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Towards Adaptable and Reusable Building Elements: Harnessing the Versatility of the Construction Database Through RFID and BIM

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Abstract

This paper outlines one approach to developing the potential for replaceable parts of buildings to be adapted to changes in user needs within the context of longer life infrastructure, and outlines the approach taken in the first live test. This idea may be realized by allowing ownership of moveable components to be re-assigned via innovative business models. This would enable components, such as walls and doors, and elements such as façades, to be taken back by their providers for reuse or remanufacture, a circular process assisted by prefabrication, modularization and 'design for adaptability'. This evolving ownership paradigm requires a robust documentation regime to archive the new form of data it would generate. The use of automated Radio Frequency Identification (RFID), including the facility to update and interrogate 'on element' data storage, can enable data on building elements to be accessed and updated over their life-cycle. Furthermore, this seamless bi-directional transfer of whole-of-life design documentation allows existing building elements to be traceable and reused in new designs, thereby promoting 'cradle to cradle' thinking, in turn promoting open and changeable built environments. This new regime creates an ongoing dynamic data repository enabling a significant change in the paradigm of life-cycle information, capturing changes in condition, performance, ownership and location.

Keywords: Adaptability; RFID; Reuse; Construction; BIM

1. Introduction

There have been many and various ways in which to record building elements, their location and physical attributes. Traditionally, as a static device with very limited possibilities for updating the attributes of a

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recorded item, paper-based drawings and specifications have been the most prevalent way to archive building information. Imperfections in the retrieval of data from these paper-based archives has been slow, inaccurate, incomplete and expensive. The widely-quoted Gallaher report identifies a $10.6 billion investment in re-establishing building information just for the US Federal Government (Gallaher, M. P. et al. 2004).

As with most industries of scale in the last few decades productivity has been underpinned by advances in increasingly convergent technologies. A new series of responses to a very frenetic technological environment necessitates new approaches to how these technologies can further long-standing goals, such as increasing the uptake of recycling and reuse of building elements. This paper outlines some of the advances of these goals in pairing them to new digital technologies. The use of RFID technologies has greatly increased the efficiency levels in asset management and related industries (Sørensen et al. 2008). At the same time the Architecture, Engineering and Construction (AEC) sector has also seen efficiencies and increased adaptability via ‘open buildings’ (Geldermans 2016). These two phenomena have largely happened in isolation from each other. The technology that could underpin a series of mutual benefits now exists. Hence, building adaptability and reuse can be increased by using readily-accessible RFID and BIM data. Kieran and Timberlake (2004) outlined most of the opportunities available when new technologies are applied, and the subsequent change to traditional ways to work.

The work described in this paper intends matching the current set of technologies with the most appropriate work practices. An incremental approach has been taken so as to identify each of the discrete and contiguous steps in the ownership of data and how they can provide a more effective set of tools for designers to use, leading to the reuse of components in open buildings.

On site real-time data retrieval would aid greatly in lessening time delays for retrieval of accurate design data. There is an obvious efficiency dividend to be found in the paradigm of having up to date comprehensive building component data stored in both the virtual model and the physical component.

2. Open Building and Related Concepts

A major theme concerning this work was motivated by the development of ‘open building’ (OB) in the 1960s and 1970s (Habraken 1961). Gordon (1972) developed the 3Ls theory of long life, loose fit, low energy, while Webb (1964) developed the ‘rent-a-wall’ concept.

In the late 1970s, the notion of a circular economy emerged, whereby resources are kept in closed loops, reused and remanufactured multiple times. More recently, there has been increased focus on an open, circular built environment (Ness & Xing 2017).

In OB thinking, ‘infill’ is what is decided by or for each individual inhabitant, while the ‘base building’ is what is shared by all inhabitants (S. Kendall, personal communication, May 2017).

The notion of replaceable infill within open building has extended from interior fitouts to facades, pioneered in the Next21 Project, Osaka, in 1994: “The façade system was newly invented and considered part of the fit-out system. Providing aluminium panels and a variety of windows and doors, facades can be installed and taken apart…thus enabling easy adaptation later on” (Habraken 2003, p. 38).

Brand (1995) outlines the various life spans of building elements and how they should be managed. ARUP (2016, p. 64-67) has also shown how Brand’s ‘shearing layers of change’ form an important aspect of the

ReSOLVE framework for a circular economy (EMF 2015; McKinsey 2016). That framework encompasses Regenerate, Share, Optimise, Loop, Virtualise and Exchange.

This process of change and adaptation can be facilitated by new business models such as product-service systems (PSS), akin to renting, where the ownership of infill is separate to that of the base building. Elements/components may thus be taken back by their providers, repaired or updated, and reused or relocated many times. Increased use of prefabrication, modularisation and 'design for adaptability' adds further impetus to such circular processes.

The efficacy and management of such processes may be improved by harnessing the versatility of the construction database through connecting a set of existing, proven technologies, and this forms the main focus of this paper.

3. Development of Research Question

The development of the research question was formulated by multiple anomalies within the data acquisition and archiving of construction projects as well as a deficiency in the ability to reliably identify appropriate construction elements for reuse. A contributing factor to these deficiencies was that automated identification of building elements is common on construction sites, but rarely used beyond tracking movement to/from site and installation. Previous research papers (Ness et al. 2015; Swift et al. 2015) outlined how reconfiguring existing technologies (RFID, BIM and internet) could facilitate disassembly, take back and reuse of components, as well as improving their life cycle management.

This work was animated by a scenario whereby disused existing components/assemblies could be traced and imported into virtual models of new buildings at the design stage. This allowed a preliminary proof of concept for connecting physical RFID tags with the virtual world, which was then conducted using a rudimentary 1:50 physical model (Swift et al. 2015). Lego Blocks were also used to demonstrate the concept for inclusion in a popular science show broadcast in Australia on free-to-air television.

Previously this research did not encompass connecting RFID tags to BIM via the internet, but concentrated on the theoretical advantages of the idea (Swift et al. 2015). A paper outlining the basic technology and the reduction in energy enabled by reuse versus new production (Ness et al. 2015) was followed by a series of conferences and an industry presentation, each outlining a further iteration or particular facet. These factors informed the overarching research question: 'To what extent can digital replication, tracking and management of physical buildings/components facilitate their adaptability and reuse in an open building system?'

4. Research Method

The essence of the research method was to incrementally connect disparate but existing technologies to facilitate an end-to-end bi-directional universally available and reliable repository for construction components. After successful theoretical investigations involving issues of data pacification, wireless telemetry, embodied energy comparisons and business model investigations the research progressed to simulated data retrieval. Accordingly, the chosen tags were short range VHF type with limited data capacity, rather than UHF. Similarly, the simple and inexpensive reader was assembled by a researcher and the case fabricated using 3D printing.

The current research phase involves using selected locally available, newly constructed (award winning) facilities. The Jeffrey Smart Building, University of South Australia, and the New Royal Adelaide Hospital (nRAH) were both considered high profile flagship buildings for the University of South of Australia and the Government of the State of South Australia. After negotiation, the BIM models were made available to the research team. The images of the Jeffrey Smart Building and the New Royal Adelaide Hospital are provided in Fig 1.

Within the Jeffrey Smart Building, we selected components that could be interchanged rather than those forming base building structure. Those selected included a façade soffit panel, doorway and interior moveable partition wall. Similarly, in the nRAH, we selected a doorway to simulate the interchange of a component from Jeffrey Smart Building to this new location.

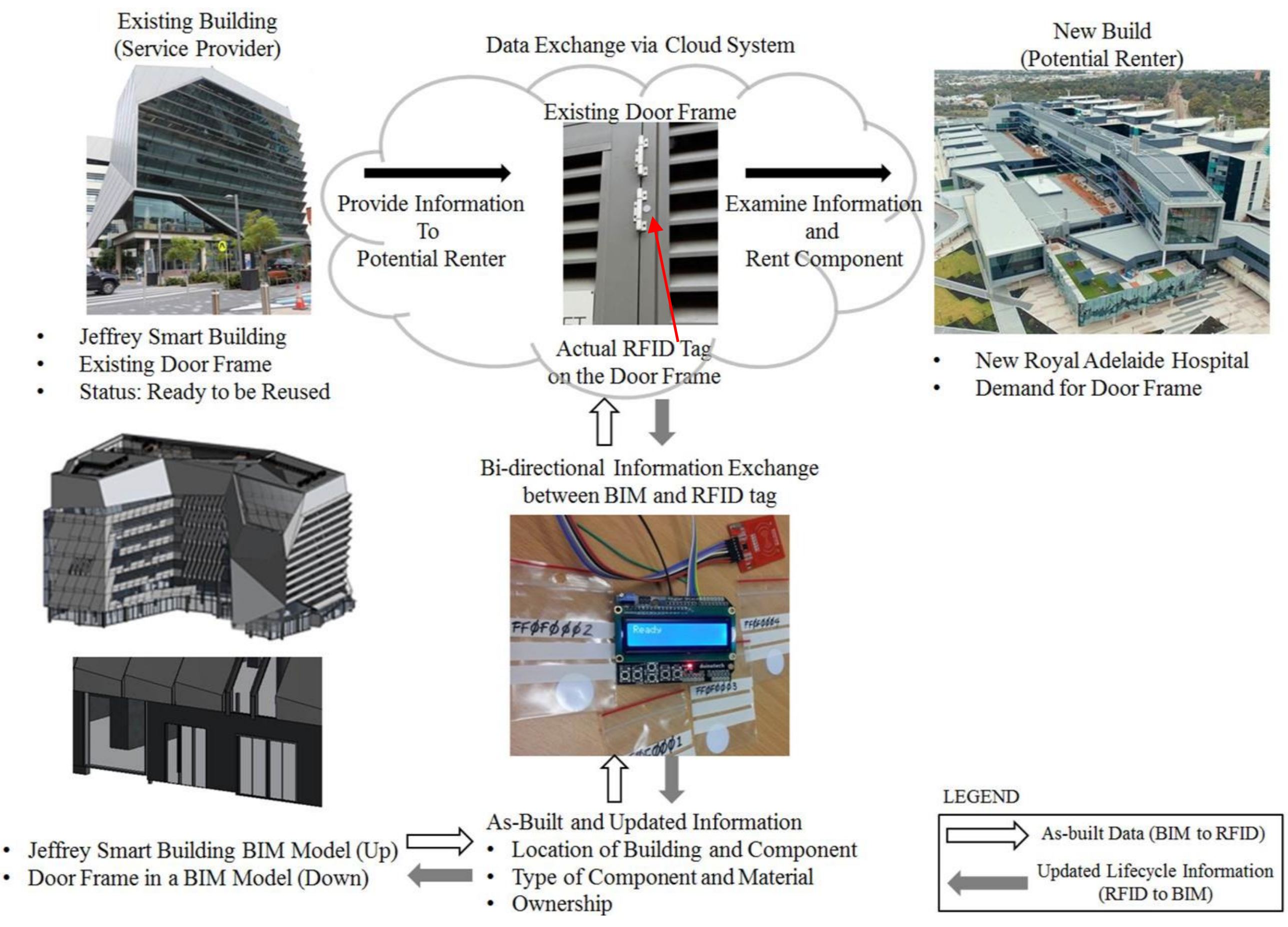

Fig 1. Schematic Diagram of Data Exchange between BIM and RFID tag based on the Cloud System

The objects used in this case study were chosen to be accessible in the existing buildings and to match between buildings, so simulating the idea that the door frame from one building (Jeffrey Smart) could be reused in the future as the door frame in another (nRAH) as shown in Fig 1.

The key data sought to be exchanged between physical tags and BIM included: location of building, location of component, type of component (e.g. façade panel, door or wall), material, and ownership. These are merely chosen for the purpose of proof of concept. Ownership may be important in a scenario where components are separable from base building, have different ownership and are provided as part of a service. Using these technologies, the research also tests how the components may be tracked when they move to a new location and the data updated.

5. Findings

The research demonstrated that it was possible to connect data relating to a physical component, via its RFID tag and the reader, to a BIM including the virtual component. Using readily available and low-priced RFID tags, it proved to be possible to store the location of the site (country and building), owner of the component or assembly, the type of component, the material used in its construction, and a unique ID referencing the component in the BIM. In addition, the tag was able to store historical data about the component, incorporating prior buildings and locations, owners, dates of installation and removal, and the previous BIM IDs.

Ideally, a RFID tag should include all information in the BIM relevant to that object, including its ‘parents’ (e.g. if it is a product, its parent system), its design standard, its manufacturer, its date of installation, its maintenance history, its location and physical connections, its geometry, plus ownership.

However, the amount of information to be held on the tags is constrained by tag capacity. In the case of this study, due to memory constraints on the RFID tags selected, data compression techniques had to be incorporated to make best use of the available space. The decision to employ a custom RFID reader/writer simplified this process, as the data could be uncompressed on site without the use of any additional equipment or software outside of the reader, providing immediate feedback about the component.

6. Discussion

There are benefits to tagging buildings at the assembly stage and tagging existing buildings. The main advantage of tagging buildings at the assembly stage would be to ensure the correct tag placement and to ensure that other attributes can be recorded and/or checked. The advantages in tagging an existing building allow for a potentially shorter lifecycle and hence provide a more statistically robust proof of concept, due to the expected shorter life-span of the construction elements.

Another advantage, applicable to new and existing buildings, is that service providers may be able to manage components over their life cycle, including tracking their location, interchanging their location and adapting them to new uses, taking them back for updating or repair, and managing their condition and performance.

The BIM, the object RFID tags, and the ‘real’ must be kept in alignment during the life of the building, which requires careful information management. The information should also include a classification that would be from a classification system common across other buildings which may have a need for the object in future. This would facilitate interrogation of object data on the cloud. One example of such a classification system is Uniclass 2015, adopted in the UK as the AEC industry’s default classification system.

The RFID technology will be used, in further research, to facilitate the effective storage and retrieval of building information by being coupled with the cloud system as an information management platform, where stakeholders can share information such as location of building, location of component, type of component (e.g. façade panel, door or wall), material, and ownership between owners and potential renters. The seamless integration of Cloud-BIM-RFID will offer the opportunity to enhance the ability to circulate resources in a timely and environmentally responsible manner because the building components can be digitally examined and installed before actual components are physically demounted and reused. Once a building component is repurposed and installed in a different location and a building, a RFID reader will read the installed tags and send the updated information to the cloud system and also to a BIM database so the initial BIM model can be continuously updated and maintained in up-to-date status. Thus, the digital building information exchange between owners and renters can confirm if the physical building components can feasibly be exchanged and reused, and hence render a virtuous cycle of building materials that leads to the circular economy system.

RFID and sensor network technologies enhance the possibilities for life-cycle management of building façade and structural components. The implementation of such technologies and their integration with BIM open up opportunities for information management and data analytics, which can be provided to architects, engineers and other clients through 'Information-as-a-Service' and 'Application/Software-as-a-Service' supported by Cloud-based platforms. These could become new business paradigms and profit centres for stakeholders beyond those associated with the initial building design and construction, including building operators and asset management companies. Also, the information management service for building components can be accompanied by 'virtual auctions' in the Cloud environment, enabling transfer of data among various owners and facilitating recovery and resale of the building components over their life-cycle.

Taking such approaches to another level of sophistication, the 'reuse' strategy can create a platform for manufacturers or third-party firms to provide building components as a service, retaining ownership of the components over their lifetime and licensing their use or operating them directly to provide solutions to clients, as part of a product-service system (PSS). This shifts the focus of a business from selling physical products to offering a system of products and services capable of fulfilling specific client demands, which potentially leads to improved resource efficiency, reduced emissions and waste, and increased financial benefits for both providers and clients. It is understood that the use of PSS within the industry is still in its infancy. Building components are perceived as fixed objects, although fitouts, detachable parts and even lifts have been provided as a service (Von Weizsäcker et al. 1998). The application of PSS, supported by digital technologies, will inevitably increase the sophistication of service-oriented business models and business culture.

7. Conclusion

The work outlined here enhances the ability to circulate resources and adapt them to changed uses and locations in a responsible manner, and is expected to advance the application of Circular Economy principles to the built environment (ARUP 2016; Ness & Xing 2017).

The internet of things has begun to change the way stakeholders interact with increasingly sophisticated dynamics. This paper has demonstrated how the innovative application of some existing technologies extends a conversation usually reserved for academics and process-orientated architects. It represents another stage in this developing program of research.

The next stage, supported by an ARUP Global Research Grant 2017, will involve establishment of a Cloud-based BIM platform. By enabling dynamic data on building elements to be captured, it may not only facilitate open building and the interchangeability of elements but also asset management. A significant advantage to the promotion of a closed loop would be the real-time attributes available to designers to aid their decision making. In addition, real-time data on the condition and performance of components may be available remotely to asset managers.

The reliable trading of building components between parties is a key element in the successful application of such an undertaking. There are two main components that contribute to the robustness of a successful system. The first is the functionality of the infrastructure to be used in the redefinition/acquisition of existing construction elements. In this regard, the addition of the dedicated web-accessible Cloud-based BIM would provide the infrastructure required using existing and familiar technologies, integrated with a Cloud-based user interface for transactional purposes. The second component involves security of data as it pertains to the financial status of data i.e. type and identification of ownership (an item may stay in situ but the ownership may change). Thus, the further research will include scrutiny of data security e.g. ownership details.

Finally, the research illustrates the importance of information technologies in facilitating open building and adaptability of user environments, especially when components are provided as a service.

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