DESIGN FOR DISASSEMBLY AND RECYCLING – USING RADIO FREQUENCY IDENTIFICATION (RFID) TECHNOLOGY TO FACILITATE WHOLE LIFE ACTIONS FOR SUSTAINABLE CONSTRUCTION

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Summary

In Western Europe where developed economies are prevalent, the European Union (EU) defines “sustainable construction” in terms of the use of environmentally friendly materials, energy efficiency in buildings and the management of construction and demolition waste [1]. Taking a whole life view of building performance, it may now be deemed essential to consider the impact of decisions made at concept and detail design stages on the potential for buildings to be adapted for partial or complete change of use and disposal at the end of useful service life. Development of these considerations into strategic actions may make a useful contribution in the drive to achieve future waste reduction within the building construction and facilities management sectors; particularly to the safe and productive disposal/reuse of components and materials through the supply chain while minimizing impacts on local and global environments.

This approach has been called design for disassembly (DFD) [2] and focuses on the development and application of design strategies appropriate to facilitating whole life change to buildings and infrastructure. One significant aspect of developing theory and practical application of DFD techniques is making labeling information explicit on each component or assembly within a building. Increasingly, information and communication technologies (ICTs) offer significant opportunities for information exchange through defining virtual building components and assemblies during detail design and embedding them with information which can be carried through construction and service life, using building information modelling (BIM) to inform the various phases associated with whole life use. Deployment of radio frequency identification (RFID) technologies suggest potential for information exchange between real buildings and virtual models to facilitate operational aspects of whole life change and ultimately the safe and useful disposal of buildings.

Keywords: Design, disassembly, change, management, sustainable, construction

1 Introduction

Each year, in the order of three billion tonnes of raw materials may be used in the manufacture of construction products globally. [3] These materials must be quarried, processed and incorporated into materials and components and whole buildings. Associated manufacturing processes can be very wasteful. It has been claimed for example, that in the USA, construction of the average house produces seven tonnes of waste, much of which is land-filled. [4] It has also been argued that much greater attention needs to be given to the effects of whole life change on buildings, their users and the environment. This is particularly applicable at the end of useful service life when the waste which is generated in the creation of buildings may be exacerbated by their destructive demolition and disposal. This adds to negative impacts on local and global environments. It has been noted that in Europe, regulatory constraints (Directive 2000/53/EC) on the production of waste and pollution in motor vehicle manufacture has generated the concept of "extended producer responsibility" which requires those who design a product to take responsibility for it's future reuse, recycling and disposal with a view to achieving economic profitability at minimum human and environmental risk. [5] In the UK, apart from constraints on landfill, the construction industry (in its widest sense) remains largely self-regulatory in respect of responding to the environmental impacts of whole life change to buildings. Facilitation of life cycle change may not normally be considered during design and planning phases. Building construction continues to be dominated by a culture which measures objective attainment as delivering a building to a client on time, within budget and to required quality standards. In this general context, it has been argued [6] that a forward looking paradigm for a sustainable construction industry must subsume the time/cost/quality model into a belief system which embeds broader societal, economic and environmental factors into decision making (**Fig. 1**). Within that value set, a key area requiring further discussion is consideration of the whole life change on buildings as a subset of resource depletion at local, regional and global levels.

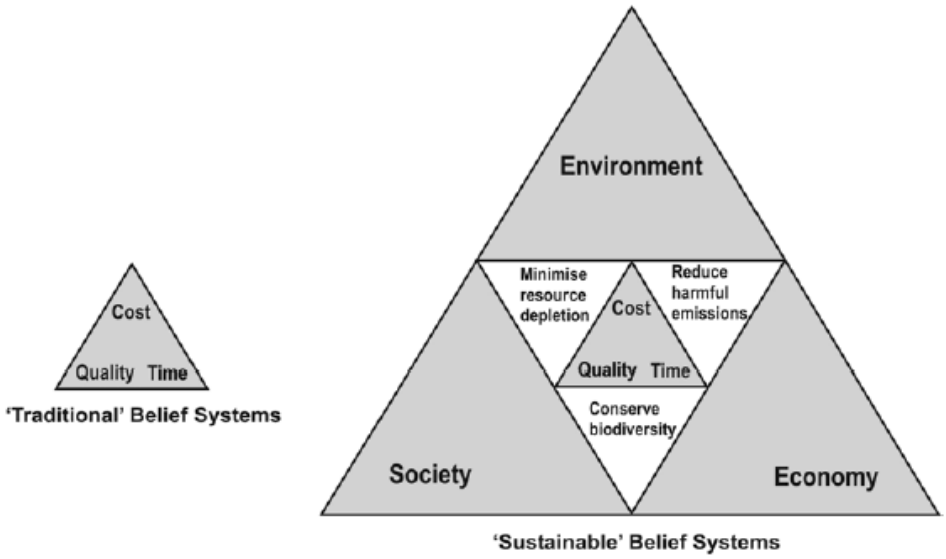

Fig. 1 Value sets – models for Belief Systems, after Crowther (2006)

2 Design for disassembly and recycling

In proposing a rationale for change, the United Nations Energy and Environment Programme (UNEP) has aimed to raise awareness among built environment professionals to consider the medium to long term effects of their decision making on local and global environments. [7]. More recently, this philosophy has been labelled the 3R approach [8] and focuses on three imperatives, reduce, reuse and recycle. The 3Rs strategy advocates setting up a sound material cycle society within the concept of a life cycle economy where consumption of natural resources is minimised and the environmental load is reduced as much as possible.

Delivering on the 3Rs template suggests taking a holistic and whole life approach to the design, construction, management and, where necessary, the safe disposal of buildings and infrastructure at the end of useful service life. One development from the broad raft of UNEP proposals is the closed loop model (**Fig. 2**) which prompts building designers to be proactive in ensuring that buildings and their associated infrastructures no longer deplete the resource base and instead operate in cycles of production, recovery and manufacture. [9]

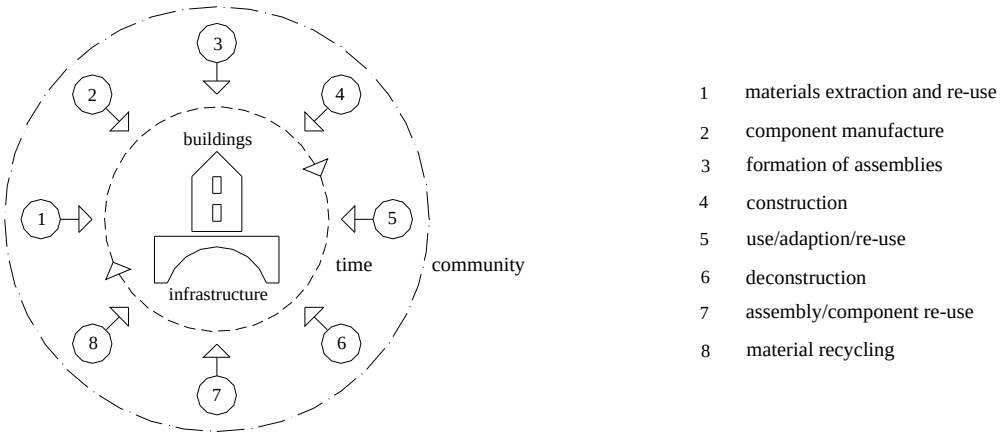

Fig. 2 Closed loop paradigm for sustainable construction, after Laing et al. (2004)

This paper builds on previous work developed [10] [11] [12] to propose theoretical guidelines for building design to facilitate future deconstruction within a closed loop model. The aim is to move the debate forward by suggesting a notional framework for implementation in alignment with the UNEP's 3Rs policy. The model proposed by this paper advocates that building components and assemblies are embedded with appropriate information which may be used at a later date to inform the processes of adaptation and ultimately deconstruction. Access to that information will be facilitated by combining the use of building information modelling (BIM) and radio frequency identification (RFID) technologies.

3 Building information modelling

Unlike conventional methods for abstracting buildings and their component parts through two dimensional orthographic drawing, object oriented design uses the powerful medium of IT to generate 3D CAD models which are constructed to represent components, assemblies and whole buildings in a virtual environment [13]. In effect, this means that because the mode of representation is transposed from 2D into 3D, the ensuing visualization looks **real**. Developing this approach is perceived to add value (sustainability) to project development by extending the domain for knowledge and understanding of the representation beyond building professionals and into a new field which includes clients and building users [14]. In this respect, and in the wider context of the current research, the use of object oriented design also extends performance concepts, for example the 3Rs approach, across a whole life spectrum of activities including designing for disassembly and recycling.

Object oriented design is not limited to the generation of virtual objects as graphic representations of buildings and their component parts. Effectively, the object oriented approach is a sub-set of the broader paradigm of building information modelling (BIM). The building information model is based on the generation of a structured alphanumeric database which can be initiated and continuously updated for a building or infrastructure under design [15] (**Fig. 3**) and developed as the building evolves through the whole life cycle. The model is accessible to a range of participants including clients, professional disciplines, contractors, facilities managers and building users. In this respect, the power of IT is manifest not as a (passive) means to an end, but as an (active) catalyst facilitating the process of attaining goals for sustainable construction through collaboration, co-ordination and integration of information. The significance of the BIM is that it may act as a virtual repository for information necessary to facilitate whole life change. International standards have been developed for data exchange [16] through the Industry Foundation Classes (IFCs), or open source based data exchange mechanisms such as DXF, DWF and XML formats can be deployed for file transfer and sharing of information.

Fig. 3 Services layouts as designated within a 3D building information model (BIM). The model can be embedded with explicit instructions for disassembly, adaptation and safe disposal of components and materials, after **Architecture Week** (2006)

4 Labelling of components and assemblies

Flannagan et al. [17] have noted that, in the built environment, embedded systems may be used to control, monitor or assist the operation of equipment, machinery or plant. It has

also been argued that embedded systems are at the core of intelligent buildings and in the future will revolutionise the process of information handling and transfer within building design, construction and use. The use of these evolving technologies may be the next step towards a more pervasive deployment of ubiquitous computing [18], a concept based on transferring autonomy for computation and information handling from desktop PCs to real world objects. It has been suggested [19] that among the strategic actions which should be incorporated into the design process to facilitate the application of design for disassembly techniques are making significant labeling information explicit on each component or material of an assembly to assist with reuse or disposal after disassembly (**Fig. 4**).

In developing the discussion, considering the application of embedded systems opens up the possibility of using information and communications technologies (ICTs) to label building components and assemblies with information. This embedded data may be used to empower the various processes associated with the whole life use of buildings including disassembly and recycling at the end of useful service life. In principle, the protocols for enacting the principles of extended producer responsibility are analogous to the exemplar earlier cited from production engineering. [20] However within the built environment, it is envisaged that best practice would evolve by consensus rather than by legislative reform.

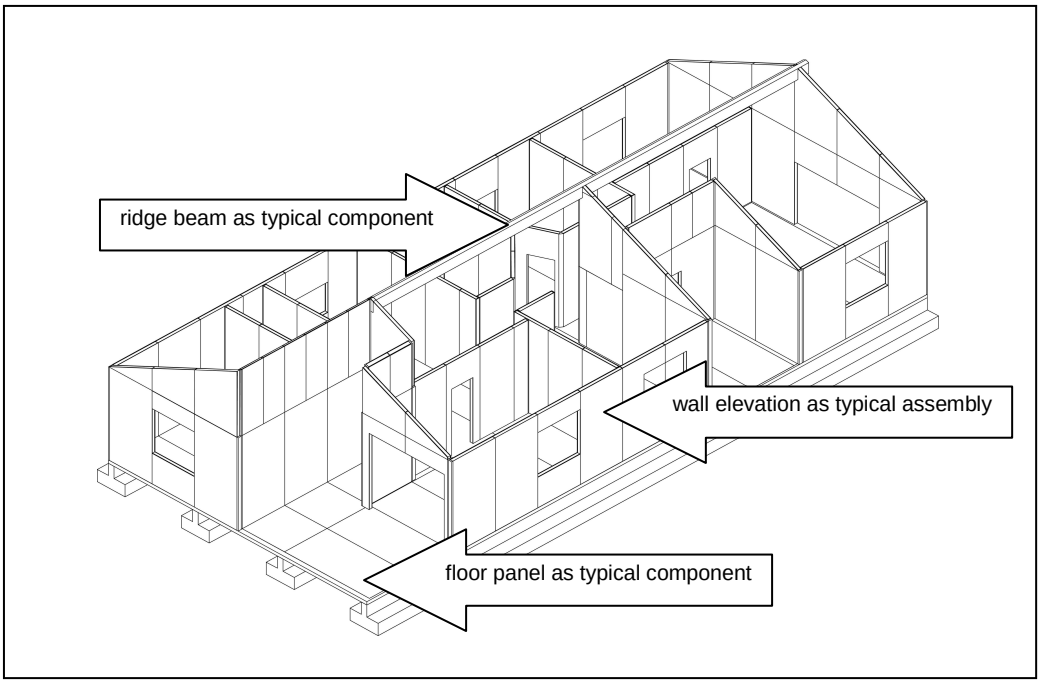

Fig. 4 Typical designation of components and assemblies as repositories for embedded information within a house designed using a closed panel timber system for adaptation, disassembly and recycling, after Moore, Paterson and Sanmarti (2004)

5 Development and application of RFID technologies

RFID technology is the most rapid growing division of the present information technology and Automatic Identification and Data Capture (AIDC) industries. Automatic identification involves an object such as a building component or being marked with a label, tag or coding device that can be scanned or read automatically. The information on the label or tag is then read by a compatible reader either a scanner or frequency interrogator, to

identify information held within the label and transfer this data to an output source such as computers, PDA's, and databases so that the end user can view specific information upon request. Other technologies under the title of automatic identification technologies include bar coding, optical character recognition, infrared, smart cards and voice data entry.

Radio frequency identification, developing as an information handling technology is considered to be a replacement for the more conventional bar coding (**Fig. 5**) due to the considerable increase in read range, read rate and the advantage of being able to develop "hands free" applications. [21] In addition the hardware and related software that are constantly being developed and improved upon are regarded as more versatile and robust than any other automated identification technology. The worldwide interest in this technology is derived from advances in silicon components and microchips, which are smaller, more sophisticated and accessible than ever before. Many industrial forecasters predict that this technology will engage and become deployed in all industries by 2007/2008 [22] with the current market value expanding from $1billion to $4billion by 2008 and a staggering $10billion by 2014.

Bar code deficiency	RFID improved solution
Line of Sight Technology	Able to Scan and read from different angles and through certain materials
Unable to withstand harsh conditions (dust, corrosive), must be clean and not deformed	able to function in much harsher environments
No potential for further Technology advancement	Technology advancement possible due to new chip and packaging techniques
Can only identify items generically and not as unique objects	EPC code will be able to identify uniquely typically up-to 2^{96} items
Poor tracking technology, labor intensive and slow	Potential to track items in real time a they move through the supply chain

Fig. 5 Table showing the advantage of RFID over existing barcodes, after Lewis (2004)

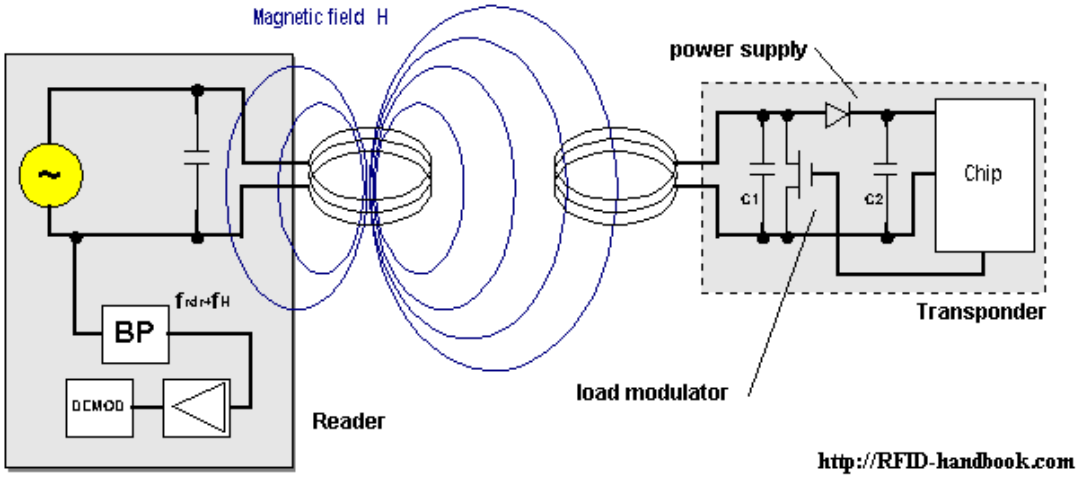

Fig. 6 Schematic diagram showing inductive coupling between the reader to the left and the tag on the right, after www.rfidjournal.com (2004)

RFID systems involve the tagging of an object with a small microchip storage device with attached coil antenna or transponder to receive and transmit radio waves to and from a source such as a reader/interrogator. The reader more often than not comes in the form of a handheld scanner that emits radio waves to trigger tags within its range. Each tag consists

of two parts, the integrated circuit (IC) and the antenna. Within the IC the microprocessor is responsible for dealing with handling all stored information, and the antenna is the communication link between the reader and tag. It is widely recognised that the read range is directly proportional to the size of the antenna [23]*(Bassi 2002),* i.e. increasing the size of the antenna will proportionally increase the read range. This form of communication via radio waves is referred to as inductive coupling, allowing the tag to utilise the waves produced by the reader to send a signal containing stored data in return. This data can then be made available to be edited in any format or application needed by the end user.

Radio frequency tags can be fashioned in a number of different shapes and forms, ranging from small circular disks, swipe cards, labels, glass tubes or even screws that can be attached directly to the object itself. It is possible for the end user to define the size and shape required for the specific application.

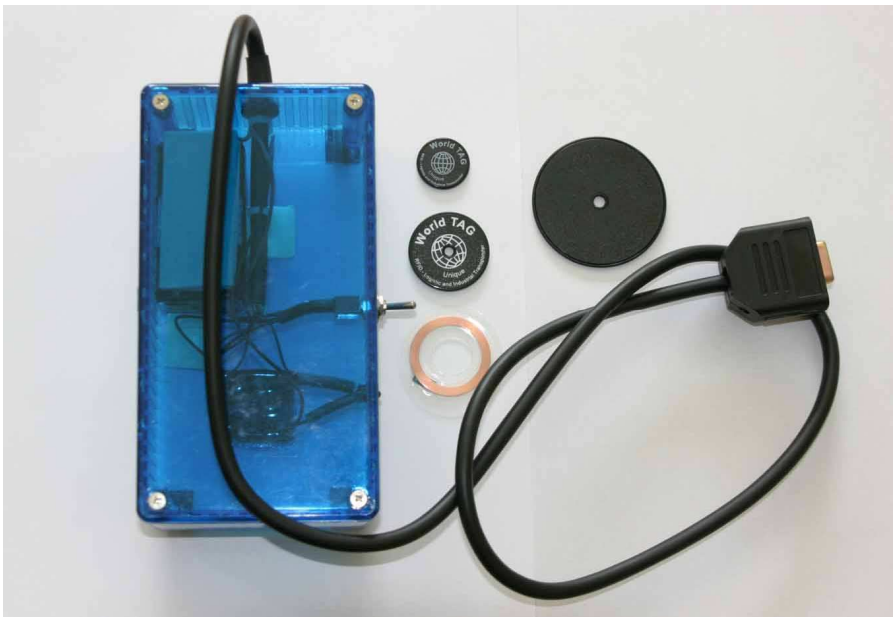

Fig. 7 Demonstration hardware including RFID tags suitable for incorporation into building components/assemblies and handheld reader for linking embedded tags with computer models and other information databases to facilitate while life change.

Portable scanners offer choice and flexibility for scanning operations by site operatives and can easily connected albeit via wireless or cable to a processor containing a database. The stored information can then be categorised and analysed. Stationary readers do offer a larger read range however the functionality and flexibility are reduced. The reader receives instructions and information from the antenna through the scanning component, this element of the scanner examines analogue output from the scanner. This embodied information is then converted into a digital format by the processor within the scanner and then ready for viewing or transfer to a laptop or desktop as, for example, a spreadsheet or computer model which, as previously discussed embodies protocols for disassembly, relocation and/or safe disposal of building assemblies and components. (**Fig. 8**)

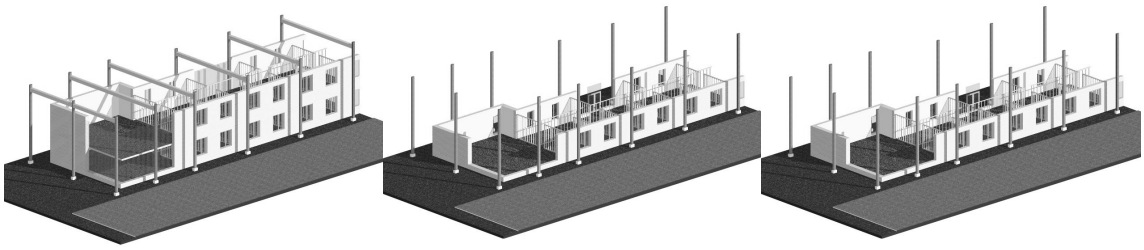

Fig. 8 Building information model showing notional progressive disassembly sequence. Accessed via tagged assemblies within actual building and remote wireless reader.

It is acknowledged that there may be restrictions on the performance of embedded tags depending on the functions of the application. These are concerned with whether or not the tags are deemed to be Passive, Active or semi Active tags are those that operate using batteries as the main source of power to transmit or return signal waves from tag to reader. They can further be divided into those that have a replaceable battery unit [24] or are completely sealed. With read ranges of up to 30m or more, these types of tag are ideal for tracking higher valued materials/components. Due to the inclusion of remote power supply active tags are classed as being re-writable and can constantly stay in contact with synchronized reader. According to Furness [25] active tags with a built in power source have the ability to transmit data over a greater distance, respond to a lower level of carrier signal than passive structures, to be interrogated without collision, store additional circuitry such as sensors and even in the future be able to communicate with each other.

On the other hand the more common passive tags rely on the magnetic field expelled by the interrogator or reading device as power source. Passive tags in general have a shorter read range than active due to power differentials and antenna construction. However these tags are more cost effective to produce, leaner in physical shape and can endure relatively harsh conditions found on construction sites.

	Active RFID	**Passive RFID**
Tag Power Source	Internal to tag	Energy transferred from the reader via RF
Tag Battery	Yes	No
Availability of Tag Power	Continuous	Only within field of reader
Required Signal Strength from Reader to Tag	Low	High (must power the tag)
Available Signal Strength from Tag to Reader	High	Low

Fig. 9 Technical differences between passive and active RFID technologies. http://www.autoid.org/

Agreeing upon a suitable standard is recognised as the biggest hurdle the construction industry faces in the deployment of RFID technology on a large scale. Standardization is only a minor problem if the application of RFID technology is within an organisations internal structure. However for RFID technology to develop currency in the built

environment, it is important to develop universal protocols for applications. Currently, there are two main competing bodies pushing for two different sets of standards for RFID. These are the Electronic Product Code (EPC) formed from the Auto Id centre and standards set by the International Organisation for Standards (ISO).

6 Conclusions

Design for disassembly focuses on the development and application of design strategies appropriate to facilitating whole life change to buildings and infrastructure. The evolution and increasing application of design for disassembly techniques may be accelerated by pressure on building designers to take responsibility for making explicit information necessary for future reuse, recycling and disposal of buildings. In maximising functionality and minimising energy use and environmental risk, developing a more widespread culture of design for disassembly may make a useful contribution to the sustainable development of buildings and infrastructure.

A significant aspect of developing theory and practical application of design for disassembly techniques is generating appropriate explicit labelling information for building assemblies and components in ways which offer whole life access. Information and communication technologies may offer significant opportunities for information exchange through defining virtual building components and assemblies during detail design and embedding them with information which can be carried through construction and service life. Building information modelling (BIM) may offer potential to inform the various phases associated with whole life use. Deployment of radio frequency identification (RFID) technologies suggests scope for information exchange between real buildings and virtual models and real buildings to facilitate operational aspects of whole life change and ultimately the safe and useful disposal of their constituent parts.

This paper has discussed principles associated with the use of BIM and RFID as information and communication technologies which may be usefully be deployed to facilitate whole life change to buildings. The research, while necessarily limited, has generated sufficient information from the literature to conclude that the use of radio frequency identification technologies may offer scope may offer considerable potential for developing practical actions to achieve sustainable construction as defined by the United Nations Energy and Environment Programme's 3Rs strategy. Further research will focus on practical consequences of the advocacy of labelling building assemblies and components using RFID technologies as outlined by the authors.

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