Identifying Barriers to Address During the Delivery of Sustainable Building Renovation Projects

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IDENTIFYING BARRIERS TO ADDRESS DURING THE DELIVERY OF SUSTAINABLE BUILDING RENOVATION PROJECTS

A Thesis
Presented to
the Graduate School of
Clemson University

In Partial Fulfillment
of the Requirements for the Degree
Masters of Science
Civil Engineering

By:
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Accepted by:
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Dr. Lansford Bell
ABSTRACT

Architects, engineers, and contractors are continuously searching for tools and methods to reduce the unique risks associated with the delivery of construction projects. Since national policies to reduce carbon emissions and energy consumption will require drastic improvements to the existing building stock, one specific area in need of such tools is the sustainable renovation of existing buildings. The purpose of this research is to identify the barriers to address during the delivery of sustainable renovation projects and offer solutions that overcome these barriers. For example, typical renovation projects do not coordinate energy retrofits with building system renovations, resulting in poor use of resources and inefficient building performance. Reaping multiple benefits from single expenditures and optimizing planned capital costs is a strategy for overcoming this barrier. This research searches for the best opportunities to improve the delivery of sustainable building renovation projects.

A literature review and case study were performed to identify barriers to address during the delivery of sustainable renovation projects. Exploratory case study data was obtained through interviews with the project owner and contractor, site visits, and review of project documents. Results show that barriers found in sustainable renovation projects include issues regarding unforeseen existing conditions, interactions between building systems, financial analysis, and lack of experience, education, and awareness. Identifying methods to overcome these barriers may render existing buildings more sustainable. Methods for further exploration include: Policies and tools for promoting sustainable renovation, education and training of industry professionals and end-users, and enhancing
the role of government and other public bodies to create a market demand for sustainable renovation.
First and foremost, I would like to thank Bill Asdal for the use of his Raritan Inn project as a case study. Throughout this research, he willingly devoted his time and effort to improve my understanding of sustainable renovation. His outstanding commitment to educating others about green solutions deserves special recognition. Appreciation is also given to my advisor Dr. Leidy Klotz for guiding me in conducting this research. Also, thanks to Dr. Steve Sanders, Dr. Lansford Bell, and the ESSo Research Group for reviewing my work and providing invaluable feedback. Lastly, I thank my parents, whose love, encouragement, and support have greatly influenced my success at Clemson.
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CHAPTER ONE: INTRODUCTION

In order to reduce carbon emissions and energy use in buildings, there is a need to focus on efficiently renovating the existing building stock in a sustainable manner. In response to this need, this study examines a literature review that identifies barriers to address during the delivery of sustainable renovation projects. Using these barriers and the solutions offered in the literature, a comparison to a case study is made with the intentions of describing techniques and tools used in practice to remove these barriers. The purpose of this chapter is to introduce the context of the problem, define the scope of the research, state the research questions, identify the objectives of the research, and outline the structure of this report.

1.1. Context

Although sustainable renovation projects are challenging, there is a great need for building renovation projects in today’s world. As of 2006, buildings use approximately 40% of energy consumed in the United States (D&R International, Ltd., 2009). In order to cut the climate change emissions in half by 2054, the United States must decrease building energy use by 25% (Pacala and Socolow 2004). This requires energy reduction efforts in both new and existing buildings. However, even if every new building in the U.S. were designed to be a net-zero energy user (meaning the building generates its own energy through renewable resources and is not dependent on the energy grid), this would contribute less than half of the needed 25% reduction. Achieving this goal would require the majority of the 25% savings to derive from reduced energy consumption in the
existing building stock through sustainable building renovations and energy retrofits (Pacala and Socolow 2004).

Additionally, the 2030 Challenge adopted by the American Institute of Architects (AIA), the United States Green Building Council (USGBC), American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE), and others, calls for the renovation of existing buildings stock to equal in square footage that of newly constructed buildings. The 2030 Challenge also states that newly renovated buildings must use half the fossil fuel of average existing buildings (Wilson and Wendt 2007). Currently, buildings are renovated at an average rate of 2.2% (2 billion square feet) of the existing building stock per year; the corresponding average energy savings from this is roughly 11% as compared to the U.S. Energy Information Administration (EIA) Commercial Buildings Energy Consumption Survey (CBECS) average energy use intensity. In order to accomplish the goals of the 2030 Challenge, the U.S. must increase the rate of building renovations to 13% (about 12 billion square feet) of the existing building stock, amounting to over 55% average energy savings between now and 2030. Therefore, starting now, the U.S. must renovate more square footage per year, and/or must achieve significantly greater energy savings per building renovation (Olgyay and Seruto 2010). The 2030 Challenge is only one initiative that further increases the need for sustainable renovations within the United States.

Other established initiatives that promote sustainable renovation are government incentives that reward owners for building energy improvements and green renovations.
The American Recovery and Reinvestment Act (ARRA) allocated $26-$30 billion to encourage private commercial investment in green renovation projects as well as energy efficiency improvements in existing buildings. The Energy Policy Act of 2005 provided tax credits for energy efficiency and renewable energy in buildings; these tax credits were extended to 2013 by the Emergency Economic Stabilization Act of 2008. The Energy Independence and Security Act (EISA) of 2007, signed by President Bush, allocates more than $1 billion of federal funds to focus the private sector on improving energy efficiency in existing buildings; also EISA established the Zero Net Energy Commercial Buildings Initiative which set a national goal for all commercial buildings to be carbon neutral by 2050 (Burr 2008). The Obama Administration recently issued the Federal Leadership in Environmental, Energy and Economic Performance Executive Order of 2009 that requires federal agencies to measure, manage, and reduce greenhouse gas emissions. This order includes the implementation of the 2030 net-zero energy buildings requirement as well (McGraw-Hill SmarkMarket Report 2009; Roulo 2009).

Additionally, the need for sustainable renovation projects is made clear through examining the current construction market. Renovation projects represent a large percentage of the overall construction market and have become increasingly popular throughout the construction industry. Currently, the United States contains 76.9 billion square feet of existing building stock and only a small fraction consists of energy efficient buildings. According to the McGraw-Hill Construction 2009 SmartMarket Report, the green building retrofit and renovation market share is valued at 5-9% ($2-4 billion) and is projected to increase to 20-30% ($10-15 billion) by 2014. Furthermore, an
even greater opportunity in the renovation market for energy efficient buildings (one aspect of a green building) is present. This market share, currently estimated at 66-75% ($27-30 billion), is predicted to increase to 85-95% ($43-48 billion) within the next five years (Russo et al. 2009).

1.2. Scope

Renovation projects are defined as projects that primarily focus on an existing facility. The process of renovating the facility may include repairing and restoring building features, adding or removing structures and systems, and overall improvements that increase profitability, safety, security, performance, durability, and code compliance. Outside of this study, renovation projects may be referred to as retrofit, reconstruction, rehabilitation, refurbishment, and redevelopment projects; these are all aliases for renovation projects and shall be considered the same process of improving an existing facility (Gibson et al. 2007). A sustainable or green renovation project is one that, “employs multiple practices, products and processes covering a minimum of three out of five aspects of green building – energy, water or resource efficiency, improved indoor environmental quality or responsible site management” (McGraw-Hill Editors 2009). An energy-efficient renovation project however, is one that employs only one aspect of green building - energy efficiency.

As seen in Figure 1.1, a wide distribution in the age of buildings is undergoing sustainable renovation. Similar to the industry, this research is not confined to a specific age of buildings or to ones originally built during a specific era.
1.3. Sustainable renovation compared to the alternatives

At the beginning of every renovation project the key stakeholders must weigh the feasible construction options before they define the project scope and objectives. Ultimately, the stakeholder providing the funding for the project is responsible for the final decision. The typical alternatives for a building renovation project are as follows (Shohet and Perelstein 2004):

- Leave it as it is – resulting in a poor level of performance
- Partial renovation – improvement of selective building components
- Complete renovation – significant improvement in performance
- Construct an alternative building on a nearby site – will satisfy performance needs but increase cost as well
- Demolish and construct a new building on the same site – will satisfy performance needs but increase cost, energy use, and construction waste

Figure 1.1: Age of sustainably renovated buildings (McGraw-Hill Editors 2009)
Even when compared to sustainable new development, sustainable renovation is truly the more sensible option. Despite excellent intentions, the majority of sustainable new development is only slowing our decline towards negative social, environmental, and economic impacts. Storm Cunningham, founder of the Revitalization Institute, describes sustainable new development as, “Destroying things in a greener manner is an improvement: if you’re going to put that shopping center on top of the last natural wetland in the region, you might as well put solar panels on the roof. Sustainability is certainly a worthy goal, but what about the vast majority of the planet that’s already badly damaged (Cunningham 2008)?” Although he uses an extreme example, Cunningham’s main point is that sustaining our environment is only protecting it from further damage; however, restoring our environment is leaving the world better than we found it.

Sustainable renovation of the existing environment is the alternative that sets our generation on a path towards recovery and renewal. It can be seen as a change of course from reducing our rapid decline towards negative implications to improving our current status, and advancing towards future positive implications. Figure 1.2 depicts how sustainable renovation compares to other alternatives. “Business as usual” refers to any type of new construction that is not sustainable and, as indicated, this is the fastest way to reach negative consequences. Sustainable new development is heading in the negative direction because it merely slows or “sustains” the rate of depletion and pollution. However, sustainable renovation is the alternative that heads in the positive direction by restoring our natural and built resources.
1.4. Problem statement

Although the alternative of renovating a building in a sustainable manner is the only viable option that leads to positive implications, sustainable renovations can be one of the most difficult types of construction projects to undertake. A study done in 2000 analyzed 25 renovation projects and 15 new construction projects; the results showed that renovation projects have a higher tendency for schedule delays, have a worse cost performance history than new construction projects, and underperform new construction projects in terms of quality performance (McKim et al. 2000). Similarly, a separate study interviewed 23 owners and 17 contractors who have experience in both new construction and renovation projects. From these interviews, a few significant characteristics regarding renovation projects emerged: difficulty of scope definition, operational concerns, safety considerations, and cost and schedule constraints (Gibson et al. 2007).
These problems with sustainable renovation projects most likely occur because the optimal delivery processes for sustainable renovations are not the same as those for sustainable new construction or new construction in general. According to Klotz et al. (2007), sustainable new construction projects, “tend to be more challenging to deliver due to increased levels of building system integration, untraditional materials, and requirements such as recycling, total commissioning, and increased project documentation.” Delivering a sustainable renovation project would be even more challenging since they are more complex than sustainable new construction projects. Other issues that hinder the pre-construction processes of sustainable renovations are mainly derived from the fact that little is known about the best processes to deliver and plan for sustainable renovations.

1.5. Research questions

This research aims to identify the barriers to address in the delivery of renovation projects using a literature review and a case study. Specifically, this study answers the following questions:

- What are the barriers that need to be addressed during the delivery of sustainable renovation projects?
- What has previous research offered as solutions to these barriers?
- How do these solutions compare to the strategies used on a successful case study?

Answering these questions is meant to help improve the delivery process for sustainable renovation projects. Improvement in this area will reduce the risks associated with
sustainable building renovations and improve the cost and schedule performance for such projects.

1.6. Research objective

The objective of this research consists of three parts: (1) identify the barriers to address during the delivery of sustainable renovation projects, (2) discuss potential solutions to these barriers, and (3) contribute to the current body of knowledge by comparing solutions offered in the literature review to strategies used on a successful sustainable renovation project.

1.7. Research steps

The following steps will be achieved in order to meet the research objective:

- **Identify background information on the delivery phases (planning, design, construction, and operation) for sustainable renovation projects.** This objective requires a comprehensive literature review of journal articles, published books, and internet sources. The literature review covers sustainable construction, renovation construction, and delivery processes on a broad level, then concentrates on barriers to innovation and success factors for sustainable renovation projects.

- **Use an exploratory case study method to collect data and generate results with a broad impact.** This approach will require qualitative research methods to discover the strategies used to deliver a successful case study project. Results will compare the strategies used on the case study to the solutions offered in the literature review.
• **Report implications, limitations, and conclusions.** The research included in this study will produce results valuable to academia and industry professionals. It is important to clarify the implications, limitations, and conclusions for future applications of this research by individuals in professional work.

• **Identify areas for future research.** This research describes a focused topic that leads to many other questions and opportunities. The purpose of this objective is to present various directions for future research within the field of sustainable renovation.

1.8. **Report structure**

This study will outline research focused on reducing the unique risks that are present during sustainable renovation projects by identifying the barriers to address in the delivery of such projects. Pursuit of this research involves conducting a comprehensive review of the literature and examining the techniques used to deliver a successful sustainable renovation project. The literature review in Chapter Two provides evidence that sustainable renovations are one of the few construction alternatives that lead to positive implications. Even still, several critical constraints and barriers, discussed in Chapter Two, hinder the efficiency of sustainable renovation projects.

Chapter Three describes the case study project and the methods used by the researcher to collect information through interviews with project stakeholders, site visits, and review of project documents. The results presented in Chapter Four describe solutions to the barriers identified within the literature review. Methods used to overcome barriers in the case study project are also highlighted as results within Chapter
Four. Future research within sustainable building renovation, identified in Chapter Five, is focused towards policies and tools for promoting sustainable renovation, education and training of industry professionals and end-users, and enhancing the role of government and other public bodies to create a market demand for sustainable renovation.
CHAPTER TWO: BACKGROUND AND LITERATURE REVIEW

The purpose of this chapter is to introduce typical trends found in sustainable renovation projects and why they differ from traditional new construction projects. Also, the literature review outlined in Figure 2.1 discusses delivery processes for sustainable projects and barriers to innovation found in sustainable renovation projects. The majority of the information discussed within this chapter was originally published within journal articles, books, and internet sources.

![Figure 2.1: Literature review format](image)

2.1. The nature of building renovation projects

Due to constraints such as time, space, information, budget, and environment, building renovation projects are more complicated and difficult than new construction projects. If not properly accounted for, these constraints can cause variances from the planned cost, schedule, and scope of the project (Sandivo and Riggs 1991, McKim et al.)
Furthermore, construction projects that introduce sustainable building methods and technologies are even more intricate because of the additional complexity imposed by increased levels of building system integration, untraditional materials, and requirements such as performance levels, recycling, total commissioning, and increased project documentation (Klotz et al. 2007). However, sustainable building renovations that adaptively reuse outdated and inefficient buildings offer an alternative to new construction that reduces construction debris, maximizes material reuse, minimizes resource consumption, and decreases environmental impact, all at a potentially lower project cost (Laefer and Manke 2008).

2.2. Constraints

As previously mentioned, constraints that are typically unique to renovation projects are time, space, information, and environment (Sandivo and Riggs 1991). The following sections describe each constraint in detail and how it affects the productivity of sustainable renovation projects.

2.2.1. Time

Time is a constraint on almost every construction project because, in essence, time is money. However, with sustainable renovation projects, time can play a more intricate role in determining the success of the project. Contractors involved in reconstruction projects are sometimes given a shorter and more exact time frame within which all work must be completed. Many renovation projects must be completed during a narrow window of opportunity during a facility closure (Sandivo and Riggs 1991). For
example, renovations of academic buildings typically take place during the summer or winter breaks when the majority of the student population is absent and the buildings are vacant. In such a project, the contractor has only a few months to complete the work. If the project isn’t properly executed and variables such as weather, unforeseen conditions, material delivery, and subcontractor organization have not been accounted for, then the contractor has a greater risk of finishing behind schedule and over budget.

Another example of a project with a time constraint is one where an owner relocates and rents a separate building during the renovation of their existing facilities. Typically, contract documents state that the contractor must pay any liquidated damages that may have been incurred by the owner if the project finishes behind schedule. In such a case, the contractor is obligated to pay for fees such as the rent for however many days or months the project was late. Additional constraints on time might be competition or reputation driven or pressure to bring a product to market within a given season (Sandivo and Riggs 1991).

2.2.2. Space

Another constraint of nearly all renovation projects is space. Like time, space may be a constraint for new construction projects as well; however it is almost always a constraint for a renovation project. Space congestion may also introduce problems of laydown areas, access to the facility for construction workers, and work sequencing of specific equipment (Sandivo and Riggs 1991). The physical space of a jobsite varies for every reconstruction project but in most cases, the existing conditions of the building may
limit the design from satisfying the function required by the owner. Challenges such as the coordination of material delivery and storage require detailed planning and scheduling in order to reduce congestion on the construction site (McKim et al. 2000).

Limited space also introduces the concept of project disturbance. Disturbance generally refers to the negative impacts that influence the construction operation as well as the existing facilities operation. In such a case, certain variables in one operating system may result in changing the output of the other operating system. Therefore, on a sustainable renovation construction site, two types of disturbances are present: (1) the disturbance of infrastructure functions due to construction, and (2) the disturbance of construction functions due to infrastructure (Shami et al. 1997). An example of disturbance of infrastructure functions due to construction is a situation where construction noise and air pollution, due to improper quality control measures, cause the occupants of a nearby building to become uncomfortable and distracted. Similarly, construction productivity may be deterred due to infrastructure functions in an example where the limited parking spaces that provide construction site access for materials and equipment are occupied by building tenants.

2.2.3. Information

Available information about the existing facility and site history will vary for all sustainable reconstruction projects. In many cases, adequate as-built drawings and limited information about the existing structure may decrease productivity and delay construction. Additionally, demolition work on a sustainable reconstruction project often
reveals conditions that cannot be reasonably foreseen such as asbestos or location of utilities. In such a case, the initial plans developed for the project do not correspond with the existing conditions which can only be completely investigated during demolition (Krizek et al. 1996). Therefore it is important to have a structured plan set forth during the project delivery phases of how the contractor, owner, and designer must proceed after encountering an unforeseen condition.

2.2.4. Environment

Renovation projects are more susceptible to health and safety risks than new construction projects mostly because working within an occupied building or enclosed structure imposes additional constraints and restrictions for safe practices. Environment is constrained by extreme temperature and weather conditions, working with hazardous or toxic materials, and construction noise and vibration (Sandivo and Riggs 1991). Health and safety risks typically originate from two sources in renovation projects. First, during the renovation of an outdated, dilapidated building, the contractor is likely to encounter existing building components that contain hazardous materials such as asbestos, polychlorinated biphenyl, or lead. The removal and handling of these materials must be performed using the proper safety equipment and measures. Second, similar to the space constraint, the building occupants impose constraints on activities and equipment that produce air or noise pollution. If not properly planned for in the early stages of the project, these environmental concerns may result in cost and schedule overruns (McKim et al. 2000).
2.3. Sustainable delivery processes

The delivery of sustainable building projects is adapted from traditional building processes where decisions made during project planning, design, construction, and operations attempt to optimize time, cost, and quality without compromising safety. However, several key characteristics differentiate the delivery of a sustainable building from a traditional building. As compared to traditional building projects, the delivery of sustainable building projects tend to be more complex in nature due to the implementation of new techniques and strategies. As seen in Figure 2.2, sustainability is an added criterion to all project decisions by integrating sustainability into daily decision-making processes (Klotz 2008).

![Figure 2.2: Traditional vs. sustainable building delivery](Image)

Another way in which the delivery of sustainable buildings differs from traditional ones is the interaction between various stakeholders. The delivery of traditional building projects is generally structured in a linear and vertical hierarchy where one process leads to another (Cacciatori and Jacobides 2005). For example, in
traditional building delivery, the client specifies their particular needs to the architect, the architect presents drawings to the engineer, the architect and engineer provide details for the contractor, the contractor organizes a schedule including subcontracted work, and finally the contractor and subcontractors construct the building originally specified by the client. This approach is prevalent for traditional building delivery because it has been tested over time, various stakeholders are familiar with the process, and it is based on project level optimization.

The delivery of sustainable building projects are structured in a cross functional and horizontal fashion in order to facilitate a collaborative stakeholder environment (Palanisamy 2009). Sustainable building projects typically use design charrettes to ensure intense interdisciplinary collaboration between project stakeholders. These design charrettes are periodic meetings held early in the project delivery between the stakeholders to facilitate decisions that optimize the project on a global level. For example, in these “round table” meetings, a contractor is given the opportunity to provide input on the design of the building in order to optimize the construction phase and ensure safety. Although increased integration contributes to the complexity of delivering a sustainable building, stakeholders must understand that their involvement, expertise, and perspectives are crucial when generating sustainable solutions.
2.4. Barriers and solutions from literature review

This section identifies and discusses the barriers to address during the delivery of sustainable building renovations found within the literature review. Possible solutions to overcome these barriers offered in the literature review are presented within this section as well.

2.4.1. Barrier: Pre-existing hidden conditions are identified late in the design process (Mitropoulos and Howell 2002).

Existing building conditions may have several impacts on the renovation project. First, they affect the cost and time required to construct the features specified in the design. For example, the existing condition of the floor is poor and requires leveling work but does not affect the design. Second, the existing building conditions may limit the design options for the proposed architectural, mechanical, electrical, and plumbing designs. For example, when conducting the final checks to determine where the new system would connect to the existing building system, the mechanical contractor discovers that the designed connection is impossible. This is a situation that requires redesign of the mechanical connection; however, if the original design proceeds without identifying such constraints, multiple iterations and rework can delay the schedule and increase the cost (Mitropoulos and Howell 2002).

Solution: Identify project constraints that design and construction have to meet early in the planning phase and accelerate the discovery of existing conditions (Mitropoulos and Howell 2002). The design process must include a process for early and systematic discovery of project constraints. A thorough inspection of the existing
building envelope and exploratory demolition measures are two actions that must be conducted early in the design process in order to discover project constraints and otherwise unforeseen conditions. Exploratory demolition must be considered before the design process begins, rather than during the beginning of construction. For example, if a mechanical contractor is aware of space constraints within the wall, ceiling, and floor cavities through early exploratory demolition, then he/she can coordinate with the architect during the design phase to account for the space needs of mechanical, electrical, and plumbing fixtures. This early coordination between stakeholders may eliminate downstream issues that cause design rework and increase the project cost (Mitropoulos and Howell 2002).

2.4.2. Barrier: Typical retrofits do not account for interactions between systems (Olgyay and Seruto 2010).

Design teams tend to consider the architectural, mechanical, electrical, and plumbing systems as individual systems within the building. This siloed thinking approach results in a lack of communication and collaboration between project stakeholders. Ultimately, design teams that fail to account for interactions between systems produce a costly building that falls short of its potential energy and resource efficiency. For example, a mechanical design that does not take into account architectural elements such as building orientation, thermal mass, and natural air circulation may include unnecessary elements that increase energy demand and project cost.
Solution: Whole-systems thinking can be applied to the delivery processes to optimize the building as a whole for resource and energy efficiency (Olgyay and Seruto 2010). Whole-systems thinking is an interdisciplinary approach to analyzing how the various building systems and components interrelate with each other in order to maximize the benefits available in a building renovation project. One significant advantage of systems thinking is that it allows the stakeholders to meet as many needs through passive solutions before considering efficient systems to supply the remaining loads. For example, automated dimming ballasts reduce unnecessary artificial light during the brightest daylight hours. This saves energy costs by reducing the electricity used for artificial lighting as well as the heat that must be removed by the air conditioning system. Since the air conditioning system now has a smaller demand due to the heat removed, it can be sized smaller or used less often, which saves energy costs (Olgyay and Seruto 2010).

2.4.3. Barrier: Limitations of downstream systems that were not accounted for in upstream decisions (Mitropoulos and Howell 2002).

Because typical retrofits do not account for interactions between systems (Olgyay and Seruto 2010), mechanical, electrical, and plumbing designs are each completed by specialized engineers during different stages of the project. Typically, these systems are designed in the order they are installed in. Being the bulkiest equipment, the mechanical system is designed first, followed respectively by plumbing and electrical. If the mechanical engineer designed the mechanical building systems during week six of the
project and the electrical engineer’s calculations in week eight reveal that the required energy loads exceed the available power and the demand must be reduce, then the previously completed mechanical design must be reconsidered and reworked (Mitropoulos and Howell 2002).

**Solution: Select the project team early and accelerate iterative design process with a team-based rapid development of schematic design (Mitropoulos and Howell 2002).** Early selection of the project team allows the stakeholders to assess conceptual designs and evaluate if the designs meet project constraints and client requirements. Mitropoulos and Howell recommend the use of rapid prototyping (a term used in manufacturing) for accelerating the processes of design, evaluation, and verification of the proposed design concepts. Identical to design charrettes, rapid prototyping uses fully coordinated, interdisciplinary team meetings between project stakeholders to develop design solutions and check their feasibility against project requirements and constraints. Advantages to design charrettes and rapid prototyping include:

- They provide a systematic process for design evaluation and verification that allows stakeholders to better understand each other’s requirements and check their decisions against the other stakeholders’ constraints.
- They facilitate collaboration and immediate feedback for design decisions. Also, they allow for concurrent planning of the design and construction phases.
- They accelerate the positive iterations early in the design process, resulting in design improvements and corrections that are made before the design is finalized.
For design charrettes and rapid prototyping to be effective, several conditions must be met. First, full involvement of all key project stakeholders including clients, designers, contractors, suppliers, and end-users (not just managerial representatives and superiors) must be present. Second, the stakeholders must identify both the project constraints (time, space, information, and environment) and the client’s functional needs and requirements. Design charrettes and rapid prototyping overcomes barriers and constraints at the lowest possible costs and increases the stakeholder’s ability to develop more efficient end designs (Mitropoulos and Howell 2002).

2.4.4. Barrier: Design teams use first cost and simple payback more than life cycle cost analysis (Olgyay and Seruto 2010).

Project stakeholders typically do not coordinate the financial analysis with the energy analysis which may lead to poor investment decisions. It is often perceived that energy efficient retrofit techniques are associated with high capital costs. Depending on the scope of the project and the technologies used, this misconception can deter owners from selecting energy efficient measures in fear that their budget will escalate (Olgyay and Seruto 2010).

Solution: Comprehensively analyze life cycle cost and energy together; use deep efficiency savings to avoid capital costs (Olgyay and Seruto 2010). When design teams compare life cycle cost analysis with the possible engineering options that meet the building’s space and requirement needs, viable solutions that optimize passive designs may arise. Using the life cycle cost analysis, project teams are more likely to meet as many building needs as possible through passive solutions before turning to efficient
systems to meet the remaining building loads. One proven way to accomplish this is to use total present-valued life-cycle occupancy cost as a financial objective function (Lovins 1992). As seen in Figure 2.3, Olgyay and Seruto offer a method for ranking packages of energy efficiency measures by the net present value (NPV) of each package. This figure depicts the financial and energy implications of project decisions or options. Using this analysis, project teams are more likely to select energy efficient renovation measures that lead to higher levels of building performance (Olgyay and Seruto 2010). Life cycle cost can also impact the green renovation market since 76% of building owners cited lowering building life cycle costs as a key business motivator to conduct sustainable renovations to their buildings (McGraw-Hill Editors 2009).

![15-Year NPV of Package versus Cumulative CO2 Savings](image)

**Figure 2.3: Ranking NPV in terms of carbon savings** (Olgyay and Seruto 2010)
2.4.5. Barrier: Energy retrofits are not coordinated with other building system renovations (Olgyay and Seruto 2010).

Since the budget and financing are not always available for full renovations, the owner may choose to address superficial building improvements with little or no efficiency considerations. For example, an owner decides to replace the existing HVAC system in his/her building with one of an equal size and failed to consider sizing a smaller HVAC system, improving building insulation, and optimizing passive heating/cooling techniques all within the same budget (Olgyay and Seruto 2010).

Solution: Reap multiple benefits from single expenditures and optimize the planned capital expenditures (Olgyay and Seruto 2010). Building owners must coordinate planned building improvements that fulfill multiple needs through a single expenditure. For example, an owner decides to replace the existing incandescent lighting system with an automated fluorescent lighting system. This planned capital improvement saves energy through reduced wattage since a 20-watt compact fluorescent light bulb provides lighting comparable to a 60-watt incandescent bulb (Jordan 2004). Also, the automated controls eliminate unnecessary usage due to daylight sensors and motion detectors. The reduced wattage and usage result in less heat that the HVAC system must remove from the building during warmer temperatures. Ultimately, a single capital improvement leads to energy savings and lower utility costs. This improvement coordinated with other energy efficient measures such as use of daylighting and efficient appliances further increases the benefits of an energy renovation by piggybacking off of planned capital expenditures (Olgyay and Seruto 2010).
2.4.6. **Barrier: Industry lacks experience with the processes and knowledge required to perform deep retrofits (Olgyay and Seruto 2010).**

Only a small portion of practicing designers can be considered experienced in integrating current energy-efficient and sustainable options into existing buildings. One reason for this is the fact that most designers are given limited opportunities for continuing education. Education for industry professionals is more focused on traditional practice rather than on how to integrate into design continuing advances and innovative techniques made on a holistic scale. Little is being done to address issues such as oversizing systems to compensate for liability, obsolete rules-of-thumb, and the need for engineering optimization (Lovins 1992). Another reason for lack of knowledge is companies involved with renovation projects tend to assign inexperienced people in the well meaning effort to provide them with valuable experience. These young and inexperienced project team members may potentially impact the project in a negative manner (Sandivo and Riggs 1991).

**Solution: Professional education (Lovins 1992).** Although reeducating design and construction professionals throughout the industry will take decades, it is imperative for these professionals to deviate from traditional methods in order to learn innovative tools and techniques that optimize cost and performance. Simultaneously, emerging green technologies and design options for improving building performance will continue to rapidly evolve. Therefore, today’s design and construction professionals must have access to current user-friendly systems that ask the right questions, in the right sequence, to produce optimal solutions (Lovins 1992).
2.4.7. Barrier: There is a noticeable lack of sufficient measurements of the benefits achieved in green renovations reported by owners and tenants (McGraw-Hill Editors 2009).

Legislative policies are advancing toward required public reporting of building performances. Building owners that do not currently have systems in place to measure performance will struggle in the market and will ultimately realize that it will cost them a significant amount of money not to have these systems in place (McGraw-Hill Editors 2009). Furthermore, documentation of how the building was designed to perform and how to maintain and operate building systems in an optimal manner is rarely provided to building operators and owners. Poorly trained building operators tend to disable complex systems and functions they do not understand, resulting in suboptimal building performance (Lovins 1992).

Solution: Setting effective benchmarks and measures (McGraw-Hill Editors 2009). To demonstrate returns on investments and the cost savings achieved in sustainable renovation projects, owners must create benchmarks for building performance and ensure these benchmarks are met through operation and commissioning. Owners can measure energy use through tracking tenant and building utility bills and compare these to projected values. Simulation models using Building Information Modeling (BIM) software can help the owner estimate a renovation project’s future energy performance and track a building’s current performance (McGraw-Hill Editors 2009).
2.4.8. **Barrier: Lack of education and awareness of sustainable renovation issues.**

Many building owners have misconceptions about sustainable renovation especially regarding financial issues such as perceived higher first costs. Also, greenwashing plays a significant role in misleading owners and tenants about sustainability issues (McGraw-Hill Editors 2009). Greenwashing is when consumers are misinformed about the environmental practices of a company or the environmental benefits of a product through misleading advertising. Also, building tenants and end-users that significantly impact the building’s performance are rarely educated on behavioral issues regarding energy and water conservation. They are practically never given a manual or operating instructions on lifestyle improvements that optimize energy efficiency (Lovins 1992).

**Solution: Increase project reporting, transparency, and end-user education (McGraw-Hill Editors 2009).** Public reporting of building performance data may help clarify the general misconceptions about sustainable buildings and increase awareness of the positive implications of sustainable renovation. The USGBC has put forth the new Building Performance Initiative which embraces an effort to collect building performance data from all LEED certified buildings. Other programs and tools used to report building performances include the Energy Star program, Portfolio Manager, and the Department of Energy’s High Performance Building database. Public reporting of such data not only promotes energy efficiency but also creates a competitive environment, especially for commercial building owners. A study done in 2009 by Siemens and McGraw-Hill Construction reported that 66% of a representative sample of executives from the largest
firms in the United States claim that competitive advantage is driving their corporate sustainability efforts (McGraw-Hill Editors 2009). Additionally, increased project transparency results in improved stakeholder awareness. This in turn, may lead to a more sustainable building, better stakeholder relationships, and optimal designs that reduce project costs (Klotz 2008).

Educating the end-user on behavioral issues that impact building performance is another solution to overcoming this barrier. Tenants, occupants, and end-users can significantly influence energy and water use through their daily operational habits. During the recent Empire State Building Energy Efficiency renovation, designers identified that 58% of the annual energy savings available were limited to tenant associated measures such as daylighting, plug loads, window strategies, demand control ventilation, and overall tenant energy management (Olgyay and Seruto 2010).
As the literature review demonstrates, many barriers exist during the delivery of sustainable renovation projects. The purpose of this chapter is to establish the research approach, introduce the Raritan Inn case study, and describe the methods used to perform this research. Furthermore, this chapter discusses how Robert Yin’s process for case study research is adopted as the framework for this study (2009).

3.1. Approach

This research is focused on investigating the barriers to address during the delivery of sustainable building renovation projects. Furthermore, this research will compare the solutions offered within the literature review with the techniques and tools used to deliver the Raritan Inn project in Califon, New Jersey. In order to achieve this goal, this research is designed as an exploratory case study focused on a single case. Case studies are typically used to interpret a single instance of a broader class of phenomenon that requires an extensive or in-depth investigation (Yin 2009, Thomas 2004). Therefore, the Raritan Inn project is a single instance of a broader class of sustainable and energy efficient renovation projects. Additionally, an exploratory case study is directed towards defining the questions of a subsequent study or determining the feasibility of the desired research procedures (Yin 2003). In this research, it is most appropriate to use the Raritan Inn project as an exploratory case study to compare the preliminary information found in the literature review to the processes used on a successful sustainable renovation project.
To begin addressing the need for market penetration of sustainable renovation projects, this research offers a case study that provides insight into success factors for the Raritan Inn project and how they compare to the solutions offered in the literature review. Specifically, the case study:

- Interviews an industry professional for expert opinion and advice
- Identifies barriers to innovation for the Raritan Inn project
- Highlights management practices and strategies that led to a successful project
- Explores how the Raritan Inn project incorporated attributes found within the literature review

Importantly, the case study presented in this research is not intended as representative of all sustainable renovation projects and practices; rather, in closely examining one successful project, it discovers important practices that can be adopted by professionals throughout the construction industry.

3.2. Raritan Inn project

This research presents a case study of a residential home renovation project and investigates the successful strategies used to overcome barriers common to renovation projects. This project is unique because the general contractor is the owner of the project and has extensive experience in sustainable renovation work. Also, innovative renewable energy technologies and sustainable building techniques were used throughout the project. The barriers encountered throughout the case study project are not uncommon, therefore the successful strategies and lessons learned are applicable to many sustainable
renovation projects. This section describes the project in detail and discusses the innovative technologies that were used.

The Trimmer family homestead that is now known as the Raritan Inn was purchased by building remodeler Mr. Bill Asdal in 2002 with the intentions of transforming the dilapidated building into a functional bed and breakfast. The 24-acre property in Califon, New Jersey consisted of an existing 4,000 square-foot 1898 Victorian style house built over a 1732 stone bank house, a 1,500 square-foot wood frame cottage, a 4,000 square-foot barn, and a shed. Although all of these structures were renovated by Asdal Builders llc using sustainable technologies, the scope of this research highlights the renovation of the Victorian style house shown in Figure 3.1.

![Figure 3.1: Trimmer family homestead circa 2002 (courtesy of Bill Asdal)](image)

By 2002, the Trimmer family homestead had been vacant for almost 30 years and was in need of significant structural, architectural, and efficiency improvements. Working closely with the National Association of Home Builders (NAHB) Research
Center, Mr. Asdal and his company conducted a two year renovation of the structure that produced the country’s first zero-energy home achieved through renovation rather than new construction (shown in Figure 3.2) (Jordan 2004). Additional pictures of the Raritan Inn before and after the renovation can be viewed in Appendix A and B respectively.

![Raritan Inn circa 2007](image)

**Figure 3.2: Raritan Inn circa 2007** (courtesy of Bill Asdal)

Mr. Asdal viewed the full renovation or “gut rehab” of the Victorian home as an opportunity to demonstrate how a 100 year old building can be renovated to perform at today’s energy efficient standards. The challenge of transforming an abandoned, otherwise landfill bound house into a durable, energy efficient, and comfortable home at an affordable cost was great. The following conditions created uncertainties, limitations, and constraints that Mr. Asdal had to overcome during the delivery of his project:
Since the building was built in 1898, there were no blueprints or as-built drawings. Therefore, information was limited regarding the existing conditions of the structural elements and building systems.

The house had been vacant for almost 30 years, was inhabitable, and had been vandalized when Mr. Asdal first purchased the property.

The house had been built over a 1732 stone bank home which Mr. Asdal wanted to restore for historical preservation.

Using the strategies later described within this research, Mr. Asdal successfully delivered this project to achieve the countries first zero-energy building renovation and serve as an educational tool for future sustainable renovation projects. These successful strategies are presented as the results in Chapter Four.

3.3. Methods

The research framework used in this study to answer the research questions consisted of three main phases: Plan and Design; Prepare, Collect, and Analyze; Analyze and Share. These phases are depicted in Figure 3.3 and described in further detail throughout this section. This tested framework is adapted from Robert Yin and shows that case study research is a linear yet iterative process. In his book “Case Study Research: Design and Methods,” Yin comprehensively describes the design and use of the case study method as a valid research tool. Among others, his case study research design and methods are proven to be useful in the fields of engineering, medicine, management, and education (Yin 2009).
3.3.1. Plan and design

The plan and design stages of this research began with the initial motivation and interest from the researcher to study topics within the field of sustainable building renovations. Upon preliminary review of the literature, the researcher developed the problem statement that sustainable renovations can be one of the most difficult types of construction projects to undertake due to their increased risk from project constraints and barriers. The comprehensive literature review conducted in this research began with the three broad topics of building construction, building renovation, and delivery processes for construction projects. This expansive overview provided the background information.
required in order to investigate the subject of this research. The literature review was then concentrated on documents that identified constraints, barriers to innovation, and success factors for sustainable renovation projects. The narrow approach focuses on the scope of this research and provides the information that is most valuable to this research.

This collection of information that respectively followed a “less relevant,” “more relevant,” and “spot on” pattern developed from Alan Thomas’s view of a comprehensive literature review illustrated in Figures 3.5 (2004). In essence, “less relevant” material was considered related to the research topic, yet more remote; “more relevant” fell into the intermediate zone that represented material directly related but not quite so close to the research topic; and “spot on” material represented literature very closely related to the research topic such as model papers or articles (Thomas 2004).

![Figure 3.5: Literature review relevance funnel, adapted from (Thomas 2004)](image)

The majority of the literature review for this study began in January of 2010 with recommended articles and publications from the research committee chair. Once these
resources were examined, an online database search of Clemson University’s Libraries Catalog was conducted using keywords such as renovation, rehabilitation, retrofit, reconstruction, and sustainability. Next, every volume of ASCE’s Journal of Construction Engineering and Management from March of 1983 (Volume 109, Number 1) through October of 2010 (Volume 136, Number 10) was investigated using EBSCOHOST’s Electronic Journal Service (EJS). Articles with relevant titles and abstracts were put aside for further review. Finally, a general search through relevant civil engineering journals was conducted using the Libraries Catalog and the previously mentioned keywords. Significant publications related to the research topic found using these three databases were filtered and prioritized by relevance for review. While reading each publication, the researcher highlighted important information and recorded one-page summaries for each resource for future reference.

Also a part of the plan and design phase was the selection of the case study and preparation for data collection. The Raritan Inn project was selected as the case study for this research for several reasons. First, being a sustainable building renovation, the Raritan Inn project fell within the scope of this research. Multiple sources of renewable energy and sustainable technologies were implemented during the renovation of the existing facility. Secondly, Bill Asdal generously volunteered his valuable time and effort to collaborate with the researcher throughout the data collection process. Due to a cooperative program with the National Association of Home Builders Research Center and the National Renewable Energy Lab, Mr. Asdal possessed a remarkable amount of project documentation and data for his Raritan Inn renovation. Through personal
interviews, telephone conversations, and email correspondence, Mr. Asdal was both congenial and accessible in providing these documents and behind the scenes information that would otherwise be unattainable for the researcher. Finally, the location of the Raritan Inn project was geographically convenient for the researcher during the data collection phase.

After selecting the Raritan Inn as the case study, initial data collection methods were designed using interviews to collect qualitative data. The first interview with Mr. Asdal consisted of general questions to further understand the logistics, objectives, and purpose of the Raritan Inn project. This background information was necessary as a foundation for further investigation. More detailed and focused questions were developed later in the data collection phase.

3.3.2. Prepare, Collect, and Analyze

The prepare, collect, and analyze phases of this research accomplished two main tasks: (1) to identify barriers and solutions from the literature review, and (2) to design interview questions, collect case study information, and identify successful strategies used in the case study. The later task consisted of multiple iterations of designing interview questions and collecting data through interviews as shown in Figure 3.6.
The barriers and solutions identified within the literature review were selected from articles and reports that were most relevant to this research topic. These “model” papers represented studies that were similar to this research but in a different scale, scope, or context. The four most relevant papers were Panagiotis Mitropoulos and Gregory Howell’s “Renovation Projects: Design Process Problems and Improvement Mechanisms,” Victor Olgyay and Cherlyn Seruto’s “Whole-Building Retrofits: A Gateway to Climate Stabilization,” the McGraw-Hill Construction SmartMarket Report on “Green Building Retrofit & Renovation,” and Amory Lovins’ “Energy-Efficient Buildings: Institutional Barriers and Opportunities.” Also, Victor Sanvido and Leland Riggs’ “Managing Retrofit Projects” technical report was important in identifying project constraints associated with typical renovation projects. These five papers served as models for this study and helped the researcher gain a better understanding of the sustainable renovation industry.
The data collection for the Raritan Inn case study began in July of 2010 with several site visits to the project site. During these visits, the researcher met with Mr. Asdal to tour the facilities and discuss sustainable renovation techniques used throughout the project. Also, semi-structured interviews were conducted with Mr. Asdal to further collect project information. During these interviews, Mr. Asdal provided relevant project documents such as financial modeling documents, decision making tools, and the Strategies for Energy Efficient Remodeling (SEER) Case Study Report. These documents along with the information personally provided by Mr. Asdal were utilized to present the successful strategies found in Chapter Five. In between interview sessions and site visits, the researcher reviewed collected information and formulated new interview questions to further investigate the case study. A total of four interviews were conducted with Mr. Asdal, consisting of two site visits and two phone conversations. The researcher also corresponded periodically with Mr. Asdal via email. A questionnaire is provided in Appendix C that lists semi-structured interview questions developed by the researcher.
3.3.3. Analyze and Share

The final phase of this research first focused on analyzing the data collected in the literature review and case study, then on sharing the results within this study in a clear and concise manner. For each identified barrier, at least one possible solution was offered along with a description of how to execute the solution. Throughout this phase, the researcher cross-analyzed the model papers in order to discover common themes and trends as to how to overcome the identified barriers. For example, one common theme found in several of the model papers was to optimize design by applying whole-systems thinking and multi-disciplinary collaborative design charrettes to the delivery of sustainable renovation projects. Another common solution found within the literature review was the use of life cycle cost analysis to maximize financial benefits. Also analyzed within this phase was the successful strategies used to overcome barriers on the Raritan Inn case study. In many cases, the successful strategies used on the Raritan Inn were closely aligned with the solutions identified within the literature review. The
discussion of these issues can be found as the results and analysis in Chapter Four within this document.
CHAPTER FOUR: RESULTS AND ANALYSIS

Using the previously discussed research methods to review the available literature and study a successful case study, evidence is found on solutions and strategies to overcome the identified barriers associated with sustainable renovation projects. The purpose of this chapter is to present these strategies as results and analyze how techniques used to deliver the Raritan Inn case study compare to the solutions offered in the literature review.

4.1. Successful strategies used to deliver the Raritan Inn project

This following section discusses the strategies used to overcome the barriers encountered during the delivery of the Raritan Inn case study.

4.1.1. Barrier: Pre-existing hidden conditions are identified late in the design process (Mitropoulos and Howell 2002).

Raritan Inn Strategy: Use of a seven part inspection guide to identify project constraints. The Raritan Inn was a gut renovation project where all existing building systems (plumbing, electrical, mechanical, etc.) were removed from the building and replaced with newer, more efficient systems. This significantly reduced the risk of unforeseen existing conditions since project stakeholders did not have to consider reusing or integrating existing building systems. However, the existing shell and structural components of the building were used and in order to assess the condition of these features, a seven part inspection guide was followed. In order to accurately assess the condition, safety, usefulness, and renovation potential of existing residential buildings,
the Residential Rehabilitation Inspection Guide provided by the U.S. Department of Housing and Urban Development (HUD) establishes technical information for evaluating the existing conditions of a residential home. The step-by-step guide is organized into seven checkpoints: site, building exterior, building interior, structural system, electrical system, plumbing system, and HVAC system (Residential Rehabilitation Inspection 2000). When asked about the inspection of the Raritan Inn, Mr. Asdal stressed that, “It takes some amount of experience. You must have a trained eye for quality control and problem identification.” Since the existing building systems were not salvaged at the Raritan Inn, the first four checkpoints were applied to the Raritan Inn.

- **Site:** Due to the high water table and proximity to the South Branch of the Raritan River, the existing house was located in a flood plain region. Therefore, the drainage of the entire property and adjacent properties were a concern when evaluating the site. Also, the site was littered with debris and overgrown by untamed weeds and plants.

- **Building exterior:** Upon initial inspection, significant building exterior damage was noticeable (Figure 4.1). Replacement of the roof, gutters, drains, porch, windows, and doors were needed, and repairing the existing siding was necessary. The building’s Victorian architectural style was hidden through the deteriorated shell and Mr. Adal was determined to restore the integrity, character, and elegance of the home.
• **Building interior:** Due to the age of the building, no building insulation existed in the wall, ceiling, or floor systems. As shown in Figure 4.2, interior walls were in need of significant repair. Although the interior was in need of repair, it boasted desirable design features such as ten-foot ceilings on the first floor and nine-foot ceilings on the second.

![Existing exterior building condition](image1)

**Figure 4.1: Existing exterior building condition** (courtesy of Bill Asdal)

![Existing interior building condition](image2)

**Figure 4.2: Existing interior building condition** (courtesy of Bill Asdal)
• **Structural system:** Upon investigating the structural components of the building, it was determined that there were no major structural defects at the Raritan Inn.

4.1.2. **Barrier:** Typical retrofits do not account for interactions between systems (Olgyay and Seruto 2010).

**Raritan Inn Strategy: Use of a process for understanding and analyzing the project as a whole.** There were two priorities identified at the beginning of the project by Mr. Asdal: (1) durability, and (2) performance. Throughout the four interviews, he placed emphasis on how important durability was to him on this project. Essentially, he defined durability as how long the building will last. The older, inefficient homes are subjected to significant change in indoor temperature and humidity swings that may cause swelling, shrinking, and additional wear to building components (Wiehagen and Drumheller 2004). Mr. Asdal was determined revive the 100 year old building into a historical landmark that would stand the test of time with periodic yet minimal maintenance. Along with durability, he stressed that performance was also a high priority when taking on this project. With the use of on-site renewable energy resources and other sustainable technologies, the project stakeholders set out to achieve a zero-energy building.

In order to accomplish these two goals, Mr. Asdal and the project stakeholders adopted a systems-thinking approach. He describes that in the building, “there is nothing that stands alone,” meaning that all building systems and components are interrelated and influence the overall performance of the building as a whole. In one interview with a Partnership for Advancing Technology in Housing (PATH) representative, Mr. Asdal
mentioned how the project team removed barriers common to typical renovation projects, “We took the perspective of a whole-house approach for energy efficiency systems, instead of looking at it piecemeal, as many remodeling projects might do (Success stories n.d.).” An example is used to best describe how the project team incorporated whole-systems design. The project team “tightened” the shell of the building by air sealing the entire structure. This was achieved by caulking around window and door frames, gluing interior wallboards to the framing, sealing the sill seam and band joists areas with spray foam, and installing drywall adhesive at floor and wall seams. To improve thermal retention, cellulose insulation was blown into the wall, floor, and ceiling cavities and double-pane low-E insulated windows were installed. According to Mr. Asdal, the Raritan Inn is “seven times tighter than a comparable house (Success stories n.d.).” Based on the improved envelop, a smaller and highly efficient heating and cooling system was selected to maximize installation and operation costs. This holistic approach to analyzing the building envelope called for increased insulation costs that optimized mechanical costs and energy efficiency.

4.1.3. Barrier: Limitations of downstream systems that were not accounted for in upstream decisions (Mitropoulos and Howell 2002).

Raritan Inn Solution: Interconnectivity between project members. During the Raritan Inn project, Mr. Asdal worked closely with NAHB researchers to deliver the most cost effective and sustainable building renovation. Additionally, an estimated 50-60 different trades were hired throughout the project. Since Mr. Asdal served as both the owner and general contractor of the project and had significant experience with
sustainable renovation projects, communication between project stakeholders occurred early and often to eliminate confusion and situations that cause rework. Mr. Asdal successfully delivered the project using a strategic planning cycle shown in Figure 4.3 which requires communication between project stakeholders and resources.

![Strategic Planning Cycle](image-url)

**Figure 4.3: Strategic planning cycle (courtesy of Bill Asdal)**

In this cycle, the plan revolves around the goals. Mr. Asdal identified the primary goals of the Raritan Inn project to be durability, performance, and affordability. Also, a common theme mentioned throughout the interviews was the goal to use the Raritan Inn as an educational tool to demonstrate the benefits of green renovation. Once the goals were set, a strategic plan was put into motion to accomplish the goals. Then, resources such as time, assets, labor, and materials were organized to utilize toward achieving the goals. The execution stage consisted of carrying out the plan and starting the renovation
process. The monitoring of the project required benchmarks to be set and continuous tracking of the progress against the benchmarks. Importantly, the monitoring stage allowed for adjustments to be made as the project advanced. This strategic planning cycle shown in Figure 4.3 was created by Mr. Asdal and is adopted on many of the projects he undertakes.

4.1.4. Barrier: Design teams use first cost and simple payback more than life cycle cost analysis (Olgyay and Seruto 2010).

Raritan Inn Solution: Fuzzy logic decision models to account for life cycle cost. When asked about how he made decisions on investing in the property, selecting subcontractors, and choosing between sustainable technologies, Mr. Asdal had one answer for all: Fuzzy logic decision models. These models are organized in a table that analyzes different options based on weighted criteria. The weight of each criterion is determined by its importance in the decision to be made. Once all options and weighted criterion are entered into the matrix, a score for each option is generated and the highest rated score is the best option. Examples of criteria used in many of Mr. Asdal’s Fuzzy logic decision models consisted of: first cost, operating and annual costs, life cycle cost, durability, quality design, character, environmental considerations, and energy performance. A sample model of the Fuzzy logic decision models used by Mr. Asdal is provided in Figure 4.4.
4.1.5. Barrier: Energy retrofits are not coordinated with other building system renovations (Olgyay and Seruto 2010).

**Raritan Inn Solution: Perform “gut rehab” that includes on-site renewable energy.** A “gut rehab” was performed at the Raritan Inn that replaced all existing building systems with newer, more efficient systems. For example, instead of installing a typical heating system that relies on fossil fuels the project team decided to take advantage of the large property and high water table by installing a closed-loop geothermal system. As compared to the fossil fuel dependent base model estimated at 50 to 65 percent efficient, the geothermal system cuts half the energy use for heating and cooling the house (Jordan 2004). Furthermore, Mr. Asdal was able to capitalize on the New Jersey Clean Energy Program (NJCEP) which offered up to 70 percent rebate for homeowners who incorporate solar photovoltaic systems in their homes. He had solar photovoltaic panels placed on the south-west facing roofs of the nearby cottage and garage (see Figure 4.5) and installed a power generator. The two systems feed renewable...
energy to the entire property that’s estimated to generate 9,000 kWh per year or approximately $1,100 worth of energy. Other energy retrofits performed at the Raritan Inn included the installation of compact fluorescent (CFL) lighting and Energy Star Rated appliances such as the refrigerator, dishwasher, and clothes washer (Jordan 2004).

Figure 4.5: Photovoltaic panels on garage provide solar energy to the Raritan Inn

4.1.6. Barrier: Industry lacks experience with the processes and knowledge required to perform deep retrofits (Olgyay and Seruto 2010).

Raritan Inn Solution: Hands on training and education paired with diligent management. The disadvantage or barrier to using the latest energy efficient technologies is that the systems are unfamiliar to the laborers. Therefore, when considering new innovative technologies, Mr. Asdal stressed that every single person on the job must be well trained and educated. He also acknowledged that using local trades to build an entire project team from scratch is a great challenge to overcome. On the Raritan Inn project, Mr. Asdal described that communication with the project manager, foremen, and laborers about proper ways to perform work was necessary. When air
sealing the house, if he noticed a laborer installing caulk incorrectly or in the wrong places, Mr. Asdal would personally demonstrate the proper methods to that laborer. He mentioned that no matter how many years of experience they may have, many laborers are unaware that they have been performing tasks the wrong way. The only solution to fixing this issue is diligent management and hands on training and education for all project members.

4.1.7. **Barrier:** There is a noticeable lack of sufficient measurements of the benefits achieved in green retrofits reported by owners and tenants (McGraw-Hill Editors 2009).

**Raritan Inn Solution: Public reporting of building performance.** The Raritan Inn’s energy use, production, and efficiency in real-time data can be publicly viewed on its website (www.raritaninn.com). Using Noveda Technologies, data is streamed to the web that reports the amount of greenhouse gas emissions avoided per month, total solar energy produced, total energy consumed, and energy imported/exported to the grid. Figure 4.6 and 4.7 respectively show screenshots of the technology during day and night time. Larger images of these screenshots are provided in Appendix D.
4.1.8. Barrier: Lack of education and awareness of sustainable renovation issues


Raritan Inn Solution: Education and training of end-users about how to properly operate the building. Since Mr. Asdal had previous experience and knowledge on successfully delivering sustainable renovation projects, this barrier was not applicable to the Raritan Inn case study. However, Mr. Asdal did comment about the need to educate and train the building occupants on how to efficiently operate their
building. This gap in knowledge is further discussed within section 5.4 of this report and the need for future research within this area is acknowledged.

4.2. Summary of results

The results from this research are summarized and presented within Table 4.1 where each barrier, solution, and strategy is described. A comparison of the results can be found in section 4.4.
Table 4.1: Summary of results

<table>
<thead>
<tr>
<th>Barrier</th>
<th>Solution</th>
<th>Raritan Inn Strategy</th>
</tr>
</thead>
<tbody>
<tr>
<td>▪ Pre-existing hidden conditions are identified late in the design process</td>
<td>▪ Identify project constraints early and accelerate the discovery of existing conditions</td>
<td>▪ Use of a seven part inspection guide to identify project constraints</td>
</tr>
<tr>
<td>▪ Typical retrofits do not account for interactions between systems</td>
<td>▪ Whole-systems thinking can be applied to the delivery processes to optimize the building for resource and energy efficiency</td>
<td>▪ Use of a process for understanding and analyzing the project as a whole</td>
</tr>
<tr>
<td>▪ Limitations of downstream systems that were not accounted for in upstream decisions</td>
<td>▪ Select the project team early and accelerate iterative design processes with design charrettes</td>
<td>▪ Interconnectivity between project members</td>
</tr>
<tr>
<td>▪ Design teams use first cost and simple payback more than life cycle cost analysis</td>
<td>▪ Comprehensively analyze life cycle cost and energy together; use deep energy savings to avoid capital costs</td>
<td>▪ Fuzzy logic decision models to account for life cycle cost</td>
</tr>
<tr>
<td>▪ Energy retrofits are not coordinated with other building system renovations</td>
<td>▪ Reap multiple benefits from single expenditures and optimize planned capital expenditures</td>
<td>▪ Perform “gut rehab” that includes on-site renewable energy</td>
</tr>
<tr>
<td>▪ Industry lacks experience with the processes and knowledge required to perform deep retrofits</td>
<td>▪ Professional education</td>
<td>▪ Hands on training and education paired with diligent management</td>
</tr>
<tr>
<td>▪ Lack of measurements of the benefits achieved in green retrofits reported by owners and tenants</td>
<td>▪ Setting effective benchmarks and measures</td>
<td>▪ Public reporting of building performance</td>
</tr>
<tr>
<td>▪ Lack of education and awareness of sustainable renovation issues</td>
<td>▪ Increase project reporting, transparency, and end-user education</td>
<td>▪ Education and training of end-users about how to properly operate the building</td>
</tr>
</tbody>
</table>
4.3. Comparison of results

Organizing the results in Table 4.1 allows for a direct comparison between the barriers and solutions identified in the literature review and the successful strategies used on the Raritan Inn case study. In comparing the results, several common themes emerged:

- **Whole-systems engineering optimizes designs that are both resource and energy efficient.** Both the literature and the strategies describe by Mr. Asdal emphasized the value of using a systems thinking approach to sustainable renovation projects.

- **Interconnectivity and collaboration between stakeholders improves the decision-making process and reduces the risk of rework.** Although the Raritan Inn project did not use a design charrette, communication and interconnectivity between project team members was a common practice throughout the project.

- **Life cycle cost and energy analysis maximize financial benefits.** The solutions offered within the literature review to evaluate life cycle cost and energy analysis were much different than the strategies used on the Raritan Inn project. However, both methods were successful in maximizing financial investments.

- **Hands on training and professional education are crucial when implementing innovative technologies and energy efficient strategies.** The literature and strategies used on the Raritan Inn project both conclude that professional awareness on sustainable renovation issues through training and education is one of the most important aspects in delivering a successful project.
● Increased end-user education on how to efficiently operate the building results in optimal performance throughout the life of the building. The literature and Mr. Asdal both recognize that the building users have the greatest influence on the energy and resource efficiency. Also, both sources identify the need for future research within this area.

These common themes found between the literature and case study confirm that these solutions and strategies are viable options for removing barriers during the delivery of sustainable renovation projects. Furthermore, the solutions and strategies that are not directly aligned show that there are many ways to remove the barriers and deeper investigation is needed to discover other methods for removing barriers.
CHAPTER FIVE: CONCLUSIONS

The conclusions resulting from this study are organized within this chapter. The purpose of this chapter is to summarize the research presented, discuss implications and limitations of this research, and present topics for future research.

5.1. Summary

Renovating an existing building in a sustainable manner is the only viable option that leads to positive implications. Even still, sustainable renovations can be one of the most difficult types of construction projects to undertake due to project constraints and barriers encountered during the delivery of such projects. Therefore, in order to investigate the issue at hand, this research poses the questions:

- What are the barriers to that need to be addressed during the delivery of energy efficient and sustainable renovation projects?
- What has previous research offered as solutions to these barriers?
- How do these solutions compare to the strategies used on a successful case study?

In order to answer these questions, the primary objectives of this research were to:

1. identify the barriers to address during the delivery of sustainable renovation projects,
2. discuss potential solutions to these barriers, and
3. contribute to the current body of knowledge by comparing solutions offered in the literature review to strategies used on a successful sustainable renovation project. The first objective was achieved through conducting a comprehensive literature review that covered sustainable construction, renovation construction, and delivery processes on a broad
level, then concentrated on barriers to innovation and success factors for sustainable renovation projects. The second objective required collection of qualitative data to discover the successful strategies used to deliver a sustainable renovation case study project.

The results of this study identified eight barriers encountered in typical renovation projects and offered solutions to overcome these barriers found within the literature review. Additionally, successful strategies used on the Raritan Inn case study to overcome barriers were discussed. In comparing these results, several common themes emerged:

- Whole-systems engineering optimizes designs that are both resource and energy efficient.
- Interconnectivity and collaboration between stakeholders improves the decision-making process and reduces the risk of rework.
- Life cycle cost and energy analysis maximize financial benefits.
- Hands on training and professional education are crucial when implementing innovative technologies and energy efficient strategies.
- Increased education, awareness, and training about sustainable renovation issues throughout all project stakeholders are necessary to deliver a successful project.

The differences found between the solutions offered in the literature review and successful strategies used on the Raritan Inn case study prove multiple solutions to effectively overcome these barriers are available. Therefore, project stakeholders must
consider all options and be flexible to the many ways in which barriers can be overcome on sustainable renovation projects.

5.2. Implications

Two primary contributions result from the research described within this report. Both contributions are related to improving the education and awareness about sustainable renovation issues throughout the construction industry.

- By identifying and consolidating the barriers into one comprehensive study, the current body of knowledge is organized and presented in a valuable manner. Prior to this research, the content of the literature review was scattered throughout individual articles and reports. With the completion of this research, the various barriers and proposed solutions are included in one encompassing report. This contribution has implications for the construction industry by increasing awareness of the barriers encountered during sustainable renovation projects. Also, this contribution is valuable to academia by presenting the need for research within this field.

- In closely examining one successful case study, this research discovers important practices and strategies that can be adopted by professionals throughout the construction industry. The comparison between solutions offered in the literature and strategies used on a successful case study provide invaluable results that can be universally applied to most construction and renovation projects.
5.3. Limitations

Importantly, when evaluating the results, analysis, and conclusions of this research, the following limitations should be considered:

- **Literature review:** The literature review only focused on journals published within the United States. Therefore in some cases, the barriers and solutions to remove these barriers may be limited to the construction methods and equipment found only within the United States.

- **Case study:** The single case study presented in this research is not intended as representative of all sustainable renovation projects and practices. A multiple case study would allow for “cross-case” analysis which may yield more wide-ranging results. Also, the Raritan Inn case study is a very unique project because Mr. Asdal served as both the owner and general contractor of the project. He also has a significant amount of experience in sustainable renovation projects and is well aware of the issues and constraints of such projects. Because of these limiting factors, this study would be hard to replicate in most projects.

- **Data collection:** Semi-structured interviews were conducted with only one project stakeholder. This research can be enhanced by performing multiple interviews with other key project participants such as individuals from the National Association of Home Builders (NAHB) Research Center who were heavily involved throughout this project. Also, these interviews were conducted
several years after the completion of the project. Therefore, the recollection of exact information may have been a limitation.

5.4. Future research

In order to assure a potential impact on the existing building stock, future research must cover a broad scope including concepts that support education and training of industry professionals and end-users, socio-economic policies and tools for promoting sustainable renovation, and enhance the role of government and other public entities to create a market demand for sustainable renovation.

5.4.1. Education, training, and awareness

This area of future research must occur in two parts. First, one of the barriers discussed in this research identifies that many professionals in the construction industry lack the education and knowledge to perform deep renovations. Multi-disciplinary research is needed to discover how to educate and train veteran and young professionals about how to efficiently and correctly perform sustainable building renovations. This research must discover methods for increasing the knowledge about sustainable renovation among key decision makers so that innovative sustainable concepts become desirable for all stakeholders. Common trades and craft professionals such as plumbers and electricians must be educated on how to properly install sustainable technologies such as tankless water heaters and photovoltaic solar panels. To ensure proper learning, the education of these professionals may require demonstration, hands on training, and even apprenticeship. Trades and craft professionals who are unfamiliar with the latest
green technologies will be less competitive in a demanding market and ultimately struggle to keep pace with the continuously evolving industry. There is a great need for a developed system or program for properly educating and training industry professionals.

The second and equally important half of this future research is the development of educational tools for the end-user. Construction professionals can only have an impact on a small portion of a building's life. Their job is complete once the final product meets the designed specifications and desired performance standards. The building end-users (consumers, tenants, occupants, etc.) are truly responsible for how the building actually performs. Their daily habits and behaviors directly influence the energy and water efficiency of a building. Currently, there is a significant gap in the knowledge and resources available to building end-users about how to efficiently operate a building. This research must measure the awareness of end-users and investigate the interactivity between building users and the energy and water usage of their buildings. Once this is discovered, the research must address the need for educational tools and techniques for increasing the awareness of building users on how to efficiently operate their building.

5.4.2. Enhancing the market through socio-economic, governmental, and financial instruments

As identified in the context of this research (see section 1.1), increasing nationwide demand for renovation of the existing building stock is evident and various incentives are in place to promote sustainable renovation. Even still, the sustainable renovation market is not operating at its maximum potential. There is a need to investigate how improved economic incentives and political instruments can be used to
remove barriers that obstruct the quality and quantity of sustainable renovations. This research must look into how the role of government and other public entities can be used to enhance the demand for sustainable renovation. Additionally, research is needed to remove the challenges owners encounter when obtaining financing during the current economic crisis. Currently, Energy Service Companies (ESCO’s) aid owners in acquiring financing for the initial investment of sustainable renovations. In return, an Energy Saving Performance Contract (ESPC) between the owner and the ESCO rewards a percentage of the savings achieved by the upgrade to the ESCO over the length of the ESPC. However, today’s ESPC tends to be long, complex, and otherwise expensive to carry out. Therefore, in order to achieve a substantial return, Energy Saving Performance Contracts and Energy Service Companies are limited to larger scale renovations with large private ventures (McGraw-Hill Editors 2009). To remove the financial and contractual barriers that owners encounter, future research must investigate the need for shorter and simpler Energy Saving Performance Contracts in order to tap into the commercial and residential sustainable renovation market.

5.5. Final remarks

Recently, the U.S. Department of Energy (DOE) reported that existing buildings nationwide consume more than 70% of electricity and over 50% of natural gas as compared to other sectors. Investing in the sustainable renovation of existing buildings will yield: cost savings for home and business owners, reductions in peak energy demand, and sustained reduction in carbon dioxide emissions. According to the U.S. DOE (2010), “By speeding market adoption of today’s proven energy-efficient
technologies and by researching new technologies that will drive up performance and drive down costs, our nation can profoundly transform the energy footprint of the built environment, and lay the foundation for a sustainable energy future.” This research, through using a literature review and a case study, has identified the strategies needed to deliver affordable, energy-efficient, and sustainable renovation projects as described above. The use of this information throughout the construction industry will contribute to the reduction of existing building’s energy and environmental footprint which, in turn, will ultimately lead the U.S. towards a more sustainable future.
REFERENCES


APPENDICES
APPENDIX A: RARITAN INN BEFORE RENOVATION

Figure A-1: Existing building conditions - front and side view (courtesy of Bill Asdal)

Figure A-2: Existing building conditions – front balcony (courtesy of Bill Asdal)
Figure A-3: Existing building conditions – front view (courtesy of Bill Asdal)

Figure A-4: Existing building conditions – rear view (courtesy of Bill Asdal)
APPENDIX B: RARITAN INN AFTER RENOVATION

Figure B-1: Raritan Inn today – front and side view

Figure B-2: Raritan Inn today – rear view
Figure B-3: Raritan Inn today – side and rear view

Figure B-4: Raritan Inn today – side view (courtesy of Bill Asdal)
APPENDIX C: INTERVIEW QUESTIONNAIRE

1. Initial interview on June 8, 2010

1.1. Please summarize the history of the project from the initial concept to building operation and maintenance.

1.2. Who were the project stakeholders and what was their initial commitment to sustainability and energy efficiency?

1.3. What were your overall goals and objectives as the owner?

1.4. Were there any barriers encountered throughout the project? If so, please describe them.

1.5. What key techniques or strategies did you employ to overcome these barriers? What were the key factors that contributed to your success on the project?

1.6. What were some important decisions you had to make throughout the project and what decision making process or tools did you use?

1.7. What techniques or strategies did you find to be ineffective?

1.8. Were there any project delays? If so, what was the cause and what would you have done differently to prevent the delay?

1.9. Please provide any additional information you may find interesting or relevant about your project.

2. Second interview on July 7, 2010

2.1. In our first interview, you mentioned that you used the Fuzzy logic model to select sustainable features such as the photovoltaic panels. Can you please describe the criteria you used for these models? Were there any other situations
where you used this technique? Did you use other decision making tools throughout the project?

2.2. Was there an optimal sequence of retrofits (e.g. improve insulation first then address air conditioning) to improve the energy and resource efficiency of the project?

2.3. Can you elaborate more on the “bureaucratic obstacles” that you encountered and how these obstacles were, as what you called them, “barriers to innovation?” How did you overcome these obstacles?

2.4. How did the current building codes interfere with your commitment to durability and performance?

2.5. Were there any change orders that affected cost, schedule, or the original design? If so, were these due to pre-existing conditions or other types of project constraints?

2.6. If you don’t mind, can you please describe the financial planning techniques that you used to evaluate the project cost?

2.7. Please provide any additional information you may find interesting or relevant about your project.

3. **Interview on November 3, 2010**

3.1. What processes or techniques were used by the project team to identify the existing conditions of the house early on in the planning phase?

3.2. The SEER case study report mentions how a systems engineering approach created opportunities for energy savings and improvements in durability and
comfort. How did the project team use systems thinking to account for the interactions between the building systems?

3.3. One barrier found within the literature review is that limitations of downstream systems that were not accounted for in upstream decisions. Was this barrier encountered on your project? If so, how did the project team collaborate to overcome this barrier?

3.4. How did your Fuzzy logic decision making models account for the life cycle cost, energy savings, and payback for certain building components?

3.5. Please provide any additional information you may find interesting or relevant about your project.

4. Interview on November 4, 2010

4.1. Can you describe a sustainable building component used on the project that reaps multiple benefits from a single expenditure?

4.2. What methods did you use for selecting and qualifying subcontractors? How did you account for subcontractors who were inexperienced with sustainable technologies and construction strategies?

4.3. What methods did you use to report the benefits achieved on your project through sustainable renovation?

4.4. As an experienced green remodeler, you were aware of the benefits of sustainable renovation before committing to the project. What advice/recommendations would you give to an inexperienced owner who has several misconceptions about sustainable renovation?
4.5. Please provide any additional information you may find interesting or relevant about your project.
Figure D-1: Noveda Technology screenshot during day time (Going green 2007)
Figure D-2: Noveda Technology screenshot during night time (Going green 2007)