

Opening the black box: Enhancing Community Design and Decision Making Processes with Building Performance Simulation

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Abstract

It is widely acknowledged that faced with diverse future impacts (including climatic changes, economic instability and energy supply vulnerabilities) buildings and communities' worldwide need to become increasingly resilient. The work presented in this paper investigates how Community Design and Decision Making (CDDM) processes can be enhanced through the use of *design thinking* techniques involving Building Performance Simulation (BPS). The research presented is based on findings from a real-world case study project involving the design of a mixed-use zero carbon community welcome centre planned for the Findhorn Eco-Community, in Scotland, UK.

Throughout the conceptual and early design stages the community played a crucial part in the decision making process. Extensive consultation and community engagement exercises formed the basis from which initial design concepts were produced and evaluated. BPS results and in particular the use of sensitivity analysis (SA) techniques played a major contributing role in establishing a multicriteria evidence base from which to inform the CDDM process.

1.0 Introduction

Contending with high levels of uncertainty in relation to the impacts of future climatic changes, economic stability and energy supply security; poses complex challenges for design teams seeking resilient solutions. Despite the obvious strengths of the communal decision making model, community design and decision-making (CDDM) processes are widely acknowledged as complex, challenging and time consuming, when compared to 'conventional' (client/architect/contractor) or 'Design and Build' (contractor led) models.

Almost twenty years ago the US Department of Energy (DOE) first initiated a process of consultation on the development of Tools for Community Design and Decision Making (TCDDM) (Geertman and Stillwell, 2003). Numerous benefits have been associated with the use of such tools in the CDDM process, with Snyder (1999) stating that, "tools empower people to act intelligently." The appropriate use of tools can make it easier for lay people to become better informed about design decisions, by helping to make the costs, benefits

and implications of key decisions more transparent. Tools also fulfil an educational role. By helping to educate stakeholders about the overall impact of choices, the need for regulations that enforce external laws upon a community can be minimised (Snyder, 1999).

Contemporary approaches to user-focused design typically involve concepts such as Codesign and Coproduction, which are characterised by equal and reciprocal relationships between professionals and lay stakeholders (Cahn, 2001). Although CDDM will always involve groups of community stakeholders, it may or may not involve design professionals. This paper investigates the Codesign process within the wider domain of CDDM, in a context where both lay people and experienced design professionals assume equal responsibility for the outcomes of design decisions.

Using this approach multiple stakeholder's (from both lay and professional) backgrounds were able to collaborate using sociocratic processes (Buck and Villines, 2007) in order to achieve mutually acceptable and resilient design outcomes. This paper examines the integration of BPS techniques involving scenario modelling and sensitivity analysis (SA) within a CDDM approach to the design of a multi-purpose Zero Carbon community centre in Scotland.

2.0 Background

2.1 Decision making (support) and its challenges

Design is by nature a MCDM process involving different kinds of sub-problems within a larger framework. According to Dorst (2004) "most process focussed design methods (...) incorporate strong assumptions"-this begins with the actual definition of the design problem and its corresponding sub problems.

Typically, these sub-problems may be categorised as: *partly determined* (for example, due to unalterable criteria imposed by the client or planning constraints), *undetermined* (in which case the designer is largely free to design according to his/her own taste or style) and *underdetermined* (Dorst, 2004). The latter category typically represents a large proportion of the design process and implies that potential designs (i.e. proposals and possible solutions) are put forward (to the client) by the designer(s). The decision makers can only evaluate and decide upon these different proposals during the design process itself. In contrast to the Cartesian

scientific method, whereby problems are decomposed into smaller parts and then solved individually, in order to obtain a reliable solution (Rehfeldt, 1993), in *design thinking*, optimal solutions are found where sub-problems are resolved holistically in a unified solution (Rowe, 1991).

This is one of the most challenging aspects of addressing complex design problems (which inevitably involve subjective non-computational criteria) using computational multi-criteria decision-making (MCDM) processes. Using conventional multi-objective optimization (MOO) approaches it is not always possible to find one optimal design solution that satisfies all design objectives, and this non-existent solution is often referred to as the “utopia point” (Kaftan, 2016). Indeed an over reliance on MOO approaches in the design process is likely to unduly weight the objective *partly determined* aspects of the design process to the detriment of phenomenological *undetermined* and reflectively informed *underdetermined* aspects. To the authors knowledge this issue has received only scant attention in the domain of BPS, with some prior discussion by Hopfe et al. (2013).

Despite the clear benefits of BPS in informing the early stage design process (Struck, 2012) its effective integration within the CDDM process, remains poorly documented in the literature. Anderies (2014) highlights the difficulty of simultaneously incorporating self-organisation principles and intentional design in resilient socio-ecological systems. Whilst according to Meijers (2000) the root of this problem is that, “needs, requirements and intentions and ‘structure’ belong to different conceptual worlds.” Or as Coyne (1995) and Varela et al., (1992) point out, positivism and phenomenology sit at opposite ends of the epistemological spectrum.

Another more practical challenge is that the decision process in the design progression is non-linear. There is interaction and iteration throughout the process between multiple stakeholders as *underdetermined aspects* are iteratively resolved.

The role of BPS in facilitating understanding of potentially conflicting quantifiable objectives (such as costs, energy performance etc.) is well documented (McLeod et al., 2013) (Kaftan, 2016). Robinson et al (2016) argue that BPS is used by the building physicists and performance analysts primarily to ensure that the proposed design fulfils specific technical requirement in terms of energy efficiency, thermal comfort and other performance aspects. In other words BPS is typically used *ex ante* by a specialist as a ‘black-box’ design support tool within a purely positivist epistemology.

Anderies (2014) argues that at a micro-scale (i.e. the level of an individual building or of a cluster of buildings within a community), robustness-based design approaches dominate the objective of achieving resilience. This means that instead of achieving resilience in the broadest sense (whereby the building is

able to withstand diverse impacts such as future climatic changes, economic instability and energy supply vulnerability etc.) only single or multi-objective optimization (e.g. is the building carbon neutral, or carbon neutral with a specified daylight factor) are actually considered. Hence conventional robustness approaches rarely lead to resilience because they omit consideration of compounding stressors, critical failure, wider uncertainties, and crucially whole life adaptation.

Contemporary views of resilient design concepts suggest that strategies incorporating both robustness and other attributes such as ‘redundancy’ (or spare capacity) are likely to become increasingly important even on the micro-scale. The redundancy approach differs from the robustness-based approach as design and costs optimization will entail consideration of critical risk capacity. Furthermore, local knowledge within the community and tacit awareness are not captured in conventional MOO approaches. Stevenson et al., (2016) argue that redundancy is important at all scales of design particularly when it is effectively combined with appropriate feedback loops, such as continuous building performance evaluation, within the overall system.

2.2 Established Approaches within CDDM

2.2.1 Design thinking

Design thinking is an established method to support the collaborative decision making process. It is based on the assumption that a design problem is best approached by stakeholders of different disciplines. Interdisciplinary teams define a set of requirements but try to understand the actual human needs first. Testing and validation are often more informal and participatory. User feedback should come at all stages of ideation by using process sketches, simple mockups, simulations etc.

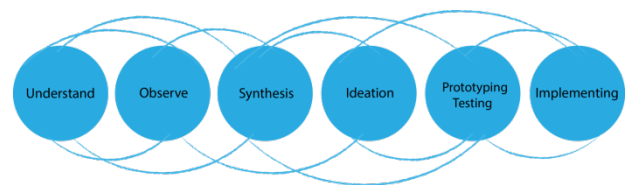


Figure 1: The design process (Wölbling et al., 2012)

For example, in the case of accomplishing a target to convince more people to use less energy, the following steps would have to be undertaken:

1. Learn from people why they use energy;
2. Find their energy usage patterns;
3. Define design principles (facilitate social interaction, special consideration to holistic set up, incl. parking, driving, motivation);

4. Make tangible goals (how might we, from design principles to specific ideas-> rough prototypes)
5. Iterate relentlessly

Potential problems occur if there are dominant experts from specific fields rather than emphatic participants (that embrace hybrid thinking). Therefore, it may be beneficial to have people that combine interdisciplinary capabilities in one person rather than interdisciplinary team.

2.2.2 Design Charrettes

Design charrettes are workshops where designers work intensively on an issue. Similarly, to design thinking, it is a multi-disciplinary process, in order to facilitate an open discussion between the stakeholders that are asked to present their findings in a public forum.

This method can be used to engage with a community or to discover community problems, in which case the stakeholders would meet with the community groups to collect information on issues or values of the members.

Charrette groups collaborate on a solution that will help to incorporate the values and realise a vision for the development. It is an intensive but supposedly

transparent process. Dependent upon its duration (typically up to 2 weeks), the charrette offers short-term resolutions by engaging the public as their input is needed. The teams are multi-disciplinary in nature and all of the key stakeholders take part in the charrettes. Through the sharing of information, trust is built between all parties.

Methodology

The work that we present in this paper is based on a real-world case study building, a multi-purpose Zero Carbon community welcome centre that is planned for the Findhorn Eco-Community, in Scotland, UK. The centre incorporates a shop, café, visitor reception space, and offices. In the context of design exploration, a number of designs concepts were developed based on the clients brief (Figure 1). Key requirements of the design brief included: a building constructed to very low capital costs (less than £1k per m², built to a low energy performance standard, e.g. the Passivhaus standard, located at the edge of a coastal flood zone, whilst being aesthetically in keeping with its surroundings and maximising views to the sea, etc.).

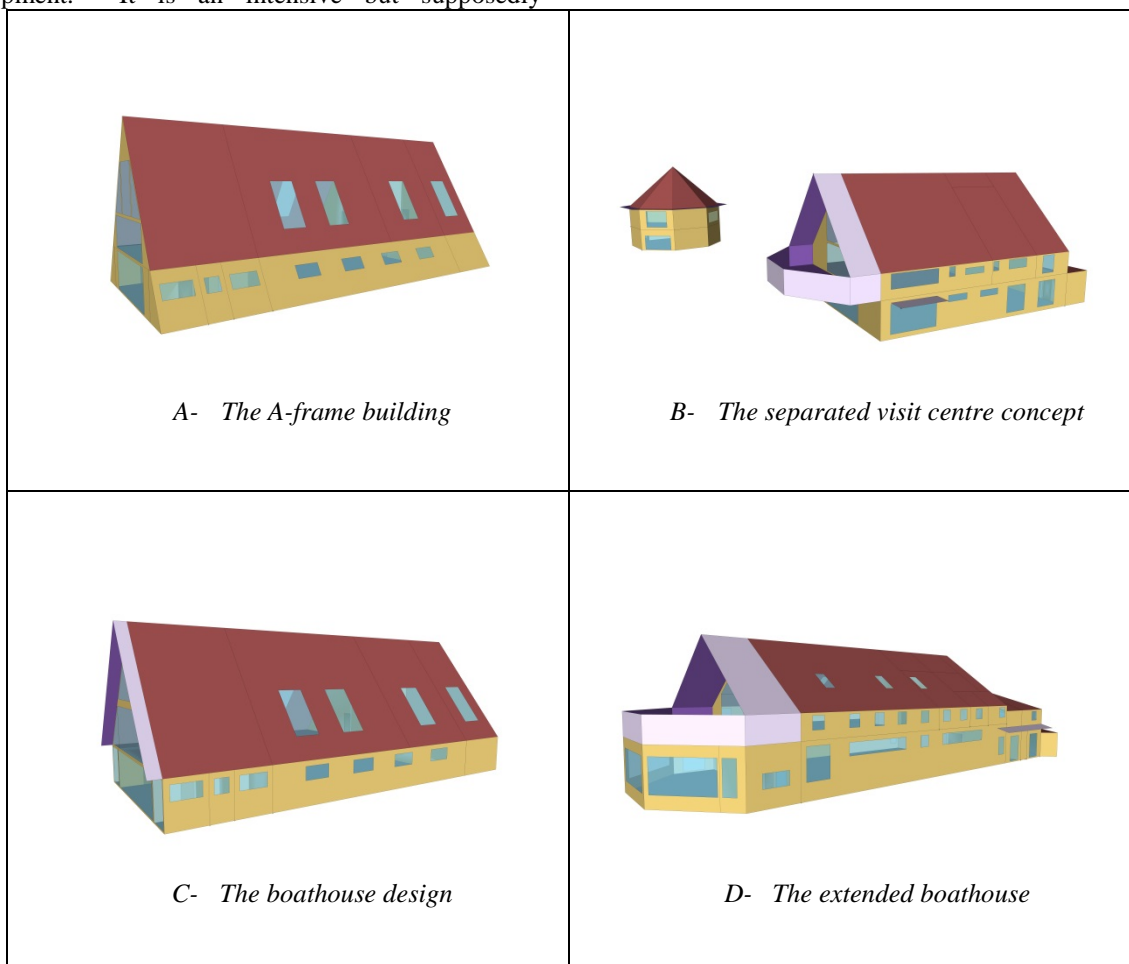


Figure 1: The Findhorn community centre – four different concepts.

In response to the brief the design team developed a number of different concepts (Figure 1). These concept designs were compared through their range of performance and design criteria such as aesthetics, functionality, capital cost, energy efficiency, operational costs and spatial arrangement.

These criteria were only partly based upon the initial design brief. Community consultation was highlighted as an important requirement in the original design brief and the refinement and importance of selection criteria evolved from the community feedback and consultation meetings.

Consultation with the community

1. Following an initial sociocratically held design inception meeting with key stakeholders two formal community consultation meetings were scheduled. During the first consultation meeting, a design engagement process was conducted in which initial concept sketches were displayed and general comments and feedback on the proposals were discussed and recorded. In a second meeting, following substantive design revisions community feedback was collated and addressed. This was conducted in the form of a design charrette. In the first meeting the process was supported by a trained facilitator with productive outcomes; whilst in the second meeting, the consultation was conducted as an open public presentation and meeting which resulted in divided outcomes. Although the majority supported the revised proposal, a vocal minority remained opposed to any form of a multi-storey building.
2. Throughout the CDDM process, the design team adopted methods of design thinking, through outreach engagement with representative stakeholder groups from the community on. This was done on multiple occasions (and at scales ranging from one-to-one to small group meetings) in order to better understand the needs of the community and to ensure that these needs remained aligned with the evolving design brief. The undertaking of these third party consultations was an important facet of Stage 2 (Concept Design) which helped to inform the wider research and development aspects of the project. In a project which is positioned at the heart of a spiritual and ecological community such as Findhorn the importance of community consultation and feedback cannot be underestimated. The

participants were seen as representative of the diverse views of the larger community.

3. In addition to the formal consultations, the design team undertook weeklong residency periods at Findhorn in order to provide extended contact time with residents of the community. This allowed a large number of informal 'one to one' drop-in sessions to be held, offering individuals a chance to air their views in private or to provide direct access to the design team on alternative days if individuals were unable to attend the community events.
4. During the second weeklong stay, an evening talk was held about the basic principles of low energy design, UK energy policies and the Passivhaus concept. The purpose of this talk was to inform lay community members about existing UK building standards and to explain how the Passivhaus concept can provide a template from which to rationally achieve Zero Carbon design.
5. A presentation was given by the design team presenting the changes from the initial draft to the current design concept (this was based on the community feedback from the first meeting as well as the ongoing design team meetings and feedback from the client(s)).

Overall, all consultations were well attended and the feedback from them was generally very positive. Design changes were presented as a transparent response to communal stakeholder priorities in terms of the design, accessibility, traffic arrangements, interior layout etc.. Throughout the design process the project timeline, including key milestones and delays was clearly documented and published. Not only were stakeholders kept informed of what decisions were made, but also why and how these decisions were taken in order to make this process as transparent as possible.

The use of simulation

CDDM methods such as design thinking and charrettes, have been used numerous times in communal design processes. But to the authors knowledge there is no example that demonstrates the use of BPS as an integrated and iterative component of the CDDM process which is why simulation and uncertainty and sensitivity analysis will be employed in the following.

Assessing resilience in context

Resilience is the capacity to adapt to changing conditions and to maintain or regain functionality and vitality in the face of stress or disturbance (Resilient

Design Institute, 2017). In simple terms, it can be described as the ability to rebound after a disturbance or interruption.

Discussions during the public consultations, design charrette workshops and seminars highlighted the high level of awareness which established Eco-communities such as Findhorn have in relation to the concept of resilience.

According to Stevenson et al., (2016) resilience can be defined as encompassing two distinct concepts (i) robustness and ii) spare capacity. Framing the concept in this way allows the key factors influencing each aspect of resilience to be considered in relation to each design proposal. The principle concerns raised during the CDDM process in relation to resilience are summarized in Table 1 and Table 2.

Table 1. Specific issues affecting design robustness

Robustness	
Vulnerability	Solution(s)
What if the site flood level predictions are exceeded	<ul style="list-style-type: none"> i) Ensure the ground floor (GF) is completely air and watertight with protective covers or flood proof entrance doors ii) Use water resistant materials and insulation in GF construction iii) Ensure GF electricity services and mechanical services are positioned as high as possible iv) Use lightweight timber construction on pier footings which can be subsequently raised if flood predictions change v) ensure drainage culverts to sea are adequately sized and have stop gates to prevent tidal surge flooding
What if electricity supply fails	i) Ensure either battery storage or a backup generator is installed
What if the water supply is cut-off	i) Assess risk and consequences and consider installing a reserve rainwater tank and filtration system

Table 2. Specific issues affecting spare capacity

Spare capacity	
Vulnerability	Solution(s)
What if climate changes and more people want to eat outside during summer?	<ul style="list-style-type: none"> i) Add in a garden servery, with additional outside seating space and ground floor WC in proximity. ii) Ensure doors to deck can retract to create inside/outside space.
What if numbers of disabled or elderly requiring access to first floor significantly increases in future	<ul style="list-style-type: none"> i) Design a second future access point and lift that can be easily accommodated on the opposite side of the building. ii) Consider a larger lift capacity.
What if the function of the building changes and internal space designations need to change	<ul style="list-style-type: none"> i) Deploy lightweight timber partitioning which can be easily reconfigured ii) Consider zonal or demand controlled heating/ cooling in relation to zones which are intermittently used

Although ‘absolute resilience’ can never be achieved since the full extent of future vulnerability is unknown) and ‘what if’ scenarios can never be exhaustive or conclusive) this does not mean such issues should simply be ignored. The process of documenting and considering possible solutions (Table 1 and Table 2) as part of the CDDM process is worthwhile since it allows the community to identify potential threats to the design and place a collective value on the importance of each issue. This in turn provides a mandate for the design team in relation to how these issues are to be prioritised and addressed in the design decision-making process.

At the detailed design stage escalating costs are often the reason for value engineering out items that are considered superfluous to the client’s original brief and budget. For this resilient design criteria must be considered and written into the Preparation and Brief Stage of a project before Concept designs are even considered. Failure to contend with the issue of resilience properly at the outset is likely to have long-term consequences and cost implications arising at some point in the future. As a result, clients (such as established communities) who will retain ownership of the building over its lifetime are likely to encounter the challenges and hidden costs embedded in these early design decisions.

Outcomes of the two consultation meetings

Comments from the initial community engagement process asked for the process to be as transparent as possible and requested that the community be informed about the reasoning behind any key design decisions made.

For clarity subsequent design decisions were broadly categorized in relation to issues affecting: energy efficiency, adaptability, accessibility, transport and parking, and functionality/interior layout etc.

Community led focus groups were formed to research and strengthen the design brief in relation to specific issues, many of which related to the building's appearance and access arrangements. A number of common themes were recorded and graphed (Table 1, Table 2) with the implementation in relation to specific concept design proposals illustrated in Figure 4.

Figure 4 shows the simulation tool based decision-making matrix. This process demonstrated to the community how objectives are linked and that improving one may lead to reducing the value of another; the initial wish of the community was for a building that had zero energy consumption, no overheating, built as a single story with a flat roof, large amounts of glazing and minimal capital costs. Based on these objectives, a synergistic design solution (Figure 2) is developed.

In order to illustrate how resilience can be addressed in relation to some of these key design issues two different aspects (robustness and spare capacity) are discussed in the following:

1, Flood level protection to provide robustness in the event of coastal flooding. The Passivhaus standard (an airtight building standard) was used for the shop and the cafe (see Figure 3). In order to avoid water ingress into the construction detailed building and site level solutions outlined in Table 1 were incorporated into the design. This flood prevention strategy informs a range of design issues ranging from the choice of foundations, through to detailed services layouts.

2, Spatial flexibility to provide spare capacity in terms of a changing user demographic and to offer flexibility in relation to climate changes. A number of issues were raised in relation to the building form as well as access connections both into and between functional zones of the building and its site. This included concerns about varying comfort levels if the Passivhaus standard was not specified throughout.

The revised planning stage design solution (Figure 2) is separated into two thermal specifications, one of which is compliant to the Passivhaus standard, and the other (unheated and intermittently-heated zones) are compliant with Building Emission Rating (BER) set out in the Scottish Building Standards (Scottish Government, 2016) (Figure 3). Figure 3 shows the revised proposal that offers flood level protection for the main part whilst

also allowing spatial flexibility in the future. A positive spin-off of this approach is the overall reduction of the project costs. The feasibility of this approach was assessed by the use of BPS and is discussed in the results section.



Figure 2: The Findhorn community centre- planning stage design

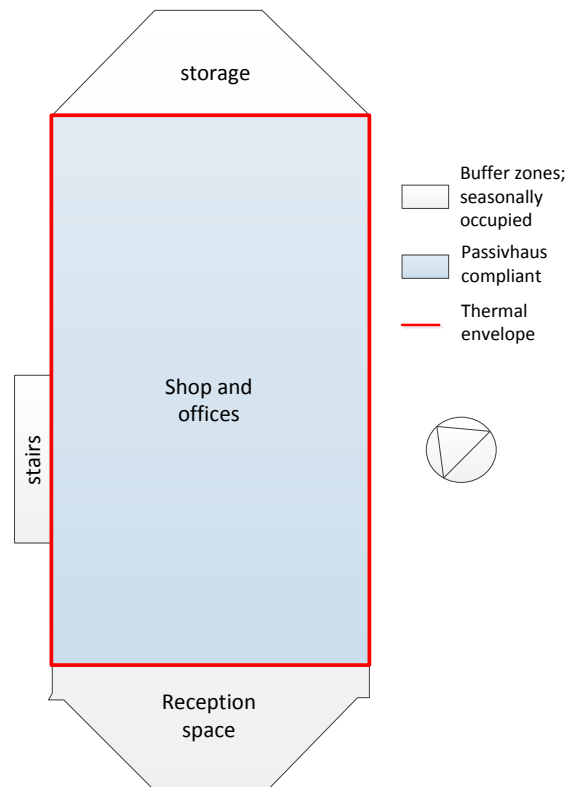


Figure 3: The Findhorn revised proposal to incorporate resilience by separating the reception space and the storage from the Passivhaus compliant part.

The assessment of factors contributing to resilience are discussed in the following section.

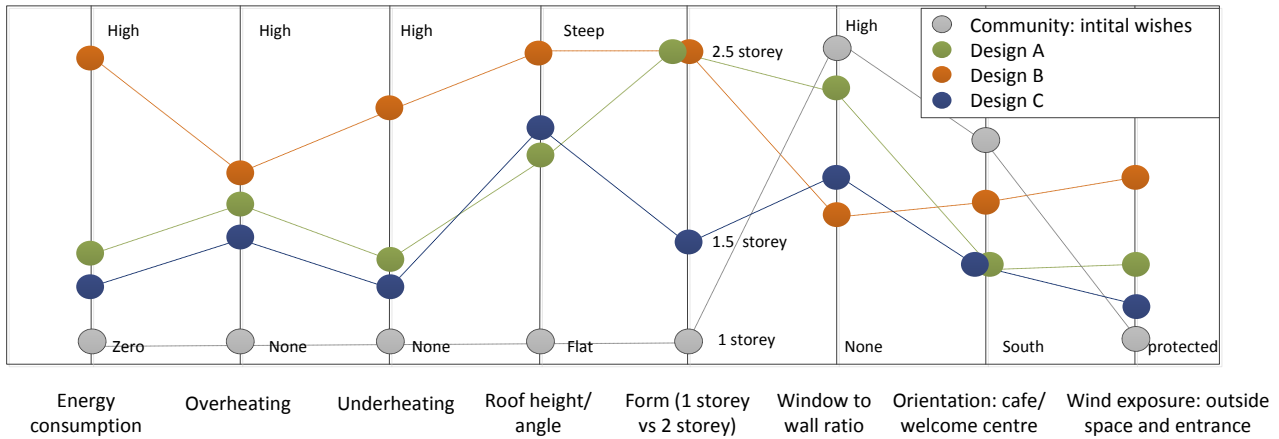


Figure 4: The simulation tool based decision-making matrix demonstrating how objectives are linked.

The use of simulation and results

Within any real case study, the sheer number and diversity of the design parameters tends to bring significant complexity to the design resolution. There is also a need to reconcile various parametric and non-parametric objectives that are often conflicting such as the aesthetics, functionality, energy efficiency and the capital cost of the building as well as the thermal comfort of its occupants.

BPS techniques including parametric studies, uncertainty analysis and global sensitivity analysis techniques were used to evaluate the various design concepts and thereby transfer knowledge from expert members of the design team to lay members. This process was found to be a useful method of informing critical issues (e.g. space heating demand of compact vs loose forms) and thereby enabling better-informed communal participation.

Diverse factors raised by the community in relation to resilience were also evaluated in order that the building is able to withstand diverse impacts such as future climatic changes, economic instability and energy supply vulnerability etc.) As a result of this synthesis an adapted concept was presented, which included consideration of many uncertain parameters, and vulnerabilities falling outside the scope of conventional BPS.

Focussing on the use of BPS, the community chose a number of uncertain parameters (out of several presented to them) which were glazing ratio, shading, U-value and orientation of the building. It was agreed to change these according to: U-value (between Passivhaus and Part L compliance); shading (different external configurations on a number of windows); glazing ratio (20-50%), orientation (0-90°). The results of these are presented in Figures 5-10.

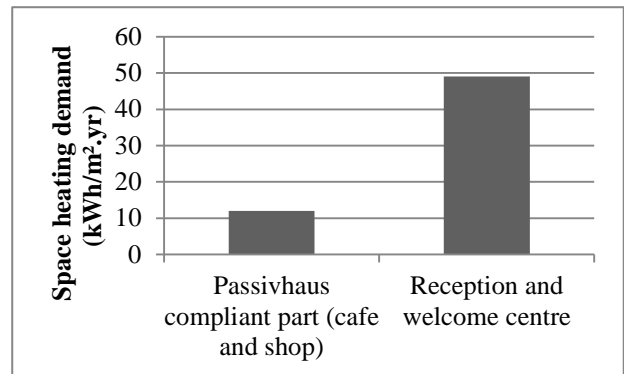


Figure 5: The mean annual space heating demand (kWh/m².yr) (normalised to 20°C) for the building showing the specific consumption for the Passivhaus compliant part zones and the reception centre

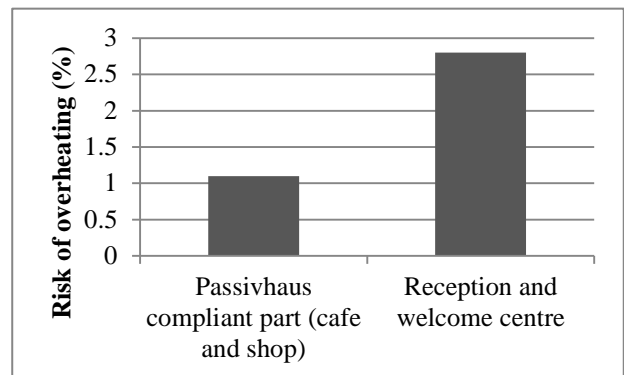


Figure 6: The risk of overheating (% of year $T_{int} > 25^{\circ}\text{C}$) for the building showing the zonal overheating risk for the Passivhaus compliant part and the reception centre separately.

The results showed that the concept of using different building performance standards within the same design, would be feasible, however it would result in a net increase in the energy consumption for the building as a

whole and specifically for the reception centre (depending on the assumed extent of its seasonal usage).

Greater concern arose when showing the likely impact this could cause on overheating in summer with the reception centre being most vulnerable to overheating due to the absence of external shading and the specification and area of glazing used. With the aid of uncertainty and sensitivity analysis techniques, the cause and effect of the main parameters influencing such decisions were highlighted to the community.

Figures 7-9 show the results of the sensitivity analysis of the most influential parameters in terms of space heating demand, frequency of overheating $T_{int}>25^{\circ}\text{C}$ and the maximum dry bulb temperature ($T_{db,max}$).

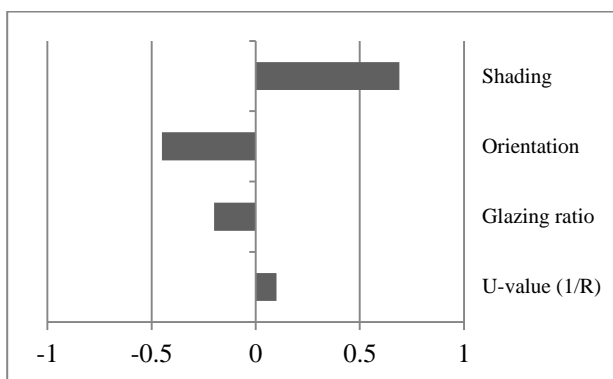


Figure 7: Uncertainty ranking using a regression coefficient (0-1) with respect to the space heating demand for the whole building highlighting shading as most influential parameter.

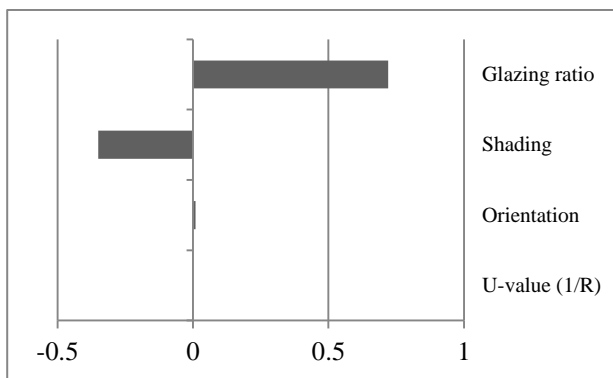


Figure 8: Uncertainty ranking using a regression coefficient (0-1) with respect to the critical overheating temperature $T_{int}>25^{\circ}\text{C}$ for the whole building highlighting glazing ratio as most influential parameter.

Figure 10 shows the global sensitivity ranking showing the influence on the absolute mean (μ^*) of combined factors for the whole building showing dominant parameters for specific heating load (SPHL), space heating demand (SHD), dry bulb temperature (operative temperature) above 28°C (DRT $>28^{\circ}\text{C}$), and maximum dry bulb temperature (DRTmax).

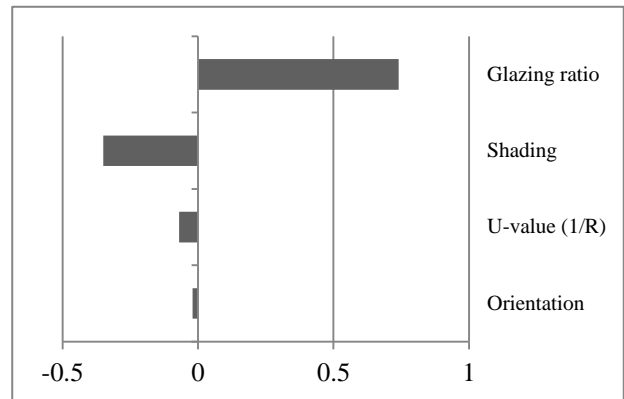


Figure 9: Uncertainty ranking using a regression coefficient (0-1) with respect to the maximum dry bulb temperature ($T_{db,max}$) for the whole building highlighting glazing ratio as most influential global parameter.

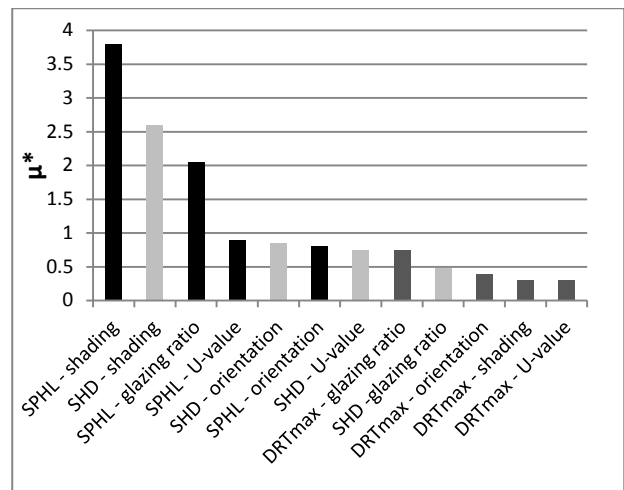


Figure 10: Global sensitivity ranking showing the influence on the absolute mean (μ^*) of combined factors for the whole building.

Based on these findings and the analysis, the community agreed on the idea of incorporating two different performance standards in the building as a means of reducing capital costs whilst maintaining a thermal performance standard appropriate to the zones intended usage. The community also requested further investigations into feasible and cost efficient overheating risk avoidance adaptations (such as reduced glazing areas and optimised g-values and/or seasonal solar shading devices).

Discussion

The general feedback throughout the CDDM process was very positive and the public consultation meetings were well attended by the community. Despite a small number of participants not adhering to the sociocratic process model, the final community consultation individual feedback suggested that the effort the design team had invested in collaborating with the community

to find resilient and holistic solutions was appreciated. BPS results and in particular the use of sensitivity analysis techniques played a major contributing role in enabling and informing the exchange of complex information with a lay community. The feedback received from the community was invaluable to both the Central Area Design group (the management team promoting the development) and the design team and helped to inform the revised Stage 2 Design Brief and further iterations of the design, up to the planning stage design freeze..

The use of BPS highlighted the evolving nature of the CDDM process: i.e. originating from extensive reliance upon intuitive and personal experience (e.g. I like it, I don't like it) to a more broadly informed approach. This process is built upon a two way dialogue between a community rich in tacit knowledge and intuition and expert design practitioners using state of the art modelling techniques involving numerical and probabilistic evidence. In this context, conventional (external) consultation approaches and design charettes are unlikely to have meaningful impact where they are seen as a 'one shot' technique, rather than as part of a larger ongoing community engagement in a collective decision-making process.

Shortcomings of the use of simulation revealed during this CDDM process were identified as follows:

- No on-the-spot analysis (community often wanted to witness instantaneous testing of ideas)
- BPS has mostly a narrow building level 'solution' focus, whilst resilience is a broad issue extending beyond conventional BPS boundaries.
- BPS can be seen as an opaque 'black box' technique unless the results, uncertainties and methods are clearly presented in tangible terms

Conclusion

Incorporating resilience into a conventional design process can be complex and challenging to implement. CDDM involving eco-communities such as Findhorn (which have a heightened awareness of environmental and resource issues) are more likely to be receptive to this approach. By working with the Findhorn community over extended periods and incorporating extensive community consultation and feedback into the process it was possible to implement aspects of resilient design within the case study presented.

Design thinking shows great potential in being enhanced for the purpose of resilient decision making using BPS by integrating the following steps:

1. Separate resilience measures into design robustness and spare capacity.

2. Establishing a context specific definition of resilience. For example, it was crucial for the design team to understand the social interaction decision-making process within the community and to give special consideration to the views of the people and what they wanted the new community centre to be.
3. After understanding the ethos of the community and what they wanted from the project, tangible goals had to be agreed with respect to form factor, energy efficiency, costs etc. We used simulation and 'what if' scenarios to compare and improve performance outcomes in order to comply with these goals.
4. Iterating relentlessly and evaluating trade-offs to find improved solutions under given scenarios. We used uncertainty and sensitivity analysis techniques in combination with BPS to guide this task and to help achieve conflicting objectives synergistically.

Reference to first principles, sketches and simulation aided in the communication of complex results and helped facilitate the decision making process, especially when communicating to lay people.

Some of the techniques we used (e.g. uncertainty analysis, resilience as a performance objective) are not yet implemented in standard (or state of the art) simulation tools but the results proved to be invaluable in facilitating the CDDM process.

It was found in this particular case that key issues to be addressed were related to acceptability of the buildings' form in this specific location. Specific constraints (such as ridge height (in particular whether it was better to proceed as a single or two-storey building)); potential flooding (due to the coastal location); and the location and orientation of the proposed welcome centre posed significant design and master planning issues.

Potential problems occur if there are perceived to be dominant experts from specific fields rather than empathic participants (that embrace hybrid thinking). Therefore, it may be beneficial to have 'experts' that combine interdisciplinary capabilities in a single person (or few people) rather than a large interdisciplinary team. Overall, the bi- directional communication (using BPS and uncertainty analysis for decision support) allowed the design process to be an integrated two-way process with the community playing a major role in the decision making process.

Future work will address the following two questions: (1) what tools and work flows can be implemented to enhance the design thinking process? And (2) in the context of achieving resilient low energy design when and how should we deploy these tools to greatest effect in the wider context of the CDDM process?

Acknowledgements

We would like to thank the Findhorn eco-village community. The Findhorn Foundation is an NGO associated with the United Nations Department of Public Information, holder of UN Habitat Best Practice designation and is co-founder of the Global Ecovillage Network and Holistic Centres Network. The Foundation is at the heart of a community of more than 500 people living in NE Scotland.

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