Engaging End Users in Green Building Design Software

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***Abstract*—Green building design is a socio-technical process, so it is important to engage end users (e.g. building occupants) in requirements gathering. Given that a majority of software tools used in designing green buildings are aimed at engineers, we must determine the most effective way of communicating information about energy use requirements to end users, who are typically unfamiliar with energy analysis techniques. The green building design community is at an early stage in considering how to include end users in the design process. Research has not yet determined how best to present environmental impact information to end users in order to engage them in the process. Research in green building design can benefit from the lessons learned from Requirements Engineering in the software community.**

This paper outlines an intended research methodology and a literature review. The research will involve an exploratory case study of a Toronto-based green home renovation company that focuses on a holistic building approach. By following clients through their renovation projects, we hope to explore two research questions: why homeowners renovate their homes, and how the industry currently presents information to end users about green home renovation and green home requirements.

I. Introduction

Our research is focused on engaging end users in the process of green building design. A green building is a building that is designed to be environmentally sustainable throughout its lifecycle, including construction and maintenance. This usually involves considering energy efficiency, water conservation, waste and pollution reduction, responsible materials, and other factors.

It is important for end users to be engaged in the design process because as the people for whom these green buildings are being built, they can provide a unique perspective. Thus, while green building professionals would continue to provide conceptual and detailed design and review energy analysis results, end users would provide opinions on aesthetic preferences, review products, and voice concerns about the building design as it progresses. In turn, end users receive feedback from professionals and learn more about green buildings.

This research is part of a larger project to develop a software platform for the green building design process, and the requirements analysis for this platform must involve requirements engineering with end users. Research in engaging end users in the green building design process is still in a fledgling state, and can benefit from the knowledge and practices that have developed around Requirements Engineering in the software community.

This paper outlines the intended research design for an exploratory case study of a renovation company in Toronto that focuses on green home renovation.

II. Motivation

Human-caused climate change threatens to impair our species' ability to thrive on our planet. As a society we have to find ways to reduce our negative environmental impacts, and focusing on buildings is one place to start. 20-40% of a developed country's total energy use can be attributed to buildings. Green buildings are one way to reduce our carbon footprint. One report in particular found that LEED (Leadership in Energy and Environmental Design) certified buildings used, on average, "18-39% less energy per floor area than their conventional counterparts" [1].

However, if end users are not fully engaged in the design process for green buildings, then that process can fall short in many ways, which include buildings that are not as environmentally friendly as they could be, functional requirements for the building not being provided for, and end users who are unhappy with the final product. These shortcomings can reduce enthusiasm for future green building projects.

Recent research on sustainable buildings reveals that many buildings perform worse than expected with respect to energy metrics. Many attribute this to the behaviour of building occupants [2]. One particular study concluded that "design teams were optimistic about the behavior of the occupants and their acceptance of systems" [3]. Another study suggested that energy wasted by building occupants accounts for 50% of the total energy used in a building [4]. A focus on end users can improve green building design, performance, and utilization.

A further motivation for our research is to get end users invested in the environmental performance of their buildings and provide them with the knowledge and tools to become conscious energy consumers. We hope that by educating and engaging end users in green building design, we can improve the design and performance of green buildings.

III. Literature Review

The existing literature highlights three ways in which green renovations are currently sub-optimal. The first problem is that

of uptake. The literature tries to determine why only some homeowners choose to undertake green renovations, and what the drivers are that influence whether green renovations will be undertaken. Two further problems concern those who do undertake green renovations. First, the literature considers why new green features are not used to their best effect. Second, the literature considers the consequences of green renovations often being coupled with changes that are not green-oriented.

A. Background: Measuring Green Buildings

To understand the context of the literature, one must understand how green renovations are measured. In their case study, Fay, Treloar, and Iyer-Raniga [5] evaluate the effects of using Life-Cycle Energy Analysis in order to assess sustainable residential buildings. The authors conducted a case study using Life-Cycle Energy Analysis for the purpose of assessing alternative design strategies in a green building.

The authors discuss the differences between Life-Cycle Assessment and Life-Cycle Energy Analysis. Life-Cycle Assessment is an estimate of the total environmental impact of a product, from raw materials to disposal. It takes into account energy use, non-renewable resource requirements, and impacts to surrounding ecosystems.

In Life-Cycle Energy Analysis, by contrast, an attempt is made to account for all energy inputs to a product - not only the direct energy inputs, but also all indirect energy inputs related to the manufacturing process. A common criticism of this approach is that the only measure of environmental sustainability it considers is energy efficiency. This analysis is not meant to replace methods like the Life-Cycle Assessment; its purpose is to aid in deciding between energy-efficient alternatives.

The Life-Cycle Energy Analysis calculates the embodied energy and the operational energy of a building. Embodied energy is the sum of all of the energy that went into creating a product, including transportation and resource extraction. Operational energy is the energy used while the product is in operation. For a building this would be the energy used in heating and cooling, lighting, or cooking.

The paper explains that there are tradeoffs between embodied energy and operational energy over the anticipated life of a building. Life-Cycle Energy Analysis allows a comparison for decision-making. The example given is insulation; while it has a high embodied energy cost, it provides savings in operational energy over time. Being able to calculate the payback period for this tradeoff is useful for making decisions about green buildings.

The findings from the study suggest that renovating an existing building is preferable to new construction as renovation saves the embodied energy cost associated with new buildings.

B. Reasons for Undertaking Green Renovations

Despite energy-efficient building renovations being cost-effective when regarded from a life-cycle standpoint, they are still being undertaken at relatively low rates. In his paper, Jakob [6] discusses the factors affecting home renovation decisions. The author considers economic, legal, and technical frameworks, and conducts a survey on homeowners to assess their perception of the aforementioned frameworks.

The author suggests that understanding legal and economic drivers promoting (or preventing) green renovations is vital to defining policy that will encourage these renovations. It was found that sustainable renovations are not triggered by the conditions of the building. For example, while energy-efficient window replacements can be done to most types of buildings, it is also true that these buildings can be lived in quite comfortably without the improvements.

Analysis revealed that one barrier was financial, as home renovation can demand a high upfront cost. Another barrier was awareness - when asked whether or not owners would add insulation to their homes, many stated that insulation was "not necessary". This implies that raising awareness and providing information is vital. In terms of green renovations, it was found that energy-efficient considerations were triggered by general renovation activity, such as extensions to the home. This suggests that part of the key to improving outcomes may be to learn how to interest homeowners in green renovations for their own sake, not as part of a general renovation/extension. This could lead to more green renovations, and also perhaps ones that a) do not lead to non-environmentally-friendly home expansion, and b) have total investment by owners in the positive environmental impacts of the changes, making it more likely they will learn how to make the most of new green features.

C. Why Are New Green Features Not Used to Their Best Effect?

Stokes, Mildenberger, Savan, and Kolenda [7] analyze the barriers to energy conservation behaviour. In studies of behaviour campaigns, it was found that despite training and information, participants generally do not maintain behavioural changes. Significant behaviour change is not observed, even if participants gain new knowledge or change their attitudes. The authors suggest that this is due to a "reliance on a misguided assumption that simply providing information can shift attitudes, and as a result, behaviors."

Maller and Horne [8] argue that one cannot hope to make fundamental changes to behaviour solely through the presentation of information. The authors suggest that there is a need for policy that "encourages 'practice' as opposed to 'behaviour' change." Current policy places too strong an emphasis on changing behaviour without considering a systems view. They suggest that a purely technical focus on building performance over-simplifies occupant behaviour. Assumptions are made based on aggregate data, and occupant preferences are usually not taken into account. This can have negative impacts on energy use and occupant satisfaction.

Vlasova and Gram-Hanssen [9] find that taking into account everyday practices of households can help reduce consumption. The study follows three projects: a do-it-yourself case, in which the family who lived in the house completed the designs and carried out the retrofit; a commercial case, in which a

contracting company was involved; and a project which was initiated by a municipality. The authors conclude that the do-it-yourself project and municipality project were "able to include feedback loops from the everyday practices of those living in the house."

Based on these results, the authors recommend that "policy focus has to switch from solely being on efficient technology to acknowledging the significant connections between the technologies and the everyday habits." They suggest that encouraging dialogue between energy advisors and end users is the best way to support these connections.

Chappells and Shove [10] argue that instead of determining the most efficient ways of maintaining comfortable temperatures in homes, we should be challenging the ideas of comfort and similar attitudes. Similarly, Maller, Horne, and Dalton [11] suggest that we should challenge social practices that are energy and water intensive, such as ideas of cleanliness convenience.

D. Contradictions between Knowledge and Practice

Maller, Horne, and Dalton [11] explore the narratives around environmental sustainability and how these shape attitudes towards green renovations, especially from the point of view of the those living in the homes being renovated. They discuss incentives set up by governments and environmental organizations intended to encourage individual citizens to make sustainable renovation choices. These incentives generally come in the form of rebates or other financial incentives, but other benefits include saving money on energy bills, improving health and air quality, and protecting the environment.

Their focus on the daily routines and home aspirations of residents provides a unique perspective to the concept of green home renovation. The paper focuses on people who are committed to environmental sustainability, and to what extent this narrative plays into their housing renovation decisions.

They conducted interviews with several households who were undertaking a green renovation. Specifically, they explored two main renovation domains: "(1) bathrooms and the practices of bathing and showering; and (2) kitchens and adjoining living areas and the practices of cooking, socializing and entertaining." Several examples are given of households that want their home to reflect their values of sustainability, but whose actual renovations are counter to this narrative. For example, most renovations increased floor size and added rooms. The authors conclude that using the narratives of environmental sustainability in green renovations is not an effective way to reduce consumption in a home.

Every household has specific daily routines to consider, and aspirations about their ideal home, and this can sometimes conflict with green decisions during a renovation. The authors suggest that a cultural shift is required in order to improve sustainability practices in the industry. This shift would encourage responsible resource use, promote a sharing economy, further the idea of households as producers of energy and resources, and re-think energy-intensive social norms. The authors propose that policy-makers should reflect on the daily routines and aspirations of households in order to encourage sustainable renovation practices.

The findings by Maller and Horne [8] indicate that, despite their passionate stance for protecting the environment, homeowners often made renovations that were counter to the sustainability narrative, such as increasing floor size or adding a pool. This suggests that while one may have genuine concern for the environment, it takes a back seat to daily routines, practices, and the evolution of housing design.

Homeowners tend to engage in contradictory practices. For example, one homeowner expressed that she was in the process of installing a front loading washing machine because "[i]t uses less water and less power and is better on your clothes." Later in the same interview, this same homeowner expressed the desire to get a swimming pool. Despite these two ideas being contradictory (wanting to use less water on the one hand, while desiring an item that is very water intensive on the other), many homeowners do not experience cognitive dissonance, perhaps due to not recognizing the contradictory nature of their beliefs.

Connolly and Prothero [12] examine green consumption generally, and how consumers relate to environmental issues. Many instances of contradictory behaviour are noted in this study as well, such as one participant who called himself a radical environmentalist, but who flew regularly.

The authors present an interesting idea that individuals feel personal responsibility for global environmental problems, and therefore feel empowered to make changes. But as consumers, they face doubts about which choices they should make. While this sense of empowerment accompanied by doubt and insecurity may seem dichotomous, the authors suggest that these feelings are linked; the feelings of confusion are a result of the feeling of personal responsibility and duty. This provides an interesting consideration for our research as we are examining individuals who are undertaking green renovations. These are individuals who presumably feel a personal responsibility to make green choices in their own and their families' lives, but feel overwhelmed or confused by the choices they must evaluate, especially if they are unfamiliar with the area of home renovation.

The literature in this area suggests that there are three ways in which green renovations are not ideal. The first is that uptake is very low, considering the fact that energy-efficient renovations are cost-effective from a life-cycle point of view. One of the reasons for this is low awareness. Where green renovations are undertaken, they are usually done as part of general renovation activity, and not for their own sake. This usually means that while certain green features are included, users are also opting for changes that increase the home's environmental impact, such as making the home bigger. Furthermore, those green features that are added in the renovation are not used to their full effect. The mere conveying of information about green features and practices does not cause users to change their behaviour in environmentally friendly ways, and so an attempt to address any of these three issues must go beyond simply presenting information.

Since the literature indicates that information alone does little to encourage green behaviour, providing information must be used as part of a participatory design process.

Carroll and Rosson [13] claim that participatory design combines two ideas about design. The first is a "moral proposition", which states that "users have a right to be directly included in the process of design." As the people for whom green buildings are being built, end users should be involved in the design process. The second idea about design is a "pragmatic proposition", which states that "directly including the users' input will increase the chances of a successful design outcome." This can be thought of in terms of the participatory design framework proposed by Sanders, Brandt, and Binder [14], specifically:

1) "probing participants",
2) "priming participants in order to immerse them in the domain of interest",
3) understanding participants' current experiences, and
4) generating "ideas or design concepts for the future."

Carroll and Rosson suggest that these two ideas about design are radical in that they challenge commonly-held beliefs about the role of a designer as a professional. When considering green building design, there are already many different types of professionals who work together, such as architects, engineers, energy analysts, and construction crews. Given that building design in general is a well-established industry with well-defined and rigid roles, green building design teams would benefit from the new perspectives that participatory design offers.

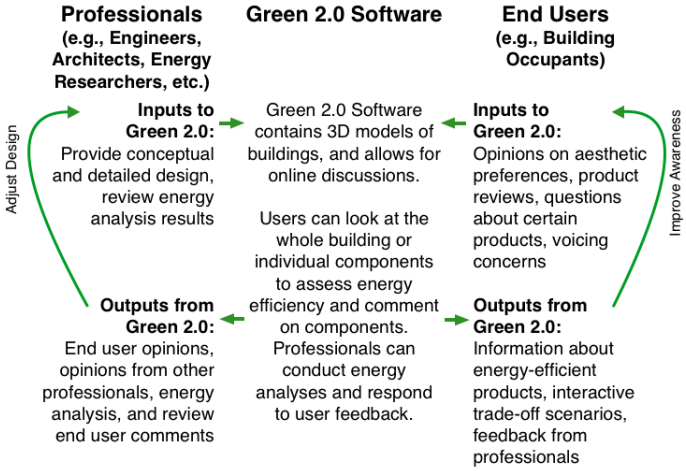
What emerges, then, from the literature is that the potential environmental benefit of green renovations is far from being met because, in spite of the technical building advances that are available to reduce a home's environmental impact, we have not learned how to effectively engage the end users of green buildings. The literature highlights three metrics by which the effectiveness of end user engagement can be measured: the extent to which it induces home owners to take on green renovations, when they otherwise would not [6]; the extent to which it causes end users to prioritize the green aspect of their renovation, rather than coupling it with other home alterations that undermine the environmental effect [8, 9, 12]; and the extent to which it enables end users to optimize the green impact of the concluded renovations [13].

Given the above literature review, our research aims to target a theme common to all these problems, which is how to engage end users in the green building design process. If there can be improvements to the current standards of green renovation projects, especially as they relate to end users and requirements elicitation, enthusiasm for and performance of green buildings will increase.

IV. The Green 2.0 Project

The Green 2.0 project is being advanced by a large, transdisciplinary research team that includes researchers in the disciplines of civil engineering, business, social studies, and computer science. It seeks to bring green building professionals (e.g., architects, engineers, construction crew, energy analysts) and end users together in a social platform that enables socio-technical analytics of green buildings. See Figure 1 for more details.

Fig. 1. A description of the Green 2.0 project.



One of the intended results of this platform's use is to reduce the problems with existing design processes that have been identified by many exasperated customers, including customers who happen to be software engineers. In 2001 Wieringa [15] wrote a Viewpoint article about his experiences with house building and renovation. In it, he identifies a problem with coordination of specifications. For example, some builders do not read specifications, but build the way they normally do. In one instance he found a builder using an outdated version of a specification. He compares bad house engineering to bad software engineering - "Both are examples of bad systems engineering." He also points out a problem with communication and coordination, as there are so many parties involved in building or renovating a house.

Wieringa also brings up the problem of specifications not being understood by users. Berry [16] also identifies this problem in his own Viewpoint from 1998. Berry lists elements of similarity between house and software requirements engineering, including:

- "the importance of the client understanding the plans/ specifications in validating that the plans/specifications capture his/her intent"
- "the usefulness of a model/prototype in the client's understanding of the plans/specification."

The developments that have been made in Requirements Engineering in the software community are very relevant to this application. For example, engaging users by using multiple approaches to requirements elicitation, or using goal models for exploring trade-offs. This can also be extended into a participatory design framework, as discussed by Sanders et al. [14]

The goal of the Green 2.0 project is to solve the issues common to building design. Because the proposed platform

hosts engineers, architects, construction crews, energy analysts, and end users, coordination and communication is done in one place. Specifications are updated for all to see, so there is no risk of using an outdated copy. The social aspects of the platform present information to end users, which has a beneficial impact on customer acceptance. Research suggests that when people are presented with visual information on an environmentally beneficial practice, such as using recycled water, they are more likely to buy in to that practice [17]. It is therefore important to think about how information about green buildings is presented to end users in order to engage them in the process, which is the motivation behind our research.

V. Research Design

This section will outline the proposed research design for the case study.

A. Research Questions

There are two research questions in this study:

1) **Why do homeowners renovate their homes?**
   We suspect that there are a variety of reasons people choose to renovate their homes (e.g., aesthetic improvements, health impacts, to save money on energy bills). But do these reasons differ for those who choose green renovations? Are people who opt for green renovations more environmentally conscious? Are they familiar with the language commonly used when discussing sustainability? Will their information requirements differ from those who choose a traditional renovation?

2) **How does the industry currently present information to end users about green home renovation, and what is missing?**
   We hope to determine the effectiveness of the various methods of presenting information to end users. For example, if a customer wants to save money on energy bills, how is the return on investment presented? When selecting materials such as floors or windows, how are the tradeoffs between aesthetics, price, and sustainability shown? Do end users easily understand the information being presented to them, and how does the information influence their decision-making process?

B. Case Description and Unit of Analysis

To help answer these research questions, we will conduct an exploratory case study on a renovation company in Toronto that focuses on green home renovation. This company's mandate is based on a holistic building approach, with the goal of minimizing the environmental impact of renovation. Through observation and a series of interviews, we hope to follow a renovation project from inception to completion. The unit of analysis will be pieces of information given to the client, such as reports or graphs. By conducting interviews with the client at regular intervals throughout the project, we hope to determine the effectiveness of each piece of information.

Given that this is an exploratory case study in an area that is currently not very well understood by software engineers, we suspect that more questions will emerge from the data, and that this study could lead to larger projects in the future.

C. Data Collection and Analysis

Data collection methods for this project will mostly consist of interviews with clients of the green home renovation company being studied, spread out over the course of the renovation project. At the project's inception, we will conduct an open-ended interview with the clients, with a focus on the information that they received. As the project progresses, we will check in with the clients to see how they feel about the information they received at the beginning of the project, and any new information they received. At the end of the project we will conduct a retrospective interview, to find out which pieces of information were ultimately useful, if there is any information that was missing, or if any improvements could be made to the way the information is presented.

Although the focus at this point is on information, we hope that through the open-ended interviews, new data will come to light that will prove interesting.

VI. Conclusion

The urgency of bringing our species' energy consumption under control is great, but potential energy savings in buildings, which account for such a significant share of energy use, are being lost even in what are intended to be green buildings, due to a lack of common ground between building end users and all those involved in designing and constructing buildings. The interdisciplinary Green 2.0 project aims to close this gap between the vision for green buildings and their execution, by creating a platform for all parties involved in the building, from design to end-use, to communicate with each other. As a preliminary step, the proposed case study of a green building company in Toronto will elucidate how end users currently receive information about their buildings during design and construction, and how such information can be more effectively communicated in order to improve ultimate energy use.

Acknowledgment

We would like to thank CANARIE for their support of this project.

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