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Innovation in Green Building Projects: An Exploratory Inquiry

Tayyab Ahmad

Department of Civil and Environmental Engineering, Qatar University, Doha P.O. Box 2713, Qatar; tayyab@qu.edu.qa

Abstract: Green building (GB) projects, although being developed and operated for more than two decades, may still be regarded as innovative. To address the socio-environmental challenges of the built environment, GBs need to continuously innovate. A comprehensive account of the innovation frontiers and factors affecting GB project innovation is missing in previous studies. In this study, for an in-depth understanding of what makes these projects innovative and how to create an enabling environment for their innovation, semi-structured interviews with 45 GB experts from six regions were conducted. Innovation in GBs was found to be a function of the GB idea, constituent building technologies, potential performance, and the project development process. Key frontiers where innovation in GB projects is needed include environmental performance, health and well-being, and the resolution of mutually contradicting project aspirations. The study also identified some factors contributing to innovation in GBs, which are primarily related to support from the government, client, and project team; availability of time and budget; scalability of innovative solutions; and nature of the construction industry. A nexus between green certifications, sustainability, and innovation is also explained. The awareness and understanding of industry experts regarding GB project innovation will add to the theory of GB projects and green innovation, and will help stakeholders to create a more enabling environment for innovation.

Keywords: green building; innovation; interviews; frontiers; regulations; certifications

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1. Introduction

To mitigate the environmental effects associated with typical building construction and operation, green buildings (GBs) have been proposed, which tend to be much more environmentally friendly, socially habitable and economically affordable in the long term [1–3]. The emphasis of GB projects on socio-economic and environmental aspects results in their increased market demand [4]. Owing to the atypical goals, outcomes, and deliverables of GB projects, they stand at the forefront of innovation. The high socio-economic and environmental performance of these projects is a result of continuous innovation. Moreover, to increase development of GB projects in the construction sector, scientific and technological innovation in this area is of utmost importance [5]. Due to its importance in GB projects, innovation has been considered a critical factor contributing towards the success of these projects [6–8].

Green innovation and the related gain in resource productivity is indispensable for reducing environmental impacts, reducing costs, enhancing product quality, and increasing global competitiveness [9,10]. Innovation is of utmost importance in progressing the agenda of sustainable development and it contributes greatly to the development of green building practices [11].

1.1. Green Buildings as Innovation

Innovation is the actual use of a nontrivial change and improvement in a process, product, or system that is novel to the institution developing the change [10,12,13]. Innovation can also be conceptualized as the generation, development, and implementation of ideas that are new to an organization and that have practical or commercial benefits [14,15].

In a construction firm, the first use of a certain technology can also be considered to be innovation [16,17]. It is important to note that the different conceptualizations of innovation specify it as the application of a nontrivial idea within a process, product, or system; the idea itself is new for the organization developing or applying it; and the application of the idea results in certain benefits. In reality, for different sectors of the construction industry, innovation is a fairly regular process, although generally it may be "perceived" as a rare occurrence for this industry [12].

While invention implies something that has not existed before, innovation corresponds to something which, although already existing in a context, has been reintroduced with suitable variations for a new context. According to Slaughter [12] "in contrast to an invention, an innovation does not require a detailed design or physical manifestation, and it does not have to be novel with respect to the existing arts, but only to the creating institution. While an innovation could also be an invention, an invention is not an innovation unless it has actually been used". In this regard, even the earliest form of GBs may qualify as innovation and not as invention. This is because most of the principles of GBs are embedded in vernacular architecture, which has materialized as the earlier form of buildings that behave in some aspects as "GBs", but are not known as GBs.

While innovation is about generating novel concepts, designs, or solutions to address the existing problems, diffusion of innovation refers to the spread and adoption of an innovative idea, product, or technology within a social system or market. GB projects qualify as a case of "innovation", as well as a case of "diffusion of innovation".

1.2. Research Aim and Objectives

An understanding of what makes GB projects innovative and how to create an enabling environment for their innovation is critical for the theoretical underpinning of GB project development. Such an understanding can be enabled by investigating the viewpoint of industry experts regarding GB innovation. Previous studies are lacking in terms of providing a comprehensive understanding of the areas of development/progress where innovation in GBs is taking place (i.e., innovation frontiers) and factors driving or hindering GB innovation.

To understand GB innovation from the standpoint of industry experts, it is necessary to know why they think GBs are innovative and what makes GBs innovative. These questions have resulted in the objectives of this study. With the aim of contributing to the understanding of GB innovation, the study has the following objectives:

- To identify the various perspectives of explaining innovation in GB projects;
- To identify the frontiers of innovation in GB projects;
- To identify the factors affecting innovation in GB projects.

While the understanding of innovation perspectives (Obj-1) will help evolve the theory of GB projects, the understanding of frontiers (Obj-2) and factors affecting GB innovation (Obj-3) will help the project stakeholders and decision makers create a more enabling environment for the innovation of GB projects. The structure of this paper is such that first, the relevant literature regarding the subject matter is discussed. This is followed by research methodology. Afterwards, results and discussion are presented, including the perspectives for seeing innovation in GBs, frontiers of innovation in GBs, factors affecting GB innovation, and a framework explaining the interrelationship between innovation, sustainability assessment systems, and project sustainability. Lastly, the conclusions of the study are presented.

2. Literature Review

Green innovation, also known as sustainable innovation or eco-innovation, refers to the development and application of new ideas, technologies, products, processes, and business models that have a positive impact on the environment and promote sustainability [18]. Green innovation is crucial for addressing environmental challenges, combating climate change, and achieving a more sustainable and resilient future. It typically requires

a combination of technological advancements, policy support, and changes in consumer behavior to be successful [19]. Some of the key areas of green innovation include renewable energy, energy efficiency, circular economy, sustainable agriculture, green materials, sustainable construction, GBs, and smart cities. Green innovation can be segregated into technology- and management-related innovation [15,17]. The former is about adopting construction safety, advanced information technology, new materials, renewable energy, and resource conservation. However, the latter is related to innovation in management ideas and achievement of sustainability by changing "traditional construction values" and methods of design, construction, manufacturing, operation, and maintenance [15,17]. GBs are a prime example and part of green innovation [6], which demonstrate how innovative design and technology can be applied to create structures that are environmentally responsible, energy efficient, and conducive to human health and well-being.

Studies have been conducted regarding enabling factors (that is, drivers) and disabling factors (that is, barriers) of green innovation across various disciplines and application areas. In terms of the drivers of green innovation, studies have been conducted for the construction industry [20], manufacturing industry [21,22], and hotel industry [23], to name a few. In terms of the barriers to green innovation, studies have been conducted for manufacturing industries [24–26], the automotive industry [27], and the construction industry [28]. While these studies have addressed drivers and barriers of green innovation in different sectors and disciplines, there is generally a lack of studies focused on factors affecting innovation in GB projects.

While there is a general lack of studies investigating innovation in GB projects [29], some studies have explored the subject of GB innovation from different viewpoints. Wang, et al. [30] investigated how different organizations such as design consultancies and local government work together to promote GB innovations. For this purpose, secondary data from 223 projects receiving Green Building Innovation Awards (GBIA) in China were analyzed. The study showed that State-owned enterprises have occupied the largest portion of GBIA. Moreover, it showed that the consulting enterprises, rather than design institutes or universities, are inclined to act as "bridges" during the innovative collaboration process. While this study is indicative of organizations driving GB innovation, there are also other factors that affect GB innovation. A study by Siva, et al. [31] is relevant in this regard, which explored the conditions that enable and obstruct GB innovation in the case of Singapore. The study showed that among the driving forces for innovation, the key role was played by the commitment from the national government. The government facilitated GB innovation by developing an integrated strategy to support GB innovations (i.e., the Green Mark policy scheme), implementing support policies, and setting up test beds. Some key barriers preventing the large-scale uptake of GB technology in Singapore were identified as (1) inflexible habits and mindsets of end-users; (2) the main push for GBs coming predominantly from the government; and (3) ineffective inter-actor collaboration.

Among other organizations, green certification organizations and government agencies primarily contribute to innovation practices. For instance, LEED (i.e., Leadership in Energy and Environmental Design) certification from USGBC (United States Green Building Council) plays a vital role in influencing the diffusion of GB innovations [32]. Moreover, performance-based regulations have a potentially positive effect on facilitating construction innovations [33]. Mollaoglu, et al. [34] considered GB guidelines and assessment systems (such as LEED) as innovation in the AEC industry. This study helped understand the diffusion of GB guidelines as innovations in the AEC industries of Indonesia and Turkey. The study showed environmental groups as innovators, large business houses as early adopters, and nodal agencies as the early majority when diffusing GB guidelines as innovation. Clients and market conditions were also found to play a significant role in the diffusion of this innovation.

Innovation is contextual in nature and the studies on GB innovation have been conducted for the regional contexts of China, Singapore, Turkey, and Indonesia. While the aforementioned studies provide detailed accounts of different factors related to GB project

innovation, they do not provide a comprehensive account of the innovation frontiers and factors affecting innovation. The highlighted gap in the knowledge domain of GB innovation is addressed by this study.

3. Methodology

3.1. Research Design

According to Lizarralde, et al. [35], innovation is a subjective perception of the emergence and adoption of changes that provide value to a variety of stakeholders. This definition rejects the notion that innovation is an objective attribute of the product or the process, emphasizing its subjective character and connecting its legitimacy with the value that stakeholders perceive. The study design is influenced by epistemic relativism, which posits that knowledge, truth, and rationality are relative and context-dependent rather than universally objective. This study employs subjective relativism, a part of epistemic relativism, which asserts that truth and knowledge are determined by the individual's subjective experience and perspective. The use of subjective relativism can open new avenues for the less investigated research areas such as "GB innovation", which is still in its exploratory stages and can benefit from the qualitatively driven approach.

Since GB innovation is a technical area of inquiry, only industry experts related to these projects are considered from a relatively large pool of GB stakeholders, which also comprises building occupants who use such facilities but lack the technical knowledge. As a GB project has a variety of industry experts involved, a constructive and comprehensive inquiry of "GB innovation" should ideally represent the views and expectations of experts with different technical roles. The use of subjective relativism in this study helped incorporate the variety of perceptions of GB experts, hence providing a comprehensive rationalization of the subject matter. An important aspect of this approach is the collection of experts' opinions from in-depth interviews, relying on the "richness" of words instead of quantitative indicators only. While interviews are a preferable mode of data collection for exploratory studies, questionnaire surveys are more suitable for explanatory studies. Since this study is primarily of an exploratory nature, driven towards the identification of innovation perspectives and factors, semi-structured interviews are a preferable mode of data collection, and therefore, were used in this study.

3.2. Sample Size for Interview-Based Data Collection

When using purposive sampling for qualitative research, as in the case of this study, the sample size is often determined by data saturation. Saturation is a state when the collection of new data does not shed any further light on the issue under investigation [36–38]. As the analysis begins to take shape, it is important for the researcher to become more disciplined and cut data where necessary. Even though a larger sample may seem like a relatively safe approach, a very large number of respondents can hinder the researcher's ability to provide "in-depth" findings and miss the opportunity of obtaining an understanding of each respondent [39]. Regarding saturation, Guest, et al. [40] suggested that 12 interviews are enough for most research studies aiming to understand the common perceptions and experiences among a group of relatively homogeneous individuals. However, 12 interviews may not be enough for studies in which the domain of inquiry is diffuse or vague and participants are relatively heterogeneous. In this study, interview participants were heterogeneous, i.e., belonged to different professional roles, had varying experience of GBs, and had been working in different regions. As a result, a reasonably large sample size of 45 GB professionals was used for interview-based data collection. This sample size is larger than the samples used by other studies conducted on GB project innovation. For instance, Siva, Hoppe and Jain [31] used 11 interviews, Herazo and Lizarralde [41] presented the findings of 19 interviews, and Jain, et al. [42] used 25 interviews.

3.3. Attributes of Interview Participants

Interviews with subject matter experts were conducted in Australia (n = 14), the UK (n = 11), Singapore (n = 8), the UAE (n = 6), Hong Kong (n = 5), and Pakistan (n = 1). Semi-structured interviews were deliberately conducted with GB experts from different regions to develop a richer understanding of innovation in GBs. The interview participants had primarily worked in GBs as sustainability consultants and managers (n = 27), design consultants (n = 15), engineering consultants (n = 7), and sustainability experts with builder organizations (n = 3) (see Figure 1). Two interview participants had been mainly employed in government departments, and the majority of participants had been involved in publicly funded projects alongside private projects. Hence, the findings are based on both public and private sector viewpoints. As shown in Figure 1, 38 out of the overall 45 participants (i.e., 84%) had experience of 6 or more years related to GB projects. Years of experience of participants in GBs is particularly relevant for the study topic since more experienced participants have a better understanding of the historical trends of GB development in a region and are therefore more informed about the concept of innovation in GBs. A high degree of richness, reliability, and credibility of the study findings was ensured by conducting interviews with a relatively large number of participants, belonging to 6 regions with different trends in GB development; belonging to 7 different professions with relatively different insight of GBs; and having varied experience of GBs in terms of number of years. Face-to-face interviews are the best choice when participants are geographically accessible to the researcher (Given, 2008), as it allows the researcher to have more control and access to rich information. Accordingly, the majority of interviews were conducted in person (n = 37) and some (n = 8) were conducted over the telephone.

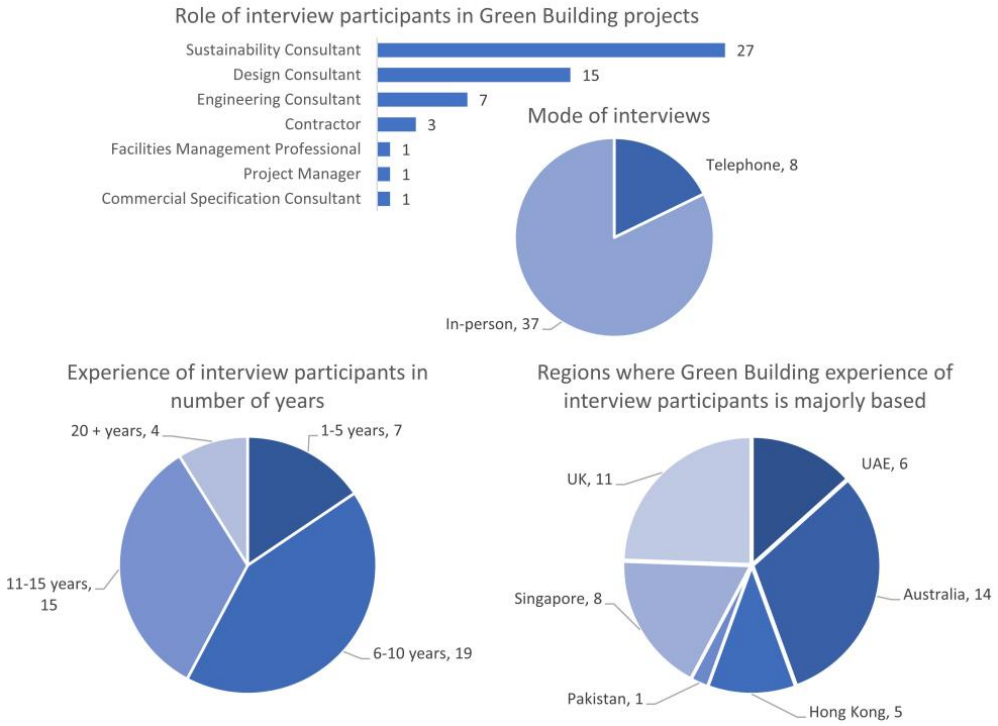

Figure 1. Role and experience of interview participants in green building projects.

3.4. Analysis of Interview Findings

The semi-structured interviews included a list of topics requiring in-depth discussion from the participants. Interviewees were asked if GB projects were innovative and, if yes, then why, or, if no, then why not. They were also asked what made GB projects innovative, whether the GB projects in their local contexts were innovative, and what affected innovation in GB projects.

The interview data were analyzed using content analysis and thematic analysis. Thematic analysis comprised identifying, analyzing, and reporting themes and was used to classify the findings into groups and categories. In the thematic analysis, codes occur at a primary level and categories or themes occur at a secondary level. Themes are based on the analysis of codes rather than of data [43]. For this study, the interviews were manually transcribed by the researcher and then coded in NVivo 12, a computer-based application which can systematically code large qualitative datasets [44]. From the codes manually developed using the NVivo 12 application, themes emerged, which were further analyzed and reported. Both the thematic analysis and coding process informed each other in a cyclic process. The coding for thematic analysis was also used to conduct content analysis.

Considering the usefulness of content analysis for this research inquiry, it has been adopted in addition to thematic analysis. Content analysis is a research technique used to make replicable and valid inferences by interpreting and coding textual material. Content analysis was used in this study to transform qualitative data into quantitative data. Content analysis helped conduct frequency analysis (that is the number of times a factor has been indicated across multiple interviews) and create a factor network.

For the discussion of interview findings in this study, verbatim descriptions of participants' discourse are provided. Participants are referred to by unique IDs which can be used to refer to the information regarding the experience, professional role, and regional location of interview participants, as shown in Appendix A.

4. Results and Discussion

Findings from the semi-structured interviews are presented and discussed in this section. The perspectives of seeing innovation in GBs are presented first, fulfilling the first objective. Then the frontiers where innovation in GBs is happening now and will happen in future are presented, fulfilling the second objective. Subsequently, the factors contributing to GB project innovation are presented, fulfilling the third objective. Lastly, the interrelationships of sustainability, GB certifications, and innovation are explained.

4.1. Perspectives of Seeing Innovation in Green Buildings

The concept of sustainable development and GB projects is not new and dates back to the 20th century; therefore, the concept of sustainable development and GB projects may not be recognized as innovative. However, the expectations from GB projects are changing and, in essence, increasing with the passage of time, and therefore requiring innovations in design approaches, building system technologies, and project development processes. In essence, GBs involve the use of innovative processes, products, and materials [10].

In the face of new expectations, as well as the changing technology and approaches of delivering better performing GB projects, innovation in GB projects can borrow multiple viewpoints. As shown in Figure 2, a GB project is considered innovative by industry professionals if it meets either of the four criteria i.e., the concept of GB development is new in the context where a project is being developed, technologies/systems being used in the building are innovative, processes used for building development are innovative, or the level of performance of GB project is so high that it is considered innovative. Innovation in GBs is perceived as not only a function of the product but also a function of the process; as one interviewee (UK-M-7) put it, "the way people deliver such buildings can be innovative and the outcomes can be innovative, if the focus is on the outcomes." Innovation as a property for construction projects can be treated as a continuous rather than a binary variable and a project can be anywhere on a range of the innovation variable depending on the technology, process of development, region of development, and the team developing the project.

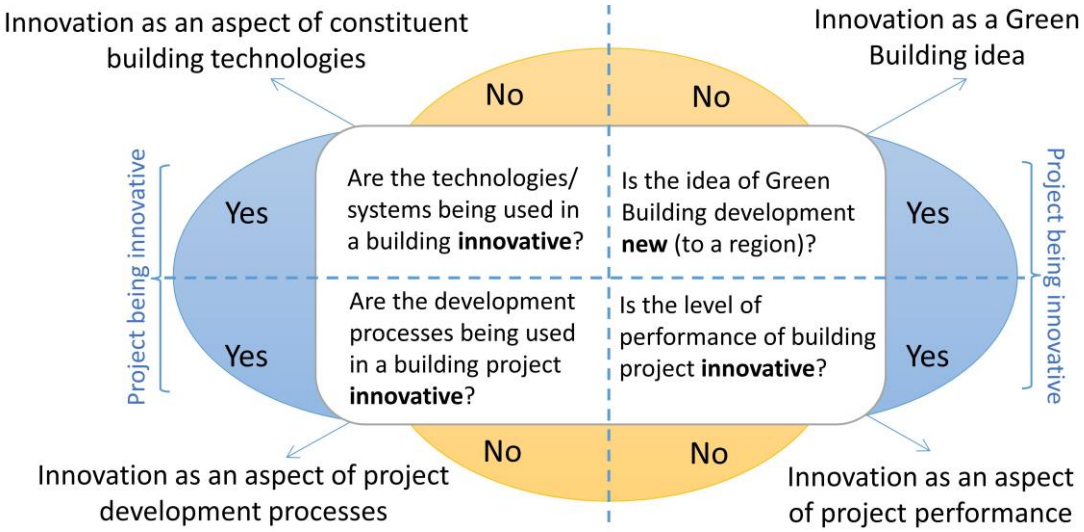

Figure 2. Perspectives of seeing innovation in green building projects.

4.1.1. Innovation; a Function of the Green Building Idea

The idea of GBs has existed for many decades, even though buildings built on these principles are more widespread in some regions and quite rare in other regions. Some interview participants hold the opinion that whether GBs are innovative depends on the duration for which the idea of GB development has existed and prevailed in a region. For the UK and Australia, interview participants reported that GBs were considered an innovation about 7 and 5 years ago, respectively. According to UK-based interviewees (UK-M-1 and UK-M-2), GBs were considered innovative in the UK about 6 years ago. What was innovative in construction 6 to 7 years ago is now considered usual practice.

According to an Australia-based interview participant (AU-M-8),

> *"In a particular region you get a chance to be innovative once, but when hundreds of projects pass through the same process or same rating system in a region than fewer are the aspects left to be claimed as innovative."*

According to this viewpoint, GB projects have become commonplace practice in some regions (i.e., UK) and this is the reason that they are not considered to be innovative projects there. With innovation being subjected to regional transitions, it could be postulated that for some other regions, GBs are still an innovation. It is important to note that this opinion from the different participants is driven by the popular belief among industry professionals that an idea is innovative when it enters the market but gradually becomes standard practice as its implementation increases (see Figure 2). While the concept of GB projects may have prevailed in a region for some time, a GB project in that region may still be innovative because of the constituent systems, materials, and technologies. This perspective is discussed in detail in the next section.

4.1.2. Innovation; a Function of Constituent Building Technologies

Even though the idea of GB projects has existed in a region for some time, due to an ever-increasing demand for high performance in building sustainability, these projects continue to rely on innovations in materials, building systems, and other building components. Furthermore, the increasing demand for improved sustainability performance and the continuous flux of technological improvement can make GB innovation a continuous process, although slow sometimes.

The scope of technology in the case of GBs is quite broad and can encompass land, energy, water resources, materials, building structure, indoor environment, and construction technology [45]. New breakthroughs in building materials and systems are resulting in ever-improving sustainability outcomes in GBs. Wood as a structural material in buildings is still considered to be an innovative green material, although having a relatively

well-established market in Europe and North America [46]. Some current popular green technologies include green roofing technology, thermal bridge blocking technology, residential ecological ventilation technology, and efficient door and window systems and construction techniques [29]. Some of the GB experts interviewed hold the viewpoint that GB projects are still innovating as their constituent technologies, systems, and materials are innovating (see Figure 2). According to interview participants (AE-M-1, UK-F-6, and AU-F-6) innovation in GBs is about the use of new materials, systems, or a combination of new materials and new systems in a project as compared to standard practices. GBs are often first in line to apply the new technologies and new systems and can be considered as innovative projects. Projects striving for high-end sustainability performance include innovation of some form. This can be in the form of a technology being introduced in the building sector and it can also be in the form of a construction method used regularly in other sectors but not in the building sector. A GB is basically a plethora of individual systems integrated together. Innovation in these individual systems also render a GB project as being innovative.

GBs may also be considered innovative when they incorporate techniques and technologies from historic contexts which are no longer mainstream; as an Australia-based interview participant said, "we worked on a project in Canberra, where thermal Labyrinth was used to precondition the outside air. The design of the system was such that it provided passively conditioned air to a school building, when the school was closed, the air was directed towards a library and when the library closed, the air was directed to a theatre. The [use of this] technique could be considered an innovation but it was not an invention as it had previously been used in Roman Empire."

Interviewed experts think of GB innovation as a function of constituent building technologies. Many systems, materials, and technologies which rendered buildings of the past as being innovative are either standard practice now or have even become obsolete and can no longer render a GB project innovative. For GBs to be innovative, they have to incorporate cutting-edge technologies or revive historic technologies in contemporary building settings. While cutting-edge technologies can render a GB as being innovative, to be innovative a GB can also use innovative development processes, a perspective discussed in the next section.

4.1.3. Innovation; a Function of Green Building Development Process

Construction organizations find it difficult to achieve the green buildings' requirements through traditional construction methods [2]. Innovation is not only about the design of a building and the technology it employs, it is also about the project development approach, i.e., how the project is designed, coordinated, and managed (see Figure 2). While a GB development requires the use of innovative systems and designs, it also requires innovation in the approach of problem solving, communication, team making, and the overall process of developing the project. Five interview participants (UK-F-2, UK-F-3, AU-M-20, AU-F-6, SN-M-7) opined that GB innovation is about the innovation in project development process.

A traditional process yields traditional outcomes and, for high-performance and innovative outcomes, innovation in the design and development approaches is sometimes required. Innovation is not always possible by following the standard design protocols. Sometimes, to innovate, deviations are required from the standard operating procedures of project planning, design, and execution. Project development involves both the design as well as procurement. Traditionally, when projects are procured, the execution of different project tasks is performed in a linear way, i.e., starting one activity upon finishing another. For instance, building services are designed by the MEP consultant once architectural designs are finalized, and the contractor is brought on-board once the design process is complete. However, because of its high design integration requirements and complexity, a GB project needs a combined effort from different trades from the project onset. To help different team members cooperate, innovative approaches to project procurement are required.

Some of the highly innovative projects use significantly different procurement methods. For instance, integrated project insurance is an approach in which, instead of having insurance for individual team members, there is insurance for the project itself, the use of which is intended to avoid the blame game that happens in construction projects. Savings are made in the project account if the project is under the cost, and these savings are shared. In case the project is over cost to a certain limit, the team pays the client. However, beyond this limit, an insurance claim is made. This approach is, however, fairly new and has been used for few projects so far.

Some of the more integrative and collaborative approaches of project development and delivery may exist in industries other than the construction industry and even within some particular sectors of construction industry. In case project teams developing building projects adopt these approaches, the adoption itself may be considered as innovation as the purely building-related project organizations may not have used these approaches before. One such approach is called "alliance", which is sometimes contractually mandated in large infrastructure projects developed over a number of years. This approach is typically not used in building projects as their development costs are relatively small. While using such an approach in big infrastructure projects such as Melbourne Metro, different consultants including architectural, civil, structural, and transport engineers work in the same office for many years. This type of setting helps with the collaboration among project team members and the building sector can learn from this. Project teams for GBs can benefit from the use of the alliance approach, which is innovative for building projects, although not innovative for infrastructure projects.

While GB projects can be innovative by employing innovative project development approaches, they are also considered innovative when the project aspirations involve non-standard and high-performance goals, a topic discussed in the next section.

4.1.4. Innovation; a Function of Potential Performance

Innovation in the GB sector is mostly considered in terms of achieving higher benchmarks than usual practice during project development (see Figure 2), as according to a UAE-based interview participant (AE-F-2), "often what sustainability ends up being is what the best practice is, in the rest of the world." Eight interview participants (AU-F-1, AU-F-4, AU-F-6, AE-F-2, AE-M-4, HK-M-2, SN-M-5, UK-F-6,) opined that GBs are innovative when their performance is beyond the typical standards and benchmarks. This is the popular definition of innovation often used by third-party GB rating systems. The definition of innovation by GB certification systems is of much significance, as systems such as LEED, BREEAM, and Green Star have played an important role in materializing sustainable development within the building industry and may also be credited for setting innovation trends in GBs. These systems, in fact, also promote innovation to some extent by dedicating certain assessment points for it. For instance, Green Star (Design & As Built-v1.2) allocates 10 points for innovation from a total of 100 points. GBCA maintains an understanding of the construction industry and uses what people are normally doing to benchmark what is innovative. In the case where most buildings in the region are using about 50% recyclable materials, an innovation would be a substantially higher use of recyclable materials, for example, 100%.

GB certification systems define and acknowledge innovation in GBs as being more than standard performance. When the high-performance benchmarks become commonplace in a region, even higher benchmarks are adopted to define innovation. For instance, some of the requirements that previously were defined as innovation according to the Green Star system have become business as usual. Consequently, Green Star has revised its innovation requirements and has set the benchmarks higher than before.

If a GB project is striving for low level green certification, then this is quite standard and not innovative. However, the buildings that are innovative in contemporary times are those that strive for the highest levels of green certifications, such as LEED Platinum. Regarding this, a Singapore-based interview participant (SN-M-5) said, "in order to move

to Green Mark Platinum, we need to put a lot of novelty factors in a building. This pushes us forward, helps us realize where problems are so that innovations can be made there. Systematic innovation is required in the workflow process and finally going beyond green to blue green networks, Biophilic designs, regenerative designs, circular economy, etc." The efficiency benchmarks for such GB developments are so high that they require a continuous improvement in building development approaches. In other words, GBs are still a part of the innovation continuum rather than becoming standard practice because the aspirations of sustainable development continue to be raised. As project teams continue to push the limits to provide better performing buildings, GB projects keep on innovating.

The potential performance of GBs is shaped by human imagination of sustainable development, as according to a UK-based interview participant (UK-F-6),

> *"For the notion of sustainable design to become a normal design practice depends on how far we look into the future. In case of a distant future where circular economy is achieved and the building development also follows the human-centric focus by ensuring comfort for the occupants, sustainable project design can be thought of as a normal design practice. We are currently far from achieving this."*

While facing the side of innovation that is driven to meet high-performance benchmarks, a question arises, i.e., will the innovation stop at some time when the human vision of sustainable development is fulfilled? Regarding this, Hawken, et al. [47] established that whenever the practical limitations of the innovation, or "the laws of physics" are about to be approached, man is able to escape these bounds by "redefining the problem". For GBs, ultra-high energy efficiency is not the only goal. These projects also need to strive for health, well-being, and cost efficiency. Achieving these goals individually is possible, but collectively reaching these goals poses significant challenges and requires a continuous process of innovation for better performance.

A GB project may be considered to be innovative for one or multiple reasons, as stated above. Although minor, there exists the possibility that a GB project may not be innovative considering any of the aforementioned perspectives. For instance, it may be developed in a region where GBs are a norm and not considered innovation, it may have used mainstream and time-tested technologies and development processes instead of breakthrough technologies, and it may only be striving for standard performance that is easier to achieve with the standard design, technologies, and systems. To address the second objective of this study, the next section provides a detailed understanding of the frontiers that GB innovation is currently addressing and needs to address in future.

4.2. Frontiers of Innovation

Sustainable development in the built environment faces many challenges and non-traditional deliverables which need to be addressed or fulfilled using innovation directions/approaches (that is innovation frontiers) that are advancing GB projects. While talking about innovation for non-standard deliverables, one interviewee (UK-M-7) said,

> *"There are many factors that make such buildings innovative including, the reduction in environmental impacts, workplace that drives good performance, and health and well-being which is becoming important, recently. Mainly, the environmental impacts are of significance as typically the construction can easily have a highly negative impact on environment and green buildings have a special consideration in this regard."*

Climate resilience, maintainability, and intelligent systems in buildings can also be seen as innovation frontiers. In the words of a Hong Kong-based interview participant (HK-M-7),

> *"There are some new considerations for Green Buildings these days including design for climate resilience, design for durability, and ease of maintenance. Furthermore, there are some considerations towards smart construction making a building a sensible entity which constantly collects information related to building users. The integration of these*

ideas is still in early stages. How these can be understood, managed and tackled is another key challenge. These aspects are the frontiers of innovation in green building."

Hence, the GB frontiers are defined by the environmental challenges and social needs, and also the challenge of optimizing multiple deliverables. The following are some key frontiers of GB innovation discussed by the interview participants.

4.2.1. Energy Efficiency, Resource Efficiency, and Environmental Protection

The process of a GB project development and delivery has to be different from that of a traditional building project. This is because many of the variables needed to be optimized in a sustainable design are either non-existent or ignored in a non-GB project. Some important features of a sustainable building requiring a different design development approach include energy efficiency and environmentally conscious development. These requirements themselves make the GB projects innovative, since standard building development typically disregard such concerns.

GB projects are defined by energy efficiency, resource efficiency, and environmental protection. While being the innate aspects of GB projects, these characteristics also stand out as the frontiers of GB innovation. The reduction in operational energy use, according to interview participants, stand out as a distinction point for innovative GBs. Energy efficiency and environmentally conscious development show up as frontiers of innovation, particularly when comparing GB development with non-GB projects. As a UK-based interview participant (UK-M-7) said, "traditional contracting is cost driven and is more about outcomes per unit area. Normally the office buildings are classified by the amount spent per unit area. However, in the case of GB projects, the requirements also circulate around energy use, water use, eco-friendly materials, etc. So, it can be quite innovative." While talking about this issue, another interviewee (AU-F-8) said, "in Australia we are not pushing envelope far enough to qualify the Green Building development as innovation. The progress in regards of the Living Building Challenge is encouraging. They are pushing the envelope [making GBs developed on those standards as innovative] and we should be heading in that direction." Hence, technologies and solutions related to energy efficiency, resource efficiency, and environmental protection in building projects are regarded as innovative. A focus on health and well-being of building occupants can also make GBs innovative, a topic discussed next.

4.2.2. Health and Well-Being

In GB projects, a focus on health and well-being is also regarded as innovation, as in the words of an interview participant (AU-M-14), "social sustainability as well as health and wellbeing are the new frontiers of innovation in GB projects." Reinforcing this, a UK-based interview participant (UK-M-1) said, "innovation these days is also in terms of following the WELL standard, which requires the development of healthy buildings. Although, buildings do not change much in terms of principles of development, the additional requirement of developing healthy buildings requires a difference in process, different specifications, and more design effort." Whether a GB pursues health and well-being to satisfy regulatory requirements, green certification requirements (such as that of WELL standard), or self-declared key performance indicators (KPIs) of the client organization, its pursuit will be considered innovative as health and well-being are currently "non-standard" deliverables, as shared by the interview participants.

Hence, incorporating health and well-being in project design and considering certification systems with special credits for health and well-being is currently considered a frontier of GB innovation. Along with some of the GB outcomes that can be considered to be frontiers of GB innovation, there are also some challenges in the optimization of different project deliverables, which can also act as frontiers of GB innovation, as discussed in detail in the next section.

4.2.3. Solutions for Mutually Opposing Project Outcomes

Often conflicting relationships between sustainability dimensions (that is environmental, economic, and social), and even within a dimension, exist because in a real GB project, design variables are interlinked and tuning such variables can result in high performance according to one criterion yet low performance in another criterion. An important frontier for GB innovation is to resolve the conflicting relationships from among the key project deliverables and outcomes. Some of the classic examples of conflicting relationships are discussed as follows.

Balancing Energy Efficiency and Adaptability

A building may become functionally obsolete faster than it becomes physically obsolete. Revitalizing the old and obsolete building stock is important for resource conservation and it can be achieved by incorporating the element of flexibility in a building beforehand as it is being developed. Adaptability can be defined as a building's capability to change itself to address future needs as they arise. Almost all buildings have some adaptability, but not all buildings (especially GBs) can offer a high degree of change.

A GB with a high level of sustainability performance needs to be energy efficient but it also needs to be adaptable and flexible for future use so that it may not become obsolete when functional requirements change. However, achieving both "adaptability" and "energy efficiency" together poses challenges in some situations because of their mutually contradicting interrelationships. Talking about this, a UK-based interview participant (UK-M-4) said:

> *"A building is like a crocodile, the more flexible it is for the external stimulus the longer it will survive... It is hard to predict how the market will be in future but if there is an element of flexibility in the building design then its chance of survival in future increases. However, the problem is that the Green Buildings are not intended to be changed much. Reliance on grid energy which typically comes from fossil fuels [in case of non-GB projects] can give independence in the space planning and the building design can be much flexible. For instance, a building using electricity for thermal comfort and lighting purpose will not need to plan the various inside spaces according to the sun path, etc. Contrary to this, a Green Building that avoids energy use from fossil fuels, needs to rely on the environmental factors for daylighting and thermal comfort. Because of these constraints, such a building has little flexibility in adaptive reuse to offer as compared to a traditional building. For instance, in case of a Green Building open layout office, if partitions are drawn and new spaces are formed during the adaptive reuse, then because of the permanent nature of HVAC services, windows, etc. some of the spaces may receive less daylight, some spaces may be hotter, while some places may be colder. So, when designing a Green Building, the element of flexibility is compromised to a certain extent."*

Hence, it is challenging to reconcile passive green design elements with adaptability (particularly space layout adaptability) of a building. Mutually addressing these contradictory objectives is a frontier for GB innovation. Another contradictory relationship exists between historical conservation and the use of modern technology, addressed in the next section.

Balancing Historical Conservation and Use of Modern Technology

Heritage buildings, particularly in Europe, account for a large portion of the built environment, which can incorporate some contemporary technologies to make them more sustainable in terms of environmental performance, as well as health and well-being. When developing a GB, the use of high-tech building components may become necessary to achieve a certain performance in terms of energy efficiency and user comfort. There may arise different situations in which heritage conservation, a key aspect of social sustainability, may hinder the use contemporary building systems necessary for environmental and economic performance. For instance, a UK-based interview participant (UK-M-3) said: "in one of the residential projects in a conservation area, the aspiration was to achieve

Level-4 certification [on "Code for Sustainable Homes" rating system]. However, for conservation reasons, the planning requirement for the project was downgraded to a Level-3 certification. The front façade of the project had to be kept similar to other buildings in the area and therefore PV panels couldn't be placed in the front which was the best orientation. Historical conservation, somewhat compromised environmental performance." Based on advancements in building systems and services, as well as architectural design and planning, it can be speculated that in the near future, historical conservations will be reconciled with contemporary technologies.

Balancing Cost Efficiency, Environmental Performance, and User Comfort

One way of defining innovation in the built environment is by considering it as a technology that leads to reduced "installed cost" and increased "installed performance" [15,48]. For instance, renewable energy technologies can significantly contribute to the sustainability of GB projects; however, owing to the high costs of these technologies, their use still faces critical obstacles [49]. Even though the construction industry is sufficiently mature to develop highly sustainable building projects in some parts of the world, the industry still faces the challenge of realizing this at a reasonable cost. As an Australia-based interview participant (AU-M-18) put it, "some of the frontiers for innovation in Green Building development are to reduce the costs of such buildings, and to increase the construction efficiencies and on-site efficiencies." Interview participants find that financial models and innovation are closely linked and innovation currently needs to be considered in terms of more cost-efficient ways of doing the same thing. For instance, developing a carbon-neutral building is possible, but developing it cheaply is an innovation frontier.

Some work in regards of the cost frontier have already been accomplished. According to interview participants, a sustainable building does not have to cost more than a traditional building. If the orientation, massing, and insulation of the building are correctly provided, then it is possible to develop it at a comfortable cost. Although there is shown to be some cost premium for a high level of GB certification, the industry is continuously changing. What was sustainable and innovative 10 years ago has become standard practice and now does not cost any more than usual. Hence, some building professionals believe that the GB development costs are already reducing as a result of good design practices. However, the potential for further cost reduction still exists. To achieve higher cost efficiency, the design process may need to be relearnt and a major shift in design mentality may be required. In this regard, Hawken, Lovins and Lovins [47] pointed out that "Tunneling through the cost barrier requires not a change in what we know but a shift of what we already know into new patterns- patterns that can lead to innovations as rich and diverse as the Hypercar, the superefficient passive building, the New Urbanist neighbourhood."

Some GBs are designed and built following the adaptive comfort model, which relies more on natural elements for heating and cooling instead of energy from the grid. Such buildings do not operate in a narrow range of temperature and, therefore, may gather some skepticism even though they cost less and are healthier. Talking about such a building approach, an Australia-based interview participant (AU-F-6) commented, "People in such a building need to accept that at some time of the year it will be 18 degrees and at some time it will be 26 degrees. In case occupants agree to this, such a building can be developed with a far lower cost . . .. . . Client's mentality is the key defining factor in sustainable buildings." Hence, balancing cost with environmental performance and user comfort remains a key frontier for innovation in GB projects.

Optimization among sustainable outcomes is a critical frontier of GB innovation and has also attracted the attention of previous studies [50,51]. A continuous shift towards improved performance and varying relationships among design variables can be seen in many areas, supporting the notion that innovation in GBs will also change the otherwise contradicting relationships among design variables. During the previous century, a remarkable transition in GB projects took place and the development constraints and challenges of the past seem to no longer prevail today. This is because the constraints are technology

dependent and, with the continuous improvement in the technology, previous constraints will seize to exist and new ones will come into existence. To address the third objective of the study, factors affecting GB project innovation are discussed next.

4.3. Factors Affecting Green Building Innovation

A GB project is developed under the influence of many factors, including budget performance, sustainability regulations, and third-party GB certifications. Such aspects as indicated by the interview participants (listed in Table 1) can drive or obstruct innovation in GB projects. The frequency count of these factors in Table 1 shows the number of times they were identified across multiple interviews and is based on the content analysis discussed in Section 3.4. A frequency count of more than one for a factor indicates that more than one interview participant indicated the same factor, hence adding to the significance of that factor. While some of the factors listed in Table 1 have been studied previously as drivers, barriers, and success factors of GB projects, their interpretation for GB innovation is a novel contribution of this study.

Table 1. Factors affecting innovation in green building development.

Theme	Factors Affecting Innovation in GB Development	Frequency
Budget and Time	Budget available for innovation	8
	Time available for innovation	3
Client's aspirations and fears	Big developer as project client	1
	Project client as building occupant	1
	Client's interest	3
	Client's risk aversion attitude	2
	Client organization having internal policies to support innovation	1
	Leadership skills of project client	1
Marketing	Marketing advantage	1
Regional support	Regional support to attract investments	3
	Regional support to mitigate environmental issues	1
	Financial support from government to experiment new technologies	2
	Government becoming the early adopter of technologies	1
	Regulatory environment encouraging the use of innovative technology	1
Precedence	Existence of a precedence for the use of innovative technology in the local context	3
	Available public record of the usefulness of innovative technology	1
Physical constraints	Building location	2
Project team attributes	Team composed of experts who understand sustainability	2
	Leadership skills of project team	1
	Project team's risk aversion attitude	1
	Architectural consultants innovating to differentiate their projects	1
	Suppliers innovating to differentiate their products	1
	Consideration towards sustainability by project management team	1
Timing of team involvement	Early involvement of different team members particularly design consultants	1
Timing of considering sustainability	Considering sustainable measures from the project start	1

Table 1. *Cont.*

Theme	Factors Affecting Innovation in GB Development	Frequency
Testing	Availability of projects to act as testing grounds	1
Scalability	Scalability of innovative approach	1
Skillset for innovation	Experience and understanding of human comfort, problem solving and theoretical knowledge	1
Design SOPs	Deviations from design SOPs	1
Nature of industry	Nature of construction industry	1

The identified factors are not only associated with innovation, they are also associated with each other (see Figure 3). For instance, "nature of construction industry" affects budget and time available for innovation as well as project team's risk aversion attitude. "Budget available for innovation" is affected by "client's interest' in innovation." As a government becomes the early adopter of technologies, it contributes to the public record for an innovative technology and also helps create precedence for the use of innovative technology in the local context. Architectural consultants and suppliers are typically interested in innovation because this provides them with a marketing advantage. Existence of a precedence for the use of innovative technology in the local context affects the risk aversion attitude of clients and project teams, and also contributes to a publicly accessible record for an innovative technology. Moreover, the early involvement of team members in a project helps the consideration of sustainable measures in the project from the onset. A detailed discussion regarding some key factors is provided as follows.

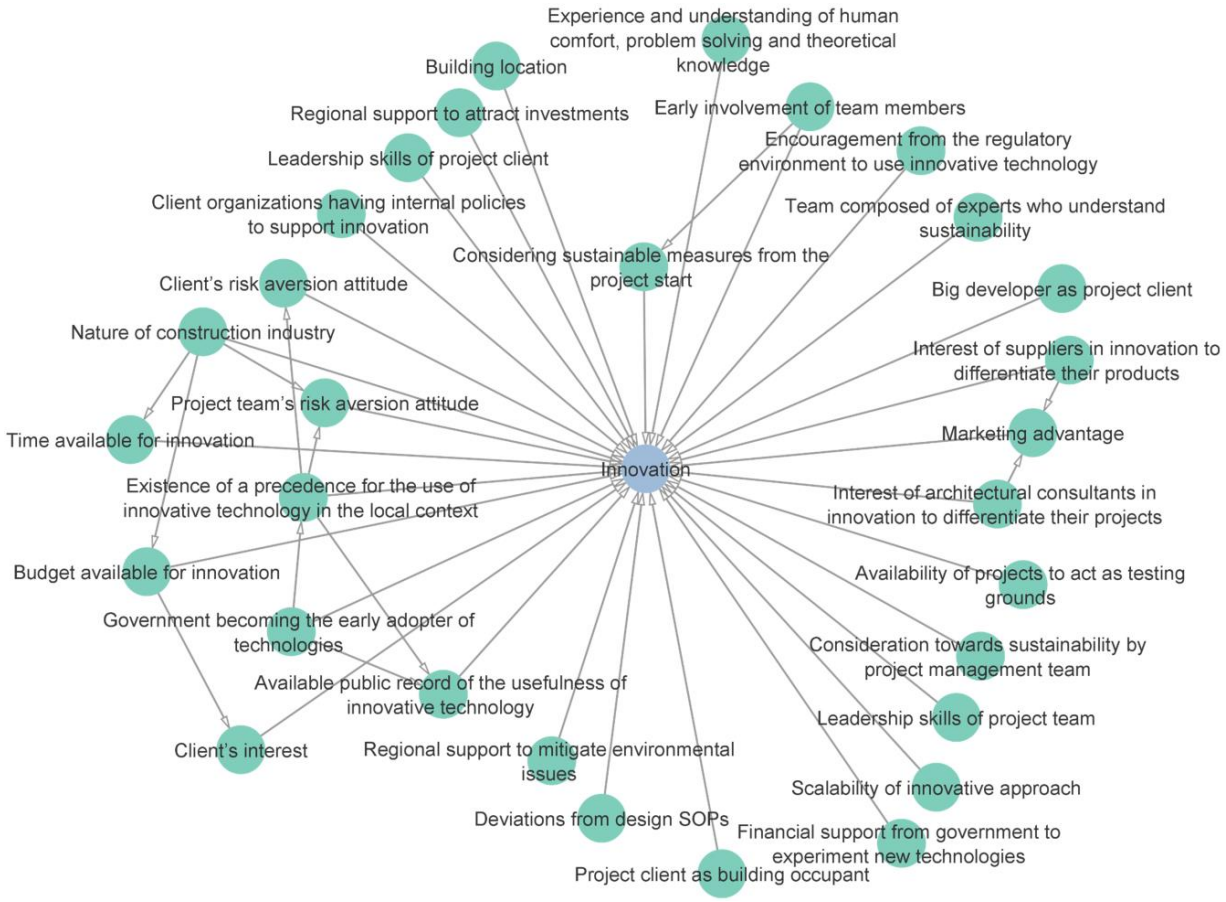

Figure 3. Associations of the identified factors with innovation and among themselves.

4.3.1. Scalability of Innovative Approach

For the diffusion of innovation in the construction industry, the scalability of innovative solutions plays a fundamental role. Not all innovative solutions are easily scalable, which hinders the diffusion of these innovations on real-life projects. Some classic examples of the scalability of innovation were shared by a Singapore-based interview participant (SN-M-5), who said:

> *"I designed a bio-inspired house for a veterinary doctor. The home had 7 gardens. The design of this house later became an inspiration for Khoo Teck Puat Hospital we designed, and this turned out to be an exemplary hospital in the Asian region. This hospital was the first one to win the biophonic award in the world and had 10 gardens in it. So, once you have a good project, you can scale it up. We can take inspirations from small things and scale them up, while following the main philosophy of design ..... We were also involved in the Gardens by the Bay project [A landmark project in Singapore]. It is a glass building, as we need to bring in the light for plants. But before we built this project, we built prototype projects in the Horticultural park. In those prototypes we tested every technique, technology and system to be later used in the full-scale project. So, in essence there was a lot of study and research involved."*

4.3.2. Availability of Time and Budget

The time and budget available for a project strongly influence innovation. If the project focus is on cost performance, with little or no budget set for innovation, the project is unlikely to result in innovative outcomes. According to some interview participants (AU-F-6, AU-M-3, SN-F-2), a limited project budget often confines the project to previously tested techniques, therefore hampering innovation. Basically, the pressure to design and build within cost and on time hiders innovation. Even though there is much potential for projects to include further innovation, costs involved in the process remain a key issue. Allocation of appropriate time to innovate is a critical factor since the construction industry is typically under significant pressure to deliver the projects in a timely manner. Unless there is the budget and time to innovate, the traditional workflow of the construction industry does not facilitate innovation. Talking about this, an interviewee (AU-M-3) said:

> *"Industry these days is focused towards 'speed' rather than 'the time to consider', and this is same across traditional and Green Building projects. This means that the designers have less and less time to reflect upon different ways things can be done or the opportunities that can be embraced. This makes them default [back] to previous ways of doing things as they don't have the time to consider other things. Right amount of budget also needs to be allocated for sustainable development of buildings."*

4.3.3. Nature of Construction Industry

Overall, the construction industry is fast paced and profit driven, and prioritizes risk management. The focus of the industry on these factors can act as a significant hindrance to GB innovation. Owing to the work pressure and limited resources in projects, the development of good ideas is not encouraged unless they are highly applicable. While commenting on this issue, an Australia-based interview participant (AU-F-5) said

> *"No one wants to put his name on a non-standard system as it makes him liable for risks. An engineer often wouldn't design a system innovatively unless it is made risk free. A head contractor also doesn't try to innovate. This is because innovation costs money and in case the innovation is not part of the documentation, the contractor will not be putting [quoting] a price for that and therefore will not innovate as it saves him no profit. Because no one in the construction industry has time to invent something, the way innovation is introduced in GB projects is by buying something [innovative] from overseas."*

4.3.4. Physical Constraints

The location of a GB project has a significant effect on the technological innovation that can be incorporated within building design because the immediate surroundings of the building constrain the design in certain aspects. As a UK-based interview participant (UK-M-1) said: "an office building being developed in a high-density urban area may have limited amount of daylight and may not be able to use PV technology for generating energy because of the surrounding tall buildings causing shadows. If a building is in a forest it is one thing, however in a cityscape there are many constraints which restrict the freedom in building orientation, etc. Therefore, in such circumstances, it is very difficult to deliver an innovative design."

In some cases, as argued by the interview participant above, the site and other physical constraints may limit the use of green concepts, methodologies, and approaches. In such situations, it may appear that innovation, as defined by the construction industry (i.e., through higher performance benchmarks), may not be applicable on the project. While some may argue that physical constraints hinder the use of some innovative technologies, a counterargument can also be made that the physical constraints serve as stimuli for more radical ideas and innovations. For instance, buildings where PV technology cannot be employed may use other means of renewable energy generation as alternatives, and such revisiting of energy solutions may itself be considered as innovation.

4.3.5. Integrating Sustainability in Project Requirements

Instead of considering sustainability in GBs as a bolt-on or add-on requirement, it is necessary to incorporate it within the basics of project development to yield potential benefits of sustainability. In this regard, the timing of considering sustainability in projects is important. This is because the standard approach to project development is the incorporation of sustainable measures at the end of the project design. However, more innovative sustainable measures are incorporated from the project onset.

4.3.6. Timing of Team Involvement

The earlier involvement of the project team in the project can play a crucial role in innovation of a GB project. According to interview participants (UK-F-3, UK-M-5), innovative GB projects have early involvement of the project team, and particularly the design team, in the project. To innovate, GBs not only require sustainability consultants and design consultants to be engaged at an early stage, but also need the earlier engagement of facility management professionals. The design process in GBs is used to identify the issues related to energy use. These issues are discussed and consulted with the user-client. Facility managers and the people who will be using the building are engaged in the design. The project team work with them and understands their needs, so that once the building is delivered, it meets the energy targets.

4.3.7. Client's Aspirations and Fears

Project clients have a critical role in green innovation and they influence innovation in many different ways, such as requiring the project team to improve the lifecycle performance of the building, or by setting up green requirements for contractors. According to some interview participants (UK-F-4; AE-F-2), if the client is only concerned about satisfying the bare minimum requirements of a regulation or GB certification, innovative outcomes cannot be achieved. A client's drive towards a socially and environmentally sustainable project, coupled with their will to pay for such a development, can result in more innovative outcomes. If the projects are to be sold to customers with little financial restraints, more innovative measures can be incorporated. The clients who are big developers and also owner-occupiers are typically willing to spend time and money in innovative green developments.

Interview participants shared that in innovative GB projects, senior project managers and other members from the client's side take sustainability seriously. However, in the

case of less innovative projects, senior project management do not substantially buy into the sustainability concept. The client organizations having internal policies to support innovation are more likely to embrace innovation in GB projects. Australia-based interview participants (AU-M-2, AU-M-3) noted that both the private and public sector under different circumstances may pursue or obstruct innovation. Sometimes, in the private sector, the developers are open to trying new ways of project development and can embrace technology and innovation. Sometimes, government clients, and particularly higher education institutes, can facilitate innovation more than the private sector as, unlike for the private sector, for the public sector the pressure to cut costs is not as debilitating.

Innovation in a GB project is highly driven by the deliverables a client establishes for a project. The client's motivation, attitude, and beliefs also matter significantly when innovating. A client needs to show leadership to achieve these outcomes. While the encouragement from the project client can drive innovation, the client's skepticism driven by fear can significantly obstruct innovation, as multiple GB experts highlighted in the interviews. Some interview participants shared that many clients are mainly driven towards risk aversion in the long term rather than rewarding risks in the form of innovative technology.

Hence, the client's motivation for innovation, fears of underperformance or failure, and the nature of the client's organization play an important role in the innovation of GB projects. A key issue playing a role in the client's fear mentality is the lack of precedence regarding the use of an innovation.

4.3.8. Precedence for the Use of Innovative Technology

For innovation in GB projects and for the diffusion of innovative solutions, precedence of the use of innovations in the same or a similar context plays a critical role to gain public trust. While project clients may aspire to achieve ultra-high performance in GB projects, delivering such performance may require non-traditional approaches, systems, and technologies. Precedence for the use of such systems and technologies may help eliminate fears among potential clients. Regarding this, a Singapore-based interview participant (SN-M-9) said, "even if there are Green Mark incentives and schemes from government promoting the use of innovative technologies, in the market a developer won't like to be the first one to use a new technology. Although in the energy savings area the new technology may be quite attractive, it may have maintenance issues." According to Singapore and Hong Kong-based interview participants (SN-M-9, SN-M-10, HK-F-1), clients often wait for other people to use an innovative technology and, if the results are successful, they adopt it. If a consultant brings a technology to the client and recommends its use, the senior management would ask if the same technology has been used locally before; if not, the management would say that they would like to wait and see. Developers have this attitude even if there are many incentives for adopting new technologies. Typically, the developers do not want to bear the risks and they do not have tolerance towards errors. Indicating a similar risk aversion approach in Australia, an interview participant (AU-M-21) said, "we [as consultants] know how to do well in design, but we are looking for proofs of technology and solutions by our peers and partners in Europe. When it comes to adoption of technology, in Australia we are not trying to copy the technology of other regions, but we try to see how safe the technology is based on the experience of other regions."

To facilitate the diffusion of innovation, publishing the results of innovative technologies can help significantly; as an interviewee (SN-F-2) said, "in Singapore, new innovations are being tested and results are being published to give the clients an evidence of proven track records. This encourages more adaptation of innovative ideas as it is easier to convince clients with published data." Hence, precedence for the use of innovation in a context is looked upon eagerly, as it helps the project clients and team members avert costly risks.

4.3.9. Project Team Role in Innovation

If the project team players having a significant influence in a project are motivated towards innovation, they can develop a culture for innovation. Such a culture is of key

importance because, for "managing innovation", it is essential to capitalize and support an organization's capacity and motivation to innovate [52,53]. Further, the loss of ideas from the "daily business" and from within an organization can be prevented if there exists a culture that motivates innovative improvements along with new solutions [53]. According to an interview participant (AU-M-1), project team members need to have strong leadership qualities so that they can decide on something new, which is often the case with GB projects. Leadership is required in the team as they need to push the status quo and do something different.

A project team composed of building professionals who understand sustainable development can make a significant contribution in the innovation of such projects. UK-based interview participants (UK-F-3, UK-M-5) shared that the team members involved at an earlier stage in innovative GB projects are not only from the design consultancies, but they also belong to the contractor's team and facility management. In these projects, senior project managers and other members from the client's side take sustainability seriously. Designing a low-energy building is relatively easy. However, delivering such a building is difficult as the client needs to put the right people in the room who understand the problem well.

The team composition is such an important element in the development of an innovative project that the lack of an appropriate team can highly likely lead to an underperforming end-product. According to interview participants (UK-M-5, UK-M-7), the development of innovative GBs depends on the individuals. It can be less innovative if the design team and the client management team is not right.

Being involved in innovative GBs acts as a distinguishing attribute for project teams. Mentioning this, a Hong Kong-based interview participant (HK-M-6) said:

> *"Often the architectural consultants like to innovate in their projects. Designing Green Buildings can be considered as innovation because it can redefine the rules of game in competition. By innovation, the architects may differentiate their projects from the conventional practices. This gives them certain leverage over the market as there is little competition for such kind of projects . . .. It is good for suppliers to keep on innovating. They are always competing against the rivals which have almost equally sound products. The competitors also offer their services at a similar price. Whoever is more innovative by creating value or differentiate in services, will win."*

4.3.10. Availability of Projects to Act as Testing Ground

The idea of using ongoing projects as a testing ground for new technology can significantly contribute towards innovation in GBs; as indicated by a UAE-based interview participant (AE-M-2), "the process of delivering Green Buildings as well as the overall construction process in Dubai is on a pathway of increased optimization. This is because of the large number of ongoing projects acting as testing grounds and large number of people from diverse backgrounds who learn from each other." A particular case regarding this is that of "Universities as living labs", which implies that university campuses are used as real-world testing grounds for sustainable and innovative solutions [54]. The availability of ongoing projects, however, is a complex factor affected by the regional economy, construction policies, and regional vision.

4.3.11. Regional Support

The GB sector is highly dependent on a region, its economy, and its policy to drive innovation. The construction industry in a region can be driven to innovate GB development to mitigate the environmental risks of traditional project development. On the other hand, a region may also be driven to innovate GBs, to increase the marketability of its real estate developments or to mitigate the environmental impact of building construction. The regional support is not the same as government support. Instead, it is a mix of both public and private sector efforts to innovate or create a fertile ground for innovation.

Some regions are particularly innovation-enabling and innovation-demanding, as in the case of the UAE, and the reasons for this regional drive can be the intention of boosting the local economy. Building projects can act as pinnacles in the economy of a region, not only by mobilizing the construction activity, but also by attracting foreign investments. As one interviewee (AE-M-2) put it: "most of the big multinational architectural companies have offices in Dubai because it is a region where land is provided to designers to innovate. The large spans of land, big number of ongoing projects and many developers in Dubai enable innovative ideas to become reality. The trend in Dubai is basically to involve an international consultant for the conceptual design and then bring on-board a local consultant to develop the detailed design. For instance, Masdar city in Abu Dhabi is acting as a hub to test new sustainable designs." As shared by interview participants, sometimes innovative GBs are those that are iconic buildings with a high budget and where cost is not a big concern. In terms of iconic GB projects, the drivers are from the client, the developer, or the government to boost the economy of local region. Such innovative projects striving towards the ideals can be found in the Middle East region. Sometimes, innovation is driven by the regulations from the local government that require delivery of more than the standard approach. A detailed understanding of the government support which primarily drives regional support is provided in the following section.

Government Support

In case the lead of GB innovation and diffusion of GB, innovation is undertaken by the government and can act as a decisive force, especially because the private sector often awaits government incentives or regulations as a reason to change the typical approaches of project design and development. In terms of energy performance in buildings, European countries, most notably Germany, have developed high benchmarks, which have been stringently followed [55]. Ultra-high performance in building projects can be considered innovation and is typically made possible by innovative building systems and technologies. In Singapore, the government supports innovation by being the early adopter and by providing financial support to individual projects for the use of new technologies. A Singapore-based interview participant (SN-M-6) said:

> *"The government building sector in Singapore becomes a pilot for every new policy. Before a policy is implemented on the private sector, government will implement the policy on its own buildings to lead the way. So, all the stringent requirements are put on the government buildings first and then these requirements are moved to the private building sector. The government adopts the new models to make it a showcase for the industry to follow. Since, the government receives the money from public, when the government spends the money in the building sector it wants to ensure the money is spent in the best ways possible. For instance, by 2020 all the government building projects are expected to reach a certain level of green rating. In essence, within Singapore, the government is leading the innovation in construction industry."*

By playing the role of an early adopter in innovations, the Singapore government can collect critical data which can help assess the efficacy of different technologies. Regarding this, a Singapore-based interview participant (SN-M-12) said, "a lot of innovative projects in Singapore have some support from the government. There is a lot of data which government collects and can use. So, there is a lot of room for the innovation to happen. Although it may appear that not a lot is happening at the moment, but with time we will see a lot of innovation coming up."

While a government can play the role of an early adopter, it can also facilitate innovation by reducing risk exposure for private sector parties as they innovate. While talking about this, a Singapore-based interview participant (SN-M-9) said:

> *"The Singapore government takes the lead when it comes to using innovative technologies on building projects. Now, Singapore has a new scheme that promotes new technology for your buildings. According to this, the government can compensate as much as 70% of the cost of technology. There are some targets for the installations to achieve and in case*

the systems installed cannot achieve the target, the government will give you the money you spent. So, there is some improvement for promoting innovation in Singapore, these days. With the increased tolerance towards errors, it will be easier to adopt innovation."

In support of this, another Singapore-based interview participant (SN-M-10) said, "This scheme [of cost compensation] by government does encourage developers and consultants to try new technologies." While some regions such as Singapore have aptly implemented policies for incorporating innovation in sustainable development, other regions still lag behind. As an Australia-based interview participant (AU-M-3) put it: "in terms of innovation, the GB sector is stagnated, and probably it is going backwards. This is because the federal and state government are not stepping up and taking the environmental changes seriously. This promotes the notion among the public that they do not need to do anything. The biggest problem for innovation is that there is no statutory push behind it."

A key reason for a region to promote innovation in GBs can be the drive to reduce the impact of building project development on the environment. The regulations imposed on the development of the built environment can lead the way to innovation. According to Porter and Linde [9], innovation can be one of the industrial responses to stringent environmental regulations and the costs of their compliance. The outcomes of this innovation can be in the form of increased productivity and enhanced resource efficiency. A detailed overview of the regulations used to support sustainable development is provided in the next section.

Regulations to Support Innovation

An exemplary area where sustainability drives results in innovations is in the case of regulations. The adoption of green-innovation-related strategies and practices has been driven by regulations [56–58]. The support provided to green innovation by regulations can materialize in a variety of ways, such as specifying particular environmental targets that need to be accomplished, using environmental reward and penalty costs to establish economic measures, and even by suggesting the use of certain technologies [20,53]. Talking about this issue, an Australia-based interview participant (AU-F-6) said: "instead of promoting individual innovations, government can raise the minimum standards which can automatically drive innovation. Green Building Council of Australia used to consider Australian first technology as innovative in the past but now they consider higher than standard benchmarks as innovative. What government needs to do is to set trajectories for minimum compliance."

The regulations may appear to make a significant contribution to green innovation, as they help bring the overall performance of building stock to a certain benchmark, and the construction industry then innovates to meet this benchmark. However, after a certain time, when the construction industry has obtained the capacity to cost efficiently meet the set benchmark, achieving the previously claimed "innovation goals" may only be regarded as standard practice. Therefore, for a construction industry segment primarily led by regulations in terms of innovation, if the regulations are not revised regularly and even higher benchmarks are not introduced at adequate intervals, the particular industrial segment may become dormant in terms of innovation. Moreover, a substantial hindrance is created for innovation when meeting regulations is the only key driver for GB developments and many developers take more interest in barely satisfying regulatory requirements, for reduced project costs, rather than pursuing long-term sustainability-related benefits by using innovative measures. Some regions also mandate the use of green certifications for building projects. Some UK-based interviewees indicated that, if a green certification is voluntary rather than mandatory, there is a higher probability of innovation being involved.

Innovation, regardless of the discipline, is almost always resource intensive as it requires a substantial shift from the routine processes. More labor-hours and more financial commitments are required to innovate. Therefore, if there are no strong drivers for it, a project or a process cannot be expected to innovate. If a GB project is only developed sustainably to fulfil regulatory requirements or GB certification requirements, then it often

is driven to do that with minimum expense, and therefore innovation cannot be expected as an outcome. According to Qi, Shen, Zeng and Jorge [20]. Although environmental regulations can significantly contribute to the adoption of green innovation in the construction industry, it is necessary that these regulations are not strict enough to be the main driver for innovation adoption. Hence, the regulations as well as the managerial commitment should act as complementary aspects in the adoption of green innovation.

A conflicting relationship may also exist between regulations and innovation. This happens when the regulatory requirements imposed on building projects are highly standardized and do not acknowledge and incentivize the innovative measures in projects, and subsequently the developer loses the motivation to pursue innovation. While regulatory frameworks are a form of regional support for innovation, the marketing advantage of innovative GB projects is another attribute of the regional support, as discussed in detail in the next section.

Marketing Advantage through Innovation

Innovation in GBs can act as an effective marketing strategy for developers. As indicated by interview participants, innovation in sustainable development of building projects is being used by some developers as a marketing strategy. Regarding the marketability of GB projects, a Singapore-based interview participant (SN-M-3) said: "innovation is one of the five paths by BCA [Building and Construction Authority] green initiative in Singapore. Things have changed during the years and the demand of innovation in green building sector in Singapore has been uplifted. Today when a building is being sold, it is asked that which innovation the building has."

However, it needs to be kept in consideration that a project has many conflicting priorities and if the GB certification is for marketing purposes, there is an understandable urge to pursue easier-to-achieve credit points which may not require innovation. As a UK-based interview participant (UK-F-3) put it: "about 80% of the GB projects are not innovative in any way. [Although, as much as] 20% of the projects can be regarded as innovative, from them a very small proportion can be considered truly innovative. The reason is that in case a developer is interested in a GB for marketing purposes only, his inclination is to get a certificate, only." Interviewees indicate that the GBs using innovation for marketing purposes are partially innovative, and not holistically innovative. A detailed overview of GB certification systems and their role in GB innovation is provided in the next'section.

Innovation as a Requirement of Green Certifications

The majority of GB projects opt for green certifications (such as LEED, BREEAM, and Green Star) owing to the regional drivers. For instance, some local governments have made it compulsory to use green certifications. In some other regions, the use of green certifications is voluntary, but to compete in the regional real estate market, green certifications are necessary.

Third-party GB rating systems have allocated significant points/credits to innovation, for instance, Green Star (Design & As Built-v1.2) allocates 10 points for innovation from a total of 100 points. This seems to be awarding the effort for innovation in GBs; as an Australia-based interview participant (AU-F-4) said: "some frameworks like Green Star in Australia play a supportive role for innovation in projects." Although this may seem to be a significant driver for innovation in GBs, rewarding innovation in this way may still have its limitations as the motivation behind voluntary certification may not be enough for innovation to take place in a project, particularly if the primary motive is anything other than having a high-performing GB project. A UK-based interview participant (UK-M-5) said: "GBs are often not innovative. If the project is trying to achieve a GB rating, it is often doing so by satisfying the bare minimum requirements and is not innovative."

A GB project pursuing innovation points may be inclined to do so for reasons other than to innovate. As an Australia-based interview participant (AU-F-5) put it: "projects

may strive for innovation points in Green Star as it involves lower costs than achieving some other credits. Further, innovation-related credits may be necessary for some projects striving for higher Green Star ratings as the project may already have achieved credits in other categories and need more in order to achieve a high rating." This therefore indicates that the achievement of innovation points in a third-party GB rating system may not be an absolute indication that a project's development is driven by innovation. The credits for innovation in GB certification systems help, but project decision makers sometimes need more motivation than this reason alone to purse innovation.

GB projects are typically developed under the influence of innovation, regulatory requirements, and green certifications. The identification of factors affecting GB innovation has led to an understanding of the nexus of innovation, regulatory requirements, and certifications, which is explained in detail in the next section.

4.4. Nexus of Innovation, Regulations, and Green Certifications

In the words of an Australia-based interview participant (AU-M-18), "innovation is still happening in Green Building projects, although many of these projects being developed cannot be stated as innovative." Likewise, GB certifications and government regulations for sustainability are being mandated in some regions, but this does not imply that building projects following these certifications and regulations are truly sustainable. The understanding of innovation, sustainability, and green certifications in GB projects shared by interview participants helped in the development of the conceptual framework shown in Figure 4. This framework explains different scenarios, for instance, how some buildings are GBs but do not have green certification and how some GBs have green certifications but are not innovative. Many overlaps are possible between a group of innovative building projects, non-GB projects, traditional projects, GBs meeting certifications/regulations only, and GBs striving for self-aspired sustainable goals (i.e., buildings developed based on preselected KPIs). In essence, Figure 4 is a representation of the co-existence of green certifications, innovation, and green regulations in the building sector. The sizes of the spheres in Figure 4 do not represent the number of buildings belonging to particular sets.

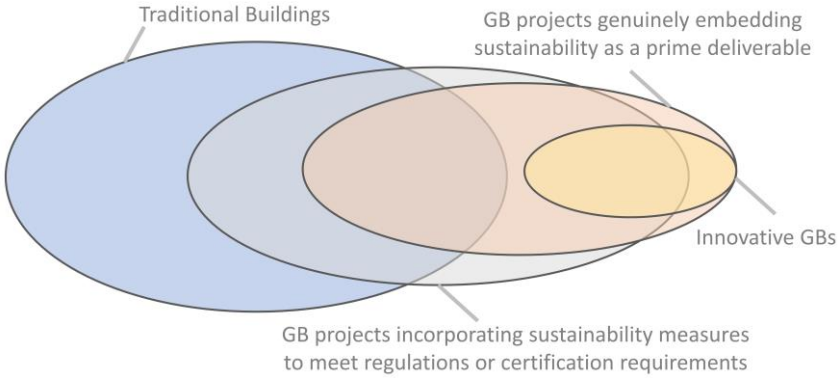

Figure 4. Different sets of building projects and their overlaps.

GBs and buildings with green certifications: Some GB projects are developed with the core values of sustainable development and often result from high aspirations of a client or a developer. These projects have specifically tailored sustainability KPIs and go beyond fulfilling regulatory and certification requirements. On the other contrary, some other GBs only consider sustainability to fulfil regulations and requirements of GB certification criteria. These two project types also have an overlap, resulting in buildings with aspirations of meeting sustainability goals while also meeting regulations and third-party certification requirements (see Figure 4). The group of projects with its own KPIs provide the right environment for innovation in the project outcomes as well as the process of development.

GBs with green certifications and innovative GB projects: Not only are GB certifications not a surety of ultra-high performance in sustainability, they also do not guarantee

innovation; as a Hong Kong-based interview participant (HK-M-2) said, "The reason why green buildings are hardly innovative these days is because of the certification trend. The certification systems provide us with guidelines which are well structured. If the project team follows the guidelines, achieving targets is easily possible and does not require innovation." GB projects developed in a region can be traditional or innovative depending on the drivers involved (see Figure 4). Interview participants indicated that the difference between standard GB projects and innovative GB projects is that the standard GB projects are more driven towards conformance and compliance while the innovative projects are more focused towards outcomes.

Traditional projects, GB projects, and non-GB projects: In addition to the group of GB projects following their own sustainability KPIs and following the sustainability regulations, there is also a group of traditional projects, which can also be regarded as non-innovative projects. Depending on their geographic location, GBs meeting regulatory requirements may also be considered as traditional projects. This is because for some developed regions it has become common practice to follow environmental regulations in developing buildings. Lastly, innovation is not only restricted to the GB sector, and may also involve non-GB projects (see Figure 4).

It must be kept in consideration that innovation, industry standards, and regulations are strongly linked in the case of GB projects. The current innovation makes room for the building standards of the future. Industry professionals may comprehend the innovation in GBs by a comparison with building standards of a region at a particular time. According to interview participants, GBs can be developed through innovative as well as standard approaches. However, if new standards need to be introduced in the future, innovation is required now. So, innovation in GBs is a comparison of the buildings with the industry standards at a particular point in time. If the building is ahead of the standards, it can be termed innovative. To summarize, a GB project can be a traditional project, an innovative project, or a project with green certification.

5. Conclusions

Green innovation has been the focus of many studies and has been studied well in terms of the factors involved. However, GB innovation, which can be considered a niche of green innovation, has not gained much attention in previous studies. To contribute to a deeper understanding of GB innovation, interviews with 45 GB experts from six countries have helped in the identification of the innovation viewpoints of GB experts, innovation-related frontiers, and factors contributing to innovation.

There are multiple reasons why GB projects can be considered as innovative. The mere idea of GB development can be innovative. In particular, in a region where GB projects are non-existent, a GB can be innovative because of its constituent building technologies, it can be innovative when it achieves rarely pursued performance targets, and lastly the use of innovative development processes can also make it innovative. Frontiers of current and future innovations in GB projects include energy efficiency, resource efficiency, and environmental protection; health and well-being; cost efficiency; and solutions for mutually contradicting project outcomes. These are the areas that industry experts find challenging, even for contemporary designs, technologies, and systems. Industry experts expect these areas to keep requiring innovations in future. Key factors that affect innovation in GBs primarily include budget and time for innovation, client's interest, regional support, and existence of a precedence for the use of an innovation.

This study has rendered a detailed understanding of the factors related to GB innovation by using the subjective viewpoints of GB experts. The empirical validation of these factors was beyond the scope of this study and can be undertaken by future research in this area. While this understanding will contribute to the theory of GB project innovation, it will also help GB practitioners in different roles to understand the various perspectives of seeing innovation in GBs. Moreover, the knowledge of factors affecting GB innovation will enable the GB practitioners to create a more enabling environment for projects to innovate.

By considering the viewpoints of GB experts practicing in six countries, it was possible to compare and contrast the innovation-related observations. However, GB innovation is highly contextual and to help policy making related to GB innovation, studies focused on particular regions can prove more effective and relevant, and are therefore suggested for future advancement of this research area.

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Appendix A

Table A1. Details of interview participants.

Participant ID	Interview Mode		Demographic Details of Interview Participants		Years of Involvement in GBs
	Telephone	In-Person	Region Where Experience Based	Role in GB Projects	
AU-M-1		×	Australia	Sustainability Consultant	5
AU-M-21		×	Australia	Commercial Specification Consultant	5
AU-F-4		×	Australia	Sustainability Consultant	6
AU-F-6		×	Australia	Sustainability Consultant	8
AU-F-8	×		Australia	Design Consultant	9
AU-F-1	×		Australia	Sustainability Manager with GB certification organisation	10
AU-M-4		×	Australia	Design Consultant	10
AU-M-13		×	Australia	Sustainability Consultant	11
AU-M-20	×		Australia	Sustainability and Design manager with Contractor	14
AU-F-5		×	Australia	Sustainability Consultant	15
AU-M-14	×		Australia	Sustainability Consultant	15
AU-M-8		×	Australia	Project Manager	15
AU-M-3		×	Australia	Engineering Consultant; Sustainability Consultant	28
AU-M-18	×		Australia	Sustainability Consultant	35
HK-F-1		×	Hong Kong	Sustainability consultant	2
HK-M-2		×	Hong Kong	Sustainability consultant	7
HK-M-3		×	Hong Kong	Design consultant	10
HK-M-6		×	Hong Kong	Environmental and Applications Engineer with HVAC manufacturer	15
HK-M-7		×	Hong Kong	Design consultant	24
PK-M-2	×		Pakistan	Lead Engineer with contractor	1

Table A1. *Cont.*

Participant ID	Interview Mode		Demographic Details of Interview Participants		Years of Involvement in GBs
	Telephone	In-Person	Region Where Experience Based	Role in GB Projects	
SN-M-6		×	Singapore	Sustainability consultant; Engineering Consultant (Mechanical)	7
SN-F-2		×	Singapore	Sustainability Consultant; Design Consultant	8
SN-M-8		×	Singapore	Engineering Consultant (Mechanical); Sustainability Manager	10
SN-M-10		×	Singapore	Engineering Consultant; Sustainability Manager	12
SN-M-7		×	Singapore	Engineering Consultant (Mechanical); Sustainability Manager	12
SN-M-3		×	Singapore	Facilities Management Professional	13
SN-M-12		×	Singapore	Energy Manager	14
SN-M-5		×	Singapore	Design Consultant	22
AE-M-1		×	UAE	Sustainability Consultant	3
AE-F-2		×	UAE	Sustainability Consultant	7
AE-M-3	×		UAE	Sustainability Manager with GB regulatory organisation	9
AE-F-1	×		UAE	Design Consultant	10
AE-M-2		×	UAE	Sustainability Consultant	10
AE-M-4		×	UAE	Design Consultant	12
UK-F-3		×	UK	Sustainability Consultant	4
UK-F-4		×	UK	Sustainability Consultant; Environmental Designer	5
UK-M-5		×	UK	Sustainability Consultant; Design Consultant	6
UK-M-3		×	UK	Sustainability Consultant	7
UK-F-1		×	UK	Design Consultant	10
UK-F-6		×	UK	Sustainability Consultant	10
UK-M-1		×	UK	Sustainability Consultant; Design Consultant	10
UK-F-2		×	UK	Design Consultant	11
UK-M-2		×	UK	Sustainability Consultant	11
UK-M-6		×	UK	Design consultant	11
UK-M-7		×	UK	Design Consultant; Contractor	12
Number of participants	8	37			

Key to participant ID: AE = UAE; AU = Australia; HK = Hong Kong; PK = Pakistan; SN = Singapore; UK = United Kingdom.

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