The Potential of Living Labs for Smart Heritage Building Adaptation

John Counsell

Cardiff Metropolitan University, Llandaff Campus, Cardiff, CF5 2YB, United Kingdom.

Abstract. This paper examines: smart buildings as part of 'smart cities'; the particular challenges of heritage buildings; whether smart heritage buildings have any specific characteristics; the lack of data to inform appropriate refurbishment and retrofit; the emerging potential of technologies to engage people in acquiring that data and build bridges towards smart heritage, so easing the task of sustaining heritage buildings for the benefit of current and future generations; and 'Living Labs' as a key enabler. It is increasingly argued that there is a need to involve citizens in city development, so urban areas may be rendered more suitable to their needs and social problems be prevented. Meanwhile it is held that the value and significance of Heritage buildings and landscapes needs to be maintained, despite increasing pressures to adapt all building stock to address climate change and reduce increasingly expensive energy use. To convincingly engage citizens, such adaptation needs to enhance rather than reduce quality of life for users. Over the last decade there has been a move to repeated post-occupancy evaluation (POE), including some heritage building stocks, to ensure these goals continue to be achieved. Yet it can be argued that the number of such POE studies is limited by shortages of expertise, to the extent that in most cases we still lack sufficient data about the existing building stock, and in particular Heritage buildings, to make reliably informed judgements on suitable adaptation and mitigation measures. Simultaneously the sustainable transformation of Heritage buildings and landscapes into Smart Heritage can be held to be a key component in the metamorphosis of existing cities into Smart Cities. Thus this paper examines how Living Lab processes of engagement may deliver innovative approaches to POE, and thus support the scaling and speeding up of the transformation of Heritage into Smart Heritage.

Keywords: Living Labs; Smart Cities; Smart Heritage; Post Occupancy Evaluation; Community

1 Smart Cities

Cities, it is argued, will have become 'smart' "when investments in human and social capital and traditional (transport) and modern (ICT) communication infrastructure fuel sustainable economic growth and a high quality of life, with a wise management of natural resources, through participatory governance" (Caragliu et al 2011). Saunders &Baeck(2015)show that cities create wealth and opportunity, but also acute

Y. Bahei-El-Din and M. Hassan (eds.), *Advanced Technologies for Sustainable Systems*, Lecture Notes in Networks and Systems 4,
DOI 10.1007/978-3-319-48725-0_5

challenges in transport, infrastructure, and safety. They claim ‘smart city’ ideas offer solutions (although warning of exaggerated claims both for and against), arguing that combinations of “sensors, data and advanced computing has promised to speed up information flows, reduce waste and sharply improve how efficiently resources can be managed.” To this end Juujärvi & Pesso (2013) identify a general and “growing trend to involve citizens in city development to make urban areas more suitable to their needs and prevent social problems”, and others argue that: co-creation enables both users and producers to become active innovation agents (Platoniq 2015); the “social value of co-creation is fuelled by aspirations for longer term, humanistic, and more sustainable ways of living” (Pallot&Pawar 2012).Saunders & Baeck(op.cit) claim there are five elements necessary to achieve the goals of a smart city. These are to establish: ‘a civic innovation lab using collaborative technologies; open data and open platforms to mobilise collective knowledge; that human behavior is as important as technology; investment in smart people, not just technology; collaborative technologies for all parts of society.’ It is these last two points that this paper particularly addresses; how occupants of heritage buildings may engage with collaborative technologies, and thus both augment their efficacy and enhance their wellbeing, while improving the sustainability of the heritage fabric itself.

2 Smart Buildings

Many ‘smart buildings’ definitions narrowly focus on enhanced building management systems in new constructions. Yet smart buildings should be defined as key ingredients for the development of smart cities. Buckman et al (2014)suggest that the ‘upper bound of the Smart Building is defined by (the future development of) the predictive building’. Philips “Digital Living Room” project first described ‘Ambient Intelligence’ arguing that an ‘unconscious tool becomes an extension of the user’ (Epstein 1998). The key elements were that ICT devices (those we now term IoT) should be pervasive, invisible, but above all predictive in anticipating and responding to people’s needs in any environment, perhaps via predefined user profiles. This takes the focus towards the building as a facilitator, more than a moderator of the external conditions, that supports an alert, proactive supportive and responsive environment making ‘our whole lives relaxed and enjoyable’ (Crutzen, C, 2006). Siemens (2010) argue that smart buildings will only be sustainable long-term via “synergies between energy efficiency, comfort and safety and security … solutions that turn buildings into living organisms: networked, intelligent, sensitive and adaptable”. For the technologies to become sufficiently pervasive, the cost must be low and operation reliable. Yet it is evident that it will be much more difficult to modify existing buildings to form such ‘organisms’. This is the larger challenge, since existing buildings, and in particular heritage buildings and their contexts, cannot sustainably be subject to wholesale clearance and replacement, so need to be modified without damaging their qualities.

3 Some reasons why existing and heritage buildings need to be enhanced

It is regularly stated in the UK that over 80% of current buildings will still be in use in 2050, and in need of substantial retrofit just to meet carbon and energy targets (Dowson et al 2012).There is close correlation between levels of greenhouse gas emitted from buildings, and levels of demand, supply and source of energy (U.N.E.P. 2009). A narrow UK measure "lists" approximately 2% of that stockas significant heritage, with many already identified at risk, without addressing future climate change challenges (Brightman 2012). A broader UK measure identifies over 20% as dating from pre 1919, and in Wales that figure rises to 34%, amongst the highest proportion of heritage buildings in Europe. At over 25%, Wales also has double the UK average of households in fuel poverty, with a consequential reduced quality of life (Howarth2010). Historic England argue viable economic uses are needed to fund: initial refurbishment; repayment of investment; and income enough for maintenance in the long-term (Brennan & Tomback 2013).So 'heritage buildings' pose major challenges in affording and achieving adequate measurable retrofit, while simultaneously conserving their value and significance, and maintaining curtilages and broader landscape settings. Equally adaptation needs to steadily enhance, not reduce wellbeing, in order to convincingly engage citizens, Some enhancement may come via broader employment.Rypkema (2008) argues historic buildings are essential for the revitalisationof city centres, and that in "Europe, historic rehabilitation creates 16.5% more jobs than new construction, and every direct job in the cultural heritage sector creates 26.7 indirect jobs," far more than many other sectors.

4 A dearth of information on the current performance of existing and heritage buildings

Sustainable refurbishment must avoid waste, but there is little measured data on how occupied older buildings perform. Some, e.g. terraces, were originally standardised, but now each is probably unique via later ad hoc upgrades, alterations and structural movement. Over the last decade there has been a move to obtain irregular and occasionally repeated 'snap-shot' post-occupancy evaluations (POE), (including some heritage building stocks,) in order to determine progress towards key targets. Such POE involves both quantitative and qualitative measures. Yet it can be argued that despite the need for much more extensive POE studies, numbers are limited by shortages and the cost of expertise. The UK is said to have over 26 million buildings. A tiny percentage of that stock has been evaluated. Many evaluations remain proprietary and are not published. So in most cases we still lack sufficient data about the existing building stock, and in particular Heritage buildings, to make reliably informed judgements on suitable adaptation and mitigation measures.

5 Other means of evaluation are needed

Now real-time quantitative data and to some extent qualitative data collection is increasingly affordable, due to the advent of smartphones and low cost sensors. Leading members of ICOMOS (Jigyasu2105) also identify needs for "developing innovative low cost and culturally sensitive technology for mitigating disaster risks to cultural heritage". Such monitoring is the first stage in establishing a future alert, proactive supportive and responsive environment. We need to discover what is happening over time, in order to make reliable predictions; to use "modern technologies to continuously monitor the condition and operation of infrastructure and to intervene before problems arise and to develop better solutions for the future"(AGI 2015).Predictions may then be used to better inform user actions, or in the longer term automatically matched to user profiles to create the 'sensible and adaptive environments' that may in future give rise to smart buildings and smart heritage (NRCC 2010; Herbert et al 2008).

6 How to engageusers in predicting performance of, and managing heritage buildings

The performance of a building depends not only on its fabric and systems, but also on the way it is used. Human behavior can massively affect the performance of ostensibly identical buildings or dwellings. Yet much current real-time data collection remains building fabric focused or room centric. Therefore some, e.g. Pedersen &Petersen(2015),now argue that person centric data collection leads to more useful analysis. It is also claimed that people have more time to engage via ICT, to the extent that it is creating a 'cognitive surplus' that can be tapped into (Oomen&Aroyo2011). Kim &Paulos (2010)identified that environmental data is not generally perceived as private, and that "data sharing can persuade behavior change", but that people remain disengaged with real-time data unless it is linked to causes and solutions, so empowering them. Users should be engaged in meaningful co-design of their interaction with the environment, and the level of on demand or automated response they wish. Such engagement is core to the Australia ICOMOS Charter (2013), which states "groups and individuals with associations with the place as well as those involved in its management should be provided with opportunities to contribute to and participate in identifying and understanding the cultural significance of the place. Where appropriate they should also have opportunities to participate in its conservation and management."Steele and Clarke(2012)claim that much can be obtained with occupant engagement in participatory sensing via automated apps on individual smartphones… "it enables and creates potential personalization via two-way communication with the occupants of a space where occupants become active participants in monitoring of the environment, collecting data that affects them and receiving meaningful analysis or updates in return". They conclude that the most benefit can be gained from "a composite model that allows the collection of both fixed-infrastructure sensor based data and person-centric data collection through mobile devices", ie deploying "smartphone-internal sensors, smartphone-external sensors and also infrastructure-fixed sensors”. To enhance wellbeing Clarke and Steele (2014) suggest that “capabilities are further extended with the addition of ubiquitous external sensing components such as activity monitoring and other wearable consumer health sensors.” Where challenges arise in sensor data analysis they suggest that “human-sensing and feedback allows for validation to be performed by requesting subjective details or clarification of the data collected”. Heritage buildings may demand greater reliance on person centric mobile sensors than fixed, since mobile sensors are less intrusive, and potentially less damaging to the heritage structure, and may capture data in places that cannot be directly linked to wired or wireless networks, for later upload.

Fig. 1. A variety of forms of non-destructive measurement, and real-time data capture at the CADW cottage

7 Recent relevant experience in Cardiff Metropolitan University, Wales, UK

In 2004 Johnson Controls commenced a funded research project to study how workers used the space in open plan offices, and analyse the usage of meeting rooms. This was the first ‘Living Lab’ project of which the author had direct practical experience, advising on the use of RFID to track the workers in headquarters buildings near London, and in the USA. Workers voluntarily wore RFID badges. There were RFID readers in the reception, in each meeting room, and at each hotdesk, enabling the use of space to studied in real-time. This system enabled unpopular desk-choices to be identified, and that space then to be reassigned to other more beneficial use. Users benefitted by being able to pre-book desk space prior to arrival, find out who else was around, and remotely check the current occupancy and thus availability of meeting rooms. It was also predicted that better advance prediction of building and zonal occupancy levels enables more targeted use of building systems, reducing the blanket energy consumption incurred by running all areas at targeted temperatures, just in case.

The author and other colleagues have since used fixed infrastructure monitoring of existing and heritage buildings for several years. One study for the Welsh heritage organization CADW has involved measuring a traditional pre-1919 miner's cottage since early 2014. Every form of measurement was trialled, including the collection and analysis of data from sensors throughout the building, and through the solid stonework walls. All the methods used in that trial have proved highly expensive. Therefore a more recent project explored how costs could be lowered enough to enable widespread installation, using the very low cost computer, the 'Raspberry Pi' as a data logger with low cost cable connected sensors. This project involved applying pre-cast pre-dried hemp-lime panels to internally insulate a solid stonework external wall in a heritage cottage in Wales. Thin 12 volt heated panels (developed by Specific, Swansea University) were also applied to the wall, one between the insulation and the original stone, one on the newly formed interior surface. The combination of internal wall insulation and heated panels were then monitored over a season to analyse their performance in use. Temperature and humidity sensors from 'Tinkerforge' were mounted on the surface of the wall inside and outside, but also at two locations between the hemp-lime and the stonework inside the refurbished wall. The data from these sensors was read at 5 minute intervals by a script running on the Pi and written to a csv file, which could then be transferred via wifi using the home owner's router, and analysed in open office. When the router was changed, the home owner was able to restart the monitoring without difficulty. The system ran reliably, and the data provided valuable information on how the hemp lime enhanced the thermal performance of the wall, while still allowing it to breath.

An ongoing project with the same colleagues is now exploring how, at low cost, users can be actively engaged via their smart phones. An open source project 'aircasting.org', launched in New York, has developed schematics and an app to engage schools and other community groups in mapping local pollution and by inference well-being. They provide an android app to collate and upload data from mobile phone sensors, including heart rate (an indicator of stress or wellbeing). Their 'aircasting' app uses sensors on the smartphone to measure noise levels, which may be extended to use other built-in sensors such as light levels. The app uses 'Bluetooth' to read, map and graph real-time data from external portable 'Arduino' based sensors for humidity, temperature and particulate levels. The external sensor device can be extended to add other sensors. The smartphone is then used to upload recorded data to the web, and display 'pollution' hot spots on digital mapping. This approach will shortly be used to engage secondary school pupils in Wales in evaluating their own environments, which will further inform studies on the effect of physical environment on well-being and learning. A recent EPSRC funded research project led by Salford University (Barrett et al, 2015) studied the effect of the classroom environment on primary school children in 150 Classrooms in 30 UK schools. This study demonstrated a 16% variance in learning progress over an academic year attributable to differences in the physical environment of classrooms.

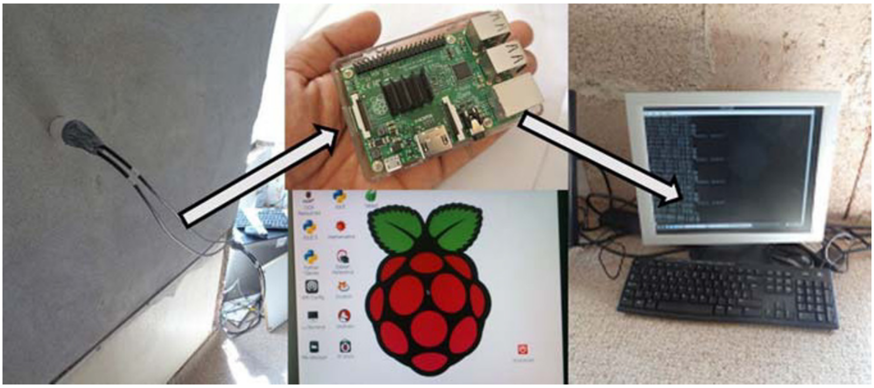

Fig. 2. The low cost sensor approach (a) sensors within wall. (b) Raspberry Pi. (c) displaying real-time data, optional screen, keyboard

8 The relevance of 'Living Labs'

In Europe, "Living Labs" use new and emerging technologies to involve participants in their 'everyday habitat' rather than to attempt to recreate that habitat in a lab, (founded on previous studies relating 'ambient intelligence' to cities and urban life). Nokia and others in the Intelcities FP6 research project set up the first EU network of Living Labs. They recognized the importance of actively engaging users in both exploration of their needs and desires and in exploring the capacity of emerging technologies to meet these (WING 2009). They saw that mobile phones were already augmenting peoples' capabilities in unforeseen ways: greater sense of security for young women in public spaces to be always in virtual contact with a supportive friend; virtual socialization for the housebound; prosthetics for memory, for disability, and for aging. Later Nokia acknowledged that their initial approach was "too corporate and projects should aim to be user-driven"(Niitamo, V 2007). Hirvikoski (2016) claims that now "Living Labs operate as intermediaries among cities, regions, firms, third sector and research organisations as well as citizens for joint value co-creation, rapid prototyping or validation to scale up and speed up innovation". It has become an accepted participatory research methodology, [it has also been termed an environment and a system (Bergvall-Kåreborn&Ståhlbröst)].Hirvikoski (op.cit) goes on to particularly describe the close relationship between living labs and the development stages of emerging smart cities. Bergvall-Kåreborn&Ståhlbröst(op.cit) set out the key role of a living lab as "to engage and empower users to participate in the generation of valuable and sustainable assets towards objectives set-up by its partners and customers". ENoLL (2016) have since refined this key definition, and now claim that to be a living lab five key elements must be present: "**active user involvement** (i.e. empowering end users to thoroughly impact the innovation process); **real-life setting** (i.e. testing and experimenting with new artefacts "in the wild"); **multi-stakeholder participation** (i.e. the involvement of technology providers, service providers, relevant institutional actors, professional or residential end users); **a multi-method approach** (i.e. the combination of methods and tools originating from a.o. ethnography, psychology, sociology, strategic management, engineering); **co-creation** (i.e. iterations of design cycles with different sets of stakeholders)."

9 Conclusion

"Smart city solutions must start with the city not the smart" (Schaffers et al 2011). Similarly, engagement must start with the needs of the participants, not the data. It is not yet clear to what extent and in what circumstances users can or will effectively engage in conservation and management, what tools will be sufficiently barrier free and easy to use, how their experience of heritage buildings can be enriched, nor what if anything makes a smart heritage building different from a smart building in general. For example, smart cultural heritage buildings such as museums involve some aspect of either tutelage or 'edutainment', perhaps more so than other smart buildings, but is that all? It is probable that in the future we are likely to have (too much) automated data, and we need easy to deploy and use mechanisms for filtering and analysing it, so people can make sensible decisions about heritage, and responses later be automated. Currently that data is collated by experts, making perhaps too many assumptions based on too little building centric data, let alone person centric information. What form will heritage information take when it is substantially crowd-sourced? These understandings are best achieved via Living Lab approaches. In the longer term the sustainable transformation of heritage buildings and landscapes into Smart Heritage can be held to be a key component in the metamorphosis of existing cities into Smart Cities.

References

Barrett, P. Zhang, Y. Davies, F. Barrett, L. 2015. 'Clever Classrooms – Summary report of the Head Project (Holistic Evidence and Design)'; University of Salford. ISBN 978-1-907842-63-4. available online at: www.salford.ac.uk/cleverclassrooms/1503-Salford-Uni-Report-A5-DIGITAL.pdf

Caragliu, A., Del Bo, C. and Nijkamp, P., 2011. Smart cities in Europe. *Journal of urban technology*, 18(2), pp.65-82

Saunders, T &Baeck, P. 2015. 'Rethinking Smart Cities from the Ground Up', *NESTA report*, online at: www.nesta.org.uk/publications/rethinking-smart-cities-ground#sthash.duoyO0Nz.dpu

Juujärvi, S. &Pesso, K. 2013. 'Actor Roles in an Urban Living Lab:What Can We Learn from Suurpelto, Finland?'.*Technology Innovation Management Review.*

Platoniq2015. 'Co-creation made agile', online at: https://issuu.com/platoniq/docs/platoniq_co-creation_eng

Pallot, M. and Pawar, K., (2012.'A holistic model of user experience for living lab experiential design'. In *18th International Engineering, Technology and Innovation Conference*, pp. 1-15. IEEE.

Buckman, A. Mayfield, M. Beck, S. 2014. 'What is a Smart Building?' in *Smart and Sustainable Built Environment* 3:2, 92-109.

Epstein 1998. 'Digital Living Room' online at: http://epstein.org/wp-content/uploads/Digital-livingroom.ppt

Crutzen, C.K., 2006. 'Invisibility and the meaning of ambient intelligence'. *International Review of Information Ethics*, 6(12), pp.52-62.

Siemens 2010. 'Smart buildings - the future of building technology', online at: www.youtube.com/watch?v=gCuPx9shWT0

Dowson M, Poole A, Harrison D, Susman G, 2012. 'Domestic UK retrofit challenge: drivers, barriers and incentives leading into the Green Deal', *Energy Policy*, 50, pp 294 305

U.N.E.P. 2009. 'Buildings and climate change: Summary for decision-makers'. United Nations Environmental Programme, *Sustainable Buildings and Climate Initiative*, Paris, pp.1-62.

Brightman M. 2012. 'Is the Conservation of the United Kingdom's Built Heritage Sustainable?' in *BCUR 2012 Special Issue*

Howarth, S. 2010, "Living in Wales 2008: Fuel Poverty", Welsh Assembly Government, Cardiff.

Brennan, T. Tomback, D. 2013. 'Heritage Works: The Use of Historic Buildings in Regeneration; a Toolkit of Good Practice'. English Heritage.

Rypkema, D.D. 2008. Heritage conservation and the local economy. *Global Urban Development Magazine*, 4(1).

Jigyasu, R. 2015. 'Building Resilience by Reducing Disaster Risks to Cultural Heritage'. PreventionWeb guest editorial, online at: http://www.preventionweb.net/experts/guest/collection/44401

AGI 2015, 'AGI Foresight Report 2020'; online at: www.agi.org.uk/about/resources/category/100-foresight

NRCC 2010, 'A day in the life of an intelligent building', online at: www.nrc-cnrc.gc.ca/eng/dimensions/issue4/intelligent_building.html

Herbert, J., O'Donoghue, J. and Chen, X., 2008. 'A context-sensitive rule-based architecture for a smart building environment'. In *2008 Second International Conference on Future Generation Communication and Networking* (Vol. 2, pp. 437-440). IEEE.

Pedersen, S. Petersen, S., 2015. 'Desktop polling station for real-time building occupant feedback'. *Rehva European Hvac Journal.*

Oomen, J. and Aroyo, L., 2011, 'Crowdsourcing in the cultural heritage domain: opportunities and challenges'. In *5th International Conference on Communities and Technologies* (pp. 138-149). ACM.

Kim, S. Paulos, E., 2010. 'inAir: Sharing Indoor Air Quality Measurements and Visualizations'. In *SIGCHI Conference on Human Factors in Computing Systems* (pp. 1861-1870). ACM.

Australia ICOMOS. 2013. 'The Australia ICOMOS Charter for the Conservation of Places of Cultural Significance - (The Burra Charter)' Australia ICOMOS.online at: http://australia.icomos.org/wp-content/uploads/The-Burra-Charter-2013-Adopted-31.10.2013.pdf

Steele, R. and Clarke, A., 2012.'A real-time, composite healthy building measurement architecture drawing upon occupant smartphone-collected data'. In *10th International Healthy Buildings Conference*

Clarke, A. and Steele, R., 2014. Health participatory sensing networks. *Mobile Information Systems*, 10(3), pp.229-242.

WING (2009) "Impact Analysis in the Domain of eBusiness& New Working Environments - Annex: Case Studies Report". online at: http://cordis.europa.eu/pub/fp7/ict/docs/enet/wing-ebusnwe-case-studies-report_en.pdf

Niitamo, V. (2007) quoted in Cordis Newsletter online at: http://cordis.europa.eu/news/rcn/28537_en.pdf

Hirvikoski, T (2016) 'Living Labs and Open Innovation' online at: https://ec.europa.eu/digital-single-market/en/news/living-labs-and-open-innovation

Bergvall-Kåreborn, B &Ståhlbröst, A (2007) "Living Lab - An Open and Citizen-Centric Approach for Innovation" in *International Journal of Innovation and Regional Development* 1(4), pp.356-370

ENoLL (2016) 'Introducing ENoLL and its Living Lab community' online at: https://issuu.com/enoll/docs/enoll-print?e=23453591/33195876

Schaffers, H., Komninos, N., Pallot, M., Trousse, B., Nilsson, M. and Oliveira, A., 2011, May. Smart cities and the future internet: Towards cooperation frameworks for open innovation. In The Future Internet Assembly (pp. 431-446). Springer Berlin Heidelberg.