An interactive and adaptive building layer: Strategies for allowing people to become advanced building-users

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ABSTRACT
This paper reports outcomes of a pilot study to develop a conceptual framework to allow people to retrofit a building-layer to gain better control of their own built-environments. The study was initiated by the realisation that discussions surrounding the improvement of building performances tend to be about top-down technological solutions rather than to help and encourage bottom-up involvement of building-users. While users are the ultimate beneficiaries and their feedback is always appreciated, their direct involvements in managing buildings would often be regarded as obstruction or distraction. This is largely because casual interventions by uninformed building-users tend to disrupt the system. Some earlier researches showed however that direct and active participation of users could improve the building performance if appropriate training and/or systems were introduced. We also speculate this in long run would also make the built environment more sustainable. With this in mind, we looked for opportunities to retrofit our own office with an interactive layer to study how we could introduce ad-hoc systems for building-users. The aim of this paper is to describe our vision and initial attempts followed by discussion.

INTRODUCTION
A building is a complex system. As expectations for services buildings offer continue to rise, designing and maintaining buildings require increasing number of specialists. This has made control of modern buildings out of reach for building-users and turned them into mere consumers of spaces. While the intention to regulate built-environments with building automation systems is noble, seeking for a common denominator to satisfy users through predefined comfort level should not necessarily be the only viable solution. While building systems are very complex and relinquishing controls to users may be considered inappropriate or unsafe, it can also be considered as counterintuitive in the era where users are actively and successfully involved in designing and customizing many of their own devices. Building-users could be enthralled and become expert building-users if they were given the right environment.

Building-users often have issues with their environments but the lack of direct control of building systems does not allow them to change much. Many of us do not even know anything about factors affecting our environments and how they are controlled. This is understandable considering most of us are not trained to understand how environmental performance of buildings should be optimised. With this assumption, buildings are designed to be managed by experts and there is not much left for us to do. But what if we could be trained and authorized to look after and manage our environments through daily interactions with our building systems? Our research began by speculating it would be beneficial to design systems that allowed users to manipulate and control as many aspects of their own spaces as possible, learn from consequences of changes and some keen users to become advanced building-users.

Our interest is with non-residential buildings with large proportion of shared and actively used spaces such as typical contemporary office buildings. With a view that needs in shared spaces change frequently, sometime dramatically over time, and it is difficult to design buildings that adapt to unknown needs over time, our research focus is to design a framework to allow users to retrofit buildings in ad-hoc manners.

The research began by identifying what building-users can do in their spaces. We can open and close doors to our spaces and some of us are fortunate enough to have operable windows. We typically have access to switches to control lights and occasionally a switch or more advanced interfaces to activate or control HVAC (Heating, Ventilation and Air Conditioning) systems. We can also move or relocate some furniture but usually with a great difficulty or limitation. Most importantly, however, changing anything in one’s environment is likely to affect many others in the same space and one’s move may quietly or vocally upset others. Under the conditions of most typical buildings, there is not much we can do when we are not satisfied with our environment.

This paper aims to describe our approach to deal with this by first referring to a project proposed in the late 1970s
by Cedric Price. It is followed by an explanation of our research methods. We then describe our attempts to design and fabricate digital and physical prototypes some of which were installed in our office space. They are used as props in the scenarios to evaluate how everyone can be involved and take actions to adapt environments in response to our needs. The scenarios allowed us to identify how an interactive and responsive layer can be retrofitted to our office space and help us to understand issues and challenges to discover opportunities. Reflection on our study and the future scope are discussed in the last section of this paper followed by a conclusion.

BACKGROUND

There are numerous projects that explored possibilities of technologically augmented interactive architecture (Fox & Kemp, 2009). There also are projects that discussed sensors in shared environments and their management and coordination through building information (Babsail & Dong, 2006; Liu & Akinci, 2009). We have also investigated possibilities of adaptive buildings in our past papers (Santo, Frazer, & Drogemuller, 2010, 2011). While there have been many developments, Brown and Cole discussed the lack of knowledge with regards to how modern buildings work prohibited their users from utilising them to its intended optimum level (Brown & Cole, 2009). There is however little study to identify how modern technologies are deployed to allow building-users to engage with managing and altering their spaces. The Generator, developed and nearly constructed in the 1970’s, is a rare example of such study.

The Generator was proposed by Cedric Price for the Gillman Paper Corporation for a site in Florida, USA in the late 1970s. It was referred to as "[w]hat may well be the world’s first intelligent building” (“A Building that Moves in the Night,” 1981). Price explained “the scheme as enabling staff and employees of the company to extend their own interests and activities” (“Cedric Price’s ‘Generator’,” 1979). It consisted of a kit of parts and monitored and managed by a set of programs to allow the building to be reconfigured (Sudjic, 1981). Compared to Price’s earlier and more well-known Fun Palace project, the Generator project considered much more about how the systems capture intentions of building users and respond to offer possibilities and opportunities in a more tangible manner. Working prototypes were developed and documented by Frazer et al. to study and demonstrate the Generator systems (1980). The systems were to be governed by four computer programs to manage, coordinate, facilitate and initiate the reconfiguration of the building as described below (Frazer, 1995; Frazer & Frazer, 1979; Spiller, 2002).

The first program (P1) was for what Price called the ‘Polarizer’. The role of the Polarizer was for planning the reconfiguration of facilities according to needs. The program gave the Polarizer necessary rules and limitations to reorganize components and structural units and allowed them to see and examine the implications of proposed changes.

The second program (P2) was for the ‘Factor’. Their role was to facilitate and implement changes and maintain the operation of facilities. They used the program to manage the inventory, coordinate bookings and receive alteration plans and schedules. The program was also to provide feedback to Polarizer for them to understand the usage so that they can plan for the better utilization of the site and facility.

The third program (P3) was for the users. Users were given opportunities to interactively suggest changes according to changing needs rather than merely given feedback. This was to give them incentives and control to encourage their participation. It was considered by Price that the potential of the Generator could never be maximized unless users were active participants. This is a significant feature of the Generator project that greatly influenced our research.

The fourth program (P4) gave the Generator itself the intelligence. It gave it the ability to contribute by making its own suggestion. Its unique feature was that the program allowed the Generator to become bored if the spaces were not modified regularly and frequently enough. Gordon Pask introduced the idea of boredom (Pask, 1971) but the implementing this to an architectural project remains unique even as of today (has anyone been to a building that becomes bored?). The most architectural systems we encounter today only respond to our requests or predefined conditions. The notion of boredom allows systems to be proactive. Buildings that are designed to adapt remain very rigid if people were not given incentives to use what they are designed to do. The concept of boredom allows the system to encourage users to respond by accepting or suggesting alternative plans and it allows the systems and users to be in continuous dialogue.

The Generator was never realised and there hardly is any information and data to examine if the system would have worked as desired if implemented in the 70’s. The idea however is still alive and we know we are far better equipped to realise it today. We have 30 years of technological developments in all necessary fields such as computing, networking, embedded systems, sensors, manufacturing, fabrication and various other technologies since the Generator was designed. Technologies are so advanced and readily available to the extent mere hobbyists can design and make artefacts that simply cannot even be dreamt of by engineers and scientists at the height of their career 30 years ago.

While technologies are readily available to propose a built environment similar to what Price imagined, we need a framework, methods and the mind-set for utilising available technologies prepare building-users to gain control of their environments. Price in a number of occasions responded to technology evangelists by stating that technology could be the answer but what was the question. We are technologically able to construct systems that are much more sophisticated than that of the Generator but why do we need them? Our goal is not to identify technological solutions. Our key question is to investigate whether building-users should be given better
controls over their spaces so that their environment responds better to their needs. Our vision is similar to Price’s except that we believe we do not necessarily need new buildings. We argue most buildings can be retrofitted in an ad-hoc manner and users themselves can initiate and lead it. We began this research to investigate possibilities and opportunities within the techno-social context of today to identify a number of potential scenarios.

**METHOD**

Together with colleagues, we, as users of a single open-plan office, tried to deal with what we generally call ‘wicked’ problems (Rittel & Webber, 1973). The aim is to identify actions we could take to gain the level of control beyond what the current limitation that our building imposes.

There are factors such as use of energy and other resources that we can measure and analyse quantitatively. There also are established methods to quantify more abstract information about built-environments such as comfort level of office spaces. There are many technological solutions that are known to give us better environments and it is possible to measure the effectiveness of each solution with these methods.

Our aim however is not to propose solutions to compete with existing solutions or to evaluate effectiveness of our experiments. It instead is to identify opportunities to investigate how our environments can be more actively controlled in the user level. We brainstormed limitations of our building and constructed prototype devices and scenarios to creatively but not necessarily effectively go beyond the limitation imposed by the design of our building and its systems.

The research began by identifying various ‘what if’ scenarios. As mentioned earlier, we used our office space, which we all agree hardly satisfies our expectations, to give specific context to the scenarios (Figure 1). This allowed us to generate a wide variety of scenarios based on our own wishes such as; what if windows can be opened, each individual ceiling light can be turned off, and move between floors without relaying on lifts.

Once we had a number of wishful scenarios, we tried to identify problems with scenarios. For example, while everyone typically agree that operable windows are good, it is easy to overlook problems operable windows can bring to the environment. Firstly, effectiveness of HVAC system can be hindered if the system does not take in account that windows are operable. This could lead to increased energy use. Secondly, windows that are left open can introduce weather related problems. This could, in short and long term, lead to damage of the building. Lastly, safety and security of building users as well as people outside may be hindered. In other words, they typically are headaches for facility managers. This leads to next series of scenarios such as, “what if users could consciously and effectively evaluate consequences of changes with the aid of technologies,” and so on.

What we intended to study in this process was not particularly about architectural or product solutions to directly resolve issues identified during our discussions. It instead was more about identifying why and when users want to interact with their building and how their ability to interact can lead to motivations to improve their own environments. In other words, this research is more about identifying strategies than designing products.

This method differs from a typical scientific research in that we do not have any well-defined problem or goal. It is more about identifying opportunities in our everyday scenarios. We construct scenarios and design temporary artefacts to allow us to live through ad-hoc solutions, evaluate our experiences and construct further scenarios to refine our understanding or discover new opportunities.

This research is, in Frayling’s definition, a research ‘through’ design, but in long term this process is research ‘for’ design because the research is conducted ultimately to identify what can be designed (Frayling, 1993). It can also fall under ‘interpretive’ research (Swann, 2002). Clear and concise definition given by Zimmerman, et al. (Zimmerman, Forlizzi, & Evenson, 2007) appropriately explains our position as designers (mainly architects), our research focus and our approach.

The strength of this approach is that ideas can be developed and evolved, opportunities can be identified and strategies, and knowledge can be quickly developed and studied. The risk was that this might lead to redundant and irrelevant outcomes but we took a stance that quantity is quality. We are in the environment where fully functioning digital and physical prototypes can be made rapidly. Our experiments use available and accessible technologies as much as possible to make them more relevant to wider community of building-users.

**PROTOTYPES**

Input and output devices and interfaces were built to have insight into how building-users could interact with building information and services. Before constructing prototypes, we identified relevant building stakeholders and studied what they would or need to do and how they would interact with their building. Figure 2 shows possible stakeholders of a building, type of interfaces and building systems they would have access to, and
demonstrates simple relationships between them if they were to coexist with a Generator-like adaptive building. To restrict the scope of our discussion, this paper mainly discuss the issue surrounding building-users (highlighted in Figure 2).

The diagram shows all stakeholders, regardless of their relationship to their building, are given access to the operation and management of their building. The typical role of designers, engineers, contractors and facility managers remain more or less the same because each of them would be trained differently to create, edit and/or view a virtual building model of the building whether they use a single BIM for all levels of design and operation of a building (currently very rare) or not. However, the potential role of building-users shown in this diagram is unique because they are to be given means to understand and control their own environment unlike in typical buildings where building-users are mere

Figure 2. Building stakeholders, systems and their relationships

Figure 3. DIY Building Information Layer
consumers and observers of their spaces.

This is not to say a building with its users merely consuming and observing does not perform well. Our current study does not intend to provide any evidence to support or deny this. We are interested instead in identifying possibilities and opportunities to introduce a system that allows building-users to interact with their buildings. There are strong evidences to demonstrate active user participations could improve building performance as shown by Brown and Cole (2009). The issue at stake however is with means to motivate and encourage them to sustain their participation. Our research aims to identify how an ad-hoc system could be considered as a solution to help building-users to participate.

This study also does not intend to provide a generic solution that can be applied globally to all buildings. Our primary aim for this pilot study is not to develop new technological solutions and develop commercial products. There already are countless solutions that bring building environments to desirable conditions. The issue this research is to reveal is how building-users could obtain preferable conditions through their own active participation. Our approach is to quickly construct working prototypes to realise ideas in makeshift and ad-hoc manners and report what our study began to reveal and identify.

Availability of various electronic components from online stores such as Sparkfun (www.sparkfun.com), access to laser cutters and rapid prototyping services and availability of free real-time data server such as Cosm (http://www.cosm.com), amongst many other products and services, make it possible for everyone to begin testing ideas in real life with relatively little financial and resource investment. Our current goal is to introduce possibilities to everyone with limited resources to begin considering how they can actively participate, however limited it may be, to look after their built-environment.

Figure 3 shows the DIY building system that are to constitute an additional and the 7th layer of Brand’s frequently cited 6 shearing layers of change (1997), which can also be referred to as a digital layer (McCullough, 2004). Our DIY system is consisted mainly of four components. They are (1) Sensor and Actuator Network, (2) Cosm Server (www.cosm.com) to store and serve sensor data, (3) Building Information Model (BIM) for creating, editing, managing and storing building information and (4) BIM viewer for visualising information.

These components exchange four input and output streams of data via the LAN and the Internet. They are, (a) sensor data, (b) Cosm feed, (c) IFC objects (Industrial Foundation Class objects stored in BIM) object data, and (d) IFC object manipulation instructions. There are seven wireless sensor and actuator devices that were used for the study but many more are under construction or consideration. All wireless devices are connected to a host PC via XBee radio frequency (RF) transceivers manufactured by Digi (www.digi.com/xbee/). Device 1 (Figure 4) is consisted of light, sound, temperature, and humidity sensors and RFID reader. Device 2 (Figure 5) is designed specifically to replace a knob to control window shades in our office wirelessly. Device 3 is a winch to lift or pull an object wirelessly. Device 4 is a tangible interface device consisted of 8 LEDs, a 3-axis accelerometer and a digital compass (Santo et al., 2011). Device 5 is a motorized mechanism to turn on and off a light switch. Device 6 turns a door handle. Device 7 is an infrared object sensor. 5 and 6 are under construction.

In the following sections, we will discuss how building-users could begin to interact with the building system so that they would become an integral part of the building eco-system.

**SCENARIOS**

We ran through a few simple what-if scenarios to discuss how building-users might interact with their building through the devices that interface building-users to the DIY building system. Our particular interest was to run through and respond to combinations of 4 what-if scenarios. They are; what if we (1) could move easily between floors without lifts, (2) had better control of lightings, (3) could control the air-conditioners and, (4) could open windows.

They are extremely primitive and there would be no
shortage of solutions if we were to redesign and rebuild our building from scratch. Identifying scenarios and discussing what we could add to our building, however, allowed us to think beyond conventional solutions to resolve issues. This also made us realise and recognise building-users were given hardly any idea about and control over their own environments. Below are 2 examples of what we call ‘building-hacking’ exercises to creatively, but not necessarily efficiently, resolve issues in our office.

**Window Shades**
The total floor area of our office space is approximately 400m², and we only have one switch for all ceiling lights. Currently, all of them have to be turned on throughout the day because we rarely have sufficient natural light in all areas. We also need to close some window shades during daytime to avoid glares in computer screens. At least one-fifth of shades therefore are shut at any given time of a sunny day. The consequence is that all ceiling lights stay on even when the majority of our work area is sufficiently lit or there is hardly anyone in the office. This simply is a waste of energy.

One quick and obvious solution is to purchase an individual lamp for each desk. We agreed that having a lamp per desk is a good idea regardless of the issue with our ceiling lights, but are concerned that introducing desk lamps alone would not encourage us to use available natural light effectively and end up wasting more energy by keeping both desk and ceiling lights on. We basically felt none of us were capable of constantly monitoring changing lighting condition in all or even our own area to adjust lighting level by switching on or off desk and ceiling lights and adjust window shades all day long.

Our initial discussion revolved around the monitoring of the light level in each desk area. We began by asking what if Device 1 was on each desk and the combination of light, temperature and humidity on each desk are made available to us and other devices via Cosm. In response to available sensor data, the window shade controllers (Device 2) would adjust the level of natural light available for each area (see Figure 6).

What we tried to avoid however was to introduce fully automated system. We therefore thought about the system that allows users to make decisions based on information made available by they system. For example, if it were too dark even when shades were fully open or when we overrode the system by closing shades to avoid glare or direct sunlight, one of devices would inform us to take action. One scenario we discussed was to have a set of LEDs of the tangible interface (Device 4) blinks to alert that one’s desk is too dark. The options were to open some window shades if there is sufficient daylight, turn on a desk lamp or do nothing. The digital compass and accelerometer in Device 4 would detect when it was rotated, shook or tilted and rotate shades to a desired angle, turn on desk lamp or do nothing depending on how one interacts with Device 4. The system could also suggest lowering a set of pendulums (Device 3) acting as partial shading devices to predefined positions to avoid glare without closing window shades. To avoid users from having to respond frequently, a certain level of intelligence could be introduced so that the system could learn typical user behaviour and respond automatically until the user intervened.

To expand the scope of what the system would do, we developed a simple BIM viewer with extended IFC objects that could read and display real-time information available at Cosm. We assumed that the BIM viewer could be available on everyone’s computer or mobile device and provided each user the information about their desk area and beyond so that they could take further informed actions. For example, the BIM viewer could suggest an available hot-desk in the building that matches a predefined user preference. This could provide incentives for users to understand the building and make better use of existing natural and building resources.

When the most desk spaces were insufficiently lit or predefined conditions were met, such as most window shades were manually shut, the light switcher (Device 5) could turn all ceiling lights on. Alternatively, when nobody interacted with Device 4 for a predefined period of time, Device 5 could turn ceiling lights off.

**Moving Places**
Almost everyone in our office tried once to use
emergency stairs to visit another office floor above or below us (our office is at the 12th floor) only to realize they were locked out. Only option then would be to walk down to the ground floor level, walk out to the street through the emergency exit and re-enter the building with the front entrance to use a lift to move back up to the floor we were to visit. This was the result of us feeling it was ridiculous to use a lift to visit a floor immediately above or below. The idea of having had to use the lift somehow made us avoid casual visits and we could easily spent weeks hardly meeting anyone casually from other floors. This obviously goes against the principle of maintaining a good social environment for office workers. This would also limit the scope of the “window shades” scenario because access to potential building resources could be limited. With this in mind, we began discussing how we could provide usable physical access to other floors with emergency stairs.

The simplest solution would be to keep emergency doors shut due to the fire regulation. Providing swipe or smart card access could effectively resolve the issue but it would not be only expensive but also very slow because of various bureaucratic hurdles that typically are not set up to implement bottom-up ideas quickly. One could call someone in the floor they are to visit to stand by the door to open it. We however felt it did not give the freedom we were after to move between floors if we always had to call someone in advance.

Our quick makeshift solution was to make and attach Device 6 to the door to pull the door handle at the office side from which the door can be opened without the key simply by turning the handle. The door with Device 6 can be opened with smart-phones with a custom-made app via the Internet. This allows everyone who has access to the service to open the door. Alternatively, a sound sensor of Device 1 can detect a (pattern of) knock(s) on the door to release the door. This can give access to everyone who knows the door is to be knocked or knocked with a predefined pattern. We recently came across with the crowd-funded product by Lockitron (www.lockitron.com) that could be retrofitted easily and would work very well for this scenario.

The usage of staircases could be recorded by counting how many times the doors were opened and the record could be stored in the server. This would allow us to make an argument for further resources to be allocated for more permanent solutions. Sensors could also be used to record other information such as noise level and temperature change to monitor certain anomalies caused by the installation of ad-hoc devices. A BIM viewer that would allow us to visualise and navigate current conditions of spaces and devices could become useful to study, make decisions and take actions in response to issues that we could observe in three-dimensional space. This would be very useful for building-users to proactively learn and respond to changes and anomalies.

**DISCUSSION**

These hypothetical solutions most probably do not resolve anything effectively and unlikely to provide long-term solutions. Instead, the scenario and prototype development was a form of brainstorming exercise that was meant to lead us to identify further possibilities and opportunities in our building. As stated earlier we did not aim this exercise to lead to developments of commercial products. Our aim rather was to look for issues. The exercise was invaluable in this regards that it allowed us to identify future insights and research directions.

The benefit of the ad-hoc layer is not only with providing users with means to understand and control their environments but also with the ability to use collective information about the building and its users to give further incentive for users to participate.

Collective user actions could be stored in a database and the information could be presented effectively to communicate, for example, how much energy they might have saved by not using lifts and other building services. This might lead to more people using stairs, interacting with their light settings and many other building systems because they might feel positive about interacting with their building or its systems. The ad-hoc system could also allow building-users to determine what works and what does not and allows them to move on to improve the existing systems or design new solutions quickly through iterative processes. This could also lead to (more) permanent solutions for buildings or valid design solutions for new buildings.

To support the playful aspect of the ad-hoc systems, the Fun Theory (www.thefuntheory.com) provides a good evidence that people could be motivated to take actions to improve environments. Kronenburg was concerned that “the presence of an unseen hand controlling our environment” could undermine direct human decision-making (2007, p. 231). If users were given more access to control over what otherwise would be a ‘mysterious’ system, they would be more likely to accept its presence.

This research identified multiple opportunities for further investigation. This paper is a presentation of our approach to identify issues with current built environments and led us to identify further research directions such as:

1. Development of building user systems to manage modular or customizable components and coordination that operate as an additional element. This could become a contemporary response to Habraken’s support structure and infill scenario (1972).
2. Application of tangible user interface design principles described by Ishii and Ullmer (1997) to design interactive building systems.
3. On-demand fabrication or mass-customization of building components for standardised support structure or grid to add further flexibility and options for users to adapt building spaces inspired by modern fabrication technologies (Kieran & Timberlake, 2004; Sass, 2007).
4. Further development of the BIM viewer to provide interfaces that integrate real-time sensor data and present them effectively for building-users to learn and take action in response to issue they experience in their built-environments.

5. Developments of systems that become bored to engage users to more frequently interact with them in friendly manners.

Brand wrote “all buildings are predictions and all predictions are wrong” (1997, p. 179). This mirrors Price’s design principle. Frazer’s passion to develop design tools and prototypes was also a response to this concern. Our buildings need to adapt (Graham, 2005) and be disassembled and recycled (Crowther, 1999) to conserve our limited resources. This research was conducted ultimately in a view that all building-users, along with other stakeholders, could be given means to consciously and proactively share responsibilities to determine the fate of buildings they inhabit and use.

CONCLUSION
All necessary technologies appear to be available and they already are implemented for various use-cases. The key issues we identified lead to an idea that the infrastructure and framework could be designed to prepare and motivate users to take action so that they became an integral part of building-ecosystems. We now have access to tools, devices and the Internet with the ever-increasing level of access to information and means than anyone who came up with innovative ideas in the past.

The current techno-social contexts where we are generally used to customising our own devices make us ready to begin handling bigger artefacts and environments. We should think further about the framework for allowing people to engage with thinking about their environments and responding to issues by themselves. We believe we could help building-users by designing new or retrofitting existing buildings that are fully customisable in ad-hoc, DIY and/or more organised manners. Our ultimate aim is to design a system that allows people to become expert users of their built-environments.

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