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KEY FACTORS OF PRIORITIZING ENERGY RESOURCE CONSERVATION MEASURES IN A PORTFOLIO OF BUILDINGS: A LITERATURE REVIEW

Medal, Lysandra,[1,3] and Kim, Amy[2]
[1] Department of Civil and Environmental Engineering, University of Washington, USA
[2] Department of Civil and Environmental Engineering, University of Washington, USA
[3] medal@uw.edu

Abstract: Prioritizing energy efficiency retrofit efforts in buildings is ideally based on the rational objective of generating trade-offs between maximum benefit and minimum cost. However, current practices have demonstrated stakeholders' tendency to inconsistently adopt mental shortcuts that are built upon personal intuition, limited empirical studies, or heuristic decision-making strategies to prioritize energy efficiency retrofit projects. Thus, there is a need to understand the behavioral anomalies that influence energy efficiency investment decisions beyond economic considerations. This crucial step is usually ignored when developing prioritization models for energy conservation measures. The goal of the study is to synthesize the current practices of how facility resource conservation managers and other relevant decision makers systematically perceive and proceed with retrofits of large building portfolios. The study entails reviewing recent literature relevant to the prioritization strategies of energy conservation in buildings. The literature assessment revealed a systematic evaluation of factors that influence the retrofit decision-making process in buildings. The primary factors identified are upgrade costs, energy savings, and environmental benefit. However, other factors indicate the application of heuristic rules, which include project practicality, expert skills, team collaboration, occupant comfort, and social rewards. The conceptual representation that links both factors and processes is synthesized into causal-loop diagrams. Based on the obtained findings, challenges faced by the decision makers were explored when prioritizing energy conservation measures in a complex environment. The study results lead to diagnosing the interrelatedness of common and hidden decision factors to improve the organization management of energy conservation measures.

1 BACKGROUND

Buildings play an important role in the amount of energy used because they provide spaces for education, health care, working, and living. On average, Americans spend 87 percent of their time in enclosed buildings (EPA 1989). This time spent is consistent with the large percentage of energy consumed by buildings in the United States: 40 percent of total U.S. energy use, or about 39 quadrillion Btu (EIA 2016). In addition, buildings in the United States account for more than 38 percent of carbon dioxide emissions (USGBC 2009). Addressing ways to significantly reduce the energy consumption in buildings can increase energy efficiency and thereby help the environment (Holness 2009, Tryggestad 2013).

Retrofitting existing buildings could make a greater contribution to reducing energy consumption and improving sustainability in the United States than constructing new green buildings (Gultekin et al. 2013). New construction only adds or replaces a small portion of the world's existing building stock, far fewer than the many existing inefficient buildings. While retrofitting existing buildings offers a vast opportunity to address greenhouse gas emissions and energy independence more cost-effectively, retrofitting existing buildings is more complex than building new energy efficient buildings. Retrofitting requires replacement or upgrade of old building systems with new energy-saving technologies and practices. Some of the most significant issues include inflexibility in the redesign, uncertainty in economic markets and financing (Koslow 2009), technology compatibility and integration (Miller 2008), and interruption of existing occupant activities (Miller & Buys 2008, Milam 2013).

Strategies to overcome challenges in building retrofits are being addressed. Previous studies have developed optimization models to generate ideal trade-offs between reducing energy consumption and minimizing building upgrade costs and energy-related risks during the design process (Parrish & Regnier 2013) and financing process (Abdallah & El-Rayes 2016, Asadi et al. 2014, Karmellos et al. 2015). Energy-efficiency-related information portals and databases are becoming more available in the current market, driven by policy and advancement in technology (Mathew et al. 2015, Syal et al. 2014).

Despite advances in research, decision makers are still facing difficulties in prioritizing retrofit projects among many investment opportunities. There is a gap in understanding how humans conceptualize energy efficiency and conservation strategies in buildings. Current practices for evaluating and deciding upon different retrofit options lack a common process (Jones & Bogus 2010). The process of making decisions varies from conscious choices, deliberate reasoning, and rule-governed decisions, to automatic selection and intuition governed by habit, which are all difficult to control (Kahneman 2003). Yet common decision-making considerations involving energy-consuming products and services are biased toward financial metrics (Waide & Amann 2007). Including heuristic rules can more accurately capture the decision process behind intuitive actions (Wilson & Dowlatabadi 2007). In summary, existing retrofit decision tools are inadequate and oversimplified to represent the complexity of the human decision-making process, especially for owners that manage multiple buildings, sites, and tenants. A wide range of factors should be considered and analyzed to develop context-sensitive decision models. In order to do that, understanding the decision makers' thought process is fundamental.

2 OBJECTIVE

The goal of this study is to investigate how facility resource conservation managers and other relevant decision makers perceive and proceed with retrofits of building portfolios. This is accomplished by investigating the key decision factors and their interrelatedness to identify and implement energy efficiency retrofit projects. The result is expected to lead to (1) diagnosing the competing energy efficiency objectives more precisely and (2) improving the organization management of energy conservation measures.

3 METHODOLOGY

The study entails conducting a systematic review of retrofit decision-making factors and processes based on research literature. The factors and processes were further refined and represented in a causal-loop diagram. Figure 1 presents the flow of the research design process.

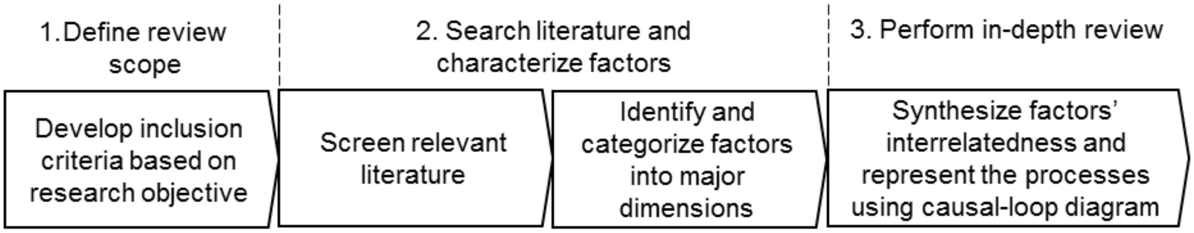


Figure 1: Research design process

3.1 Systematic Review

The systematic review characterizes literature by looking for dimensions and seeks to synthesize evidence in individual studies (Grant & Booth 2009). The scope of the study was determined with a set of inclusion/exclusion criteria to be considered relevant for identifying key factors (phase 1). These criteria were used to exclude all studies that fell outside the scope of this review. Phase 2 of the research process involved screening of relevant literature that focuses on existing buildings related to green retrofit practices and a relevant study type—such as outcome evaluations or case studies. Through the literature review, this study identified underlying factors that may affect the process of an individual or organization's decision to prioritize energy efficiency retrofits. The factors were then categorized into similar dimensions and narrowed to the most significant factors by commonalities. All sorted factors were further synthesized through in-depth review (phase 3) to find the relationships and represent the process.

3.2 Causal-Loop Diagrams

A conceptual representation of the critical factors identified through in-depth review in phase 3 is represented by causal-loop diagrams (CLDs) using the VENSIM software®. CLDs are the basis of system dynamics, which produce mental maps of the problem of interest by broadly representing the variables and feedback structure (Reddi & Moon 2011). CLDs have been used in both academic work and business practices for their ability to capture the synthesized causes of dynamics and the mental models of individuals or teams, and to communicate important feedback about a problem (Sterman 2000). Figure 2 shows the symbolic convention used to represent the CLDs in this paper.

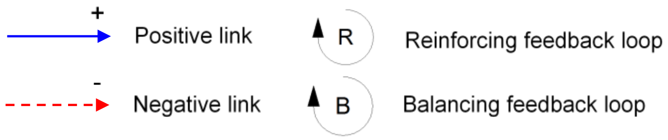


Figure 2: Symbolic convention to represent causal-loop diagrams

A CLD consists of variables connected by arrows denoting the causal influences among the variables. Variables are assigned a positive (+) or negative (−) polarity to indicate the behavior of the dependent variable when other variables change (e.g., X → Y). A positive link shows that Y would increase if X increases. Conversely, a negative link means Y would decrease if X increases. A loop identifier indicates feedback in the system being represented. The loop either amplifies (reinforcing, denoted as R) or dampens (balancing, denoted as B) the original change.

Individual CLDs were developed to depict the relationships between factors in each dimension. In order to have a more holistic view of the process, the individual CLDs were further integrated by connecting the loops to the decision output of implementing energy efficiency retrofits.

4 FINDINGS

The literature search revealed retrofit strategies to understand how decision makers perceived the need for green retrofits and factors influencing the decision makers to proceed with energy efficiency retrofit projects. These studies investigated energy efficiency retrofit decisions for various building types that were used as a case study, such as education buildings, hospitals (e.g., Buonomano et al. 2014), homes (e.g., Karmellos et al. 2015, Blaszak & Richman 2013), office buildings (e.g., Mauro 2015, Stephan & Menassa 2015), and other public and private buildings. The literature also includes technical papers and reports that discuss a conceptual framework and decision tool applicable for broader energy strategy optimization of a country (e.g., Vazhayil et al. 2012) and large organizations (e.g., Farese et al. 2012). Key factor identification involved investigating different retrofit strategies, such as building envelope, retro-commissioning, net zero energy, community engagement, and lighting upgrade.

Seventeen decision factors that influence the implementation of energy efficiency retrofits were retrieved throughout the systematic review process. The influence factors were further grouped into five major dimensions that are described in the following sections.

4.1 Dimension 1—Impact to the Occupant

Key factors categorized under the impact to occupant dimension include (1) educational programs, (2) occupant satisfaction, and (3) energy efficient behavior. Most research that used academic buildings as a case study pursued energy conservation measures as part of the institutions' goal for sustainability (Ayala 2011, Hong et al. 2012, Asadi et al. 2014, Coulter 2014, Gultekin et al. 2013, Chunduri 2014). Implementing energy conservation measures improves comfort but does not encourage occupants to adopt more energy-saving behaviors (Huber et al. 2011). Occupant satisfaction was correlated with an individual's knowledge and understanding of one's capability to control energy efficiency. These studies believed that educating the building occupants and surrounding communities will lead to behavioral changes and more energy efficiency. Measures that fall under this dimension also include factors that address occupant health and safety (Syal et al. 2014).

4.2 Dimension 2—Impact to the Environment

The key factor in this dimension focuses on carbon dioxide emissions that affect the benefit to the environment. Both public and private stakeholders shared a similar understanding about the perceived environmental benefits of conserving energy in existing buildings. Literature studies indicated the need to adopt energy efficiency retrofit strategies to minimize environmental impacts (Juan et al. 2010, Lizana et al. 2016, Karmellos et al. 2015). Juan et al. (2010) developed an integrated decision support system for building renovation that provides specific solutions for upgrading building quality in regard to sustainability criteria. Lizana et al. (2016) used the metric of environmental balance as an objective function in the multi-criteria assessment method to identify the effectiveness of energy efficiency measures. Such environmental variables included reduction in energy demand, primary energy consumption, and carbon dioxide emissions. However, only some papers considered the environmental aspect as the primary motivation for energy retrofits. Most papers considered this an auxiliary benefit. Investing in energy retrofits also offers opportunities to reduce the facilities' risk of not attaining environmental regulations. A policy perspective indicated that energy efficiency retrofits offer the most cost-effective means of addressing greenhouse gas emission reductions and energy independence (Pike Research 2010). However, retrofits in U.S. public buildings had better policy support and financing. For private owners, quantifying the benefits and cost ratio from a business perspective (e.g., cost reduction and green branding) faced significant barriers in financing due to market fragmentation.

4.3 Dimension 3—Support from Stakeholders

Factors categorized under the support from stakeholders dimension include (1) expert skills, (2) team collaboration, (3) alignment for ranking, (4) sustainable credit, (5) reputation, and (6) demand pressure. Stephan and Menassa (2015) developed a framework to effectively incorporate many stakeholders in the decision-making process of sustainable retrofit projects. The study suggests that interaction between stakeholders in highly connected networks can better achieve alignment toward a cohesive retrofit objective. Policies and regulations are part of the demand pressure, where it sets minimum energy efficiency requirements for retrofitting existing buildings. Additionally, governments that provide incentive systems to achieve a more ambitious energy performance target play an important role in the decision-making process (Fouchal et al. 2014, Syal et al. 2014, Huber et al. 2011). Community expectations are represented by a reputation factor. Clients usually target specific sustainable credits for better operations and building certification rating systems to gain superior reputation within the community and to become more attractive (Gultekin et al. 2013, Coulter & Leicht 2014). Expert skills, team collaboration, and alignment for ranking factors have connections to a feedback structure that influences the implementation of energy efficiency retrofits. In some cases, the experts' ability to provide convincing technical solutions and information about available financial aid can greatly influence decision makers' confidence. Energy efficiency retrofit projects require multidiscipline interactions during the decision process, especially for large-scale projects. Pools of experts need to work collaboratively as project teams to assess the portfolio of projects and to ensure maximum value. Highly integrated teams ensure a well-documented and coordinated change, the dependency management process needed for successful delivery of energy efficiency retrofit projects (Jallow et al. 2013), and better development for the organization’s decision support system or ranking tool (Gultekin et al. 2013).

4.4 Dimension 4—Economic Feasibility

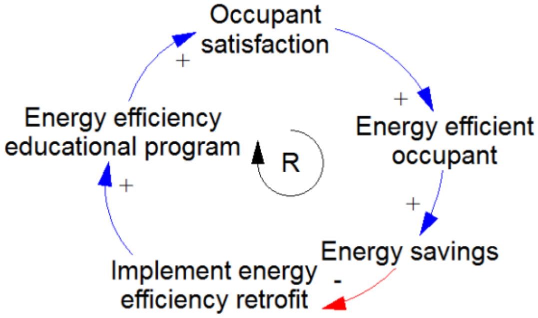
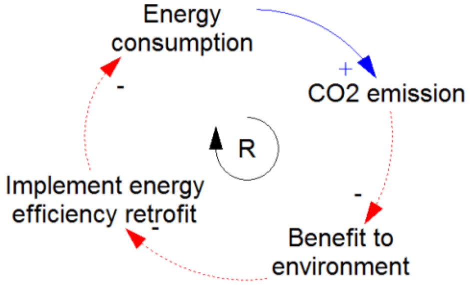
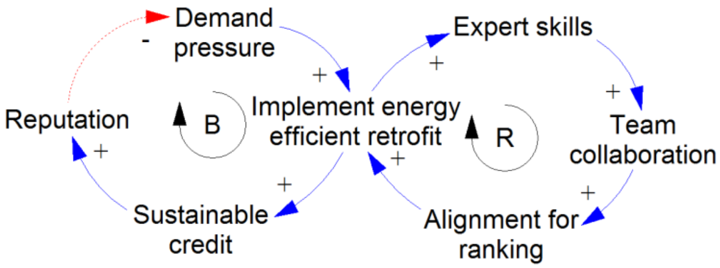
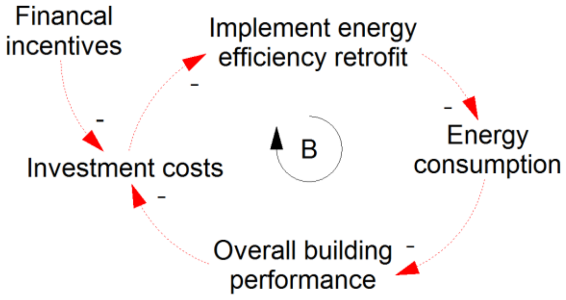
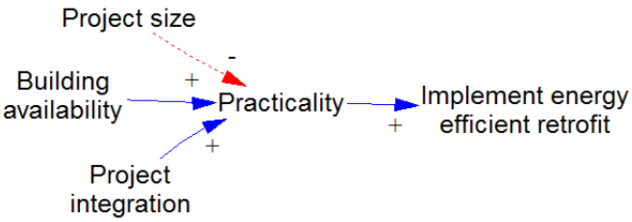
Key factors in this dimension are (1) overall building performance, (2) energy savings, (3) financial incentives, and (4) investment costs. Overall building performance involves studies that consider life cycle cost analysis (e.g., Wilson & Dowlatabadi 2007, Ma et al. 2012, Blaszak & Richman 2013, Lee et al. 2015). Chantrelle (2011) developed an optimization tool based on the building’s characteristics and performance while assessing the interactions between different objectives. The economic feasibility dimension also considers the prioritization of retrofits that reduce energy and water consumption at the lowest cost possible. Many studies investigated methods to identify energy efficiency projects using an energy savings objective (e.g., Ayala 2011, Mohammadpur et al. 2014, Hong 2011, Buonomano et al. 2014). The availability of various financial incentives, tax credit, or rebates for energy efficiency and renewable energy also drives decision makers to proceed with green retrofits. The investment costs factor refers to all considerations relevant to upgrade costs, the cost-effectiveness of retrofit measures (payback period), and risk management of project costs. In many cases, saving money was the primary purpose of retrofitting a building. Moreover, some studies assumed that the main drivers of energy retrofit projects are financial returns (Lee et al. 2015, Ham et al. 2014, Mauro 2015). These studies focused on investment cost analysis modeling for energy retrofits. Findings suggest that cost and operational practice are two energy-related factors affecting financial performance. Financial performance and energy savings criteria are the most dominating combination of objectives used to develop decision tools in assisting stakeholders achieve optimal trade-offs between energy savings and investment costs (Karmellos et al. 2015, Abdallah & El-Rayes 2016, Vazhayil et al. 2012, Mauro 2015, Fouchal 2014, Hong 2011). While a single case study building is easier to address, the decision process in a large portfolio of buildings with multiple groups of stakeholders complicates the process and increases the uncertainty. Heo (2012) presents a probabilistic methodology that can support large-scale investments in energy retrofit of buildings under uncertainty. An assessment of multiple commercial building retrofit projects recommended urgency to achieve deep energy retrofits at earlier phases (Parrish & Regnier 2013, Gultekin et al. 2013). Finally, energy efficiency investment could have direct and indirect economic benefits, including tax revenue and job generation (Pikas et al. 2015).

4.5 Dimension 5—Practicality

Three motivational factors are in the practicality dimension: (1) project integration, (2) building availability, and (3) project size. Practicality was implicitly embedded in a few studies but was not discussed in depth. This involves the use of heuristic rules in decision making, such as experience-based knowledge and other practical considerations. For example, Trianni et al. (2014) suggest that the ease of implementation of energy efficiency measures is an important attribute that influences decisions to adopt these measures. This includes the perceived amount of effort and skill required to accomplish the project. The factors in this dimension may be considered in a later phase of the decision process after performing the initial economic assessment. However, if used in meaningful ways, these factors can help eliminate many retrofit alternatives. For example, the size of the projects increases the level of difficulty, which affects how fast the project can be completed (Gultekin et al. 2013, Syal et al. 2014) and how broadly the retrofit implementation can affect the surrounding system (Fleiter et al. 2012). If the facility management team is inexperienced, then it is practical to start with smaller and less complicated projects even though they might not lead to the maximum energy savings. Practicality issues should be considered before evaluating prioritization strategies or identifying retrofit measures. This may involve analyzing immediate needs based on the existing conditions of the building and the existing occupancy condition.

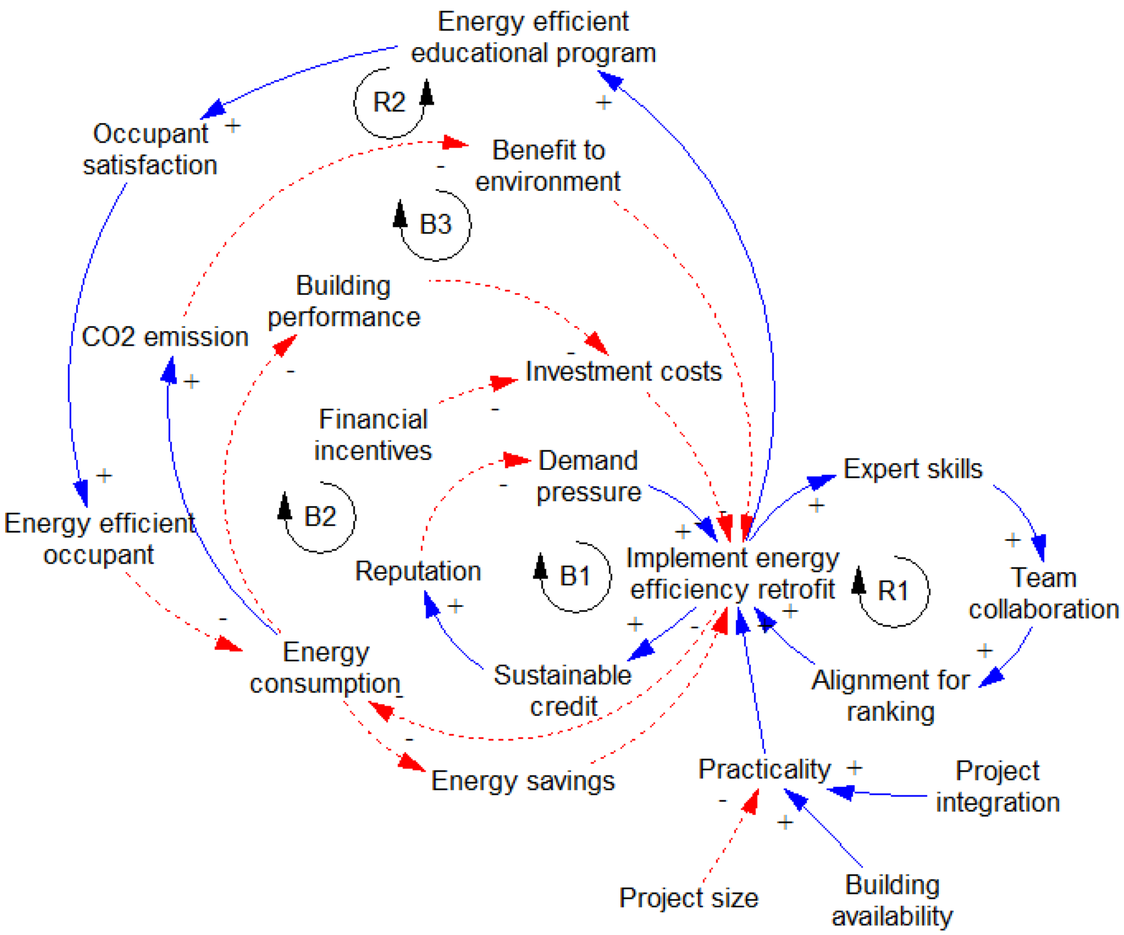
Table 1 shows the representation of each dimension using individual CLDs.

Table 1: Individual causal-loop diagram

Dimension and Explanation	Causal-Loop Diagram
1. Impact to the occupant Energy efficiency retrofit implementation requires more educational programs that will improve occupant satisfaction and change occupant behavior to be more energy efficient. An energy efficient occupant leads to more energy savings, which in turn require a less energy efficiency retrofit.	
2. Impact to the environment More energy consumption leads to increasing carbon dioxide (CO_2) emission. This has a negative impact on the environment and requires more energy efficiency retrofits to be implemented.	
3. Support from stakeholders *B loop:* lack of sustainable credit leads to lower reputation and thus increases the need to implement a more energy efficiency retrofit. *R loop:* More expert skills available lead to a more robust team collaboration, better alignment for ranking, and better implementation of retrofits.	
4. Economic feasibility Less energy consumption improves overall building performance, which leads to less necessary investment costs. The investment costs tend to correlate negatively with the implementation of an energy efficiency retrofit. More financial incentives received would reduce the investment costs required to implement an energy efficiency retrofit.	
5. Practicality A large project size increases its complexity and makes it less practical, which hinders the implementation of a retrofit. The project's practicality increases if the building is available to be retrofitted and the projects are likely to be integrated.	

5 DISCUSSION

Studies were reviewed to identify the dominating factors or objectives to pursuing and prioritizing retrofit projects. The contribution of the synthesis is in determining how the key factors fit together into a systematic framework that can be assessed holistically. This process involves determining how the factors identified relate and influence each other. The current understanding of the decision processes pertaining to energy efficiency retrofits is synthesized into CLDs as indicated in Table 1. Further, a combined CLD was developed as a preliminary conceptual representation that links both factors and processes as shown in Figure 3.



B1: Sustainable credit → (+) reputation → (−) demand pressure → (+) implement retrofit → (+) sustainable credit
B2: Energy consumption → (−) building performance → (−) investment costs → (−) implement retrofits → (−) energy consumption
B3: Energy consumption → (+) CO_2 emission → (−) benefit to environment → (−) implement retrofits → (−) energy consumption
R1: Expert skills → (+) team collaboration → (+) alignment for ranking → implement retrofits → (+) expert skills
R2: Expert skills → (+) team collaboration → (+) project integration → (+) practicality → (+) implement retrofits → (+) expert skills

Figure 3: Causal-loop diagram of decision factors

Three balancing loops and two reinforcing loops were combined into one CLD. The diagram shows the interrelated factors relevant to implementing an energy efficiency retrofit. Figure 3 shows that educating occupants will result in increased energy savings, which will reduce the need to implement more retrofits (R2). The same conclusion can be made for improving the environmental impact, where the retrofit implementation rates are expected to be lower for buildings with low carbon dioxide emissions (B3).

Growing demand for more sustainable buildings would influence the rate of energy retrofit implementation (B1). Strategies to effectively prioritize energy retrofits depend on the expert skills and team collaboration (R1) from the earlier phase of identifying energy conservation measures. A successful implementation of energy retrofits should also consider the practicality attribute that is influenced by various factors perceived by the experts. Additionally, identifying financial incentives that apply to the projects would increase the economic feasibility that drives decision makers to adopt energy efficiency retrofits (B2).

There is, however, a need to further investigate the practicality dimension, where the magnitude of the practicality implication remains unknown. In addition, the extent of potential irrational decision-making strategies performed by stakeholders is not explicitly discussed here but important. While the ideal goal is to maximize the expected benefits identified as the key factors in prioritizing energy conservation strategies, decision makers may use a wide range of heuristic rules to help simplify the technical requirements. In addition, the process of identifying, selecting, and implementing appropriate retrofits becomes increasingly complicated by the interplay between organizations holding a portfolio of heterogeneous buildings and tenants seeking a better building environment. The retrofit decision then becomes a team effort and requires iterations of discussions for better alignment of objectives.

6 CONCLUSION

6.1 Findings

The main objective of this study was to identify the decision factors of green retrofits, in particular energy efficiency retrofit selection and implementation, through the literature. Based on the findings, the underlying dimensions that emerged repeatedly are considerations of the impact to the occupant, impact to the environment, support from stakeholders, economic feasibility, and practicality. While the primary factors are upgrade costs, energy savings, and environmental impact, other factors were found. Some of these other factors include practicality (gain of usability), expert skills, team collaboration, occupant satisfaction, demand pressure, and reputation (social rewards). These factors are further represented using CLDs in order to synthesize the connection between the factors. The findings of this study are beneficial as a starting point of discussion when stakeholders are prioritizing building retrofits.

6.2 Future Research

Future research is needed to deepen the understanding of the interrelationships between identified factors both within and between dimensions. Additionally, retrofit opportunities are difficult to strategize and become even more complex for large organizations with a portfolio of buildings. Kulakowsksi (1999) suggests that energy efficiency should be seen as “a product of complex interactions between people with different values and abilities to express them through complex organizations.” While existing studies have addressed these issues, they have been limited in scope. Objective parameters have not been assessed using a rigorous human cognitive and decision-making approach. These methods have not been empirically demonstrated with more than 100 buildings to represent a city-scale approach. Solutions seldom consider the dynamics of changing requirements and ultimately lack realism. Future research should focus on defining how a group of people (i.e., teams) make retrofit decisions in a more complex environment and should demonstrate the process using a large number of buildings. Then, the performance of these strategies should be tested over time.

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