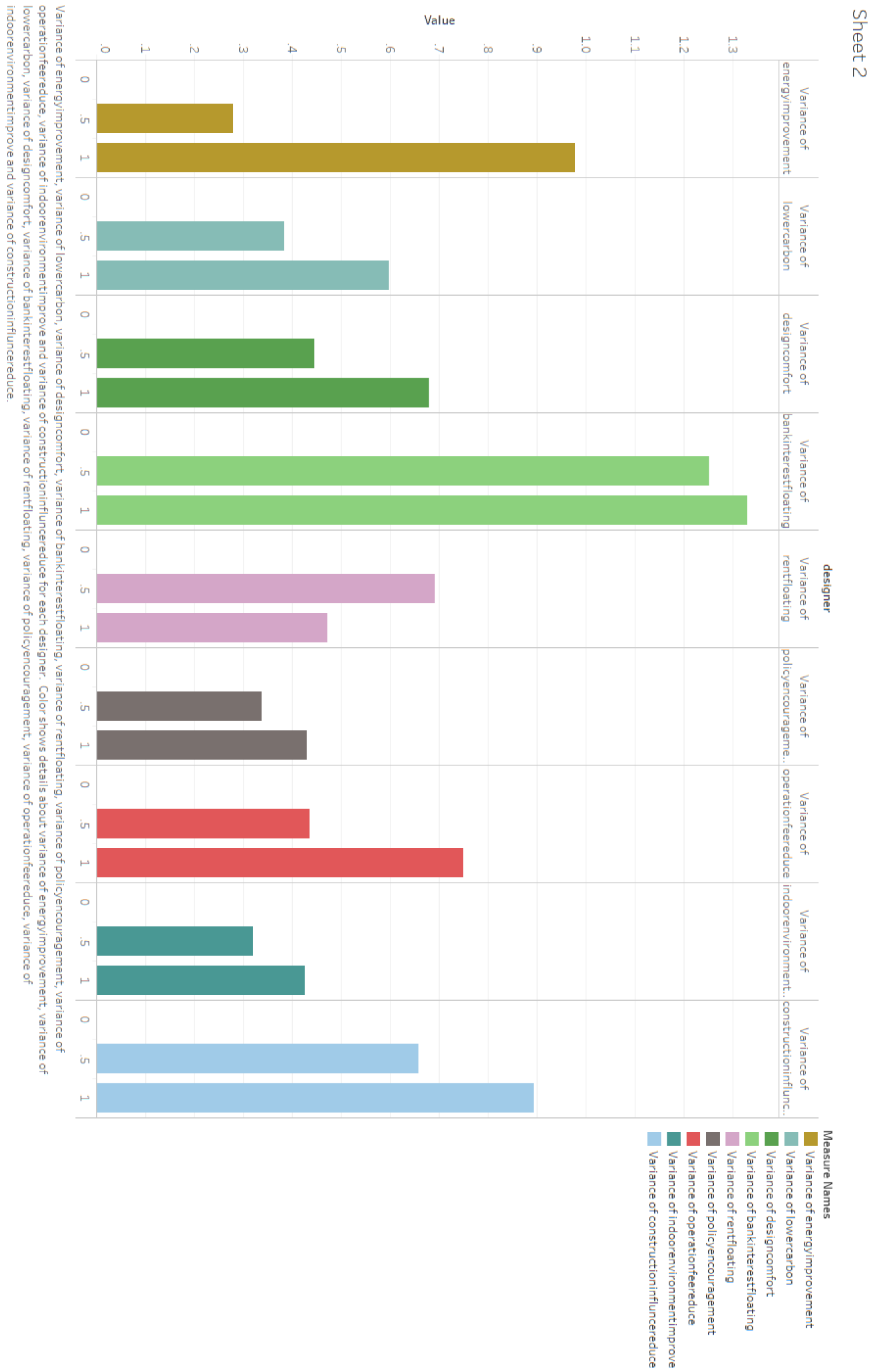

Figure 29 Variance test result (group with different characteristic)

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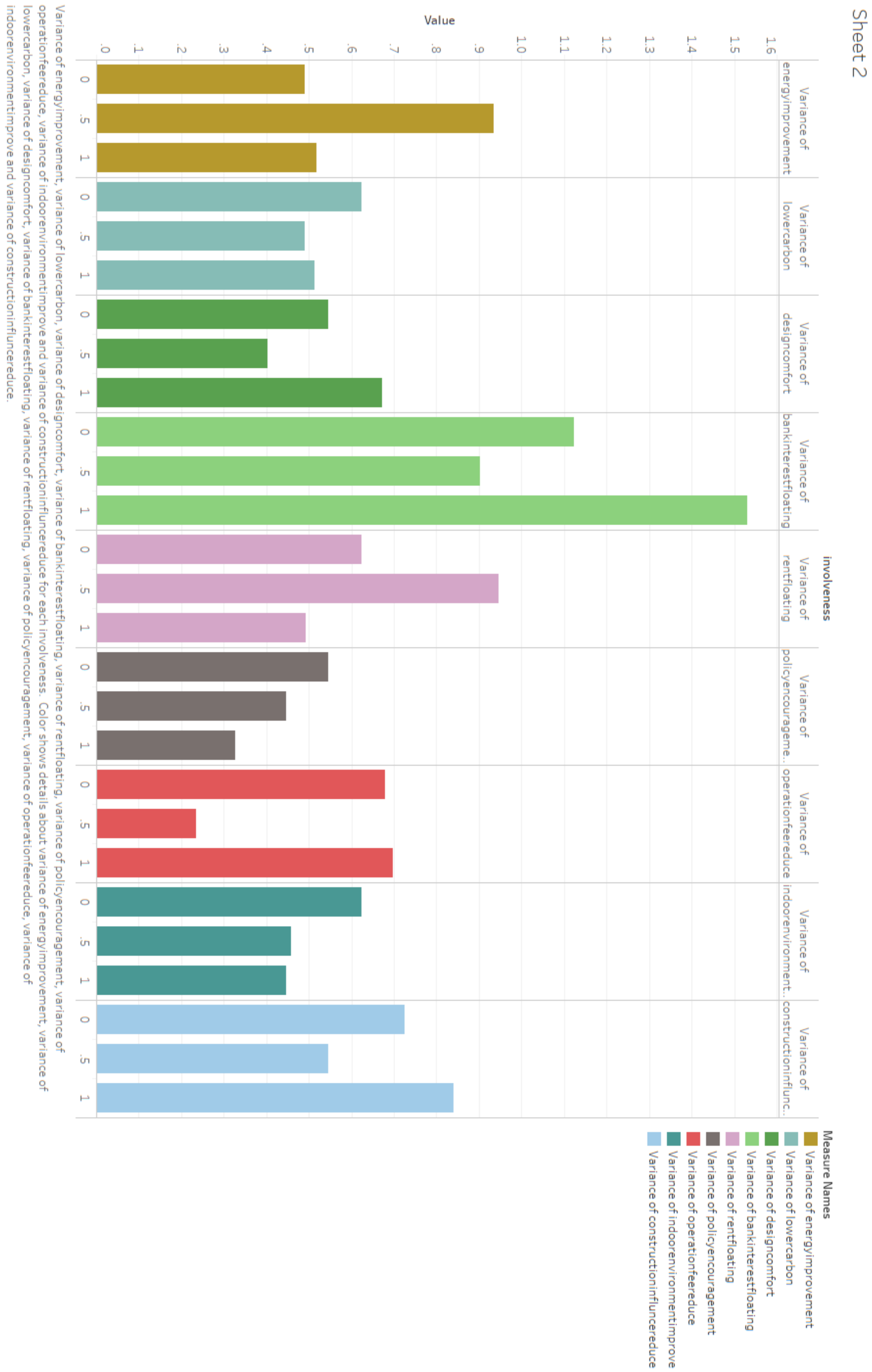

Figure 30 Variance test result (group with different involvement in GRD)

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5.5 The discussion with the research results

The variance test result shows the difference between the selected groups with their difference in experience, involvement and characteristics in the GRD process. According to the value from the diagram, the bank interest floating from all the participants shows consistency on the influence to the quality of GRD. The operation fee shows the lowest influence. The other categories shown relatively equal influence.

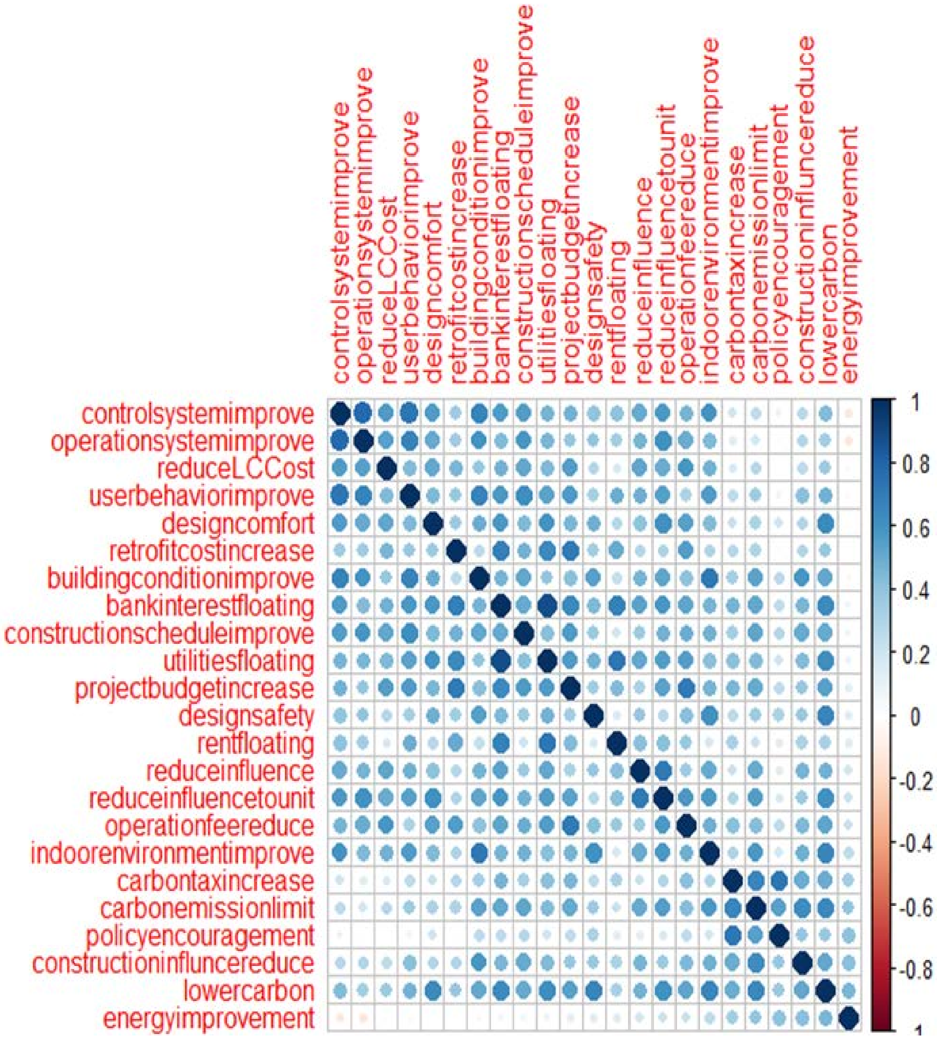

Figure 31 Factors correlation analysis from Pearson

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The first to be discussed is to use appropriate technology in GRD. This presents in this research with not much correlation in the technology with the different groups of participants. Their opinions with the positive attitude towards GRD are not shown much difference with their involvement in the projects (full result could be seen in Appendix E). More discussion shown during the interviews with the discussion of green retrofitting in public to be expensive, with most advanced, complex construction technology and construction materials. This is a misunderstanding of the GRD. In fact, GRD should be used as much as possible to apply technology and reduce the energy consumption structure. At present, there have been a lot of low cost, applicability of the mature technology which can be applied, such as natural ventilation, shading, building wall thermal insulation, building facade and green roof, etc. Traditional architecture in our country also has a lot of good examples, such as natural geographical environment, consciously use wind and solar power, to achieve the goal of sustainability.

The second is the user-behavior improvement. The correlation result shows the user-behavior improvement has big correlation with control system improvement and building condition improvement. These factors reflect in the activities, for instance changing the user-behavior for the systems like elevators which consuming large amount of energy. Therefore, GRD is not only reflected in the process of building design and construction, but also building energy conservation and emissions reduction, and construction of operating life after the process, such as recycling. Building is the carrier of energy use, through modern technology, solar, wind and

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geothermal power, the elevator drop of potential energy and the heat energy produced. The building can also be an energy generator, so as to achieve the purpose of energy saving and emission reduction.

To test the factors in multiple sample comparison, the research use ANOVA test which provides industrial strength statistical analysis (The results are shown in the Appendix G).

In China, rapid development of urbanization and industrialization has and would be continuously taken place. In the current environment, large stock of existing buildings and new buildings, with diverse geographic climate characteristics, developing green building has great potential and unique advantages.

Firstly is the tremendous energy saving potential, from 1.6 billion to 2 billion square meters for the total area. Secondly is energy intensive. In the same situation in the developed country, to get the same indoor comfort, energy consumption of unit building area would be 2 to 3 times. During the period of "12th five-year plan", building energy saving has completed around 20% of the total energy saving task in China. If the statistics reached 50% with 65% of the local standard, 354 million tons of standard coal a year could be saved by 2020, accounting for 30.7% of the national energy saving target.

Secondly is that GRD can provide users with a comfortable indoor environment with

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health and safety purposes, represents the sustainability design. However, at the end of 2016, the proportion in the existing buildings with green label is still low. In addition, the development of green building cost is still much lower compared with other developed countries, so the comparative advantages of developing green retrofitting in China is more obvious.

Thirdly is green building technology now is relatively mature. European scholars have found from the survey for over 80 technologies towards reducing greenhouse gas (UNEP, 2007). The results show that in terms of investment and energy saving benefit, energy-efficient lighting technology is one of the most effective measures to reduce greenhouse gas emissions. In terms of energy saving, improving the heating system of heat insulation and partition of cold climate area, the household heat metering, and improving the ventilation efficiency, shading, natural ventilation, heat insulation measures, and cooking stoves in developing countries, etc., are all effective energy saving measures; High EER equipment, solar water heating equipment, energy-efficient appliances and energy management system, etc., are all mature architectural energy saving technology from the existing research that could be guidance in GRD.

What more to be mentioned is the traditional architectural culture, which could be beneficial to promote green buildings. From south to north in China, there are appropriate traditional design to the regional climate and a large number of buildings, such as the local-style dwelling houses, Shaanxi caves, all have the ingenious use of

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ventilation, shallow geothermal energy to achieve the characteristics of warm indoor environment in winter and cool in summer. Some of the southern garden architecture shows respect to the nature. Chinese garden on form is a microcosm of nature, with the structure of the extension, the botanical garden in construction, opening up a garden, lawn outside the main hall, south side of the deciduous trees, deciduous after the sun can shine in the winter, and grow in summer with the leaves built shading. In a word, protecting traditional architectural culture could also build foundation for the development of GRD.

5.6 Summary

The factors which been taken from the interviews in the industry could be summarized from sustainable, technical and planning perspectives.

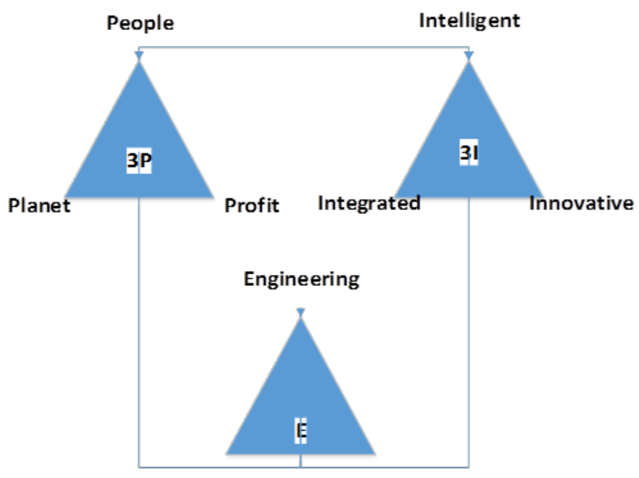

Figure 32 Sustainable and Intelligent triangle

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1) People

The strategic importance of demolishing/retrofit decision to the commercial building has been recognized and identified in the literature (Rey, 2004 & Menassa, 2011). Demolish or retrofit decision frameworks are suggested with more strategic applications to be built (CFM, 2009).

Different needs and requirements of the various stakeholders, including high efficiency, low emission, the minimum life cycle cost, comfortable and safety are considered mostly for the green retrofitting.

From the benefits that GRD bring to the clients, factors from cost to carbon emissions and health and safety reasons can be found in the literature:

- Lower mid-cost energy bills for owners (Ascione, 2011)
- Lower carbon emissions (Balaras, 2002, Balaras, 2005)
- Improving health and comfort of the occupants (Gluch, 2004, Jaggs, 2000)
- Creating jobs for a wide range of workers (Kumbaroglu, 2012)
- Positive effects on neighbourhood and community (Mahlia, 2005)

The benefits for the owners and users will draw main motivations for these factors leading the key issues like letting voids to let the developers have more market opportunity.

2) Intelligent/Engineering

Technical parameters, including the status of the existing buildings, indoor environmental quality;

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For engineers in the GRD process, core for the retrofitting process is energy control. The information blows and grows in smart control in the design process, for instance 'smart grid' (Samad, 2011). In power control system, the main source of energy, which is mainly manipulated from the fuel, is not true for renewable energy like solar, wind energy (Samad, 2011). For high performance and reliable operation, renewable energy requires advanced control techniques in GRD. This led to another challenge for the GRD process for energy controlling application.

Relevant research areas for controlling engineering (EPSRC, 2012) in the UK focus more on technology, which is going through design and analysis of controllers for individual systems (Choudhary, 2012, Yalcintas, 2008). As the next generation of smart emerging technologies coming, the transformative potential for more sophisticated control is undergoing (Yudelson, 2010). By which means, the smart technologies have a potential controlling need for management modelling. For retrofitting modelling, which may combine more than a hundred energy conservation measures, will have more sophisticated control system modelling considerations. The academic-industry engagement and time-consuming retrofitted control solutions to design problem is suggested to be earlier identified at the current level (EPSRC, 2012).

3) Engineering

The existing technology, including green technology, available maturity and cost (Theodoridou, 2012).

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Energy modelling process mainly has three missions to accomplish: building model formation, providing calculating data and generating energy saving report. Energy saving design software model refers to the wall (outer wall and inner wall), windows and doors (external doors and Windows and inner doors and Windows), cold and hot bridge member (column, beam, lintel), room (including room function set), the building outline, floor frame. For the interior wall, inner doors and windows, the three components are not to a certain generation, if stipulation index is not satisfied, carrying on the analysis of the energy consumption, must generate the three components (Nemry, 2010 & Papadopoulos, 2002). If only stipulation index validation and power consumption index calculation, then no need to born into the three components, this to a certain extent greatly reduced the time of building made a model (Swan, 2009).

4) Integrated

Influence of construction, including the influence of construction plan and the influence to users (Klotz, 2010 & Manfren, 2013) and also the use of IT technology for uncertainty analysis (Manfren, 2013).

5) Energy /Engineering

Conditions of building, including the habits of the users, control system, property management (Kaklauskas, 2005 & 2006)

6) People/Profit

Social factors, like the effects to the community, the property unit, and heating unit;

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7) Economic

Economic factors, including the bank interest, the price of water, electricity and gas, housing rents (Enreop, 2010).

With both implementation cost and ongoing costs, the economic factors also contained project budget and operating costs, which reflecting continued pressure on managers who try to balance the quality of GRD with the requirements from both owners and users (Mahlia, 2011).

8) Planet

Environmental factors, including carbon emissions, carbon tax (Fuerst, 2011)

9) Profit/Economic

Financial status, including project budget, operating costs (Gaterrell, 2005)

10) People/Innovative

Policy factors, including emissions standards, government incentives (Kolokotsa, 2009 & Juan, 2010). The hidden costs and benefit barriers in GRD when considering potential incompatibilities.

Development of green retrofit can not only reduce building energy consumption, but also make people improve living and working environment, and is beneficial to maintain a healthy body and stimulate the work enthusiasm, then extend production potential and innovation potential.

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Chapter 6 Workflow in I3-GRD Framework

6.1 Introduction

This chapter first introduces the BIM workflow and BIM base performance analysis in the I3-GRD framework. Then presents three GRD cases for a workflow description. At last the workflow is consolidated for the following I3-GRD framework development.

6.2 BIM workflow and BIM based performance analysis

For exporting BIM project information, settings for Revit platform using room tags for model preparation is no.1 step. Area and Volume Computations and checking for the computation would be followed. The project information for energy analysis and data for edit would be an import for the set inputs (such as building type, postal code, and project phase). After the information created for the rooms, check room upper limits & offsets would be the next move for elements properties setting in the model.

Exporting file would be in the form of gbXML, for the integration of BIM and Building Performance Analysis Software, IFC, ifcXML, ecoXML, IDMxml (for the new IDM form) are also the potential files to be delivered to the building simulation tools.

As discussed in Chapter 2, GBS (Green Building Studio), Ecotect, Project Vasari,

VE-Pro, Energy Plus, DOE2, TRNSYS are all the well-developed building simulation

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tools in the industry. The primary features are been discussed and the typical inputs for the simulation tools are building type, construction materials, system types (HVAC), room type (zone management), project location (weather files) etc. (Azhar and Brown, 2008).

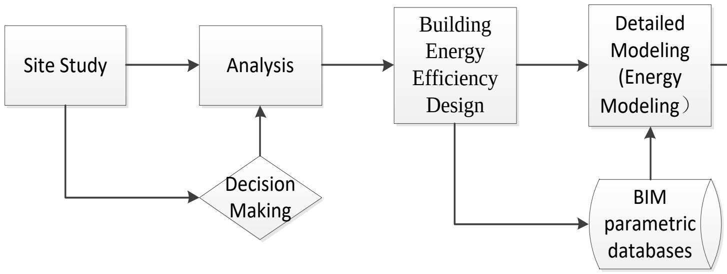

Figure 33 GRD design process in genetic level with BIM tools

When developing the collaborated BIM models, an architectural model, and consultant/subcontractor model are operatively connected through the export link in BIM in the first place. With analysis comments which are done by BIM analysis tools to various disciplines, the models then would be digested by inter discipline clash detection, construction sequencing, and material delivery conditions. BIM in the design process brings the design to the next level for the engineers to bring a more sophisticated design from the complex operation. In the civil engineering project process, BIM would be slow in practice because the BIM platform would be more focusing on architects' design but replacing the level of information.

'Green BIM' the concept in reducing the project duration and energy plus cost would be helpful for material management in the construction process, saving the energy consumption in the whole life cycle by the energy modelling.

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For coordination in the BIM process for different sectors, companies would be more enhanced by the BIM platform, government and companies with software experts. The existed software platform would be challenged by the new standards:

- Openness
- Closeness
- Patent standard

The site management from the construction company (in the diagram is GROCON), will also reflect the site behaviours through NAVISWORKS in the BIM models.

6.3 Interoperability in energy analysis tools with BIM tools

For energy analysis summary in GRD, the results of the analysis were done on the 3D model, which is an unfolded model. For Ecotect Analysis and Green Building Studio which are all been required by Autodesk, providing *improved design insight through whole building energy, water, and carbon-emission analysis, helping architects and designers to maximize building economic and environmental performance. The tools are compatible with Autodesk design software as well as software from other industry providers through the Green Building XML (gbXML) schema and can now be directly accessed from within the Revit platform for BIM with a new plug-in now available for download (Vancouver, 2012).* For Green Building Studio, the company has been launched the Green Building Studio web service since 2004. Autodesk has also developed Simulation CFD (Computational Fluid Dynamics) and 3ds Max Design for building analysis tools, Ecotect Analysis and Green Building Studio are more popular

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in energy analysis for new buildings, while Energy Plus and DeST are normally used for existing buildings.

For Project Vasari, which is a relatively new modeling tools, is a technology preview tools on Autodesk Labs. For the pre-design stage, Project Vasari has its advantages for it provide the architect and engineers with a *comparison of effectiveness and performance of alternative design strategies (Autodesk, 2012).* Project Vasari is also helpful for GRD as the initial studies from are in the areas:

- Sun studies
- Wind studies
- Conceptual energy analysis
- Basic façade/building envelop design

6.4 BIM parametric database in energy analysis tools

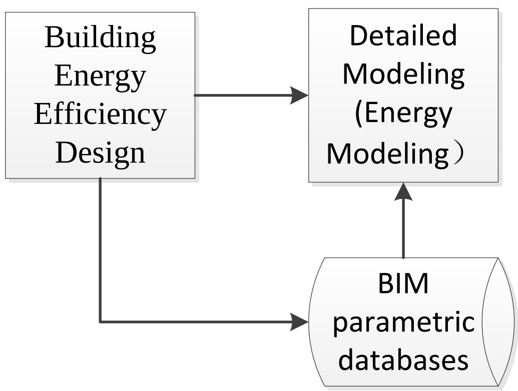

Figure 34 Building Energy Efficiency Design in GRD part in the implementation process

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In the technology competency sets in the energy modelling phase with BIM involved in, software, hardware, network are all called in. What to be managed in the 2nd level phase contains applications, deliverables, data, equipment, deliverables, location and mobility, network solution, deliverables and security and access control. The contents for documentation for initial concept of BIM mainly contain the proposed building layouts (GSA, 2010). For functional and non-functional space configuration and placement of other of geometric elements such as technical spaces, circulation spaces, shafts, etc.

- Application target
- Drawing energy audit building energy efficiency design decision
- Energy saving analysis consulting energy-saving effect evaluation
- The layout of the rooms energy consumption
- Energy saving measures calibration
- Applied the effect on the energy consumption

The GRD would have contributions to safety, energy saving, function changing and material changing (Wang, 2012).

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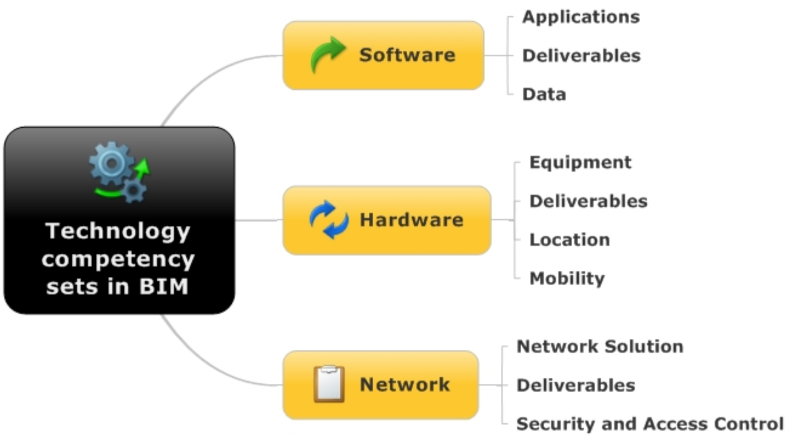

Figure 35 BIM Technology Competency Sets

6.5 Discussion on the modelling process

Energy modelling process mainly has three missions to accomplish: building model formation, providing calculating data and generating energy saving report.

Energy saving design software model refers to wall (outer wall and inner wall), windows and doors (external doors and Windows and inner doors and windows), cold and hot bridge member (column, beam, lintel), room (including room function set), the building outline, floor frame. For the interior wall, inner doors and windows, the three components are not to a certain generation, if stipulation index is not satisfied, carrying on the analysis of the energy consumption, must generate the three components. If only stipulation index validation and power consumption index calculation, then no need to diverse into the three components, this to a certain extent greatly reduced the time of building model.

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Generation model has the following three ways:

- Graphics conversion
- Direct use
- Tracing

1) Graphics conversion mainly is the use of design platform such as CAD, Revit platform, such drawing software architectural design drawings, graphics itself is only a line, through the graphics conversion was born into a 3D model, but because now designer and has no unified and correct drawing habit, so most cases, graphic article line is not standard, if for graphics transformation, then the error rate is high.

2) Direct use mainly as the example from the design company in Tsinghua using Arch2006 drawing software such as a version of the architectural design drawings, graphics itself is already a 3D model, but due to the designer in drawing attention only two-dimensional line, and 3D performance after drawing is not followed up. Some simple modification needs to be rebuilt, such as the height of the wall, door window sill is high, some do not need to delete from the structure parts, etc., and then model is correct for energy saving calculation.

Repainting three-dimensional model. This kind of method in practical engineering is for a big quantity used and tested, building this kind of model also won't be slow.

For tracing the model, contents of design may include:

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- Draw exterior wall. To shaft network node as the outer wall of the anchor point.
- Draw the doors and Windows. External doors and Windows position don't sum base map completely weight and, but deviation doesn't want too big.
- Search building outline. Building profile generation has two effects: get building area, change wall type.
- Arrangement of cold and hot bridge only and exterior wall at the intersection of column to decorate
- Establish floor frame

After model establishment, the energy model gives calculation data, including the engineering settings, thermal setting, and the external blinds settings. Engineering Settings: in the project the engineering settings determine the building geographical position, building type, wall and door window orientation information etc. Thermal Settings: in engineering structure for each member of the material composition, computational component K, D, SC R equivalent and W/W (Window Wall Ratio).

1) Heat Transfer Coefficient (K): in the steady state condition, palisade structure on both sides of the air temperature difference is 1 ℃, the unit time through the 1 square metre area of the quantity of heat transfer. Units: W/m2 ℃. It is a representation of space enclosing structure transfer heat capacity index. When K value is smaller, palisade structure of the heat transfer ability is lower, then the thermal insulation performance is better.

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2) Thermal Inertia Index (D): representation space enclosing structure of temperature wave attenuation speed degree of the dimensionless index, its value is equal to material layer heat resistance and heat storage coefficient of the product. D = S × R, including S for material heat storage coefficient W/m2K, R for material thermal resistance m2K/W. The greater the D value, temperature wave in one of the decay faster, palisade structure thermal stability better, more conducive to save energy.

3) Shading Coefficient (SC): actual through the glass of the sun radiation and heat gain through 3 mm transparent glass sun radiation heat gain of the ratio. It is the window shading performance characterization of pervious to the light system of the dimensionless index, its value in the 0 ~ 1 range change. The smaller the SC, through the window transmission system of solar heat gain is smaller, the better the performance of its shade.

4) The Window Wall Area Ratio (W/W): the window the mouth of the cave area and the ratio of the area of the facade. Generally speaking the window wall area ratio is larger, the greater the energy consumption of the building will have.

5) R value: In China, the region area in the whole country is vast, climate condition in each distinct differs significantly. The country is divided into five climate areas: cold region, cold region, in the hot summer and cold winter region, in hot summer and warm winter area to moderate area. Building energy efficiency for different climate area building palisade structure of the thermal insulation requirements has different provisions.

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External blinds Settings contents are: in the characteristic editor choose external window set external blinds parameters, so as to calculation the doors and Windows of comprehensive shading coefficient.

Energy saving design the first step is data extraction, get building area, appearance area, shape coefficient and so numerical. Energy saving design the second step is to average K value calculation. Get the average K, D value. Finally, it can generate energy saving report and other reports for approval. Whether for public buildings, residential buildings or commercial buildings, if the stipulation index is not satisfied, it must carry on the energy consumption analysis for comprehensive evaluation.

So in the energy consumption analysis preparing in the pre-design stage, interior wall, windows, and doors, the room (including room function setting) should be traced in the layout, for GRD, it would be layout reformed. Energy consumption analysis is then detailed calculated, power consumption index is simply meter calculated.

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6.6 Case studies for I3-GRD

The study mainly focused on the existing commercial buildings with either as-built green retrofit methods or potential green retrofit plan on the design stage. As the introduction mentioned in Chapter 1, the great potential need for green retrofit in China now has big policy support on the 12th and 13th Five-Year Plan. So the collected case studies are mainly from Hong Kong and Shen Zhen, where the leading GRD projects located. The case studies are selected and introduced in section 6.7.5 to 6.7.7.

6.7 Virtual Pre-Coordination in BIM

For supporting commissioning activities such as performance specifications of sustainability, the model information includes performance specification for HVAC and other facility operation equipment. From links between as-built and construction level detail components, the BIM process could be designed to stop mess (Jernigan, 2008). As the BIM models will be acting like a library for owner information and build a database for further design (Jernigan, 2008). When it comes to GRD, some uncoordinated projects may be required from the owner to piece together by the engineer. Using BIM as a tool would benefit the inter-cooperation between the owner-user group and A&E&S group in GRD, especially benefit to merge the gap between architects and engineers in pre-design stage. The different types of model

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information will provide the owner a more intuitive support when monitoring operation(Eastman, 2011).

6.7.1 Index of modelling and DSTs

According to the study of modelling and decision support tools from the Institute for Manufacturing (IfM) in in the University of Cambridge (2012), the classified index of modelling and DSTs are from the following five aspects:

- Information control
- Paradigm and simulation models
- Ways of choosing
- Representation aids
- Processes

Decision support tools have system form as:

- **DDS** Decision Support System is the newest research phase of information system
- **IDSS** Intelligent Decision Support System is the combination of DSS and Artificial Intelligence
- **AI-based IDSS** Artificial Intelligence based IDSS is the combination of artificial intelligence technology and IDSS. Branches are **ES-based IDSS**, which based on the expert system for system analysis and **Agent-based IDSS**, which based on an intelligent agent, multi-agent and agent-oriented for software design.

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Information systems are developed at different levels, longitudinally differentiate from structured, semi-structured, to unstructured; horizontally differentiate from management level as operational control, management control to strategic planning.

6.7.2 Decision Support System (DSS)

Decision support system (DSS), refers to systems which are 'interactive computer-based systems that help people use computer communications, data, documents, knowledge, and models to solve problems and make decisions' (Power, 2007). As early as the 1970s, Scott Morton (1989) first introduced the definition about DSS, as supporting information system to the 'Structured Decision Systems' (SDS).

The characteristics of DDS according to Power are that:

1) They are not automatic.
2) They are designed to facilitate decision processes.
3) They support instead of automating decision-making.
4) They should be able to respond relatively fast enough for the decision-makers to change their needs.

6.7.3 Control Information in DSTs

Control information is defined as an attribute of the relationships between things according to Corning (2001). It contains the capacity of whether the matter or energy in proposed processes. The controlling behaviours include acquisition, disposition, and utilization *per se*.

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In the information theory as early as Shannon mentioned in the book in 1948, the capacity of reducing statistical uncertainty is what information usage about. The essential of the understanding with the roles and dynamics of ‘communication and control’ (which initially called for information control) are lack of definition.

How information is defined and measured in their ‘purposiveness’ and ‘goal-directedness’ is the problem between information and management workflow (Corning, 2001). Another issue to be pointed out in the information theory is that most of the literature is about ‘statistical’ and ‘structural’ information, however, the functional aspects of the information have been ‘ignored or acknowledged passed over by the workers in the information theory’ (Corning, 2001). Information control manages the organization of data and knowledge, contains the gathering and storage and retrieval (IfM, 2012). The information contains in the building retrofitting is more complex than designing a new building. Information from brainstorming, clustering, databases and spreadsheets are supporting the decision makers in the information control.

6.7.4 Information control elements in DSTs

With the Duality Fuction Deployment and Strategic Options Development and Analysis (SODA) and Soft Systems Methodology (SSM), for example in the information control in GRD, elements in the SSM are consider from organization structures, processes, climate, people issues expressed by people and the conflicts, shown as (Shanks, 2000; Shen, 2004).

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- Requirements

For structures in the building retrofitting design, the requirements are mainly managing by supporting systems. The requirement in the I3-GRD framework is

- Processes

The processes of controlling the information are separated into three stages in the whole life cycle of the development of GRD. First one is orientation stage

- Problems

The impact factors with DSTs are complex. There are human and non-human factors effecting variation orders. Human reasons like replacement of materials change in design drawings and contracts, and changes in different needs for the workload. Non-human reasons as weather change, change in government regulations, and change for safety consideration are all effecting in GRD progress.

- People

The people who are related to GRD activities are all the people involved in the project. Usually, they make variation orders in whether design process or onsite construction processes, like owners, consultants, contractors and others.

- Events and considerations

Issues expressed from the people who get involved in a process

For example, for the people involved in the design and construction process in GRD:

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In design: issues may contain with design optimization; Design fault change; Government regulations change; Technology variations of rules; Onsite design change

Onsite: Technology difficulties; Schedule requirements; Poor procurement; No suitable materials or decoration fixed plate

For sales: Competition needs; Owner requirement for scope and orientation; Change in building support(These kinds of changes usually happen at the end of the development).

- Conflicts and Solutions

Arguments can exist between designer and owner about the drawings will lead to variations in design. Unsuitable materials will cause variations onsite. All the reasons mentioned above are all causing conflicts in the whole project. Undesirable function in use will cause conflicts at the maintenance stage.

Table 6.1 Comparison of the roles in green building design and green retrofit design in generic level

Standpoint	**GBD model**	**BIM facilitated GRD model**
Communicative intent **(semiotics)**	To site study and document the information from pre-design, construction, post-design (to extend the project ideas for the realization)	To standardize data structure used for the exchange of building information (to specify data structures for the information exchange)

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Authors **(sender)**	Owner, Architects, & Engineers & Speciality Consultant (A&E&S Group) Contractors	Owner, User Group, A&E&S Group Public bodies, Contractors
Audience **(receiver)**	Energy analyst to study potential financial and environmental values of energy efficiency	The roles in the projects have different professional backgrounds. (Cerovsek, 2011) Vendors of software presenting the process maps, function, and behavior of buildings.
Authoring environment **(encoder)**	Capture software include ImageModeler, Project Photofly, Global Link, Pictometry Online and PKNail Silo energy analysis tools such as Ecotect, Project Vasari, VE-Pro, Energy Plus, DOE2, TRNSYS with design optimization from aspects Building Orientation and Shape, Rational Planning Space and Control Shape Coefficient, Daylighting design etc.	BIM tools software packages with GBS (Green Building Studio), Ecotect, Project Vasari, VE-Pro, Energy Plus, DOE2, TRNSYS these well-developed energy analysis tools. Design-Design (DD) as-design Model, Design-Construction (DC) as-construction Model and Design-Operations (DO) as-built Model are created.
Modeling constructs **(code)**	Calibration process to optimize model and measure parameters to contribute the simulation for providing more accurate estimation of annual cost saving associated with DCV (Demand-controlled Ventilation) (Lawrence, 2007)	High-level ontological constructs parametric 3D elements and components of real-world counterparts. (Cerovsek, 2011)
Modeling result **(message)**	Actual energy conservation results and systems energy performance and	Non-linguistic data structures fo the information states the type

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	economics to individuals' competence (ASHRAE, 2010) in model views, elements, materials	of building elements and the components based on the design platform. (Cerovsek, 2011)
Message formatting **(encoding)**	in the form of gbXML, for the integration of BIM and Building Performance Analysis Software, IFC, ifcXML, ecoXML, IDMxml (Welle, Rogers, & Fischer, 2012)	Native/open model formats: rat, pln, ifc, cis, xml, pdf, for schema exp, owl, xsd (Cerovsek, 2011)

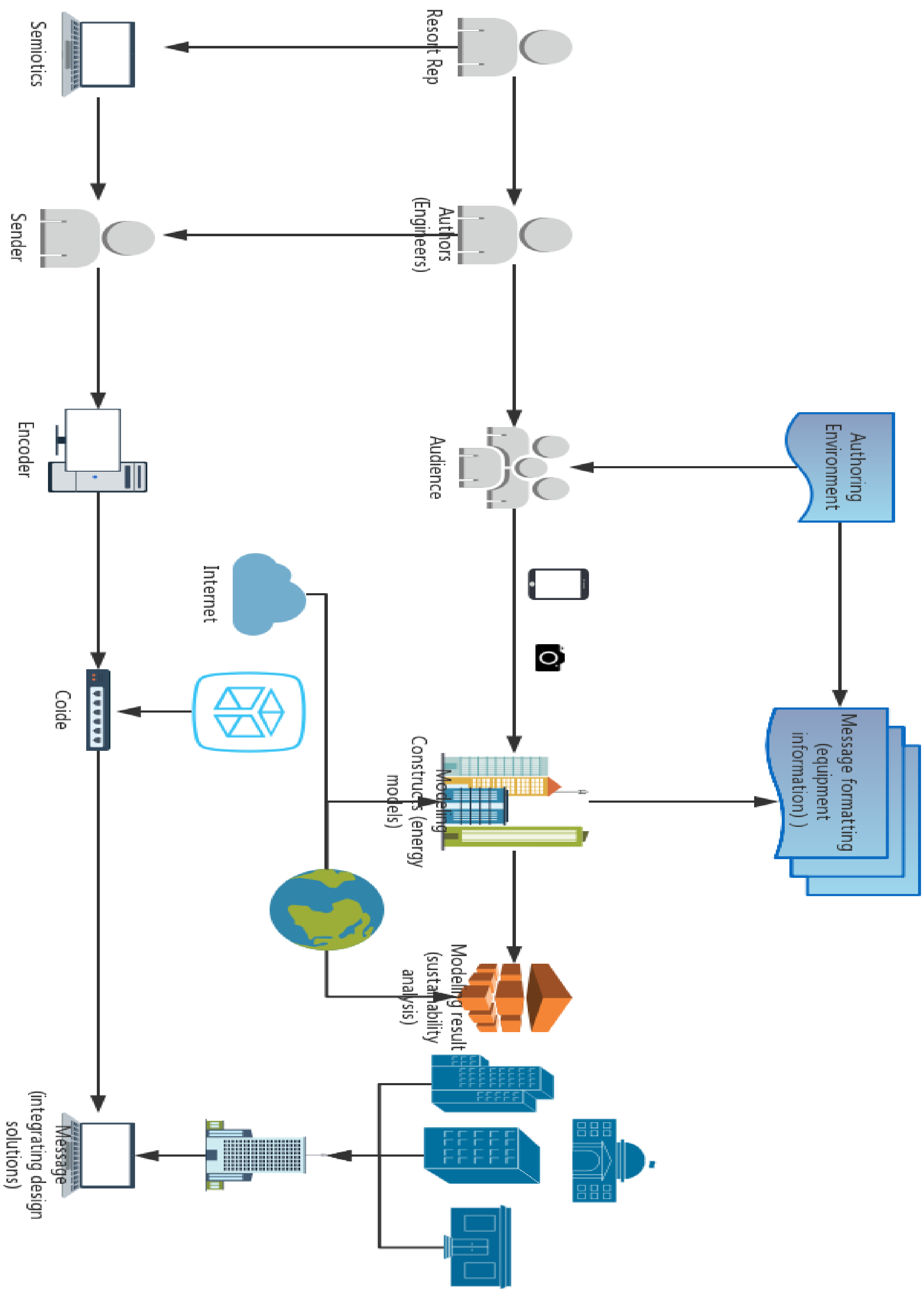

Figure 36 Communicative intent in I3-GRD

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6.7.5 Case 1. Shue Yan University in Hong Kong

During the interview of Dr. John Hui HIREA (Hong Kong Institute of Real Estate Administrators), he mainly introduced the project ‘Hong Kong Shue Yan University (Wanchai Campus)’. As the project is a university dormitory renovation project and contained facade design & interior renovation in 2007, aiming to adopt different functions to the building (contained with green features) and some eye-catching icon for the campus. For the green features Dr. Hui mentioned to the related projects, they could be concluded from the following items:

- Roof insulation

Problems to be solved from water proofing works and spelling concrete and the loading to be calculated for the drain layer.

Also, balance the value for structure change and irrigation cost for the roof load is the main challenge.

- Equipment/ facade renovation

Commercial building renovation contains the air condition, external wall, shading for sunlight (which is found not too efficient) and fire protected door.

- Cassette system change

And from passive/active design perspectives:

PASSIVE: facade design, shading design, orientation design

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ACTIVE: Rainwater collection systems, Greywater systems, HVAC systems and Kitchen waste machine, PV channel for emergency electricity use (lighting in elevator and stairs).

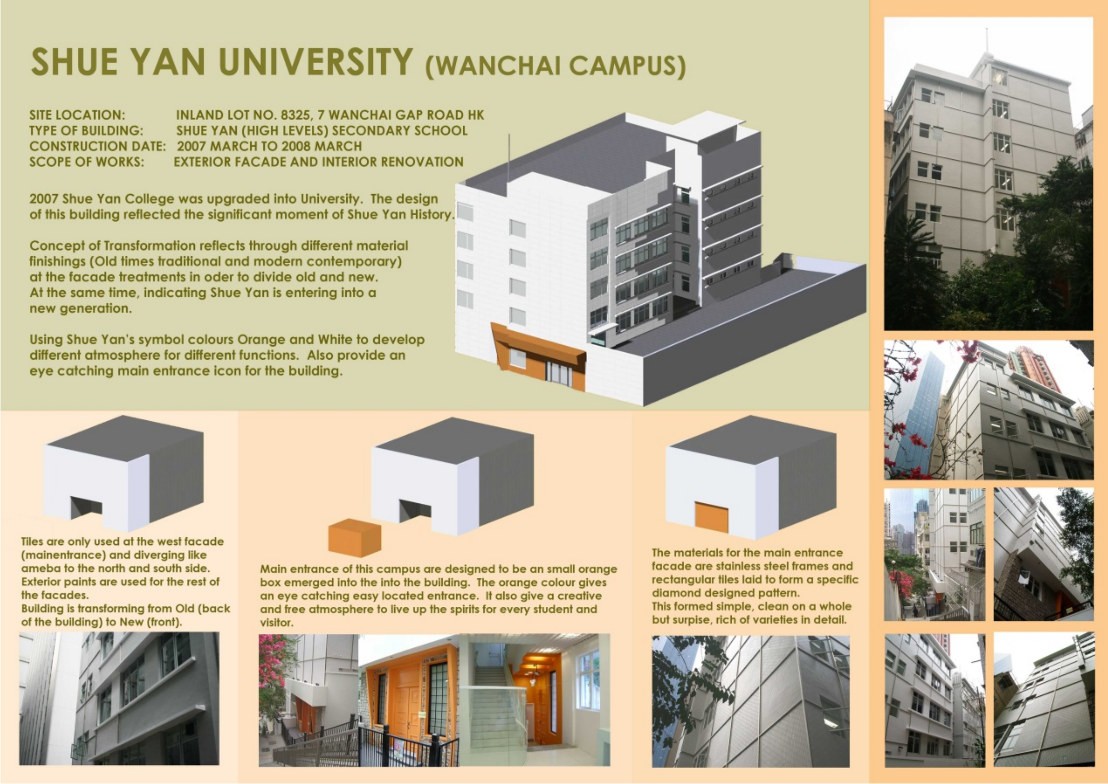

Figure 37 Shue Yan University GRD

The main works from the architectual would all consider from the environmental, economic and social perspectives. The importance of the aspects would be slightly different with items for safety, the maturity of technology and indoor/outdoor environmental design focus. For this project, re-modeling the energy model is not part of the design process. But for the new project for Shue Yan University, an energy model is new-built for the architectural design in the first stage. From this case study, re-modelling in the energy model is separated from building the I3-GRD framework, so during the the next two case studies, technology on this part is paid more attention.

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6.7.6 Case 2. China Resource Building, Hong Kong

China Resources Building is located at Wan Chai North of the Hong Kong Island facing Victoria Harbour. This building was built and started to use in 1983 which was almost thirty years of age when the contract was awarded in April 2009 under a Prime Cost Agreement and Schedules. The works to be carried out under this Main Contract comprise the A&A Works to the existing 39-storey Office Tower set above 5-storey Podium with retail, shops and restaurants facilities and 3-storey basement carpark. The total site area of this building was 3,836 ㎡ and the office area per floor is approx. 2,200 ㎡.

Figure 38 China Resource Building GRD project

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During the interview of the design team, they share their project experience and their opinion on developing energy model for the GRD project of China Resource Building.

- Unlike new projects, there was no typical floor nor the typical sequence of work. The as-fitted or record drawings were unavailable especially on M/E services. This had caused problems, especially during the demolition works. Some power or signal cables and concealed conduits in service will be easily damaged causing sudden suspension of services to the building. To prevent and minimize this kind of incidents, sufficient detection and tracing of the existing services are required well before any demolition or termination works.

- Unlike new projects, the building was under normal operation by the users. Any works which might affect their daily operation or causing inconvenience shall submit sufficient advanced notification and obtain the consent from the Property Management.

- All works should be well planned in advance especially on those works shall cause temporary suspension of the power supply, air conditioning, lift service or generation of nuisances such as smell, dust, and noise. The method statement, the precautionary measures have to be taken into consideration when the work plan is prepared (Detials are attached in Appendix H).

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6.7.7 Case 3. Nan Hai Yi Ku, Shen Zhen, China

The project is located in Shenzhen Nanshan area, with a total site area of 95816 ㎡. The retrofit area is 48000 ㎡. The function is transferred from industrial to office. The developer moved the old factory and decided to green retrofit the building to develop creative industry in Shenzhen.

This project is a typical GRD project to show design from the sustainable triangle. The design not only gets the project a large amount of energy saving and more office space but also reputation rising and glory from the national level.

The function design reflects the ecological model based on the following aspects:

- The respect to the environment

The combination of traditional and modern cultural could be presented in this project as the design is a modern art creative park based on a 1980s factory.

- Nature Fusion

The inside and outside space are connected by the North shared hall and South courtyard. Also, the organizational form could be diverse according to the natural lighting from the space.

- Extension in interior design

The interior design shows the most flexible design in the whole function design as an extension for furniture use etc.

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- Sustainability

To reach the most fundamental purpose, as lowest energy and highest quality, the design needs temperament.

a) One layer is added for service function, as increasing building outlook and office area. (People)

b) The atrium is retrofitting for ecological design to building more lighting and ventilation area. (Planet)

c) Then the outside space is designed to step back shape as building more wind area while at the same time reduce energy consumption. (Profit)

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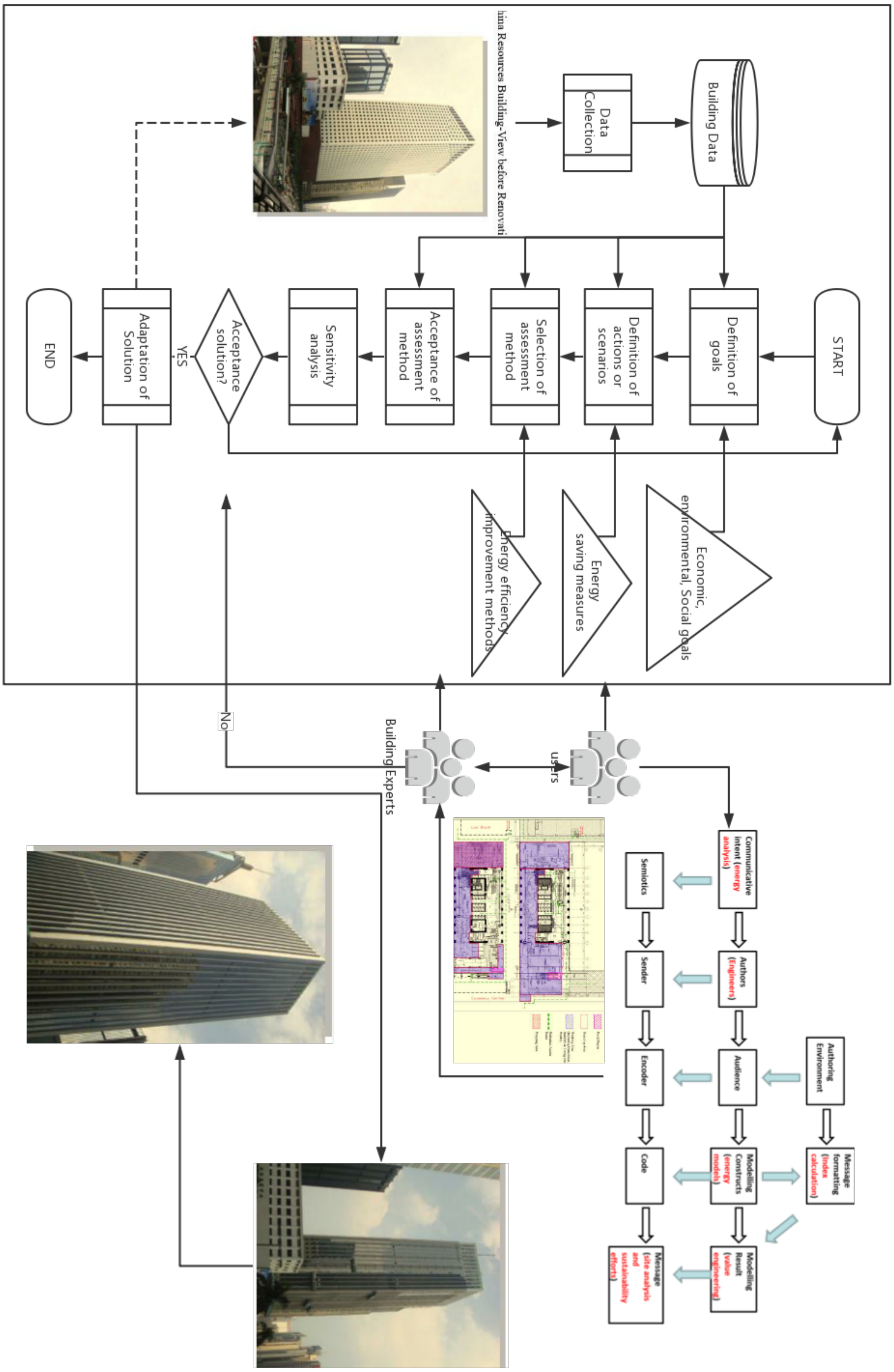

Figure 39 Workflow include in the case studies

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6.8 Summary

Case studies are based on the materials from series of integrated retrofitting solutions for existing buildings and the interviews to China Resource Building in Hong Kong, projects of Electronic Building in Shenzhen and commercial buildings in Beijing.

These projects are chosen as commercial use from a function, retrofit as existing building category and been studied from their changes from reducing, reuse and recycle.

Conjoint analysis based on the web-based interviewing where users could be asked multiple types of questions. The advancements of these hybrid methods could combine data from multiple data sources. New methods which have been proposed these years also contained as following: genetic algorithms for question design, neural networks for improved estimation and support-vector machines for higher-level interactions etc. (Toubia, 2003). For designers, HoQ and QFD are popular design tools in the industry. By integrating conjoint analysis into design tool as a user preference modelling tool, more innovative, utilized and more comparable design decisions would be likely to appear in the industry. The aim of this research is to test the method of conjoint analysis in the green retrofit design which let the Customer Importance becomes component-values.

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Chapter 7 The I3-GRD Framework

7.1 Introduction

This chapter presents the I3-GRD framework. The framework is developed by the study above containing the components identification, factors analysis and workflow development. The framework could be seen as house of Green Retrofit with contents by the above study.

7.2 House of Green Retrofit adopted from House of Quality

In both industrialized countries and developing countries, modification, retrofits, and rebuild of existing buildings are in demand. Existing Green Retrofit Design (GRD) process in the sustainable design industry is constrained by the reliance on various levels of workforce and different layers of information delivery. Especially for the huge energy consuming (over 40 percent for the building sector), buildings shall be sustainably designed from the aspects of energy modelling, renewable energy using, sustainable materials using and water saving. The Green Building (new-build) design is relevantly easier to have stable results in the sustainable assessment. On contrary, the Green Retrofit Design (for existing buildings) process facing more challenges from the existed building service systems and various technologies include methodological, cultural, social and organizational aspects, will lead to more unexpected results in the final results of the energy saving and building performance. This would require an approach conclude different requirements from architect, engineer and client sectors with design aspects, information of design technical

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parameters, green technologies, financial status, construction effects and management factors. HOGR is short for House of Green Retrofit, borrowing the idea from the house of quality, which used for defining the relationship from the perspective of customer/owner desires and the firm/product capabilities. Conjoint-HOGR analysis, which refers a combination of HOQ method with green retrofit design (GRD) process and conjoint analysis, is a quantitative method for analyzing owner requirements in the early stage of retrofitting existing buildings. The improvement of this method is based mainly on improving energy efficiency and reducing carbon emissions and analysis of participants' trade-offs, which will reveal the relative importance of component attributes. Research in GRD has been recognized as valuable by both academic and industry.

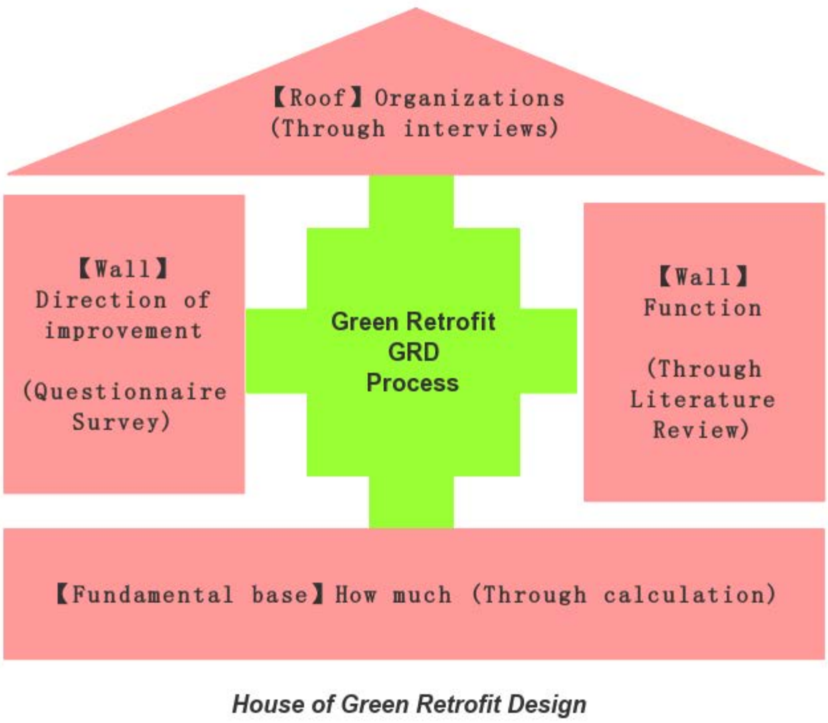

Figure 40 House of GRD adopted from House of Quality

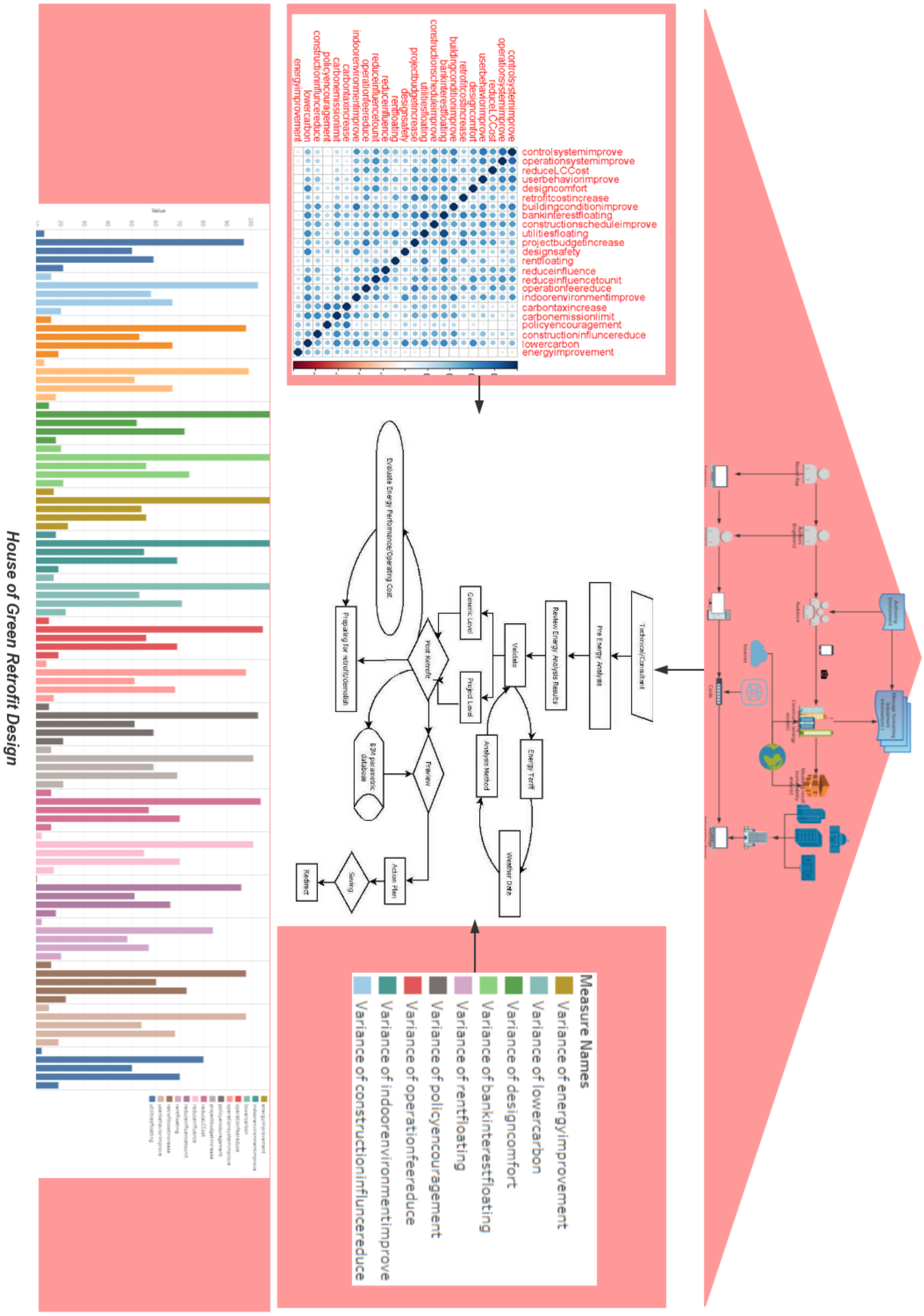

Figure 41 Proposed GRD framework adopted from HoQ

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7.3 Conjoint Analysis

The types of conjoint analysis have developed from creating Full Profile studies to hybrid conjoint techniques, the attributes of the analysis grow from originally 4 or 5 to 30. In the pioneered research of Jordan Louviere, only one choice task was used and became the basis of choice-based conjoint and discrete choice analysis.

The requirements from architects, engineers and facility managers based on the existing literature could be categorized from perspectives including social environmental, economic and technical (Menassa, 2014). The owners then would be making decisions based on the attribute input.

Conjoint design, which refers to describe a product or service area, is regarding some attributes like a television with screen size, screen format, brand, price and so on (Green, 1978). Subsequently, conjoint analysis technique is always desired which may refer to as multi-attribute compositional modelling, discrete choice modelling or stated preference research. These statistical techniques used in market research are to determine how people value different features that make up an individual product or service. When it comes to quantitative analysis in design and testing customer acceptance, social sciences and applied sciences including marketing, product management, and operations research have all implemented the conjoint design with the application.

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7.4 Summary

Based on the case studies by organizing the personnel (such as: owners, architects, environmental consultant, prospective engineers, the end user) and professionals (such as related government workers) in-depth interviews and workshops, the study explores the I3-GRD suitability and potential impact. In the chapters above, the study tries to determine the user requirements and functional specifications, and compares the results with previous studies. Case study is divided into two stages: first part is the survey of project documents and project participants in-depth interviews, and second part is the combination of the subjective and objective data research, trying to reduce the limitations of interview and questionnaire survey. In the end, the conclusion chapter sums up the process steps of green retrofit design with participants and the problems of the workflow in different stages to build up the I3-GRD framework as a whole.

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Chapter 8 Conclusion

8.1 Introduction

This chapter concludes the thesis. The objectives of this research are re-introduced, the main findings are summarised and contributions are presented. At last, future work and research directions are pointed out.

8.2 Review of the research objectives

The value for retrofitting existing buildings as building sustainable environment is both been recognized by the academic and the industry. The complexity of the green retrofit design process is huger than the regular green building design as multiple sectors are concluded in the complex, dynamic, redundant process. During the green retrofit process, macroeconomic considerations are varied from society, economy, environment, and policies from the government.

Microeconomic considerations are with sectors, requirements, design technical parameters, green technologies, financial status, construction effects, use and management factors. Many cases of green retrofit design exist and develop through the economic cycle. The literature review is based on these cases of green retrofit design. Process analysis took the main line of vertical and horizontal combination research train of thought. This suggests an efficient tool for management in between the stages. The research process provides new research ideas and methods. Intelligent agent technology, initiative, cooperative, good ability of learning and education etc.

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would come along with the development of environment with decision support system.

Establishment of GRD process model gives a quantitative and mathematical explanation of evolution process of I3-GRD. It is a support system to qualitative analysis. The research method of the literature review is also applied in this part to extract useful information from specification literature. It is established mainly based on previous literature and the current situation in projects in both Hong Kong and China Mainland. Therefore, a theoretical hypothesis is derived from a good and comprehensive understanding of relative theories.

For the variables for behavior in construction, considerations for energy consumption would mainly for technology and delivery, methods could be concluded from the sections above. For example, designate senior management roles and managing the organizations that offer minimized risks. Feedbacks from the revise and report from energy modelling and facility management would benefit the retrofit projects in the long run and be studied for the future. Relative studies are widely used to simulate and solve design, decision making, coordination, and knowledge accumulation, and other fields (Ren & Anumba, 2003; Anumba, 2008; Fan & Shen, 2008).

The research aims and objectives are realized from the following aspects:

(1) Objective 1. To define the input and output components in the conceptual I3-GRD framework through a critical review to reflect ‘Innovative’ in I3-GRD.

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This study is based on previous process-based GRD, complete a comprehensive literature review based on the GRD process.

(2) Objective 2. To identify critical factors in I3-GRD framework by integrating standards and survey to reflect ‘Integrated’ in I3-GRD.

For designers, HoQ and QFD are popular design tools in the industry. So by integrating these research methods into the I3-GRD framework as a user preference modelling tool, more innovative, utilized and more valid design decisions would be likely to appear in the industry and let the different sectors have visualization about the design condition. This research has tested the method in the green retrofit design which let the Customer Importance becomes component-values, which also reflects ‘innovative’ in this research design.

(3) Objective 3. To develop the I3-GRD framework to reflect ‘Intelligent’ in I3-GRD.

Support the GRD of information and knowledge in decision support system. Intelligent agent system is to address the more participants, more factors, and constraints, and the structural problems in decision-making is a powerful tool. The study provides methodology and tools in this field with quantitive research in the affecting factors. After this point reflects the I3-GRD in two 'I' (intelligent and innovative).

This research form the conceptual model for I3-GRD. Workflow has different characteristics of this project in the GRD (more than its core regarding process automation), process, influencing factors and constraints, the evaluation standards and

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methods of the participants and the problems facing the research based on the workflow process model was constructed. It contains two organic components: workflow process model and design content template. The former reflects the GRD of a dynamic process, namely the process and steps of GRD, participants and participate in content. The connotation of the participants to determine information needs to design provides a universal, professional, and accord with the characteristics of project contents. The organic combination of these two aspects reflects the I3(intelligent, integrated and innovative) in the first part of GRD.

8.3 Contributions

Many considerations are involved when retrofitting an existing project. The impacts on the environment and human society will be huge for the building sector consumes over 60% of the whole energy production. Managing energy saving does not only rely on equipment control; behaviors and motivations regarding retrofit design are all been considered. Contributions of this research on developing I3-GRD framework are described from the follow aspects:

Firstly, the research study the paths toward GRD by implementing different aspects of considerations into the design process. GRD, especially for commercial buildings, is differentiated from normal new green building design and retrofit design. The complex and dynamic process is influenced by society, economics, environment, engineering, and the requirements of owners and users. Some of the influencing factors are difficult to measure quantitatively or to observe. Considerations and

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motivations for retrofitting buildings from commercial and other perspectives, including workflow design from the generic level to the project level, would suggest possible solutions to practical problems in the real world.

Secondly, when owners or designers, get limited related information in decision making at the early stages, this research outcome related with GRD conditions, influencing factors, and design processes would be a practical tool for improving the efficiency of GRD and the promotion of GRD in the future.

Thirdly, the study examined the major design process framework and their possible applications in GRD through the optimization and analysis of previous studies in the design process field.

8.4 Limitations of this research

The current progress in this research is mainly developed based on the literature review, case studies, interviews and questionnaire survey. Green retrofit is a very broad topic. It is important to refine and narrow a tentative topic down from a specific angle. During the green retrofit process, macroeconomic considerations vary from society, economy, environment, and policies from the government. Microeconomic considerations are sectors, purposes, and requirements, design technical parameters, green technologies, financial status, construction effects, use and management factors.

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With respect to this research, the integral research methodology, and research process have been formed. However, due to the limited case studies and respondence rate on case studies, this research is still limited in the scale of data.

8.5 Future work

In summary, this study is to explore the questions in the construction industry for retrofitting existing building, using systematic, scientific and feasible research methods for complex problems. The results made contribution to both the industry and academic fields.

While improving the building facade and environmental design, GRD is an inspection for multiple quality and multiple layers of knowledge. Quality is included in the sustainable triangle with pursuing concept, technical and aesthetic targets. Multiple layers of knowledge require the team to have all the architectural, environmental, social, economic and historical information to have the integrated design.

At present, the world within the scope of the study of GRD is still in its infancy. GRD not only involves the engineering factors, including business, social, environmental, economic, the owner and occupants' needs, and various aspects of factors. So for GRD research to surpass the traditional mode of engineering is only considered to accomplish specific engineering design process. However, commercial buildings purpose for GRD are relatively few, which makes the research results greatly limited. In the future, expanding the scale for research objectives would be valuable.

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Appendices

Appendix A: Operation management code according to GB/T50378-2006

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General items in 3 Star Label Standard (43 in total)											
Outdoor Environment		Energy Saving		Water Saving		Material Saving		Indoor Environment		Operation Management	
6 items		10 items		6 items		8 items		6 items		7 items	
5.1.6	Outdoor noise comply with standard <Urban Environment Noise Standard> GB 3096	5.2.6	Layout design is conducive to the winter sunshine and to avoid leading direction of the wind in winter, natural ventilation for summer	5.3.6	Through technical and economic comparison, reasonable water saving, processing, and utilization plan.	5.4.3	The construction site within 500 km production of building materials building materials weight more than 60% of the total weight.	5.5.7	Architectural design and structural design measures to promote natural ventilation.	5.6.4	Good quality of construction earthwork and road facilities in use in the process of operation.
5.1.7	Outdoor pedestrian wind speed less than 5m/s with	5.2.7	Window outside the area of not less than 30% of the total area, building curtain wall can be opened with part or with a ventilation device.	5.3.7	Greening, landscaping, car wash water use unconventional water resources.	5.4.4	Using ready-mixed concrete cast-in-place concrete.	5.5.8	Indoor use convenient adjustment can improve the comfort of the air terminal.	5.6.5	ISO14001 environment management registered

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5.1.8	Green roof and vertical green solution	5.2.8	Building outside the window of the air tightness is not lower than the current national standard "building outside the window airtight performance classification and its test method of GB 7107 4th level requirements.	5.3.8	Afforestation irrigation sprinkler irrigation and microspray irrigation water-saving high-efficiency irrigation ways.	5.4.5	Reasonable structures using high-performance concrete, high strength steel.	5.5.9	The hotel class component sound insulation performance of building a surrounding structure to meet the current national standard specifications for the design of civil construction noise GBJ grade one in 118.	5.6.6	Equipment, pipes, set up to facilitate maintenance, renovation, and replacement.
5.1.9	Greening species suit local climate and soil condition of local plants and adopt stratified greening including shrub.	5.2.9	Reasonable use of cold storage heats storage technology.	5.3.9	The drinking water using reclaimed water, the use of concentrated near recycled water reclaimed water; Or by technical and economic comparison,	5.4.6	And land clearing of the demolition of the building construction, old building when the classification of solid waste treatment, and the recycled material, can be recycled material	5.5.10	The reasonable arrangement of building plane layout and space function, reduce noise interference and adjacent space outside noise effect on the interior.	5.6.7	Follow the national standard for air conditioning and ventilation system air conditioning ventilation system cleaning standard GB 19210 rules for regular inspection and cleaning.

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					reasonable choose other renewable water resources and water treatment technology.		recycling and reuse.				
5.1.10	Reasonable traffic organization, distance to public transportation less than 500m.	5.2.10	Fresh air to make use of exhaust air preheating or precooling process, reduce the new wind load.	5.3.10	Set up according to the use of water metering meter.	5.4.7	In the architectural design to consider when select material the use of materials can be recycled use performance. In ensuring safety and without environmental pollution, can use recycle material weight accounts for more than 10% of total weight used building	5.5.11	Office, the hotel building coefficient of more than 75% of the main functional space indoor daylighting to meet the current national standard "architectural lighting design standard" GB 50033 requirements.	5.6.8	Building intelligent systems for functional information network system.

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							materials.				
5.1.11	Reasonable underground space development.	5.2.11	Air conditioning system to achieve the new wind running and adjustable air measures.	5.3.11	Office buildings, shopping malls such architecture, unconventional water utilization is not lower than 20%, the hotel building of no less than 15%.	5.4.8	Integration of construction and decoration engineering design and construction does not destroy and demolition of the existing building structures and facilities, avoid duplication of decoration.	5.5.12	Building entrance and main activity space barrier-free facilities.	5.6.9	Building ventilation, air conditioning and lighting equipment such as automatic monitoring and control system technology for efficient operation.
		5.2.12	Buildings are in a part of the cold and hot load and use only part of			5.4.9	Adopt flexible partition, office, shopping malls class interior			5.6.10	Office, shopping malls with classified building electricity, cold heat metering systems.

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			the space, to take effective measures to save energy consumption in HAVC systems.				construction to reduce to decorate material waste and waste.				
		5.2.13	Adopt energy saving equipment and systems. Fan ventilation air conditioning system of unit volume power consumption and transmission of hot and cold water system can effect comparing with existing national standards "public building energy efficiency design standards" GB 50189 the first			5.4.10	On the premise of guarantee performance, using waste as raw material to produce building materials, its dosage accounted for no less than 30% of the same kind of building materials.				

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			5.3.26, 5.3.27 regulation.								
		5.2.14	Use of waste heat and waste heat utilization in architectural provide required for steam or hot water.								
		5.2.15	Reconstruction and expansion of public buildings, cold and heat source, pipeline system and lighting energy consumption of each part with sub-metering.								

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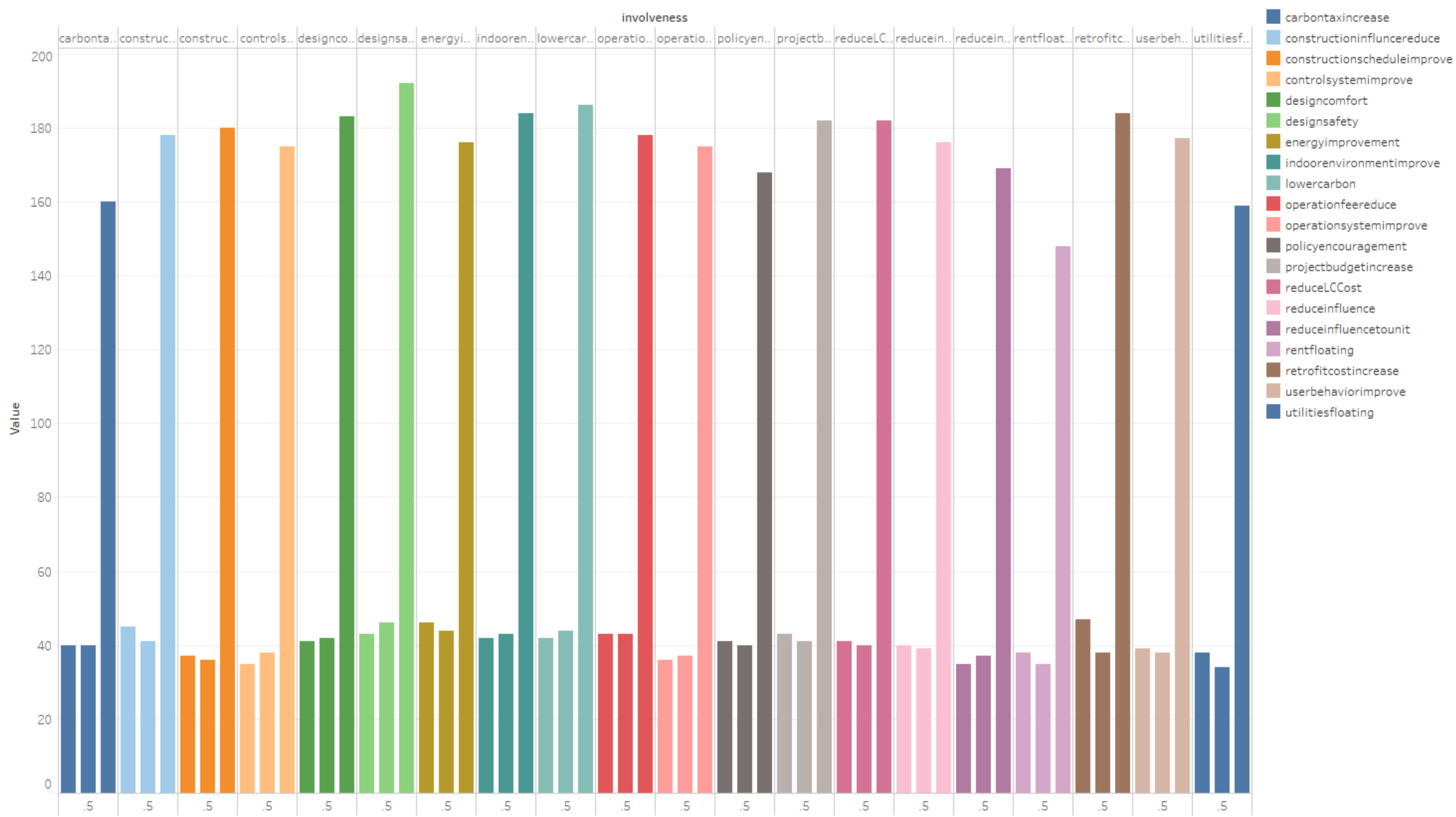
Appendix B: Variance results of the factor analysis using ANOVA test

Sheet 2



Carbontaxincrease, constructioninfluncereduce, constructionscheduleimprove, controlsystemimprove, designcomfort, designsafety, energyimprovement, indoorenvironmentimprove, lowercarbon, operationfeereduce, operationsystemimprove, policyencouragement, projectbudgetincrease, reduceLCCost, reduceinfluence, reduceinfluencetounit, rentfloating, retrofitcostincrease, userbehaviorimprove and utilitiesfloating for each involveness. Color shows details about carbontaxincrease, constructioninfluncereduce, constructionscheduleimprove, controlsystemimprove, designcomfort, designsafety, energyimprovement, indoorenvironmentimprove, lowercarbon, operationfeereduce, operationsystemimprove, policyencouragement, projectbudgetincrease, reduceLCCost, reduceinfluence, reduceinfluencetounit, rentfloating, retrofitcostincrease, userbehaviorimprove and utilitiesfloating.

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Appendix C: ANOVA test result from experience group

		Sum of Squares	df	Mean Square	F	Sig.
energyimprovement	Between Groups	5.85	3	1.95	3.79	.015
	Within Groups	28.29	55	.51		
	Total	34.14	58			
lowercarbon	Between Groups	3.79	3	1.26	2.56	.064
	Within Groups	27.09	55	.49		
	Total	30.88	58			
reduceLCCost	Between Groups	9.74	3	3.25	9.29	.000
	Within Groups	19.21	55	.35		
	Total	28.95	58			
designcomfort	Between Groups	7.55	3	2.52	5.01	.004
	Within Groups	27.64	55	.50		
	Total	35.19	58			
designsafety	Between Groups	5.29	3	1.76	3.86	.014
	Within Groups	25.12	55	.46		
	Total	30.41	58			
reduceinfluence	Between Groups	8.67	3	2.89	5.39	.003
	Within Groups	29.49	55	.54		
	Total	38.17	58			
reduceinfluencetounit	Between Groups	5.31	3	1.77	2.93	.042
	Within Groups	33.26	55	.60		
	Total	38.58	58			
bankinterestfloating	Between Groups	23.18	3	7.73	8.89	.000
	Within Groups	47.77	55	.87		
	Total	70.95	58			
utilitiesfloating	Between Groups	20.26	3	6.75	7.32	.000
	Within Groups	49.83	54	.92		
	Total	70.09	57			
rentfloating	Between Groups	4.86	3	1.62	3.75	.016
	Within Groups	23.78	55	.43		
	Total	28.64	58			

		Sum of Squares	df	Mean Square	F	Sig.
carbonemissionlimit	Between Groups	4.45	3	1.48	2.38	.079
	Within Groups	34.23	55	.62		
	Total	38.68	58			
policyencouragement	Between Groups	.31	3	.10	.29	.830
	Within Groups	19.62	55	.36		
	Total	19.93	58			
carbontaxincrease	Between Groups	1.09	3	.36	.75	.527
	Within Groups	26.54	55	.48		
	Total	27.63	58			
projectbudgetincrease	Between Groups	6.39	3	2.13	5.26	.003
	Within Groups	22.28	55	.41		
	Total	28.68	58			
operationfeereduce	Between Groups	4.00	3	1.33	2.44	.074
	Within Groups	30.13	55	.55		

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		Sum of Squares	df	Mean Square	F	Sig.
	Total	34.14	58			
retrofitcostincrease	Between Groups	13.48	3	4.49	10.03	.000
	Within Groups	24.63	55	.45		
	Total	38.10	58			
buildingconditionimprove	Between Groups	4.20	3	1.40	3.42	.023
	Within Groups	22.48	55	.41		
	Total	26.68	58			
indoorenvironmentimprove	Between Groups	3.09	3	1.03	2.35	.082
	Within Groups	24.09	55	.44		
	Total	27.19	58			
userbehaviorimprove	Between Groups	6.01	3	2.00	3.35	.025
	Within Groups	32.84	55	.60		
	Total	38.85	58			
controlsystemimprove	Between Groups	5.09	3	1.70	2.60	.061
	Within Groups	35.89	55	.65		
	Total	40.98	58			

		Sum of Squares	df	Mean Square	F	Sig.
operationsystemimprove	Between Groups	7.46	3	2.49	3.97	.012
	Within Groups	34.47	55	.63		
	Total	41.93	58			
constructionscheduleimprove	Between Groups	4.91	3	1.64	2.50	.069
	Within Groups	36.07	55	.66		
	Total	40.98	58			
constructioninfluncereduce	Between Groups	3.63	3	1.21	1.67	.184
	Within Groups	39.93	55	.73		
	Total	43.56	58			

Appendix D: ANOVA test result from designer/non-designer

		Sum of Squares	df	Mean Square	F	Sig.
energyimprovement	Between Groups	.67	2	.33	.55	.577
	Within Groups	36.22	60	.60		
	Total	36.89	62			
lowercarbon	Between Groups	2.72	2	1.36	2.82	.068
	Within Groups	28.93	60	.48		
	Total	31.65	62			
reduceLCCost	Between Groups	6.21	2	3.10	7.49	.001
	Within Groups	24.87	60	.41		
	Total	31.08	62			
designcomfort	Between Groups	3.74	2	1.87	3.39	.040
	Within Groups	33.15	60	.55		
	Total	36.89	62			
designsafety	Between Groups	2.70	2	1.35	2.80	.069
	Within Groups	28.95	60	.48		
	Total	31.65	62			
reduceinfluence	Between Groups	.75	2	.38	.51	.602
	Within Groups	44.10	60	.74		
	Total	44.86	62			
reduceinfluencetounit	Between Groups	6.32	2	3.16	4.24	.019

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	Within Groups	44.76	60	.75		
	Total	51.08	62			
bankinterestfloating	Between Groups	5.24	2	2.62	2.04	.139
	Within Groups	77.17	60	1.29		
	Total	82.41	62			
utilitiesfloating	Between Groups	10.79	2	5.40	4.71	.013
	Within Groups	67.55	59	1.14		
	Total	78.34	61			
rentfloating	Between Groups	.51	2	.26	.44	.648
	Within Groups	35.23	60	.59		
	Total	35.75	62			

		Sum of Squares	df	Mean Square	F	Sig.
carbonemissionlimit	Between Groups	1.08	2	.54	.83	.442
	Within Groups	39.24	60	.65		
	Total	40.32	62			
policyencouragement	Between Groups	.13	2	.06	.17	.843
	Within Groups	22.73	60	.38		
	Total	22.86	62			
carbontaxincrease	Between Groups	.06	2	.03	.06	.944
	Within Groups	31.65	60	.53		
	Total	31.71	62			
projectbudgetincrease	Between Groups	4.78	2	2.39	5.95	.004
	Within Groups	24.10	60	.40		
	Total	28.89	62			
operationfeereduce	Between Groups	2.87	2	1.43	2.47	.093
	Within Groups	34.84	60	.58		
	Total	37.71	62			
retrofitcostincrease	Between Groups	2.49	2	1.25	1.97	.148
	Within Groups	37.92	60	.63		
	Total	40.41	62			
buildingconditionimprove	Between Groups	3.37	2	1.68	4.20	.020
	Within Groups	24.06	60	.40		
	Total	27.43	62			
indoorenvironmentimprove	Between Groups	6.37	2	3.18	8.67	.000
	Within Groups	22.04	60	.37		
	Total	28.41	62			
userbehaviorimprove	Between Groups	8.09	2	4.05	7.17	.002
	Within Groups	33.84	60	.56		
	Total	41.94	62			
controlsystemimprove	Between Groups	6.86	2	3.43	5.58	.006
	Within Groups	36.89	60	.61		
	Total	43.75	62			

		Sum of Squares	df	Mean Square	F	Sig.
operationsystemimprove	Between Groups	8.03	2	4.01	6.39	.003
	Within Groups	37.72	60	.63		
	Total	45.75	62			
constructionscheduleimprove	Between Groups	4.65	2	2.32	3.64	.032
	Within Groups	38.34	60	.64		
	Total	42.98	62			
constructioninfluncereduce	Between Groups	1.78	2	.89	1.16	.320
	Within Groups	45.94	60	.77		
	Total	47.71	62			

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Appendix E: ANOVA test result from involvement group

		Sum of Squares	df	Mean Square	F	Sig.
energyimprovement	Between Groups	2.46	2	1.23	2.14	.126
	Within Groups	34.43	60	.57		
	Total	36.89	62			
lowercarbon	Between Groups	.21	2	.10	.20	.820
	Within Groups	31.44	60	.52		
	Total	31.65	62			
reduceLCCost	Between Groups	.50	2	.25	.50	.612
	Within Groups	30.57	60	.51		
	Total	31.08	62			
designcomfort	Between Groups	.20	2	.10	.17	.848
	Within Groups	36.69	60	.61		
	Total	36.89	62			
designsafety	Between Groups	.45	2	.23	.44	.649
	Within Groups	31.20	60	.52		
	Total	31.65	62			
reduceinfluence	Between Groups	.33	2	.16	.22	.802
	Within Groups	44.53	60	.74		
	Total	44.86	62			
reduceinfluencetounit	Between Groups	1.69	2	.84	1.03	.365
	Within Groups	49.39	60	.82		
	Total	51.08	62			
bankinterestfloating	Between Groups	.03	2	.01	.01	.990
	Within Groups	82.39	60	1.37		
	Total	82.41	62			
utilitiesfloating	Between Groups	1.27	2	.63	.49	.618
	Within Groups	77.07	59	1.31		
	Total	78.34	61			
rentfloating	Between Groups	1.04	2	.52	.90	.412
	Within Groups	34.70	60	.58		
	Total	35.75	62			

		Sum of Squares	df	Mean Square	F	Sig.
carbonemissionlimit	Between Groups	.54	2	.27	.41	.666
	Within Groups	39.77	60	.66		
	Total	40.32	62			
policyencouragement	Between Groups	.33	2	.16	.44	.647
	Within Groups	22.53	60	.38		
	Total	22.86	62			
carbontaxincrease	Between Groups	1.06	2	.53	1.04	.360
	Within Groups	30.65	60	.51		
	Total	31.71	62			
projectbudgetincrease	Between Groups	.21	2	.11	.22	.800
	Within Groups	28.67	60	.48		

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		Sum of Squares	df	Mean Square	F	Sig.
	Total	28.89	62			
operationfeereduce	Between Groups	.35	2	.18	.28	.755
	Within Groups	37.36	60	.62		
	Total	37.71	62			
retrofitcostincrease	Between Groups	4.06	2	2.03	3.35	.042
	Within Groups	36.35	60	.61		
	Total	40.41	62			
buildingconditionimprove	Between Groups	.76	2	.38	.85	.431
	Within Groups	26.67	60	.44		
	Total	27.43	62			
indoorenvironmentimprove	Between Groups	.06	2	.03	.07	.937
	Within Groups	28.35	60	.47		
	Total	28.41	62			
userbehaviorimprove	Between Groups	1.02	2	.51	.75	.478
	Within Groups	40.92	60	.68		
	Total	41.94	62			
controlsystemimprove	Between Groups	2.86	2	1.43	2.09	.132
	Within Groups	40.89	60	.68		
	Total	43.75	62			

		Sum of Squares	df	Mean Square	F	Sig.
operationsystemimprove	Between Groups	2.46	2	1.23	1.70	.191
	Within Groups	43.29	60	.72		
	Total	45.75	62			
constructionscheduleimprove	Between Groups	3.97	2	1.99	3.05	.055
	Within Groups	39.01	60	.65		
	Total	42.98	62			
constructioninfluncereduce	Between Groups	1.15	2	.58	.74	.481
	Within Groups	46.56	60	.78		
	Total	47.71	62			

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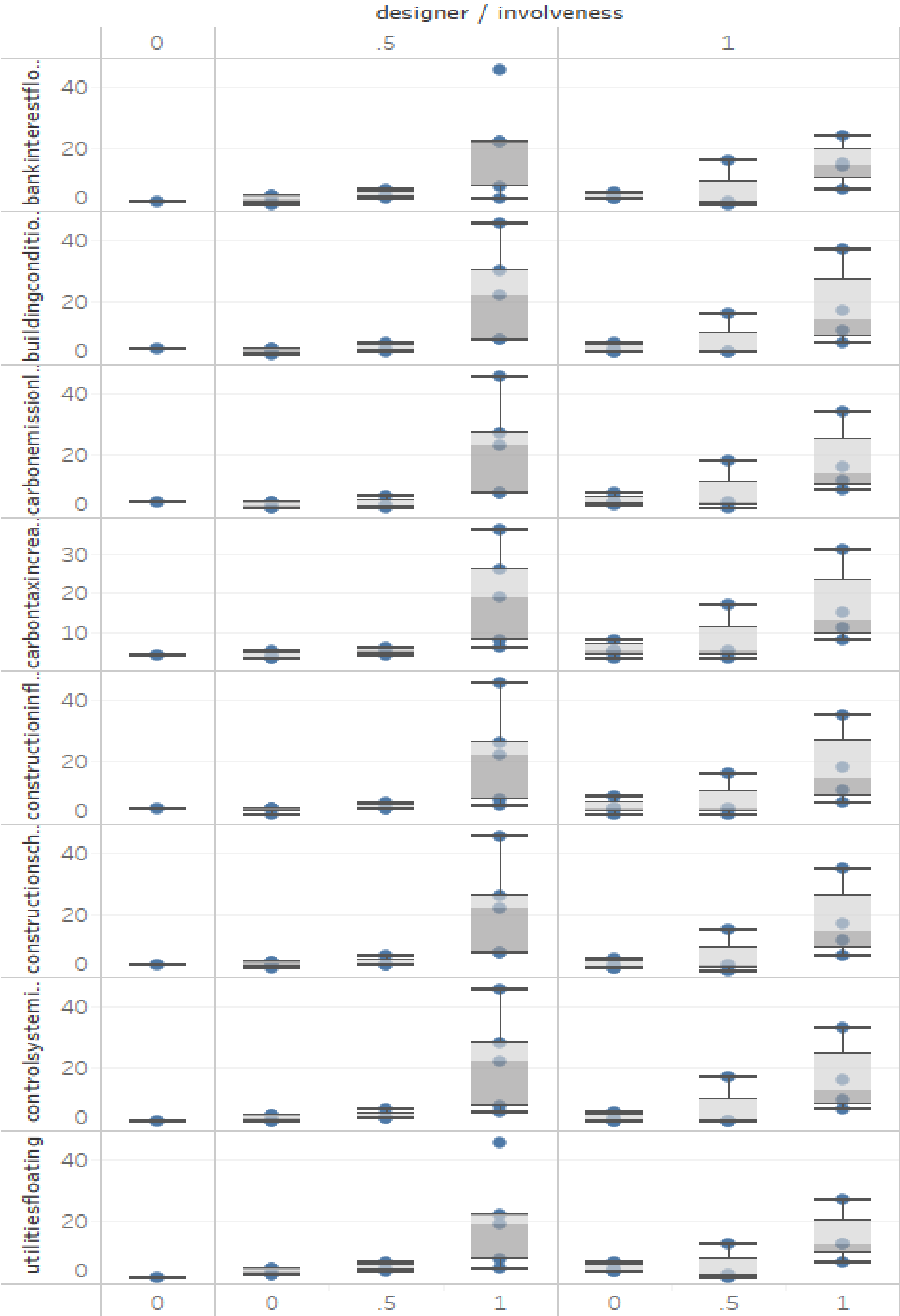
Appendix F: ANOVA test result between designer and involvement group



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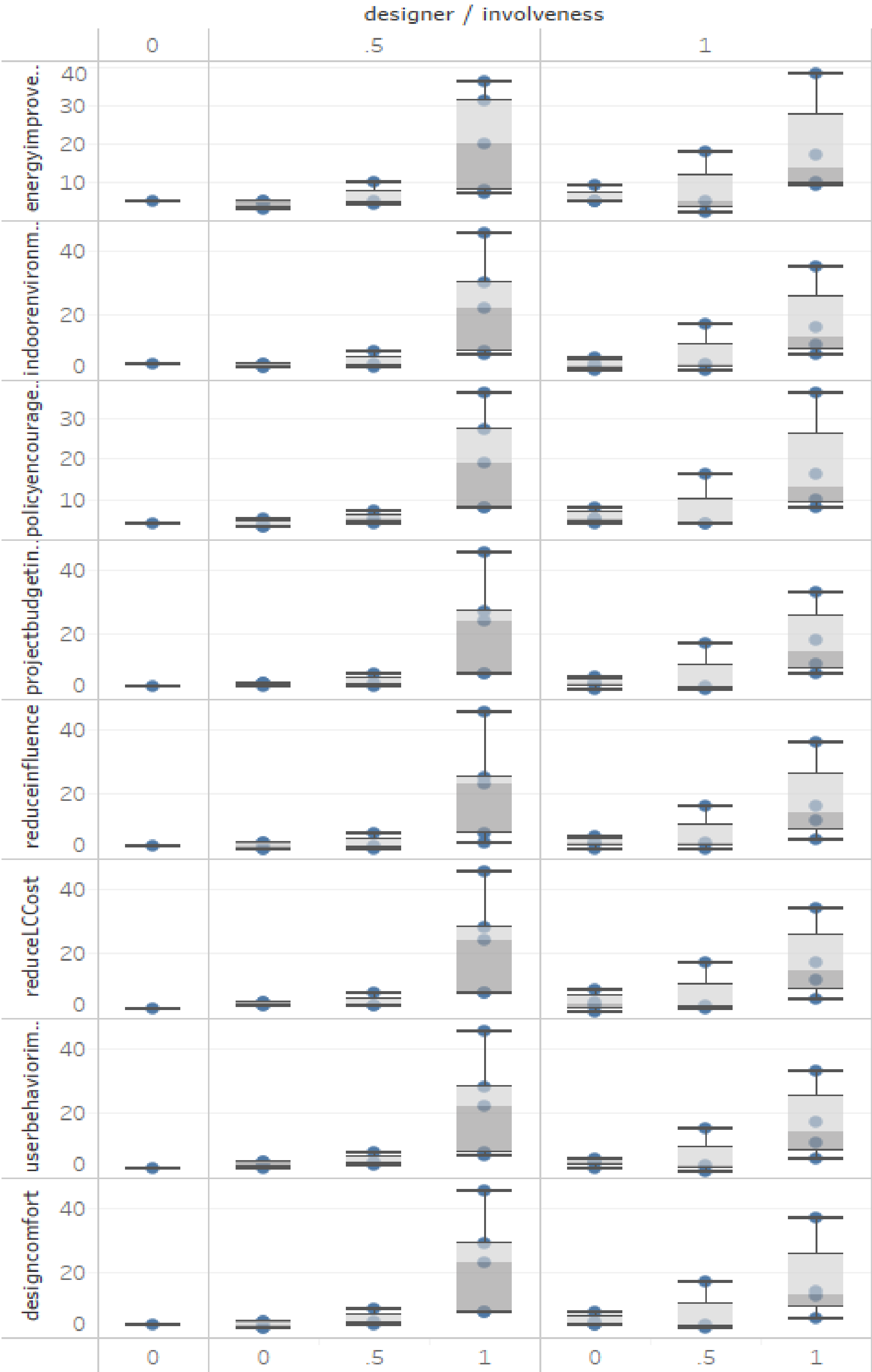
designer / involveness
0
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energyimprove..
indoorenvironm..
policyencourage..
projectbudgetin..
reduceinfluence
reduceLCCost
userbehaviorim..
designcomfort
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10
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1

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Appendix G: Sample of questionnaire survey

课题调研问卷

尊敬的受访者：

北京建筑大学经济与管理学院郭立教授牵头与香港理工大学建筑与房地产学联合对“建筑绿色改造设计方案评价标准、考虑因素重要性及工程内容与环节”等内容进行调研。“绿色改造”是指：对既有建筑进行节能、低碳、室内环境改善等改造，涵盖建筑结构、外墙、设备（空调、照明、暖通、给排水等）、材料、能源系统、自动控制等方面。如果**1）您曾参与过以绿色改造为主的建筑改造项目；2）您曾参与过以改善建筑使用功能为主兼顾绿色的改造项目；3）您虽没有直接参与绿色改造项目但对绿色改造有自己观点**，敬请帮助我们填写问卷，非常感谢！

一、背景资料

1.您在曾经参与过的项目中主要角色为：（请勾选“☑”）

☐**业主方/楼宇所有者**（指项目负责人或者参与项目全过程的业主方相关人员）

☐**设计者**（包括前期评估，能源评价，改造方案设计，施工图设计等咨询机构）

☐**租户/楼宇居住者**

☐**其他**，请注明：______________________________

2. 您从业时间为（请业主方或设计者填写）：（请勾选“☑”）

☐0~5 年 ☐6~10 年 ☐10~20 年 ☐ 20 年以上

3. 若您参与过绿色改造项目，则建筑类型为（可多选）：（请勾选“☑”）

☐住宅 ☐ 办公楼 ☐ 商场 ☐酒店 ☐ 综合型（如酒店、商场综合建筑）

☐ 其他公共建筑（如博物馆，医院，学校等）

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二、调研内容

1.您认为在评价设计方案时以下指标的重要程度：（请勾选“☑”）

设计方案评价指标	1-不需考虑 2-不重要 3-一般 4-重要 5-非常重要				
	1	2	3	4	5
经济评价					
1)初期投资成本	□	□	□	□	□
2)运营成本及维修成本	□	□	□	□	□
3)项目收益（包括改造带来的使用年限增长，租金上涨，能源费用节约等）	□	□	□	□	□
4)改造工程持续时间	□	□	□	□	□
社会及人文评价					
5)改造期间对楼宇居住者的影响（如施工期间的停水、停电、噪音、围壁等影响正常运营和居住）	□	□	□	□	□
6)居住者满意度提升	□	□	□	□	□
7)楼宇外观及使用功能提升	□	□	□	□	□
8)社会影响及名誉声望的提升	□	□	□	□	□
技术评价					
9)先进性（是否使用新技术）	□	□	□	□	□
10)成熟性（是否有较多使用案例）	□	□	□	□	□
11)易用性及易维护性	□	□	□	□	□
环境评价					
12)节约能源及减少碳排放（节约电、水、气、煤、建筑材料等）	□	□	□	□	□
13)室内环境改善（含室内空气、照明、噪音等）	□	□	□	□	□
14)室外环境改善（含建筑外观，绿化等）	□	□	□	□	□
15)垃圾、废水等回收处理	□	□	□	□	□

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设计方案评价指标	1-不需考虑 2-不重要 3-一般 4-重要 5-非常重要				
	1	2	3	4	5
其他您认为需要补充的					
16)请补充：________________	☐	☐	☐	☐	☐
17)请补充：________________	☐	☐	☐	☐	☐

2. 您认为在项目全过程中考虑的主要因素为：

改造考虑的主要因素	1-不需考虑 2-不重要 3-一般 4-重要 5-非常重要				
	1	2	3	4	5
从您角度认为参与改造的需求和要求					
1)提高节能率	☐	☐	☐	☐	☐
2)降低碳排放	☐	☐	☐	☐	☐
3)减少全生命周期管理费用	☐	☐	☐	☐	☐
4)增加设计舒适性	☐	☐	☐	☐	☐
5)加强设计安全性	☐	☐	☐	☐	☐
社会环境因素					
6)减小对周边小区的影响	☐	☐	☐	☐	☐
7)减小对产权单位和供热单位的影响	☐	☐	☐	☐	☐
8) 减小碳排放量	☐	☐	☐	☐	☐
经济因素					
9)银行利息浮动	☐	☐	☐	☐	☐
10)水电气费浮动	☐	☐	☐	☐	☐
11)房屋租金的整体浮动	☐	☐	☐	☐	☐
政策因素					
12)排放标准限制	☐	☐	☐	☐	☐

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改造考虑的主要因素	1-不需考虑 2-不重要 3-一般 4-重要 5-非常重要				
	1	2	3	4	5
13)政府的激励措施的增加	☐	☐	☐	☐	☐
14)碳排放税的增加	☐	☐	☐	☐	☐
成本因素					
15)工程预算量的提高	☐	☐	☐	☐	☐
16)运行费用的降低	☐	☐	☐	☐	☐
17) 改造技术的费用的增加	☐	☐	☐	☐	☐
房屋使用与运行状况					
18)现有建筑状态的改善	☐	☐	☐	☐	☐
19)室内环境质量的改善	☐	☐	☐	☐	☐
20)维持用户的使用习惯的改善（如电梯,照明）	☐	☐	☐	☐	☐
21)控制系统的改善	☐	☐	☐	☐	☐
22)物业管理系统的改善	☐	☐	☐	☐	☐
施工影响					
23) 提高施工计划合理程度	☐	☐	☐	☐	☐
24) 降低施工过程对用户的影响程度	☐	☐	☐	☐	☐
其他您认为需要补充的因素					
25)请补充：________________	☐	☐	☐	☐	☐
26)请补充：________________	☐	☐	☐	☐	☐

`

Questionnaire Survey

Dear Participants：

Green retrofit (GR) refers to "incremental improvements to building fabric and service systems with the primary intention of improving energy efficiency and reducing carbon emissions"

If 1) You have been involved in Green Retrofit projects; 2) You have been involved in functional improvement with Green Retrofit purpose; 3）You haven't been involved in Green Retrofit project but have opinions towards GR projects.

1. Research Background

1.1 Your role in your former projects: （please tick "☑"）

☐Owner（as project manager or owner who involved in all the process）

☐Designer（include assessment, energy audit, retrofit plan and contractor involved with design）

☐Tenant

☐Else，as: ______________________

1.2 How many years you have been involved in GR（Owner/Designer）:（please tick "☑"）

☐0~5 ☐6~10 ☐10~20 ☐ above 20

1.3. If you have been involved in GR projects, building types are（multiple）:（please tick "☑"）

☐residence ☐office ☐commercial ☐hotel ☐building complex（like hotel with commercial）

☐ other public buildings（like museum，hospital，schools）

`

2. Research Contents

1. The degree of importance for the index in the design scheme: （please tick “☑” ）

index in the design scheme	1 lowest to 5 highest				
	1	2	3	4	5
Economic					
1) initial design investment	☐	☐	☐	☐	☐
2) operation fee and maintenance fee	☐	☐	☐	☐	☐
3) project return (include longer building lifetime, higher rent and return on energy saving)	☐	☐	☐	☐	☐
4) GR duration	☐	☐	☐	☐	☐
Social					
5) influence on tenants during the retrofit process(like energy interruption during the project or noise or casing influencing the tenants)	☐	☐	☐	☐	☐
6) satisfactory improvement with tenants	☐	☐	☐	☐	☐
7) improvement on exterior	☐	☐	☐	☐	☐
8) improvement on reputation	☐	☐	☐	☐	☐
Technical					
9) advanced (new technology)	☐	☐	☐	☐	☐
10) mature (multiple cases)	☐	☐	☐	☐	☐
11) easy to use and maintain	☐	☐	☐	☐	☐
Environmental					
12) energy saving and carbon reduction(electricity, water, gas,	☐	☐	☐	☐	☐

`

index in the design scheme	1 lowest to 5 highest				
	1	2	3	4	5
coal, materials etc.)					
13) indoor environment improvement (air quality, lighting , noise etc.)	☐	☐	☐	☐	☐
14) outdoor environment improvement (facade, afforest)	☐	☐	☐	☐	☐
15) recycle of waste and water	☐	☐	☐	☐	☐
Else					
16) please add: ______________	☐	☐	☐	☐	☐
17) please add: ______________	☐	☐	☐	☐	☐

2. The degree of importance index in the whole process

Index of consideration in the whole process	1 lowest to 5 highest				
	1	2	3	4	5
Needs in the whole process					
1) improve energy saving	☐	☐	☐	☐	☐
2) lower carbon	☐	☐	☐	☐	☐
3) reduce LCA fee	☐	☐	☐	☐	☐
4) improve comfortable design	☐	☐	☐	☐	☐
5) improve safety	☐	☐	☐	☐	☐
Social					
6) reduce influence to the neighborhood	☐	☐	☐	☐	☐
7) reduce influence to unit	☐	☐	☐	☐	☐
8) reduce carbon	☐	☐	☐	☐	☐
Economic					
9) bank interest floating	☐	☐	☐	☐	☐
10) water gas fee	☐	☐	☐	☐	☐

`

Index of consideration in the whole process	1 lowest to 5 highest				
	1	2	3	4	5
11)rent floating	□	□	□	□	□
Policy					
12)limit on carbon emission	□	□	□	□	□
13) incentive policy increase	□	□	□	□	□
14) carbon emission tax increase	□	□	□	□	□
Cost					
15)budget increase	□	□	□	□	□
16)operation fee decrease	□	□	□	□	□
17) retrofit technical fee increase	□	□	□	□	□
Use and Maintenance					
18)improvement on current building condition	□	□	□	□	□
19)indoor environment increase	□	□	□	□	□
20)improvement on the usage of practical habits(lighting, elevator etc.)	□	□	□	□	□
21)control system improvements	□	□	□	□	□
22) property management system improvements	□	□	□	□	□
Construction					
23) improve construction process	□	□	□	□	□
24) decrease the influence on users and tenants during construction	□	□	□	□	□
Else					
25)please add: _______________	□	□	□	□	□
26) please add: _______________	□	□	□	□	□

`

Appendix H: Sample of interview report

The total project duration according to the owner is 4.5 years,
The first 6-8 months is the feasibility study duration, the following year is the communication period with the costumers using the CRM system, and the communication process continued in the construction period.
The construction period is 3 years, start with the roof retrofit and structural retrofit and facade change and end with the indoor refurbishment.

1 Before Retrofit:

1.1 Is “green” the main aim of building retrofit or just additional function? 您認為綠色節能是建築改造的主要目的或僅是附加功能？

The ‘green’ concept is the main aim of the retrofit and start from the beginning, mainly based on LEED standards as retrofit reference.

1.2 How to decide whether do green retrofit or not? How to balance if the cost and delay increase when green retrofit is adopted? 如何決策是否採用“綠色”改造？在成本與工期增加的情況下如何取捨，如何平衡？

The principle is to keep the occupiers’ income without asking them out or stop the commercial activities. They call it contingency plan. To reduce the effect from air pollution, noise and folding, the plan is implemented floor by floor, keeping the business of the whole building run flexible.

The occupiers can keep working during retrofitting. Owner offers “business center” to occupier if the environment is not good.

1.3 How to determine the emphasis of GRD? What is the emphasis in your project? 如何確定綠色改造設計的重點？貴公司以往項目中的改造重點是什麼？

A. air condition B. heat preservation C. light control D. energy saving equipment E. water saving system F. other______________

The plan for the green retrofit is taken from facade/ elevator/ structure and roof/ podium/ refurbishment. The focus is on the HVAC system retrofit and sensor control with CO_2 sensor (Fresh air control with Parameter control 1000ppm) to monitor indoor air quality and many industrial processes.. The water coordination control leads 10% of the water saving.

1.4 What do you think green retrofit design should contain? 您認為綠色翻新改造標準中需要的內容應該有哪些？

A. Same as in new Green Building Standards 與新建綠色建築設計標準一致 （energy saving, water and material reuse, indoor and outdoor environment and operation management 包括節地與室外，能源，水資源，材料資源與室內環境，運營管理）

B. More than Green Building Standards, please be specific 內容較綠色建築設計更多，請說明更多的內容

`

Aiming LEED standards as the retrofit target, it is mainly because of LEED's recognition importance and HKGBC standard unavailable at that time.

1.5 Do you mine and select some best former practice as reference? If yes, how to choose appropriate practices? 是否挖掘和選擇以往的案例進行參考？如果是，如何選擇合適的案例？

LEED is the main standard to refer. Owner didn't refer to practical case because at that time, there are few retrofitting project and the similar ones are fewer.

1.6 How to set the principles (or aims) of green retrofit? 如何確定綠色改造的原則或目標？

A. social (collaboration, public awareness and education, social safety, etc.);
B. ecological (ecological construction materials, energy, waste, noise, land use, heath, air quality, etc.);
C. economic (cost-efficient price, fair price and good service, energy saving reliability, etc.);
D. cultural (cultural heritage, behavioural norms, etc.);
E. architectural (comfort, aesthetics, decoration, environment, buildings purposes matching exterior, etc.);
F. technical (innovative HVAC technologies, energy saving technologies, etc.). eQuest
G. others____________________

1 building corporation reputation and image
2 building pilot project to saving energy
3 for social activities (walking more conveniently)
4 environment (air quality)

1.7 How to set the criteria of green retrofit? 如何設定綠色改造的衡量標準？

A. green building standard B. energy saving ratio C. cost saving ratio
D. others_______________________

LEED, same as 1.4

2 During Proceeding:

2.1 What is the mainly difference between green retrofit and normal retrofit in implement? 綠色改造與普通改造在實施中的主要的區別在哪裡？

1 Current situation constraints with large promotion on the outlook
2 changing structure as few as possible
3 reducing effect to occupiers
4 reducing effect to income

2.2 Do you use multi-stakeholder collaborative design platform/software? 貴公司是否

`

使用多利益相關方的協同設計平臺或軟件?
General contractor has a communication platform, which is mainly for communication, not for design or decision support.

2.3 Which parts should DSS mainly focus on in GRD? Which parts have most problems to decide? GRD 中哪些部份是決策關注的重點？哪些部份有最多問題需要決策？

A. design B. subcontract C. supply chain D. construction E. schedule F. cost G. quality H. risk I. stakeholder J. Work breakdown structure (WBS) K.others___________________________

Face to face discussions for design plans have most problems. Face to face is the efficient method to solve problem.

2.4 How to compare and select among multiple solutions? How to choose the criteria in lots of factors? How to analysis quantitatively? How is the decision process? 面臨多方案選擇的時候如何處理？如何在眾多參數中選擇評價標準？如何量化比較？方案選擇的過程採用何種方法？
Mainly based on the collaboration efficiency between clients and consultants in the form of workshops. The simulation generally are separated with qualitative simulation and model simulation. These results will directly make income effect.

2.5 What do you consider the most important questions to ask in the questionnaire design in your CRM (Customer Relationship Management) system? 在收集客戶意見反饋 CRM 中，主要收集的問題有哪些？
Generally open questions, the owner organize some forums and 'early bird' reward plan to allow the merchants avoid the rush hours during the construction phase.

2.6 How to choose suppliers? Do you consider the former performance of suppliers? And how do you get the former performance evaluation? 如何選擇供應商？是否會考慮以往表現？如何得到以往表現的評估？
Yes, the owner has database of suppliers. Only suppliers with good performance can get the chance.

2.7 Are there some controversial situations? Like negotiations, claims? How to solve them? 是否存在爭議的情況，如談判，索賠等？如何解決？
N/A

2.8 Are resources shared among stakeholders, like money, human resource, facility, information? Do you think the resource sharing could be improved in some parts? 利益相關者之間是否有資源共享，如資金，人力資源，設備，信息等？您認為資源共享可以在哪些方面有改進？

`

Buildable is the main focus and Construction Design Engineering Approach. And the owner and contractors can share the profit if the cost is below budget.

2.9 Do you use building information model (BIM) in past projects? Do you have plans to improve green retrofit by using BIM? 貴公司之前的項目中是否使用過 BIM？是否考慮通過 BIM 增強綠色改造的效果？

Haven't considered but will do in the future.

3 After Retrofit:

3.1 How do you evaluate the past green retrofit projects? Do you satisfy the past projects? 如何對之前的綠色改造項目進行評估？對之前綠色改造項目效果是否滿意？

Using AIA and HKGBC standards, allow the customers to have the satisfactory survey and testing the service and results of the retrofit, the satisfactory percentage rise from 40% to over 80% which is enormous.

3.2 Are there some discussion problems in the past projects? Are there something could be improved in future projects? 哪些決策存在問題？哪些決策可以在後續項目中改進？

提高要求争取达到 BEAM plus 和 LEED 白金的要求

3.3 Do you have some suggestions for the future green retrofit projects? What are the tips for decision support? 您對後續的綠色改造項目有何建議？決策支持中需要注意的要點是什麼？

Be more aggressive. The decision maker said he would raise the aims higher in order to reach more significant results next time.

The results of the embodied energy saving are 20%. The project team had considered PV panel, however due to the long pay-back time, they didn't choose it. The overall optimization plan has reached a 7 to 8 year payback period in total and the refurbishment part hasn't been included.

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