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Resilience, redundancy and low-carbon living: co-producing individual and community learning

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Abstract

There is an acknowledged need for buildings and communities to be more resilient in the face of unpredictable effects of climate change, economic crises and energy supplies. The notion and social practices involving *redundancy* (the ability to switch between numerous available choices beyond optimal design) are explored as an aspect of resilience theory. Practice and Social Learning theories are used as a lens through which to explore the available redundancy in housing and home environments to help prevent performance failure through unexpected circumstances or in response to varying user needs. Findings from an in depth UK housing case study show how redundancy is linked with the capacity to share resources and to learn both individually and collectively as a community. Such learning in relation to resilient low-carbon living is shown to be co-produced effectively through participatory action research. The benefits of introducing extra redundancy in housing design and community development to accommodate varied user's understanding and preferences are discussed in relation to future proofing, value and scalar issues. Recommendations include better understanding of the design, time and monetary contribution needed to implement social or technical redundancy. These costs should be evaluated in context of savings made through greater resilience achieved.

Keywords: Resilience, housing, learning, occupant behaviour, technology systems, participatory action research, adaptive capacity, agency, cohousing, social interaction

Introduction

The latest contribution to the Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report (I 2014) confirms the virtual certainty of increasing weather extremes over time. Anthropogenic climate change has made extreme rainfall and subsequent flooding around seven times more likely in the UK over any 10 consecutive days in winter, with record flooding levels in 2013 and 2015. There was also a record high in the average temperature across Europe in the summer of 2014 (Met Office, 2015). A further consequence of increasingly extreme weather is the pressure to provide resilient food and water supplies in the UK (Marsden & Robert, 2011; Watts et al, 2012). At the same time, the global economy is continuing to suffer from its worst crisis in 2008 since the 1930's (Dorling, 2014). UK housing production fell drastically from 219,000 in 2006/7 to just 135, 000 in 2012-13 (Beckett, 2014), creating enormous financial and space pressures for housing occupants, given a growing household population in the UK (Crisis, 2015). Finally, energy production is currently in short supply in the UK, with reduction of 2.2 GW in installed capacity modelled by the national grid between 2014 and 2015, an assumption of 1 GW net energy imports from Europe for 2015-16 with uncertainty for the future necessitating a constant adjustment of supply sources (National Grid, 2015, p.196). Buildings and communities therefore need to be more resilient in the face of the triple unknown and unpredictable effects of climate change, economic crisis and energy supply. Current plans for mitigation and adaptation need more development in terms of developing physical and social capacities to cope with these unpredictable events. Housing has a particular role to play here, being the largest sector of building both in terms of volume of construction and energy use in the UK and Europe (Building Performance Institute Europe, 2011).

This article focuses specifically on identifying and evaluating the role of *redundancy* as an aspect of resilience in low carbon housing in preventing performance failure at identified vulnerable points either in unexpected circumstances or in response to varying user needs. Redundancy is a system property that describes the replication of particular elements or pathways in a system, allowing some elements to compensate for the loss or failure of others (Biggs et al., 2012). It offers the ability to switch between numerous available choices beyond optimal design in response to feedback in order to maintain performance. Here, redundancy in a housing system is expanded to cover both physical aspects (e.g. fabric, services, infrastructure) and interrelated social aspects (e.g. activities, governance, communication, learning). Redundancy is a critical component of the ability of a community to be flexible enough to translate its adaptive capacity into action (Maguire and Cartwright, 2008). In this article, redundancy also refers to the extra capacities available to a housing community compared to a single individual to help them adapt and keep control of their home environments in a more resilient way.

As Hassler and Kohler (2014a) point out: *'Resilience depends upon sentience and capabilities that must be embodied within people (and not automated systems). The design of any system must provide clear feedback on its performance to allow for learning and adjustment*.' Individual social learning (Badura, 1977; Sorensen, 1996; Glad, 2012) can be greatly enhanced by dynamic collective learning in communities (Seyfang, Park & Smith, 2013) to ensure that such feedback is effectively created and utilised through the development of people's sentience and capabilities. Equally, co-production is increasingly recognised as an equal and reciprocal relationship between professionals and people to make neighbourhoods more effective agents of change through an informal economy of exchange (Cahn, 2001). It is about mobilising the untapped resources that people represent in housing developments, among other areas of concern (Boyle & Harris, 2009). Results in this article show that both individual and collective learning in relation to the appropriate embedding and use of redundancy can be co-produced effectively when a housing community collaborates with academic researchers, or similar socio-technical facilitators, during the transition stage towards low carbon living. Clearly, in the long term, such a community will need to be able to undertake this process themselves, for the greater part, to ensure that effective practices are continually re-embedded. The scope of this article is generally limited to an in-depth consideration of a single housing community as an exemplar generating key lessons for the co-production of urban resilience at this scale.

The first section of the article sets out the theoretical framework for discussing the development of such learning using the lens of Resilience, Practice and Social Learning theory. The second section describes the wider social, economic and political context of collaborative housing in the UK and beyond. This is followed by discussion of the practices identified within a particular housing case study in relation to redundancy and the action research approach developed to help improve performance and occupant understanding through co-produced learning. Finally, there is a discussion of the key themes that emerged from this work in relation to: the need for future-proofing and the critical path requirements to ensure that appropriate redundancy is built into housing developments and maintained, the potential value of redundancy over time and scaling up issues.

Linking resilience and practices to co-produced learning

There are many different definitions of the term resilience (Joseph Rowntree Foundation, 2015) and it has become a highly contested term (Reghezza- Zitt, Rufat, Djament-Tran, Le Blanc, & Lhomme, 2012). Resilience has been typically defined as being able to '*resist, absorb, accommodate to, and recover from unpredictable climate change effects in a timely and efficient manner, while preserving and restoring essential basic structures and functions*' (UNISDR, 2009). However, this concept of resilience can depoliticise contexts and situations where in fact transformations require the status quo to be challenged (Hayward, 2013, Vale, 2014). A resilient process in socio-ecological-systemic (SES) terms takes account of how human communities interact with their environment and pays particular attention to governance (Biggs et al., 2012 Figure1)

(INSERT Figure 1 HERE)

Critically for this article, Maguire and Cartwright (2008) highlight the social dimensions of resilience that are necessary for transformation to take place in communities where disturbances (such as a malfunctioning energy system) can actually increase opportunity for innovation and development in order to reach a higher state of functioning (Folke, 2006). These include the adaptive capacity of people to collectively learn from their experiences and to consciously incorporate this learning into their everyday lives. It is this broader definition of transformational resilience that is used by the current authors in order to analyse housing occupants' capabilities and learning in relation to redundancy and practices.

Social practice theory has built up a body of knowledge based on practical understandings, intelligibility, rules and general understanding (Schatzki, 2002), including '*materials*', '*meanings*' and '*competencies*' (Shove, Pantzar & Watson, 2012, p.25) , know-how, embodied habits, engagements, technologies and institutionalised knowledge (Gram-Hanssen, 2010; Stevenson, Carmona- Andreu, & Hancock,2013). Any capacity to increase the use of redundancy in housing communities depends on the nature of the wider social context and that of the occupants as agents, who in turn have different capacities according to their personal and social contexts (Middelmiss & Parish, 2010). They define these capacities as: cultural, organisational, infrastructural and personal, with the understanding that all four need to be attuned for occupants to be able to take responsibility for their learning and actions. Cultural capacity here refers to the legitimacy of any redundancy options in the light of the community's history and values, whereas organisational capacity refers to the support available for community action from formal organisations. Cultural capacity is a crucial aspect of resilience in communities to enable skills, knowledge and understanding to be passed on and understood over longer periods of time, thus ensuring continuity (Hassler & Kohler, 2014b). Infrastructural capacity refers to the physical resources and facilities available to support redundancy (e.g. housing, energy, technology and communication systems), whereas personal capacity refers to people's personal resources in relation to the use of redundancy (e.g. skills, motivation, values, understanding).

(INSERT Figure 2 HERE)

Arguably, the appropriate application of advanced technologies to the communities they serve is best utilised when formal expert knowledge is combined with tacit and in-situ types of knowledge (Vlasova

& Gram- Hanssen, 2014, p.515) and a dialogue between energy advisors and home owners holds the best potential for linking technologies and everyday habits and practices (p.523). This can help to facilitate the necessary learning which reveals practices as the entities which lie below the observable performance in any housing development, which is only ever the visible tip of the iceberg (SPRG 2013, Figure 2). Such learning can also reveal tacit redundancy which can then be utilised more explicitly. However, Arnstein's call for citizen participation (1969) demands the transformational co-production of low-carbon practices at the highest level enabling '…*residents to propose alternative projects where they live, and to foster local and greater networks, testing methods of self-management, self-building and self-production*.' (Petcou & Petrescu, 2015, p. 256). This in turn can enable co-produced social learning, which, according to Sørensen (1996,,p.6) can be characterised as '…*a combined act of discovery and analysis, of understanding and giving meaning, and of tinkering and the development of routines.'* In this way, collective learning that takes place in housing developments can play a major role in terms of improving housing performance, over and above individual social learning (Chatterton, 2013). Having both learning modes to learn how to tackle a problem increases redundancy through the extra capacity to share resources and ideas.

LILAC – an exemplary case study

Case studies can provide a rich context for understanding the co-production of learning in relation to redundancy, allowing multiple and discreet factors to be considered in relation to each other (Yin, 2009). One case study is examined here in depth because of its particularly unusual socio-economic and ecological credentials which mark it out as an exemplar for others to follow (Flyvbjerg, 2006). The multi- award-winning LILAC (Low Impact Living Affordable Community) urban cohousing community in Leeds, UK, consists of 20 straw-bale homes with a common house which is home to 35 adults and 10 children (Figure 3). It is part of a long tradition of self-managed and community housing encompassing ecovillages, low impact dwellings, intentional communities as well as collaborative housing (see Bunker et al, 2011; Durrett and McCamant, 2011; Pickerill and Maxey, 2009; Sargisson, 2007). All of these contain more or less radical elements which can be deeply transformatory, as the kinds of inter-personal connections they are based on promotes pro-social and pro-environmental behaviour. However, at the same time, some recent tendencies towards eco-focused community projects reinforce elements of the contemporary market-based neoliberal paradigm through gated and segregated residential 'lifeboat' communities (Hodson & Marvin, 2009).

(INSERT Figure 3 HERE)

Cohousing emerged in the 1960's out of historic co-operative movements in Denmark, and was subsequently adopted by other proponents in Australia, USA, Europe and the UK later (Metcalf, 1984; Franck & Ahrentzen, 1989; Field, 2004). Its rationale and underpinning methods promote housing developments with self-organised shared facilities, where occupants have a group intention from the outset to live together with shared values which aim to create better alternatives to mainstream options (Jarvis, 2015). Typically, a cohousing development contains a range of around ten and up to forty dwellings. Below that, there is not enough critical mass, and above that a feeling of community becomes diluted and fragmented (Chatterton, 2015). The definition of collaborative housing (cohousing) is contested, however, and there are a wide range of studies across Europe that reflect the diversity of collaborative housing models available due to different national planning regimes, social and cultural settings (Tummers, 2015). The design process is normally led by the residents to respond to their needs and circumstances. Car reduction is combined with car separation and car free home-zones with a clear commitment that the site layout will actively increase community interaction and natural surveillance.

Internationally there are over 600 cohousing developments in Germany, around 300 in the Netherlands, over 100 in North America and around 28 in Australia (Chatterton, 2015; Jarvis, 2015). However, this process is challenged by others who see cohousing as a relatively privatised activity due to the paucity of rental models which are genuinely affordable for those on low incomes (Chiodelli & Baglione, 2013) despite efforts by other organisations such as Murundaka in Australia to move beyond owner occupation models (http://murundakacohousing.org.au/). In the UK there are currently 45 developments at various stages of completion. LILAC is exemplary because it established the UK's first fully Mutual Home Ownership Society (Woodin et al, 2010). This was accomplished using an equity-based leaseholder approach to co-operatively owned housing which creates an intermediate housing market. This intermediate housing market has rents that are higher than for social housing, but are permanently below market levels. LILAC is also unique in terms of its efforts to reach out and encourage other communities while at the same time trying to improve its own performance (Barborska-Narozny, Stevenson & Chatterton, 2014).

The LILAC development was completed in early 2013 near the centre of Leeds, which is a reasonably large city by UK standards. It consists of twenty households with a mixture of terraced houses and three-storey blocks of apartments. The building construction is carbon positive (i.e. the overall carbon sequestered in the materials is more than the amount of CO_2e used to create these materials), consisting largely of Modcell timber frame panels infilled with straw insulation (Shea, Wall & Walker, 2013) to form walls and a flat roof, together with a concrete floor.

Each apartment has a natural gas combi-boiler with a 24 hour manual heating programmer and radiator heating system combined with a whole house mechanical ventilation heat recovery system (MVHR). The houses have a hot water heating system consisting of unvented hot water storage tank heated either by solar thermal panels or the gas boiler or an electric immersion heater as a backup, all served by an electronic weekly programmer. Photovoltaic (PV) panels on the flat roofs provide a potential of 1.25kWp for each home. The homes were designed to meet the UK Code for Sustainable Homes Level 4 standard in existence at the time.

The housing surrounds a shared 'Common House' that contains a communal kitchen and pantry, dining room, multipurpose room, laundry, post boxes, office and toilet (Figure 3). This is a vital social centre which is at the core of available environmental and social redundancy in this development.

Investigating redundancy and learning opportunities

A 15 month field study carried out from April 2013 – July 2014 included semi-structured interviews and home tours with all households (n= 20), home user guidance evaluation, a standard Building Use Studies (BUS) questionnaire, construction audit, monitoring of temperature and humidity in all homes for a year and thermal imaging. Other resilience analysis in addition to these typical methods of building performance evaluation, included analysis of the maintenance logging software, analysis of the governance system for the community, action-research interventions in relation to particular problems , and a usability survey of all environmental control 'touchpoints' in the home which the user can interact with.

Community based participatory action research involves an iterative process, incorporating research, reflection, and action in a cyclical process to achieve practical solutions for issues of pressing concern. The aim is to help empower people to take charge of their own lives (Reason & Bradbury, 2008). In the LILAC field study, this process was very much focussed on helping people to understand the new environmental technologies they had to deal with, and to equip them as clients with the knowledge to be able to challenge the design and construction team where necessary in order to improve their home environments and become more resilient. From the outset, a form of regular interaction between the researchers and occupants was mutually agreed in order to co-produce solutions through mutual learning. This included e-mail correspondence between LILAC occupants and the researchers in relation to any technical issues that were identified by either the occupants or the researchers during this period. Intensive regular dialogue and interaction between the field researcher and all households during the setting up of monitoring equipment and all the subsequent studies listed earlier resulted in significant mutual learning. The rapport and trust built up over 15 months enabled the principal field researcher to learn intensively from the occupants about the context. She could then intervene frequently with advice and suggestions to occupants about how to get the best out of their homes in terms of energy and ventilation practices, following reflection on the research findings as they developed through time. Her role was also to help disseminate useful home use learning to the wider community. Collective feedback meetings with all households occurred at the half way stage of the fieldwork and at the end of it in relation to the research findings. These meetings with the research team produced a collective reflection on the individual issues and remedial actions identified during the course of the research, which resulted in further collective learning for the community as a whole (Wilner et al., 2012). Results from all these investigations and interventions are explored below specifically to understand the types of physical and social redundancy available at the time and the learning acquired through co-production between the researchers and the occupants.

Physical redundancy

There was a high degree of physical redundancy in LILAC in relation to energy supply. The photovoltaic and solar panels could potentially supply a small amount of heating to the homes in the event of a failure related to the vulnerable gas and electricity supply from the national grid. There was also a back-up electric immersion heater which offers further diversity of supply. The Common House provided several additional redundancies not normally available in housing developments, including a refuge and an alternative supply of heating from its woodstove, should all else fail. If there was a water failure in any of the houses, the Common House also provided redundancy through its separate water system. The communal kitchen and dining room in this building offered yet more redundancy, giving people the choice of individual or collective cooking, which can be a lifeline if someone in the community is not feeling well (Figure 4).

(INSERT Figure 4 HERE)

One resident recalled '…*learning to cook differently. Which is great. Some of the members are teaching me. I've started to help with the shared meals in terms of preparing''*. Another member highlighted the inspirational impact of using common house to observe and learn from others' work: '*I knew how to work with wood but I looked at how he made his bed, he showed me his design and then I've made it. And then I've made it better. So we're sort of borrowing ideas.*' The redundancy of the common house pantry is a valued feature: *'I like having a pantry, that's the common house thing, it's a bit like having a neighbour having their door open all the time. If you run out of something you can just go. Can't find the tin opener, just run over and borrow the Common House tin opener. Mostly makes its way back, there's a very fluid exchange of crockery and things.'* The ability for occupants to grow their own food in the LILAC allotments added further redundancy, offering a choice instead of the usual shopping outlets and a potential buffer against any drop in food supplies via these. '*We had a meal last night, and we had peas and beans from the allotment to go with the meal, and we had raspberries for breakfast. So it's nice I'm having some absolutely fresh vegetables. I'm sure my diet has improved and I think my shopping habits have changed quite a lot'.*

The provision of a wide variety of robust window openings available for ventilation is critical in relation to the climate change predictions for warmer summers in UK cities in order to reduce overheating (Mavrogianni et al, 2014). A high degree of redundancy in LILAC exists compared to other contemporary housing developments in this regard. Over 50% of the overall glazing area was widely openable and fully adjustable (Figure 5).

(INSERT Figure 5 HERE)

This is vital if an MVHR system is incapacitated by any kind of power or mechanical failure in the system. There is a growing tendency to optimise the number of window openings in relation to mechanical ventilation systems to achieve cost savings in affordable housing in the UK, with no allowance for redundancy through over-ventilation options to deal more resiliently with future unpredictable climate changes. A recent MVHR study (National House Building Council, 2013) revealed that occupants were suffering from overheating due to only being able to open a patio door and no windows in the lounge at night. In LILAC there were ample window opening options in each room. The extra redundancy of a window opening in the bathroom was also vital, because a failure of the MVHR system here could lead to a degradation of the straw and timber construction or mould presence due to excessive internal moisture not being removed adequately, if not tackled promptly. Dual or even triple aspect orientation and a variety of rooms allowed occupants to choose to move to a warmer/cooler room within the home, according to orientation and time of day. Outdoor living spaces, such as balconies, gardens and communal pond patio with varied shading provided extra environmental redundancy in the housing development. The pond feature (Figure 6) provided an external communal cool place for people to retreat to in the summer if their homes or Common House became too hot.

(**INSERT Figure 6 HERE**)

Social redundancy

LILAC constitutes a very well integrated community with a wide variety of communication methods and a wide variety of different age, income, family and career stages[1]. This diversity is a key aspect of its resilience and redundancy with residents able to commit different amounts of time at different times, according the different tasks identified.

The whole process of developing the social and cultural capacity of LILAC also developed and tested its social resilience and redundancy. LILAC started when a small group of friends who lived in different cities in the UK decided to go about developing their own housing, in the face of the UK housing crisis in 2006 (Dorling, 2014) and their passionate desire for change (Chatterton, 2015). It took six years of sustained effort, despite significant changes in membership, to transform the idea into the completed physical development. The procurement process was a steep learning curve. As one resident recalls:

'…it wasn't easy to have those conversations because things were happening fast and we had to make decisions about a lot of things. We weren't expert. So what I was quite good at doing was creating questions.'

Personal capacities varied widely. Some LILAC members involved from the early stages were very determined, with a high level of learning skills and an excellent understanding of the UK grass roots activism environment, including funding options and communication. Motivations were varied: for some it was about proving that a value driven housing model could fill a gap in the mainstream housing market. For others, the ambition was to develop housing which could facilitate a sustainable lifestyle which then drew them into the wider LILAC:

'*…one thing that has struck me since I moved in is that I wasn't somebody who was really into cohousing before. I mean I wanted to be involved in this because of the more sustainable lifestyle. But actually this has been the aspect that I've been enjoying a lot – the communal living.*'

Out of all twenty BUS questionnaires returned, 17 mentioned highly positive experiences of leisure, contact or support that the community offers. All members had access to the community notice board (Figure 6) in the Common House as well as internal mail, twitter and an on-line forum. The main means of information dissemination on home use to all members was via email and informal chats with members delegated to the maintenance task team.

(INSERT Figure 7 HERE)

Many different forms of learning took place within different learning environments – individual learning through trial and error, peer to peer learning through conversations on doorsteps or at the communal laundry, in the allotments or at the Common House post room area, and collective learning through internal and external local and national events, group meetings, shared dinners (Figure 8), internet tools, twitter and email exchanges. One residents comment demonstrated the willingness to reach out to external sources for help: *'in fact the suggestion was with all this going on*

[MVHR performance issues] that we actually put somebody through a course that is specifically aimed to understand and if necessary… yes, deal with some of the problems of balancing and stuff.' Residents also acknowledged the iterative nature of learning: *'I think one of the keys is that any decisions we make don't have to be set in stone and there's a saying – "That's good enough for now and safe enough to try"…'*. Another resident highlighted their access to the pool of skills and experience of all the members: '*I like the fact that if you're not sure how to treat something or do something, there's always people around who know more than me.*' All this shows a high degree of social redundancy and capabilities overall in the housing development.

(INSERT Figure 8 HERE)

Seyfang et al (2013) note that the quality of a community group is decisive in terms of its success in achieving its aim to improve their understanding of energy use, followed by the skills available within the group. LILAC had a highly varied skill set among its members including a number of occupants who had become technically proficient. This provided greater social redundancy rather than the whole group typically relying on one 'maintenance contact' as is the case with many normal housing developments. A dedicated 'maintenance task team' managed incidents reported for all the households, organizing necessary repairs with the help of bespoke software accessible to all members. The system effectively took care of all trouble shooting needs and stored information about past issues for future reference and continuity of understanding. As one resident commented on this system: *'It's brilliant. It means we don't lose any item. It's always there. Even if you close an item [solve a maintenance issue] it's there, historically*.' This enabled a further degree of cultural redundancy through collective access to the accumulated experiences. With limited time available, members had to balance their collective desire to understand the various aspects involved in developing low impact living with their desire to communicate to others outside of LILAC and their need to try and understand how their own homes were performing. As a result little time was left for forward planning by reflecting on current home use patterns and possibilities to facilitate further improvements. Lack of time can be the chief limitation to redundancy working effectively.

Understanding redundancy in practice

The role of the handover stage for understanding redundancy

A critical stage in understanding and exploiting the redundancy available in a housing development effectively comes at the point when the physical development is handed over to the client. A two stage home handover process utilised the collective learning potential within LILAC in relation to this aspect. The subcontractor instructed selected LILAC members on the skills and understanding needed to make use of all the different technology systems installed as intended. These key LILAC members then aimed to pass on their knowledge to all other members in a subsequent tour of their homes. Action research here involved both stages being shadowed by the field researcher, video recorded and transcribed. Feedback to LILAC highlighted unexplained or wrongly explained elements requiring further investigation, a need to develop a more structured procedure with a detailed list of items to cover, as well as a need for securing hands on experience of interacting with all controls 'touchpoints' (Stevenson et al, 2013). The LILAC Maintenance task team subsequently revised the guidance for handover procedure prepared for new LILAC members and issued a bespoke guide illustrated with in-situ images of safety and emergency controls. In one case the redundancy of two water stop cocks, an electronic and a manual one, caused confusion for a resident: *'We've got an electronic switch here that switches off the water, we haven't even tested it. I don't even know why we have that and the [manual] stop cock.''* Care needs to be taken not to overcomplicate housing with redundancy features which remain unexplained to the residents.

Energy and redundancy

Given that the variety of home equipment/systems (MVHR, fridge, boiler fan, immersion heater) all used electricity in an intermittent way, it was vital for occupants to understand the role of autonomously PV generated electricity consumed on site in relation to grid electricity supplied to their homes and where they could make financial savings against any fixed tariffs . The use of the proprietary DomEARM[2] tool (Homes and Communities Agency, 2010, p.32 and Appendix 1) by the field researcher for estimating equipment energy usage times against PV energy generation. This prompted one LILAC maintenance team member to plan a thorough investigation with their own sub-meters which revealed the tacit redundancy of energy supply in the energy system that could be utilised. One occupant ingeniously utilised this redundancy by using a gas heated kettle in the evening and an electric kettle during the day in order to take advantage of the 'free' PV energy during the day and the cheaper gas supply compared to grid supplied electricity in the evenings (Figure 8). Some residents also adapted to using the communal laundry during the daytime in order to take advantage of the PV energy generated.

*Ventilation and redundanc*y

MVHR, as an additional system in relation to window openings, involved the most learning at LILAC during the occupancy stage in terms of understanding the redundancy available for ventilation purposes and utilising this effectively. Only one of the 35 adult LILAC residents had previous experience with mechanical ventilation. Initial contractor guidance received by LILAC in relation to home ventilation advised residents that their MVHR system should run continuously with no need to open the windows. This simple advice was soon rejected by most residents due to: the comfort issues experienced (excessive noise, drafts from air supply points), residents wanting to switch off electricity consuming appliances (e.g. the MVHR unit) that were perceived as unnecessary and a heatwave which caused overheating and prompted residents to open their windows instead. Each household sought its own way to ventilate the home. Some of that learning was restricted to individual trial and error and others sought support of others (peer to peer). One household had the '*MVHR often off at night because of the noise. We often open windows and have MVHR off to save energy*.' This is a classic illustration of redundancy at work, where the secondary ventilation system (window) is used in tandem with the primary one (MVHR). LILAC occupants developed no less than 17 different adaptive behavioural patterns using the MVHR and window systems in response to variable weather conditions (**Figure 9**).

(INSERT Figure 9 HERE)

The researchers and LILAC together followed up emerging issues with the MVHR system identified during the research with recommendations shared (Table 1) and discussed collectively at the interim feedback meeting with occupants. The researchers explained the intended level of user interaction with the MVHR system, the consequences of changing fan speed settings for the functioning of the system, and any internal environment issues linked with MVHR practices: specifically the condensation and air quality risks involved in keeping internal temperatures low, windows shut and the MVHR switched off. They stressed the importance of the windows and MVHR as a single ventilation system with different options, and the need to make sure both worked well.

This prompted the community to take action that resulted in:

- recommissioning the MVHR system in all dwellings
- taking down the suspended ceilings in all occupied dwellings in order to insulate supply and exhaust ducting
- opening dampers in the fan units that remained closed for months preventing proper functioning of the system in some dwellings
- instructing all the inhabitants that while cooking they need to use the cooker hood function even if their MVHR is off.

(INSERT Table 1 HERE)

Incorporating the use of redundancy into low impact living

LILAC is committed to sharing resources and asks all members to sign up to commonly held values of environmental sustainability, self-reliance, grassroots, learning, equality, wellbeing, diversity and maintaining an ethical policy (Chatterton, 2015). LILAC is also explicit about its ambition to become a best practice example to learn from. However, LILAC allowed considerable room for its membersto find their own ways to achieve the shared goal of low impact living in terms of home use control. This key quality of freedom and diversity in relation to redundancy in LILAC is one of the key attributes needed for a socio-ecological system to deliver required services in a resilient way (Biggs et al., 2012). Understanding home performance in terms of all the redundancy available in the fabric, systems, resource-use and user roles in housing development is not a straightforward process even for highly interested individuals. It was particularly difficult at LILAC due to the poor installation and commissioning of the MVHR systems, lack of feedback on export to the grid of onsite PV generated electricity (Barborska- Narozny, Stevenson & Ziyad, 2016), water meters being located in the pavement under heavy manholes that were virtually impossible to open by hand and gas meters being wrongly labelled. Research feedback both at a collective and individual level helped to overcome some of these difficulties and was instrumental for LILAC as a community being able to establish its learning needs and problem areas that need responding to in relation to its housing performance as highlighted by one resident:

'For the Community - getting help with the MVHR has been the most specific and enormous help as your findings and your knowledge have helped us to understand and then to argue out case. For me personally – talking to you in detail about my energy use and experience of living in my flat has helped me to understand and manage my home effectively. I found the presentation very interesting, and the figures for my energy use will continue to motivate me.'

Another resident explained that the research:

'… showed me how we can preferentially use electricity generated by the solar panels by changing our behaviour (eg charge appliances at the sunniest times, use a slow cooker to shift cooking to during the daytime etc)'

Using co-produced collective learning to understand how to use redundancy in housing effectively via planned action research was particularly beneficial where there were deep differences in practices, understanding and consumption between households that otherwise would have stayed unnoticed. It also helped given the 'unknown unknowns' with complex housing technology redundancy which was new to occupants, preventing them from asking the right questions to build up their own capacity for resilience in the face of any crisis. For many households, technology learning tended to generally emerge at the time where individual trouble shooting was needed, which was not ideal. Gently exposing occupants to 'best practice' through co-produced action research allowed them to try something that had been actively tested by others in the community and worked for them. However, there is no guarantee that this virtuous circle of learning in relation to developing resilience will be preserved without future active intervention by the community and other agents involved in the housing development process. As one resident explained:

'*I guess we have so many meetings that no one has just focused on taking the initiative on it [home use]. Just because people are busy and they've not felt like they've got energy for it. To some extent I haven't. It never crossed my mind to have a meeting about it.'*

An interesting comparison can be made with another similar sized housing development at Elmwell in Suffolk, where Gill et al (2010) carried out a similar post-occupancy evaluation study and evaluated the degree to which occupants' planned behaviour underpinned their heat, energy and water use. Unlike LILAC, this was a low-carbon development procured by a Housing Association and there was no element of participatory action research or apparent social learning involved in the study. A four to five-fold difference in heat, energy and water use was identified between occupants and despite a '*good community spirit*' being spoken about (ibid, p.504) it is clear that some occupants were deliberately by-passing the energy and water saving initiatives. Equally, there appeared to be no remedy for the poor understanding that occupants had in relation to the heating and MVHR system. This study highlights the need for the type of social redundancy and learning opportunities developed in LILAC to be appropriately transferred to more mainstream housing developments. However, it can also be argued that without the value system inherent in LILAC, these opportunities may not be necessarily taken up by occupants.

Future proofing the value of redundancy in housing

Useful redundancy within a resilient housing development clearly needs to be future-proofed itself given the indirect consequences of climate change such as risks to food, energy and the rising cost of living, demands for new infrastructure as well as damage or loss of property (Joseph Rowntree Foundation, 2015) as well as the simple act of individually or collectively forgetting how to do relatively complex activities related to a variety of technologies and lifestyles. Preserving non-optimal choices for comfort, food and energy sources in the face of these challenges requires early consideration at the outset of housing development feasibility appraisals, rather than as an afterthought during the maintenance stage. Proposed energy system redundancy in particular needs to be considered in terms of how robust it is in the face of changing component design, replacement and damage. It also needs to be considered in terms of how to preserve the feedback systems that enable this redundancy to function well. There are critical path vulnerabilities in terms of the housing lifecycle which are now well known in terms of these issues in relation to the design, installation, commissioning and handover as well as maintenance and retrofit stages which others have urged to be addressed by a housing ‘Soft Landings’ approach (Gupta et al., 2015).

At the same time, there is clearly a balance to be struck between the provision of extensive redundancy and the effective use of precious resources for housing developments. One clear challenge for LILAC has been the human cost of developing and managing all the physical and social redundancy now available in the community (Baborska-Narozny, Stevenson & Chatterton, 2014).

Having to learn about and keep on top of so much diversity of choice in relation to technology and human relationships is time consuming and can be exhausting (Figure 10). Equally debateable is the question of over-redundancy in relation to housing resource efficiency in terms of whether or not additional shared facilities that are provided really do save overall space and energy, particularly if occupants begin to duplicate these facilities in their own homes e.g. installing washing machines because it is inconvenient to walk to the common laundry (Stevenson et al., 2013). The redundancy that is co-produced in any housing development needs to be carefully considered and balanced against overall cost limits, both financial and in terms of the physical and social capital that is actually available in any one place.

(INSERT Figure 10 HERE) Future proofing redundancy is also a question of financial value. Where the sum paid by the home occupant for using the property is independent of market value, any capital profits can be used to maintain and develop the collective housing development. This is typically the case in traditional German and Dutch housing co-operatives (Brandsen & Helderman, 2012). LILAC has a slightly different Mutual Home Ownership Model where the leaseholding occupants buy equity shares in the collective housing through an initial deposit and subsequent fixed monthly payments. These shares can be partly redeemed against up to 75% of any change in value after three years if people choose to leave the scheme. The 25% retention in value accrued helps to accumulate essential housing reserves. There is also a 4% home charge within the monthly payments which covers maintenance and insurance (Chatterton, 2015). These financial mechanisms potentially add value to the development by helping to ensure that there is resource available to service all the physical redundancy in the fabric, services and infrastructure as well as ensuring the interrelated social aspects in the housing development are functioning well to ensure maximum resilience. At the same time, the degree of physical redundancy that a housing development embodies needs to be factored into its actual building valuation if there is to be any chance of enabling housing developers to build in redundancy as a capital investment. Collaborative housing developments can be tightly squeezed financially, owing to the inherent requirement of additional redundancy in these typologies through developing shared facilities. This can be an extra cost over and above standard affordable housing development norms. LILAC was able to accommodate these extra costs through the use of a substantial grant while maintaining an affordable price for the standard sized housing units (Chatterton, 2015).

Scale and self-organisation of redundancy

Anderies (2014) highlights the difficulty of incorporating both principles of self-organisation and intentional design in resilient socio-ecological systems. He goes on to argue that at a micro-scale (e.g. the level of individual buildings, cohorts of buildings or neighbourhoods), robustness-based design dominates and that it is only at the meso-scale (e.g. the level of cities or regions) that design which affords the capacity for learning and the transformation of a system in response to change, is relevant. Schatzki's development of practice theory (2011), on the other hand, has conceptually questioned this notion of a multi-level perspective for resilience, arguing instead for a 'flat ontology' to show the interconnections that occur between ever expanding bundles of practices and arrangements which cross scalar boundaries. This has been previously demonstrated through practices held between large scale energy providers and micro scale individual homeowners (Vlasova & Gram- Hanssen, 2014).   Based on our findings from the LILAC case study, the current authors have also established that there is clearly a need for capacity building and learning to allow *self-organised* transformations of energy use to occur at the micro-level of a housing development as well as at a meso-scale.

Perhaps this is why the notion of redundancy in housing design is so important – it allows for unpredictable failures as well as emergent behaviour to reside within a flexible housing system that can itself adapt to change at a micro-level as well as meso-level, particularly when it is effectively combined with appropriate feedback loops, such as continuous building performance evaluation, within the overall system. However, there is evidence to show that the ecological niche (Seyfang, 2010) and financial models (Woodin et al, 2010) which LILAC has adopted, similar to those used by other collaborative housing developments, offers limited opportunity for it to develop to a stage where it can engage at a broader level with urban renewal (Brandsen & Helderman, 2012). In this sense, the excellent level of redundancy which LILAC has developed, is not necessarily transferable beyond a micro-scale and more work is needed to develop alternative models of housing development and collective learning which can transcend the current socio-economic barriers to the effective linkage of micro and meso-scale systems of redundancy. One way forward might be through the effective development of place -based 'bottom-up' city, regional national and international networks to scale up their agency through interaction with other similar organisations (Watson, 2014). Another way could be through the wider dissemination of these innovative models and use of the action research as demonstrated by this article.

Conclusions

The overall aim of this article was to introduce the concept of redundancy more explicitly into discourse on housing resilience. It has identified the redundancy potentially available in a single exemplar housing development and the capacity for occupants to make use of such redundancy through co-produced individual and collective learning using action research. The background to this emphasis lies in the triple unknown and unpredictable effects of climate change, economic crisis and energy supply. Results in this case study indicate the variety and benefits of useful extra redundancy in housing design and community development to accommodate varied user preferences, increase occupant learning and their ability to cope resiliently with unexpected failures, particularly in relation to comfort, energy and ventilation practices. LILAC's articulated set of core values is unique among all UK cohousing developments and partly explains the high degree of social learning, redundancy and resilience that appears to be embedded in the community. Time is needed to see if these processes continue to flourish and the authors are keen to revisit the development in the future to provide a more long term evaluation.

Given the predicted climate changes ahead, it is vital that all homes and developments are future-proofed to some degree of social, economic and physical redundancy as shown in the case study presented, and designed in a way to allow these features to be added or activated, given that resilience contains both a preventative and a recovery aspect. At the same time, care has to be taken to avoid 'over-redundancy' through multiple choices which are not useful and serve only to confuse the occupant.

Clearly there are potentially extra time and financial costs involved in delivering the high degree of physical and social redundancy that exists in this case study housing development. A better understanding of the cost v. benefit of the time or monetary contribution required to implement social or technical redundancy is needed, however, in order to be able to justify these measures on a wider scale as a capital investment. These costs should be evaluated in context of wider resource and health savings made through the greater resilience achieved. Thinking this way will require a new approach to designing housing developments for future which have suitable resilience. It will also require changes to current economic accounting systems in housing which exclude these indirect costs. This will require more inclusive lifecycle accounting that can then be included in valuations for capital costs. At the same time there limits to economic rationality. Some economic decisions may well be value driven at the outset, requiring some post-rationalisation after the completion of the development. Housing funders will also need to accommodate this approach to development, with more flexible financial models.

Equally, it is questionable whether the high degree of action research involved in the field study presented in this article, which was enabled by a significant European Union grant, is replicable beyond a micro-scale, without greatly increased funding for research of this kind. Nevertheless, judicious use of this type of intensive case study research can reveal further insights which other longitudinal studies can then verify and feed forward to policy makers.

Key recommendations for housing developers and design team to co-produce more resilient housing are to:

- Identify the appropriate levels of physical and social redundancy within individual housing development needed to address climate change, economic crises and energy supplies.
- Ensure that these levels of redundancy are costed into housing developments from the outset.
- Adopt a co-production approach to developing housing redundancy, working with potential users to ensure that they understand what has been put in place and can feedback any issues to be acted on.

Key recommendations for policy makers are to:

- Develop more inclusive lifecycle accounting systems that allow housing developers to hypothecate their assets on the basis of resilience, energy and health benefits to GDP and invest in the necessary redundancy to address climate, economic and energy changes in the future.
- Provide guidance on how to design in essential physical and social redundancy in housing developments which addresses the need for greater resilience and acceptance of a process of regular adaptation.
- Develop policy and guidance on how to co-produce resilient housing developments involving communities and future occupants, working with researchers and/or other socio-technical facilitators.

Key recommendations for researchers are to:

- Investigate the relationship between built in redundancies and their benefits in housing developments to help optimise these in relation to cost valuations

- Quantify the redundancy elements required in housing developments to address climate, economic and energy probabilities and uncertainties.

Key recommendations for the occupants:

- Ensure familiarity from the outset with all aspects of physical and social redundancy available in the home and wider community to help develop greater resilience.
- Try out all available communication channels at a housing development level to exchange thoughts on home use – being exposed to the experiences of others increases the chance of revealing unknown unknowns and disseminating context specific best practises.

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Endnotes

[1] It is important to note that the development of LILAC's communication methods and diverse social mix was based heavily on the explicit values articulated by the original group which first started to discuss the notion of living together. This group had already been involved in urban activism for over ten years, and all had lived or worked in collective settings before. As a result, the group already had a remarkably high level of organising and communication skills at their disposal, related to their work with co-operative principles.

Consensus decision-making, non-hierarchy, commitment, core values and clear design intentions were all defined from very early on in the development process. Having these parameters clearly defined so early on, enabled the group to focus on and clarify its communication processes and helped to promote a high degree of trust during the development process between LILAC members. External communication with the neighbourhood and beyond used workshops, social media, open days, and internal LILAC communication used a dedicated internal email network, buddy systems, regular meetings, annual away-days, dining events and workshops. Interestingly, LILAC also successfully used a significant amount of printed media, such as leaflets, posters, flyers, business cards and newsletters, to publicise their activities (Chatterton, 2013).

[2] DomEARM (Domestic Energy Assessment and Reporting Methodology) is a tool tailored specifically for dwellings to help assess their energy end-use loads. The methodology has been developed by Arup UK to be applied to both existing and newly constructed dwellings. It operates at three levels: Level 1: Simple dwelling assessment - an assessment based upon total fuel and power data obtained from utility bills (procedures that an informed householder would be capable of carrying out).

Benchmarking is carried out on a whole building basis. Level 2: Simple dwelling assessment with system adjustments and renewable energy reporting - a whole house energy assessment as Level 1 but with a refinement if the assessor has knowledge of the heating and hot water system and cooking type. Benchmarks are adjusted to reflect these refinements. In addition if the dwelling has sources of renewable energy these are reported at this level. Renewables also include low carbon technologies such as ground source heat pumps and micro CHP. Level 3: Dwelling systems and equipment assessment - an assessment based upon individual pieces of equipment used in the dwelling. Benchmarking is carried out by end use loads (lighting, cooking, hot water, space heating, white goods and small power loads). This level needs to be carried out by a person with a reasonable level of competence in assessing the dwelling construction, fixed systems and appliances.