From Prototypes to Production: Overcoming the Barriers to Adoption of Sustainable Building Innovation

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Abstract. Modern interpretations of sustainable buildings are founded upon innovative application of new products and technology, often applied for the first time. However, such prototype innovations require additional development for commercialisation. In the case of sustainable building innovation, this is to align the innovation with industry requirements such as cost, constructability and building regulations, all of which impact the adoption of the innovation into widespread use. Despite a clear understanding of the barriers to innovation in the construction industry, the importance of the attributes of an innovation that lead to adoption are less well understood. This research utilises the Diffusion of Innovations (DOI) theory to analyse how the attributes for innovation adoption potential from the innovation rich Solar Decathlon building competition. This research demonstrates that there are a number of innovation attributes that are not addressed by the Solar Decathlon and this therefore results in the low rates of innovation adoption into industry from the competition.

1. Introduction
Sustainable buildings utilise new products and technology in pursuit of ecologically sustainable development (ESD) outcomes, which are often applied for the first time. Such examples are at the forefront of the ‘prototype’ nature of buildings seeking high performance and are important to the ongoing development on the industry. The height of innovation in sustainable buildings can arguably be found in the Solar Decathlon competition, where sustainable building innovations are implemented in a competition environment. Such innovations emphasise building performance over other industry critical criteria such as cost, reliability, constructability and compliance. The result is that many new and valuable innovations that reach the prototype stage in the competition are not adopted by industry due to insurmountable barriers to their commercialisation, despite their clear performance benefits.

2. Literature Review
The process of innovation has been a field of enquiry for decades since original explanations (1), with the majority of the research focusing on the manufacturing sector from which products arise (2). ‘Innovation’ as defined by the OECD in 1991 is ‘an iterative process initiated by the perception of a new market and/or service opportunity for a technology-based invention which leads to development, production, and marketing tasks striving for the commercial success of the invention’ (3). The construction industry is notoriously poor in innovating, (4) and blames industry weaknesses including investment reluctance, competitive conditions, institutional framework, seasonal and economic cycles, and the role of suppliers (5). An Australian study showed that the construction industry is behind in
innovation as a whole and has only approximately 30% of businesses in the industry innovating, which is the lowest in any sector (6). Manley (7) reports on a survey that showed obstacles in the Australian construction industry to be: cost of initiative (33%), insufficient time (29%), lack of skilled staff (9%), conservative stakeholders / clients (8%), insufficient benefits (6%), inadequate government support (5%), low volume of available work (3%) and poor staff attitudes (1%), indicating not surprisingly that cost and time are the major obstacles to innovation.

2.1. Diffusion of Innovation (DOI) Theory
Existing theoretical knowledge of innovation as a field of enquiry can assist in understanding how the process of innovation must consider adoption criteria in order to overcome ‘insurmountable’ industry barriers that prevent the adoption of such innovations. The Diffusion of Innovation (DOI) theory addresses innovation with emphasis on the generation (idea), diffusion (movement) and adoption (uptake) of innovations (8). New innovation generation can be collectively referred to as, ideas generation, project definition, problem-solving, design and development, production and marketing and communication, which describes the various stages of development (9). Innovation generation does not automatically mean it will be adopted by the market regardless of if it is radical or incremental. The generation and R&D efforts for an innovation are always aimed at eventual commercialization if the innovation is successful. Innovation adoption is therefore the ultimate measure of success of the innovation process.

The Diffusion of Innovation (DOI) theory specifically identifies relevant attributes of an innovation that lead to adoption for use. Rogers (8) notes that innovations that do not demonstrate these five attributes are less likely to be commercialized and adopted for widespread use in the industry.

i) Relative advantage - is the degree to which an innovation is perceived as being better than the idea it supersedes

ii) Compatibility - is the degree to which an innovation is perceived as consistent with the existing values, past experiences, and needs of potential adopters

iii) Complexity - Complexity is the degree to which an innovation is perceived as relatively difficult to understand and use

iv) Trialability - is the degree to which an innovation may be experimented with

v) Observability - is the degree to which the results of an innovation are visible to others

3. Methods
This research uses the DOI defined ‘attributes of an innovation’ for case study analysis of the Solar Decathlon Build Challenge Competition (SDBCC) to understand the lack of adoption of prototype innovations. The SDBCC represents a critical case in order to generalise about other innovations, in this case to view how innovations have progressed from prototype to adoption. The case study method was chosen as they are appropriate to be used to test or generate theory and are particularly appropriate for areas where the research is still in its infancy, or formative stages where there are no solid theoretical foundations. It is preferred when “how” or “why” questions are being posed (10). The case study data in this thesis is collected via primary source content analysis (11) following a visit to the 2017 U.S. SDBCC as part of an extended sustainable building innovation research project to investigate the adoption of innovation into industry.

3.1. Innovation Case study - Solar Decathlon Build Challenge Competition (SDBCC)
The U.S. Department of Energy (DOE) Solar Decathlon Build Challenge Competition (SDBCC) is an international competition that challenges 20 collegiate teams to design, build, and operate the most attractive, effective, and energy-efficient solar-powered house, with the specific goal of the competition to advance the use of sustainable building designs and technological innovation. Open to the public and free of charge, the SDBCC allows visitors to tour ultra-efficient houses, gather ideas to use in their own
homes, and learn how energy-saving features can help reduce power bills. The decathlon by name consists of ten contests governed by detailed rules which are directly measured or juried, representing high performance building innovation.

4. Results
Analysis of the SDBCC shows that the attributes of an innovation required for adoption by industry are not achieved in the SDBCC. Table 1 explains the weakness of the competition’s ability to drive adoption and recommendations based on the DOI theory for improvement are shown.

| Attribute          | Definition                                                                 | SDBCC Analysis                                                                 | Weakness of approach                                                                 | Required modification for Adoption                                                                 |
|--------------------|---------------------------------------------------------------------------|--------------------------------------------------------------------------------|--------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------|
| Relative Advantage | The degree to which an innovation is perceived as being better than the idea it supersedes. | the competition environment emphasises relative advantage for high performance in the absence of other constraints that are required for adoption | The innovation relative advantage is focussed by the competition leading to high operational performance solutions that do not address critical industry requirements | The competition requires a stronger industry involvement to ensure innovation for high performance efforts are likely to be adopted |
| Compatibility      | The degree to which an innovation is perceived as consistent with the existing values, past experiences, and needs of potential adopters. | The focussed competition criteria do not attempt to address industry standards for size, cost, constructability, compliance resulting in low compatibility of the innovations | Industry does not perceive the innovations from the SDBCC to be compatible with industry requirements due to the lack of compliance with industry standards | the innovation must be able to directly replace an existing solution in order for it to be utilised easily within industry, resulting in minimal down time during the exchange, this includes the ability of operators and maintenance to integrate the new innovation into the system |
| Complexity         | The degree to which an innovation is perceived as relatively difficult to understand and use. | The innovations from the SDBCC range from simple to highly complex requiring specialised construction techniques and operation | Suitability of the SDBCC innovations varies based on their complexity and the willingness of industry to integrate the innovation | Complexity of the innovation must match the capabilities of the adopter’s uncertainty for the user, including not just its operation, ongoing installation and maintenance |
| Trialability       | The degree to which an innovation may be experimented with on a limited basis. | The SDBCC provides excellent trialability at the competition completion but not during the preceding 2-year development process | The SDBCC provides excellent short term trialability to a small number of users that can be further explored by interested parties | Trialability of innovation from the SDBCC must reach a broader audience to maximise diffusion of innovation. |
| Observability      | The degree to which the results of an innovation are visible to others. | The SDBCC provides excellent observability at competition completion but not during the preceding 2-year development process | The SDBCC provides excellent short-term observability that can be further explored by interested parties | Like trialability, the observability of SDBCC innovation must reach a wider audience in order to have greater diffusion |

Table 1: Analysis of Innovation Attributes

5. Discussion
The analysis of the SDBCC using the DOI ‘attributes of innovation’ shows that the fundamental challenge of innovation adoption from the SDBCC is the lack of relevance of the innovation to industry due to the competition specific rules and criteria, and the accessibility limitations of built prototypes to increase diffusion. To address the issue of relevance, solutions are proposed. The first is to achieve a greater involvement of the industry into the competition. This could occur through the use of more compatible criteria of the competition design, such as house size, cost per metre squared, compliance with regulations and standards beyond those already incorporated into the competition rules. Secondly, the direct participation of industry in the competition would increase relevance of the innovations. This could be achieved by requiring industry partnerships in the teams, requiring use of a proportion of
industry standard products or even a financial commitment to the teams. The involvement of industry in the competition would address the challenges found in the attributes of relative advantage, compatibility and complexity.

Addressing the accessibility for industry decision makers to trial and observe innovation is difficult due to the fixed nature of building, climate specific design, and the fragmented nature of the parties involved, and creative solutions must be employed, such as widespread promotion of the winning designs, promotion of products, components and systems by the industry suppliers directly, and a greater awareness of the competition what it offers to designs, builders, clients and the public. Despite these challenges, the prototypes displayed at completion of the competition excel at providing an opportunity for judging, trialling and observing by the other teams, public and industry that would not be possible otherwise. The display of the prototypes is therefore an excellent outcome of the competition for industry accessibility to consider adoption of the innovations. Other strategies to improve adoption of innovation form the SDBCC relate to factors outside the individual competition, such as frequency and location of the competition, rule changes to advance innovation or adoption attributes, and staged competition where the innovation process is encouraged to evolve across multiple competitions to progress from a prototype to a commercial product.

6. Conclusion
This research demonstrates how the application of innovation theory can be used to improve the adoption of sustainable building innovation into industry. Five defined attributes are required to be provided to increase the chances of adoption. These five attributes were analysed in the Solar Decathlon Build Challenge Competition (SDBCC) which is a specialised building competition designed to advance high performance building innovation. The research demonstrates the importance of consideration of the DOI attributes of an innovation, specifically the relevance of the competition with industry goals and accessibility for decision makers to view and trial innovations as critical factors for diffusion and adoption of sustainable building innovation.

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