UNIVERSITY OF CAMBRIDGE
Centre for Digital Built Britain

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Building Impulse: A novel digital toolkit for productive, healthy and resource-efficient buildings

Final Report

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Abstract

Future cities will generate an unprecedented demand for resource-efficient, healthy and productive buildings that cater for an additional 2.5 billion urban inhabitants by 2050 and simultaneously mitigate the impact of climate change. Dynamic building components and controls have the potential to shape novel responsive and resource-efficient environments that help to meet actual occupant demands. A major barrier to the uptake of dynamic technologies in buildings is that the transient effects on occupant satisfaction are poorly understood, in particular there is a paucity of methodologies for capturing and assessing transient effects on occupant satisfaction, productivity and wellbeing. This reports describes a research mini-project called “Building impulse”, The project, funded by the Centre for Digital Built Britain, aims to assemble and develop a so-called Building Impulse Toolkit (BIT), consisting of a novel array of digital sensors and other methods for capturing overall occupant response in terms of occupant comfort, satisfaction, productivity and well-being.

1.Research Question

1.1 Research problem and gap

Transient changes in levels of indoor environmental characteristics (e.g. visual, thermal, acoustic, air quality, vibration and interaction) underpin occupant comfort and satisfaction and have a significant effect on occupant productivity and wellbeing . Digital and dynamic building controls and sensing technologies provide an opportunity to shape novel interactive and responsive environments that meet actual occupant demands in real-time and in a resource efficient manner. However, there is a lack of knowledge on how multiple environmental characteristics acting simultaneously affect holistic occupant satisfaction and how these in turn lead to gains / losses in productivity and wellbeing. Furthermore, the transient nature of the environmental characteristics require the corresponding holistic effects on occupants must to be captured in real-time. By definition, retrospective post-occupancy questionnaires are ill-suited for this purpose and the resolution of the information they capture is insufficient.

1.2 Research question

What is the most effective (least intrusive and sufficiently accurate) means of capturing holistic occupant response to transient environmental characteristics in buildings?

1.3 Research objective

Building Impulse has assembled a novel toolkit of methods for capturing holistic occupant response to transient environmental characteristics in buildings. The toolkit will provide a means of establishing quantitative relationships between variations in environmental characteristics and overall occupant satisfaction and productivity. The toolkit consists of a range of existing sensors and additional devices that together capture the wide effects of novel resource-efficient technologies, such as the occupant responses to dynamic façade systems and the effects of material-efficient structures on occupant productivity and well-being.

2. Methodology

A novel Toolkit, called BIT (Building Impulse Toolkit) was developed to capture occupant response to transient environmental characteristics in buildings. The Toolkit addresses three fundamental aspects

(Fig.1): Environmental monitoring; Unobtrusive systems for high frequency occupant feedback; Indirect systems for capturing occupant preferences.

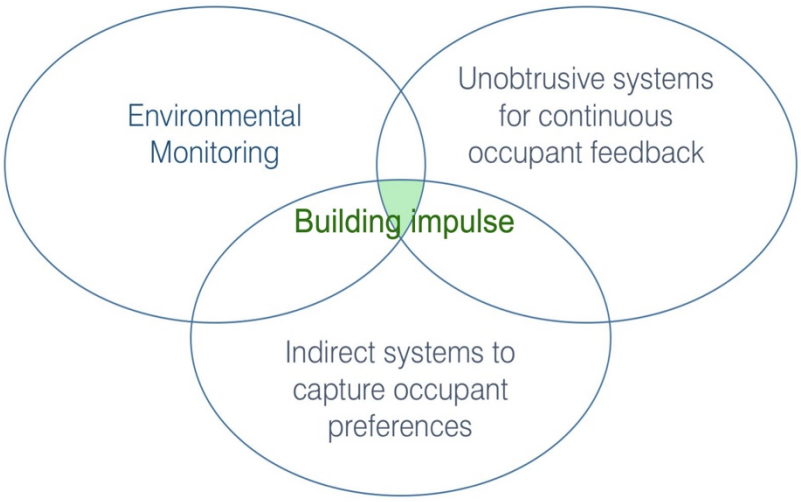

Fig.1 Venn diagram of the three different aspects of the novel methodology

All three aspects of the toolkit were developed with the aim of testing them in real-world offices in London and in a novel office-like test facility in Fig.2, called MATELab (Mobile Adaptive Technology Experimental Lab), located at the University of Cambridge.

Fig.2 MATELab: External and internal view

2.1 Environmental monitoring

Environmental workstation sensors (Fig.3) were designed to monitor the salient environmental characteristics and their inter-effects (Fig.4), namely: Thermal environment, Visual environment, View, Personal control and Interaction, Vibrations, Acoustic environment and Indoor Air quality (IAQ). The workstations sensors also include accelerometers for capturing high frequency vibrations, of the type induced by underground transport or building services.

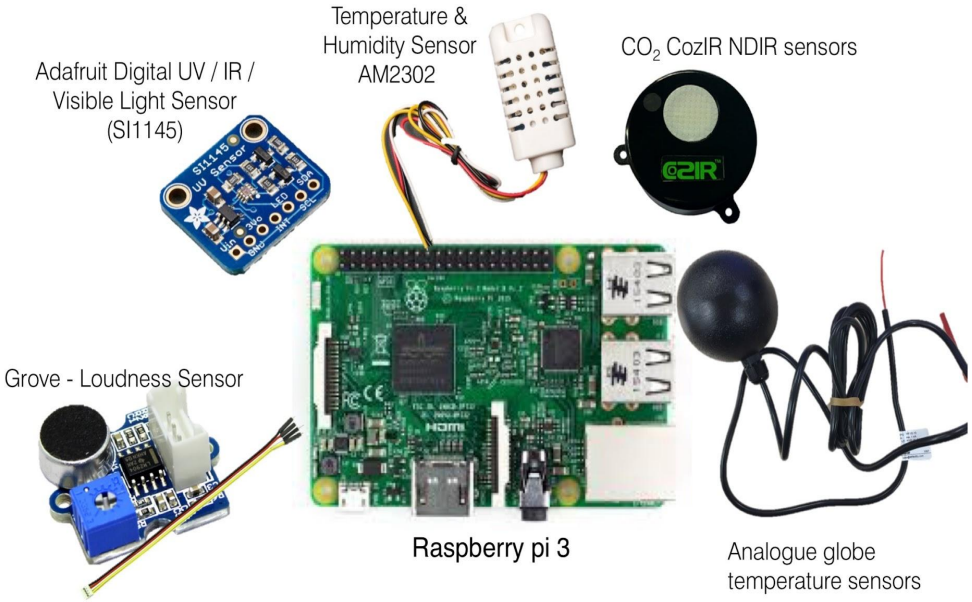

Fig. 3 Components of environmental workstation sensors

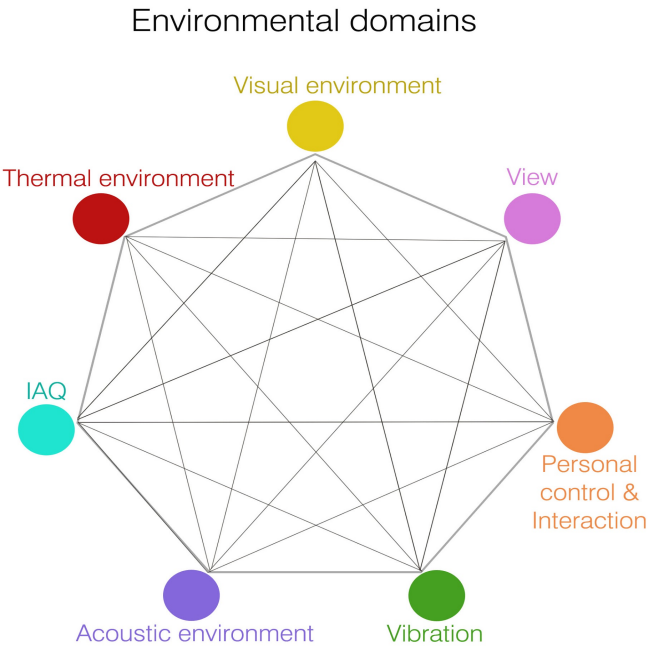

Fig. 4 Environmental domains and their inter-effects considered for Building Impulse

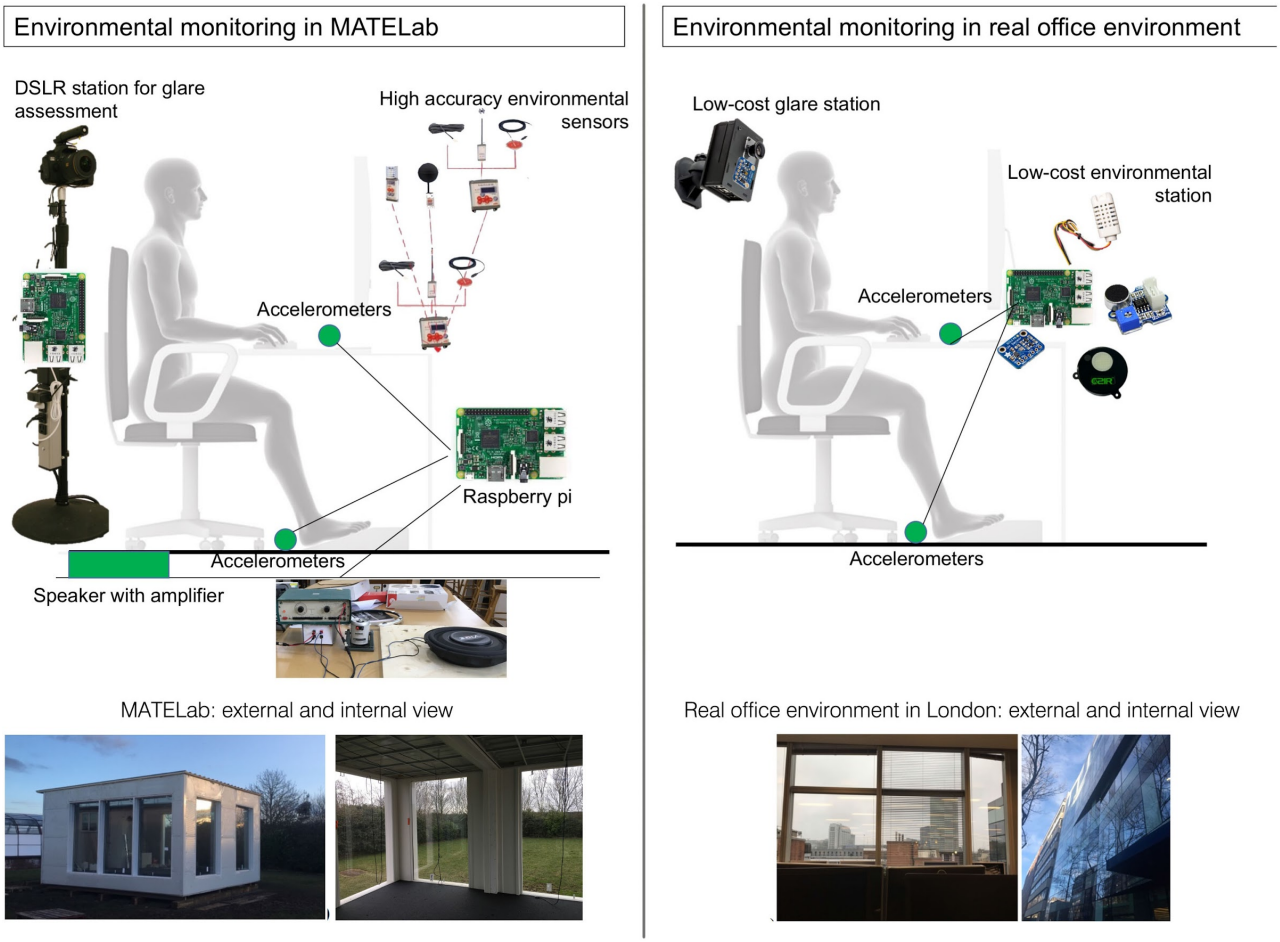

Fig. 5 Environmental monitoring setup in MATELab and real offices

As shown in Fig. 5, Building impulse has developed two versions of the environmental workstation sensors: (i) A cost-effective version intended for large scale deployment in real-world offices, based on raspberry-pi technology: (ii) A lab-grade version for high-accuracy and control of the environmental monitoring for use in MATELab. The two versions provide a cost-effective and accurate solution for each experimental context.

In the on-going development of BIT it is also important to identify (i) the environmental characteristics that have a significant effect on occupant satisfaction, well-being and productivity and (ii) the optimal sampling frequency and spatial resolution for capturing occupant response to transient environmental changes. Research is currently underway in MATELab and real-world offices to test different environmental scenarios and setup configurations with a view of providing insights on (i) and (ii) above.

2.2 Direct systems for high frequency occupant feedback

Collection of direct occupant feedback is traditionally done by means of survey or interviews. However, the dynamic control of responsive building components requires a high frequency of occupant response and a minimum amount of disruption to occupant activities. A novel polling station has been developed to allow occupants to provide feedback in a simple but robust manner. The polling stations were support a dual mode of interaction i.e. they capture both dissatisfaction and satisfaction of occupants. Every two hours occupants are asked to register their environmental preferences via the polling stations, but they are also able to register their dissatisfaction with the

environment by simply pressing the so-called “discomfort buttons” at any intervening time. The polling station was developed in collaboration with the Department of Psychology and the preferred design was selected after testing and validating alternative solutions. The final design solution provides a good balance between accuracy, unobtrusiveness and cost and is currently under final assessment. User-friendly design / ease of use is an important requirement and alternative polling stations were assessed in terms of ease of use by recording the amount of time required by new users to operate them. In order to preserve the accuracy of the data collected in MATELab and in the real-wordl offices, each polling station is individual and identified by personal identification codes. The number of times occupants are required to express their preference can be then adjusted according the workplace environment, however a minimum of 4 times per day were considered as fundamental to draw meaningful conclusion on the dynamic building performance in terms of occupant satisfaction. In order to ensure accurate data collection, the polling station were designed in collaboration with the Department of Psychology and careful consideration was put on the psychometrics behind the prompts used in the polling station. For instance, habituation to the workplace was measured for new occupants in MATELab.

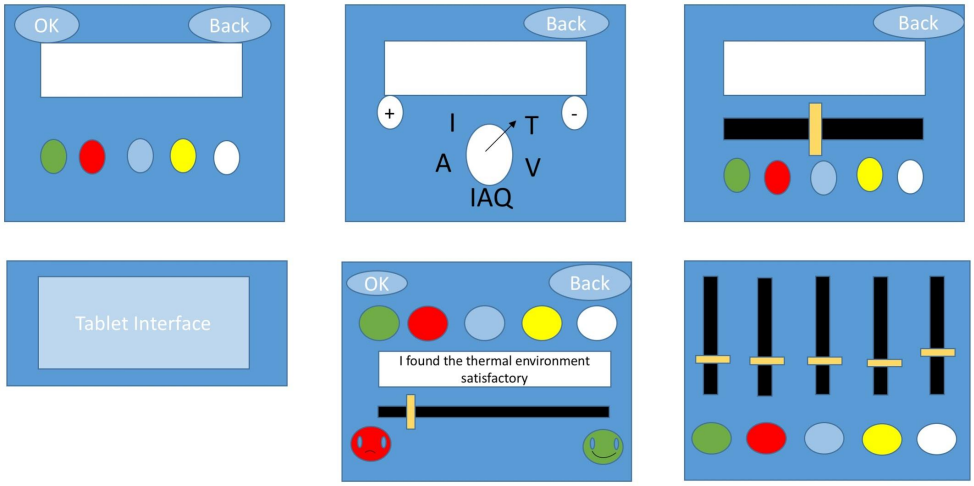

Fig. 6 Alternative solutions of polling stations under assessment. Eventually, the fifth solution has been selected.

2.3 Indirect systems for capturing occupant satisfaction

In addition to the direct means of capturing occupant feedback, several methods, including physiological monitoring, have been combined to capture occupant response in an indirect manner (Fig.7), thereby reducing or eliminating occupant disruption. Indirect means of collecting occupant reactions consist of conventional physiological characteristics such as heart rate and skin temperature, as well as more novel aspects such as facial expressions. Data collected on these characteristics will be used to ‘gauge’ occupant satisfaction, by correlating them to the direct feedback gathered from the polling station and surveys. The ultimate aim is for these novel ‘indirect’ systems to be used as proxies for the direct measurements, thereby providing an unobtrusive means of collecting high frequency, high quality data on comfort, satisfaction and well-being of the occupants.

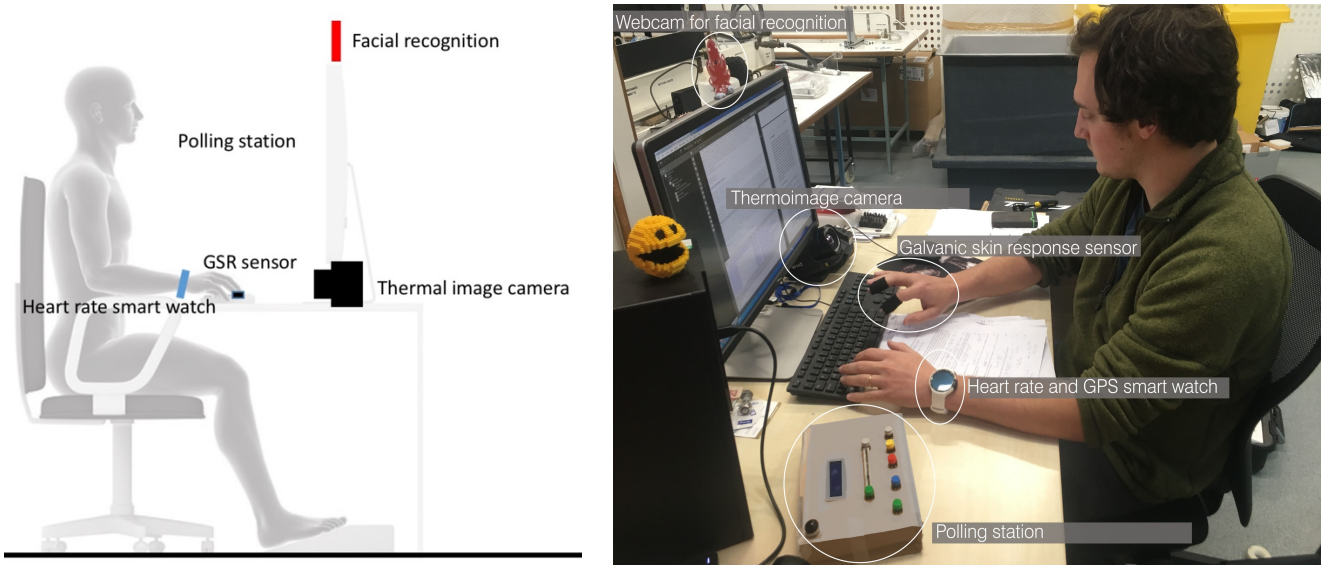

Fig. 7 Equipment set-up for capturing occupant feedback / preferences to transient changes in environmental conditions.

3. Discussion

This reports sets out the design and assembly of a novel, experimental toolkit (BIT - Building Impulse Toolkit) which aims to capture data on occupant satisfaction with indoor environmental characteristics. The longer term aim is for this data to inform the design and control of current and future buildings in a manner that maximises occupant satisfaction, comfort, productivity and well-being. BIT should therefore provide an unobtrusive and cost-effective means of collecting the relevant data with sufficient accuracy and frequency. A full quantitative assessment of BIT, has yet to be performed (and is expected to be completed by June 2018), but this mini-project provides a qualitative insight on the following important features of the novel toolkit: (i) unobtrusiveness of the system, (ii) accuracy of the data collected and (iii) potential further implementation and limits.

3.1 Unobtrusiveness of the system

The use of polling station for the gathering of occupant response provides a less obtrusive medium than traditional survey or interviews. Although polling stations offer a less obtrusive means of collecting occupant feedback and they represent a fundamental step to understand the relationship between environmental changes and user preferences, direct assessments of occupants retain a level of disruption. For this reason, “Building impulse” mini-project also explored an indirect means of capturing occupant reactions through physiological readings, namely galvanic skin response, skin temperature and heart rate monitoring, and more novel indirect methods such as facial recognition. These indirect means are currently under assessment together with surveys and data from polling stations in order to assess their usefulness and to set the basis for future research on unobtrusive systems for occupant satisfaction. Building impulse is currently assessing and analysing which of the aforementioned indirect methods has the potential to provide a seamless tracking of occupant response that could inform dynamic building controls on user preferences.

3.2 Accuracy of the data collected

Traditional post-occupancy methods, such as surveys or interviews, are a robust and accurate means of capturing occupant response, however their strong limitation is that they always require occupants to “remember” their environmental satisfaction. Therefore, they are of limited use for capturing high

frequency transient data, they could complement alternative methods, such as polling stations, to provide a comprehensive and holistic assessment of occupant condition. Polling stations are therefore the method of choice for gathering large amounts of data from occupant in short intervals.

3.4 Potential and further implementation and limits

BIT has the potential to push the boundaries of the traditional control and assessment of buildings towards human-centric affective buildings, which would bring us significantly closer to intelligent buildings.

Critical issues which need further development are: cost-efficiency, reliability, resolution and accuracy of data collected and the full development of indirect means of gathering occupant satisfaction. This latter one will be possible once the relationship between transient environmental changes and occupant satisfaction and productivity will be understood and linked to changes in physiological and facial response. Furthermore, ubiquitous and continuous tracking of occupant response raise ethical issues on the privacy of users. The associated risk need to be identified and managed carefully and the users must be made fully aware of these issues.

4. Conclusion

This CDBB mini-project has created a toolkit of sensors and methods (called BIT) that provide a step-change in the quality and quantity of data about occupants and the indoor environment. This will be further refined and tested in the future to create an affordable and robust means of post occupancy evaluation. BIT captures the holistic and transient relationship between environmental conditions and occupant response and is essential for developing the next generation of intelligent, adaptable and user-centred buildings. Data from BIT should allow us to control novel building technologies in a far more effective and evidence-based manner. For example, it would be possible to: (i) devise control strategies for switchable glazing that reduce energy demand and simultaneously respond occupants' reactions to these dynamic changes and; (ii) reduce the mass of a building frame without compromising safety, by accounting for occupants' response to deformations / vibrations. In the absence of this holistic measure of occupant comfort and satisfaction, the use of resource- efficient measures and technologies can (and often do) result in dissatisfaction or discomfort for occupants. BIT is not limited to future building. Indeed several existing buildings could benefit from a low cost toolkit for informing possible improvements in their performance, particularly in terms of occupant satisfaction and wellbeing.

Related and Further Work

The Building impulse mini-project consists of the assembly of a novel, experimental toolkit for capturing data on transient and holistic occupant response to changes in indoor environmental conditions. The data will help to inform human-centred manner the control and design of current and future buildings and maximise occupant satisfactions, comfort, productivity and well-being. However, there is also a need for the systems to be both unobtrusive and cost-efficient, while still providing data with sufficient accuracy and resolution for it to be useful. Consequently, "Building impulse" has endeavoured to develop a toolkit with the following characteristics: unobtrusiveness of the system, accuracy of the data collected and cost-efficiency.

Further development is required in maximising cost-efficiency, reliability, resolution and accuracy of data collected and investigating other indirect means of gathering occupant satisfaction. This latter one will be possible once the relationship between transient environmental changes and occupant

satisfaction and productivity will be understood and linked to changes in physiological and facial response. Lastly, ubiquitous and continuous tracking of occupant response raise issues on the ethics and privacy of users, which need to be identified and managed during the future development of the toolkit.

Acknowledgements

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