EVALUATION OF AN AUSTRALIAN SOLAR COMMUNITY: IMPLICATIONS FOR EDUCATION AND TRAINING

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1. Introduction

1.1 Housing sustainability – from fragmentation to integrated system

Sustainability in housing has tended to be addressed in a segmented manner with product criteria being examined in isolation [1], such as energy efficiency, passive solar design, renewable energy technologies, zero carbon approaches, behavior change and materials [2-8]. The housing construction sector has also attempted to identify and address sustainability in their processes [9-13]. This literature shows the challenges of producing a product that is long lived and needs to meet diverse requirements such as functionality, cultural sensitivity and local climatic conditions [10], in a context where industry diversity, fragmentation and complexity can make it difficult to assign sustainability responsibilities [14]. The key barriers identified by this literature could be categorized:

- *stakeholder engagement and communication issues* (level and stage of active involvement; knowledge of sustainable options)
- *technical issues* (availability and reliability of technologies and the expertise to utilise them)
- *economic issues* (affordability and perceptions of costs and trade-offs)
- *regulatory issues* (what is allowed, encouraged or disallowed by regulations)
- *residential construction industry culture and practice* (conservatism, poor communication skills, procurement practices, design/building process, contractual relationships, perceptions of risk)
- *lack of feedback mechanisms* (post-occupancy and post-construction performance)
- *End-user / occupant factors* (behavior; knowledge of options; market influences)

It has been argued that a focus on the construction sector processes alone is bound to have limited affects [15] unless the focus expands to the broader housing sector to simultaneously address issues such as urban planning and design [16, 17], householders [18, 19], infrastructure [20, 21], costs, value and benefits [22-24] and housing markets and regulation [25-27]. As an integrated system, then, the housing sector could be classified into six broad segments (legislative, market, planning, design, construction and occupancy/ownership). These broad segments collectively determine the nature of national housing stock and the impacts that housing has on occupants, the environment and society as a whole [28, 29]. At an individual level a house is also an integrated system of building form, materials, services, technologies and appliances. A sustainable house could be classified as an environmentally sound technology (EST) that sustainably manages natural resources, reduces its pollution outputs and minimizes and manages its waste [30]. The successful transfer of and EST through the market to the end-user (the occupant) requires the end user to recognize the benefits of the technology and understand the technology in the sense of their operation, responsible use and systems context [31]. Informed decision making, Halls argues, is a key component of the successful transfer of an EST, comprising four key requirements: a clear understanding and documentation of the end-user needs; the characterization of the environmental, social and economic impacts of the alternatives; decision support tools to enable rational choice of an optimal solution; and the capability to operate the technology so that it fills its potential and meets the identified needs of occupants. This is a role for education and training.

1.2 ISES, education and solar communities

A cursory exploration of the International Solar Energy Society website (www.ises.org) reveals numerous references to education and training, referring collectively to concepts of the transfer and exchange of information and good practices, awareness raising and skills development. The purposes of such education and training relate to changing policy, stimulating industry, improving quality control and promoting the wider use of renewable energy sources. The primary objective appears to be to *accelerate a transition to a better world for everyone* (ISEE), as the greater use of renewable energy is seen as key to climate recovery; world poverty alleviation; advances in energy security, access and equality; improved human and environmental health; and a stabilized society.

The Solar Cities project – Habitats of Tomorrow – aims at promoting the greater use of renewable energy within the context of long term planning for sustainable urban development. The focus is on cities or communities as complete systems; each one *a unique laboratory* allowing for the study of urban sustainability within the context of a low carbon lifestyle [32]. It was within this context that a research program was commenced in 2009 with an objective of investigating the complex nature of sustainable housing in an Australian solar community. Two research questions were posed: (i) what are the goals, expectations and experiences of early adopter families in the design, construction and occupation of their sustainable solar homes?; (ii) what processes, supply chain agents and strategies enhanced or inhibited the attainment of the sustainability performance objectives of these homes? The purpose of this paper is to present the key findings from this study and to pose the implications these findings may have for our understandings and practices in renewable energy education and training.

2. Methodology

2.1 Research approach and methodology

The complexity of both the drivers and the potential solutions for sustainable housing requires a whole-of-science, trans-disciplinary approach [33-35]. This study adopted the *trans-disciplinary approach to sustainable affordable housing* [1] that encompasses the different phases in the lifecycle of a house, the trans-disciplinary and collaborative relationships required, and the need for both regulatory and market drivers. Sev's *conceptual framework for evaluating sustainability in the construction industry* [9] was modified to develop a new *Framework for defining and evaluating a sustainable house* (Fig.1).

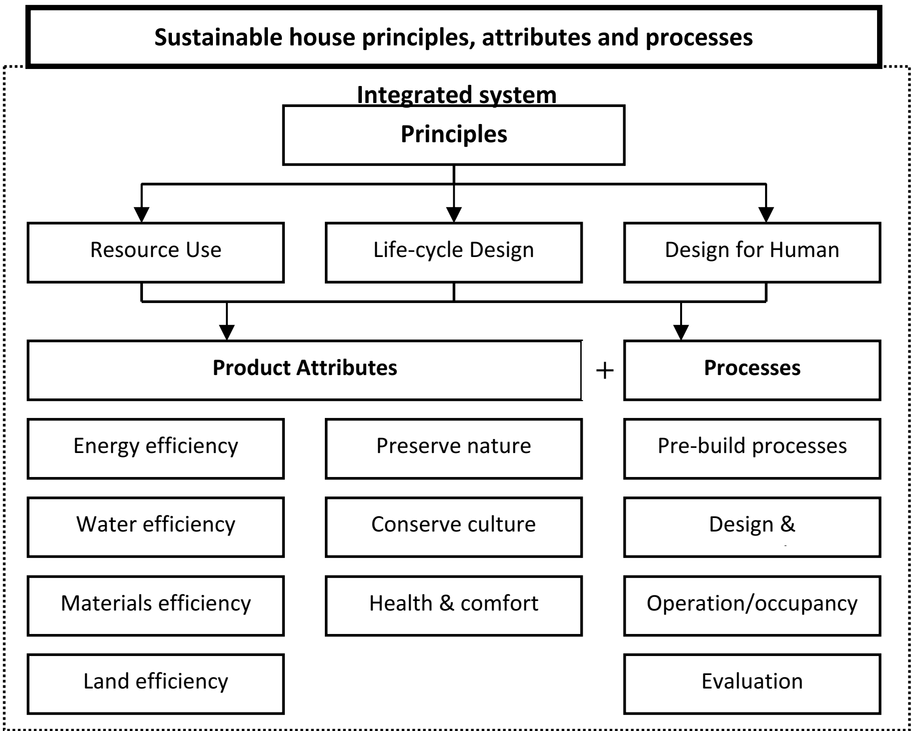

Fig. 1: Framework for defining and evaluating a sustainable house

This framework shows a sustainable house as an integrated system that embraces three core principles through the attributes of the product itself, and the processes through which a sustainable house is envisaged, constructed and occupied. These attributes and processes informed the selection of case study houses, data collection methodologies, and the analysis and evaluation of performance outcomes. Innovation diffusion theory was applied to the concept of a sustainable house as an environmentally sound technology (an integrated system) that needs to diffuse into the general market [31]. Early adopters of sustainable houses were utilized as a means of exploring this diffusion process, drawing on the Model of Innovation Adoption [36] and the Information Awareness Model [37].

A case study research strategy was adopted which enables the in-depth and longitudinal examination of a bounded phenomenon (e.g. a sustainable house) within a real-world context, and the utilisation of both qualitative and quantitative approaches involving multiple sources of data [38]. The qualitative methodology, encompassing document analysis, in-depth face-to-face interviews and direct observation, captured the richness and complexity of families' experience of sustainable housing and placed emphasis on the processes and meanings [39]. A thematic approach was used to code and condense the data [40] and a transformative perspective was adopted in the evaluation and discussion of the results [41]. Quantitative data was collected from building approval documents for each house, building simulation software (BERS Pro 4.1) as approved by Australian regulations for thermal simulations for resident properties (www.nathers.gov.au), visual inspections and each home's Intelligent Metering and Control System (IMCS). The purposes of the IMCS are to measure and display usage of resources involved in each utility service; enable the aggregation of end use data at a community level; allow the community to optimize its utility infrastructure with a view to future self sufficiency; and to use the data to inform policy and regulation [42]. The IMCS measures and displays electricity consumption and generation (general power, lighting, water pumping and solar generation), water consumption (potable rainwater, recycled water, hot water), gas consumption and internal thermal environment (temperature and humidity). Raw data from participating households was extracted from the IMCS main data base, and analysed using Matlab and Excel. The building approval documents for these homes were analysed to determine key design strategies such as size, orientation, insulation, thermal mass, glazing etc. These building approval documents included site plan; floor plans; elevations and cross-sections; schedule of materials; landscape plan; services plans for plumbing, power, gas and communications; thermal modeling report; construction management plan and solar penetration diagrams.

2.2 Physical context and case study participants

The physical context is a residential Ecovillage (a solar community) in sub-tropical Queensland, Australia (latitude 28^{o} south). The area zoned for housing (20% of estate land) is divided into hamlets of equatorial facing lots of various sizes to encourage a mixed demographic and social interaction. Hamlets are linked with cycling and walking paths, as well as vehicular laneways. The vision of the developers of this estate was to inspire sustainable living and inform further ecologically sustainable developments [42]. An extensive Architectural and Landscape Code (A&LC) '*premised on the interconnectedness of all things*' and embracing '*both local and global concerns*' governs the design and construction of housing in the estate: this building code is in addition to state building regulations. All houses are constructed off-ground and incorporate a hybrid approach to the building envelope (mixed use of thermal mass and light-weight materials). Passive solar architecture, solar water heaters with instantaneous gas boosting, and photovoltaic systems (minimum 1kWp) are all mandatory, whilst high energy use appliances such as air conditioners and clothes driers are not permitted.

All lot owners registered on the Ecovillage's community intranet were invited to participate in the research, and this research is based on the experiences and quantitative data of eight families (15% of the completed residences at the time the study commenced). Each of the eight participating families ad been through the design, construction and occupation phases of sustianable solar homes in the period 2007 – 2010.

Despite the small sample size and the voluntary nature of the case study recruitment process, the age, education level and family type of these participants provided a representation of the demographic diversity one finds in the home ownership market in Australia. Influences on the sustainability outcomes of the case study homes were studied at a macro and micro level (Fig. 2), encompassing product attributes (building envelope, sustainable energy systems and resource monitoring) and processes (end-user goals, design and construct process, a zero-energy approach and urban planning). The evaluation of the subsystems and processes, and the interactions between them, enabled a deeper understanding of the integrated system.

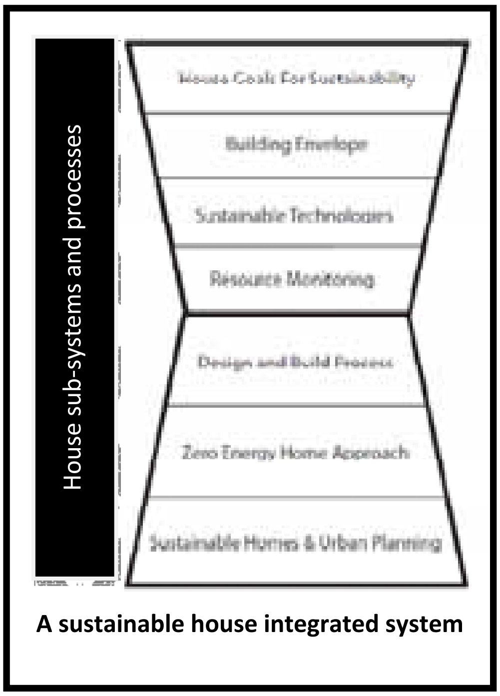

Fig.2: Sustainable house subsystems

3. Results

3.1 End-users define a sustainable house

End-user expectations for their sustainable solar homes had three areas of focus: (i) an environment focus (reducing the impact of the home on the environment); (ii) a practical focus (functionality, comfort, adaptability, appropriate size and cost effective operation); and (iii) a lifestyle focus (a house with character and a particular 'look' and 'feel', social interaction, and better quality of life). For these participants, *a sustainable house embraces the collective and integrated aspects of environment protection* (energy, water, materials, land), *resource management* (natural, built and economic resources) *and social wellbeing* (personal values, health, comfort, community). *This product is an expression of personal and social identity and enables and supports its inhabitants in living sustainably.* These motivations and drivers are somewhat consistent with research on adoption of pro-environmental behaviour and the uptake of energy efficiency and renewable energy technologies [4, 43-45]. Participants incorporated into their homes a range of features that would assist them in reducing their direct impact on the environment as well as enable pro-environmental and social interaction behaviours. These features were not necessarily part of their original goals, but were included because of the urban context (e.g. they were either mandated or strongly recommended in the estate's building code). Once implemented and experienced, these features were subsequently valued.

3.2 Housing context and regulation affect sustainability aspirations and outcomes

The urban context was of key importance in shaping both the vision of a sustainable lifestyle and the resultant actions and outcomes. The urban context played a leadership role in supporting and enabling end-users to live sustainably by (i) helping to shape, refine and extend end-users' sustainability vision and aspirations beyond their own experience, market standard and government refulation, and (ii) assisting in the conversion of the vision into reality through its requirement for an integrated design and approval process and the IMCS. The prescriptive building codes of this urban context also revealed an interesting phenomena about end-user and supply chain responses to regulation. Regulation was often used as a benchmark against which to make sustainability decisions, with end-users and their agents interpreting regulation either as defining the end goal (i.e. the best performance) or as establishing minimum performance standards (which were considered by some to be advisory rather than mandatory). This had the effect of inadvertently creating false expectations of performance outcomes or limiting aspiration for higher levels of sustainability performance. Solar water heaters and building envelope thermal performance were two examples , with end-users expecting that meeting the state government regulations in these areas would mean they would have free hot water and a thermally comfortable house (with negligible operational costs). There was little evidence from designers, contractors or end-users of optimisation of these technologies to enhance performance outcomes.

3.3 Supply chain agents affect sustainability performance outcomes

The extent of the sustainability measures incorporated into these houses and participants' lifestyles was supported or limited by many supply chain agents that contributed to, or impacted on, the physical form, function and operation of their house at different stages and levels. These supply chain agents included the land developer, sales people and estate level architectural review committee; architects, building designers and specialist engineers; building contractors and trade subcontractors; building certifiers, surveyors and inspectors; product designers, manufacturers and suppliers; and end-users and their social networks. Failures in communication, systems thinking and informed decision making impacted on the end-users' goals and sustainability outcomes economically, environmentally and socially. One technical example of this was the estate-wide poor performance of solar water heaters, conceivably attributable largely to plumbers' lack of understanding of the purpose of the system (i.e. the optimisation of solar input for heating water) and the operation of the system as a whole (how each of the components contributed to the purpose). The interaction between solar water heating performance and building design, energy consumption, greenhouse gas emissions and the economic sustainability goals of end users, appeared to be poorly understood by most supply chain agents. Other examples related to ethical differences among families and design and construction professionals in areas such as attitudes towards building regulations, professional silos vs trans-disciplinary collaboration, conflicting views on cost and value, and professional practices that alienated end-users. Decisions and actions by supply chain agents impacted on overall sustainability goals by affecting environmental performance (e.g. higher use of gas for water heating; lower output of photovoltaic systems), economic performance (e.g. higher operational costs) and social sustainability (e.g. houses that are not as thermally comfortable as expected). Overall there was scant evidence of performance optimisation of the key sub-systems (e.g. building, energy and water services, materials, land) and the system as a whole.

3.4 A sustainable house is an integrated system

End-user experiences and performance outcomes reinforced the need to consider a sustainable house as an integrated system (Fig. 3) that is centered on end-user goals and aspirations, and incorporates the interconnections between these goals and aspirations, specific building elements and sub-systems (e.g. the building envelope, its technologies and its metering and management), design and construction processes and practices, and the urban context. These interactions take place within the context of multiple supply chain agents. Collectively the end-users, urban context, building elements, supply chain agents and processes and practices contribute to the product – a sustainable house. The success of the integrated system is highly reliant on good communication – of the goals, processes, and performance outcomes – and robust decision support tools and processes to identify and evaluate options.

Fig.3: The integrated system of a sustainable house

3.5 Early adopters identify ten categories of barriers to a sustainable house

These early adopter experiences lead to the classification of ten key categories of barriers to a sustainable house (Tab. 1), based on the work of Reddy and Painuly [44] in identifying barriers to renewable energy technologies.

Tab.1: Taxonomy of barriers to a sustainable home

Broad barrier	Barriers to implementation of a sustainable house
Awareness & information barriers	Bounded rationality in decision making Restricted knowledge / perspectives of what is possible Trust / lack of trust in information source Mixed / conflicting messages
Behaviour barriers	Value related to previous experience, so may not value something unfamiliar Need to be trained in how to use / operate / behave
Communi-cation	Informed consent Language and terminology
Economic and finance barriers	Timeframes associated with cost calculations (focus on upfront costs) Lack of clarity of parameters included in cost decisions, making accurate comparisons difficult Lack of analysis of bundled costs / savings
	Value generally limited to market value (cost) Lack of application of other value considerations (value in use; social, cultural, emotional, image values and environmental value (Lorenz, 2010) No decision support tools to enable value / cost / benefit analysis
Education & training barriers	Poor communication skills Lack of integrated systems thinking (understanding of desired outcome, and how the components integrate and impact on the whole system) Lack of decision making tools / application of decision making tools Innovation diffusion
Institutional practice & culture barriers	Supply chain lack of responsibility for performance outcomes Professional silos (not trans-disciplinary) Professional ego Lack of decision making tools / application of decision making tools Supply chain relationships; relationship management Professional and trade practices
Market failures & barriers	Demand- lead approach Common metrics (m2 and $\$/m^2$) Lack of 'bundling strategy' that captures synergies of individual sustainable houses and sustainable urban development
Regulatory barriers	Level of regulation Level of enforcement Lack of performance verification
Technical risk	Product failure: identification and rectification processes Matching product design with end-user need Product reliability and support Purpose of product: consumption, end-user needs or optimisation of environmental performance
Values, beliefs, world views	Environmental ethics Perspective of social responsibility and sustainability

4. Discussion

This study reinforces the concept of a solar community as an integrated system that encompasses an urban context, housing forms and their subsystems that shape, support and enable sustainable low-carbon lifestyles of the community's inhabitants. End-users' definition of a sustainable house (i.e. embracing the collective and integrated aspects of environment protection, resource management and social well-being) is consistent with literature that suggests that a sustainable house should make efficient use of energy, water, materials and land, and preserve, conserve and protect human and natural conditions through the design, construction and operation processes [9, 18, 46, 47]. This is reflected in the *framework for defining and evaluation a sustainable house (Fig.1)*. The findings show that both regulation and the market influenced the aspirational goals and the performance outcomes of these homes, lending support to Salama's approach to sustainable housing [1]. The study also highlighted that a sustainable house is not the only enabler of a sustainable lifestyle: urban and social contexts play an important role in shaping both the house and the lifestyles of inhabitants. This is consistent with communication of innovation theory [37]. The *taxonomy of barriers to a sustainable house*, as developed through this study, raises questions relating to the solar industry's education and training efforts and practices. Transferring and exchanging information and good practices, awareness raising and skills development in the areas of energy efficiency and renewable energy technologies are undoubtedly important, but these efforts do not appear to be sufficient to ensure optimised sustainability outcomes for our solar homes and communities. Two key areas are suggested as needing consideration.

First, as a large number of supply chain agents affect the performance outcomes of sustainable homes and communities, there appears to be a need for formal and informal training and education that targets the legislative, market, planning, design, construction and occupancy/ownership segments of the housing sector. Trans-disciplinary courses that break down the traditional silos of university education are especially lacking, with little coverage of solar homes, solar communities and the low carbon lifestyles that they support, included in non science and engineering courses. Second, the taxonomy indicates that this education and training needs to incorporate foundational skills in systems thinking within and beyond each specific segment, leading to an understanding of inter-relationships and interdependencies. These systems include economic, natural and social systems; technical systems (such as a building and its service technologies) and different system scales (e.g. a household scale, a community scale, and regional and national scales). A deeper knowledge and understanding of how each sector's practices and supply chain relationships impact on aspirations and outcomes may lead to a more equitable sharing of responsibility for the performance outcomes. The optimisation of systems and subsystems requires advanced decision making skills and the development and utilization of decision support tools. This skills set encompasses the concepts of information gathering, knowledge management and transfer, performance evaluation and end-user engagement. Lastly, this study indicates a need for education on the role personal ethics, values and world views have in influencing actions and decisions taken in professional practice.

5. Conclusion

Through an analysis of the experiences of early adopters of sustainable solar houses within a solar community, this study revealed that housing markets, regulation and multiple supply chain agents can impact on the aspirational goals and performance outcomes of sustainable solar homes. Whilst the study confirmed that a sustainable house is an integrated system that is influenced by its urban context, it also found that a lack of systems thinking, poor decision making skills and practices, and conflicts in ethical positions impacted on the sustainability goals and lifestyles of the end-users. The experiences of these families raise the question of whether the solar industry's education and training efforts need to be broadened in target market and scope to enhance trans-disciplinary knowledge and collaboration in order to enhanced environmental performance.

6. References

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