(Source: Strongbuild P/L)

RFID Technology in Prefabricated Timber Construction - User Guide

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Introduction

This user guide is intended to provide a brief overview of the use of Radio Frequency Identification Technology **(RFID)** for use in prefabricated timber construction – especially panelised construction as may be applied to multi residential and commercial buildings. For full details about the research underpinning this Guide, the reader should reference the technical report **Trialling the Value of RFID Technology in Prefabricated Timber Construction** (Forysthe & Fini Fard Ahmadian 2018).

RFID technology can potentially play a significant role in improving productivity as it can automate information systems, monitor production and in addition, onsite construction processes as well. Importantly, objects are tracked in accordance with readings at pre-defined locations which can provide continuity from when feedstock materials arrive at the prefabrication factory, through to production of a given panel, then upon its storage into inventory, followed by its delivery to site and finally, installation in the finished building. RFID can be used to provide tracking and product information on a global scale as presented in **Figure -1.**

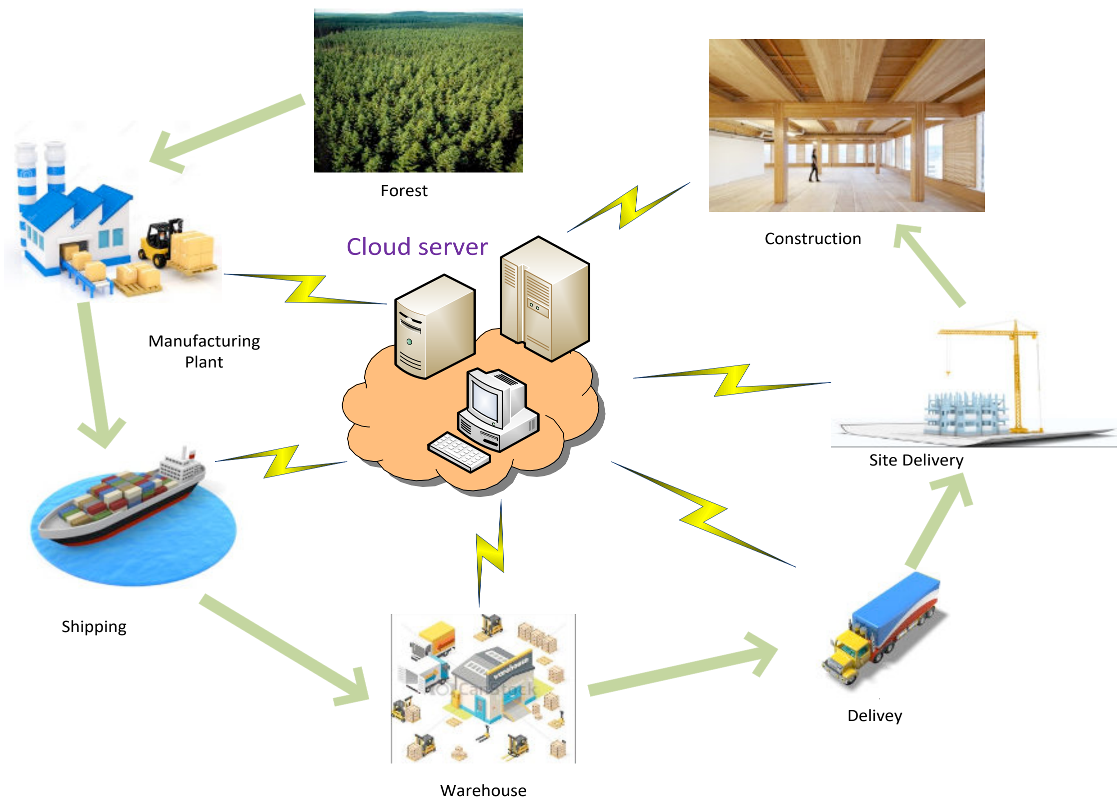

Figure 1 Logistics and Cloud Based Server Model

The technology is facilitated by tags attached to each panel which allow a read and write capacity whereby small amounts of information about the object can be sent from the tag to a reader unit. The tags include a minute computer chip with an inbuilt antenna. Tags are available under many different form factors but the most obvious for prefabricated timber panels are synthetic paper labels stapled to the panels, or, if weather is not a problem then paper stick-on labels represent simplified option. The data transmits between the tags and RFID reader using radio waves, thereby giving details and information about the object. This commonly involves a time and date stamp at each specific location in the defined process which identifies where the object is, at a given point in time (Forsythe and Carey 2017). Other details can be included according to need – as discussed later in this Guide. The RFID reader can be connected to the cloud to assist with data storage, access and management – this becomes important as the amount of information associated with the object increases in size and complexity.

Typical RFID tags and readers are displayed in Figure 2 RFID tags and reader.

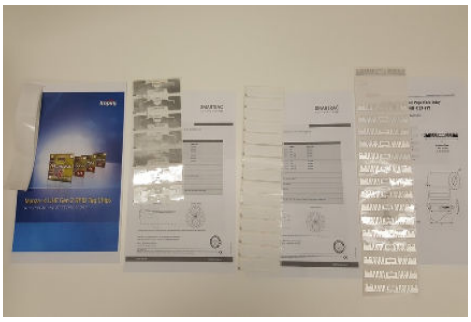

Figure 2 RFID tags and reader

Unlike the traditional manufacturing processes where high degrees of standardisation exist, construction projects typically involve many unique panels and elements for an individual project. Figure 3 shows an indicative floor panel layout of a multistorey residential building project where panels come in different shapes and dimensions. Hence, the RFID technology is effective in creating positive identification from the many different pieces involved.

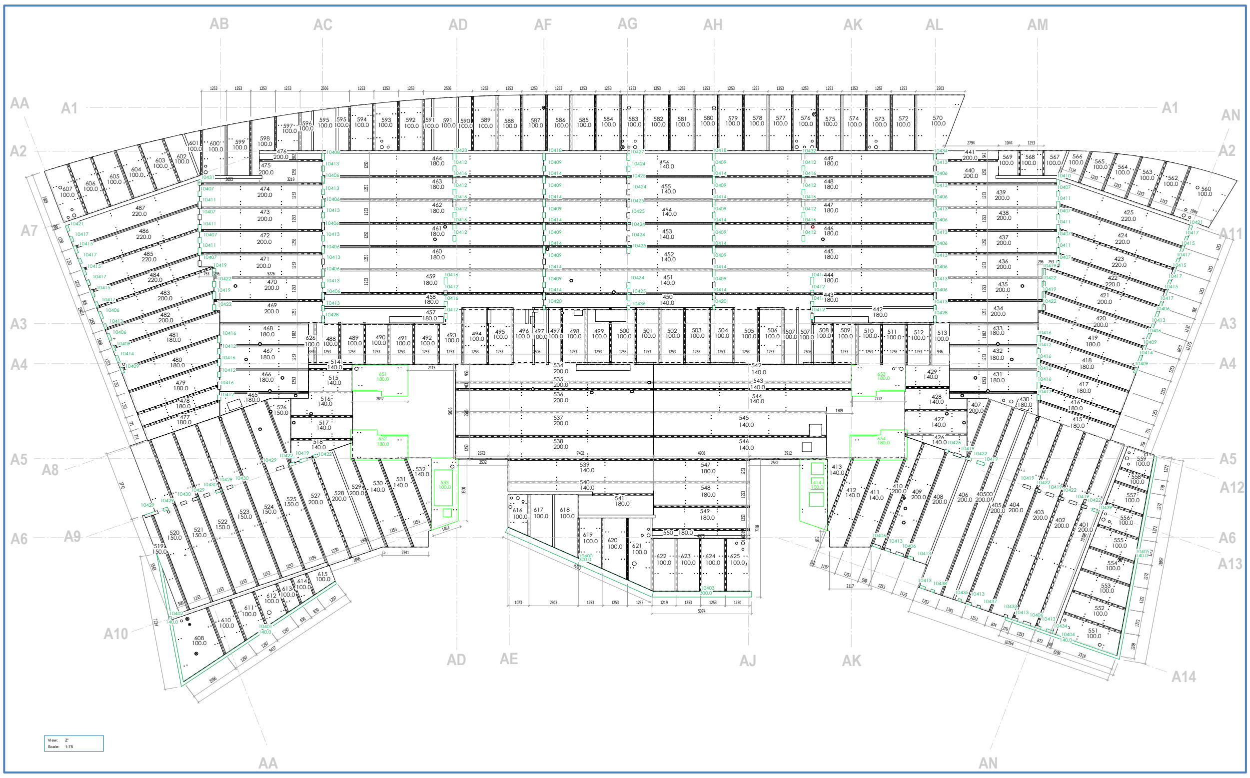

Figure 3 Indicative floor panel layout from a multi-storey residential building project (Source: Strongbuild P/L)

The technology can be used to assist in the marshalling of components for logistics and factory-based processes. For site, the technology can help contractors to plan the order and sequence of deliveries, check the completeness of deliveries, determine how much work has been produced or installed in a given time period, and trigger the release of subsequent deliveries. Once the building is occupied, the tags can be used to assist maintenance regimes and recycling upon the eventual demolition of the building.

Technology Overview

One of the benefits of RFID technology over the likes of barcodes, is that the reader does not need to be very close to the tag in order to read information. To a degree, it can also read through the surface layers of a prefabricated element, to read the tag beneath. The reader can also read multiple panels at once, hence making it possible to interpret an entire stack of wall frames or floor cassettes, quickly, as they leave the yard for delivery to site, rather than scanning each one individually.

Tag information is stored in non-volatile memory but this memory is limited and may only be in the order of 50 characters which prompts the need for inclusion of a cloud database to manage the bulk of the data storage. Since RFID tags have individual serial numbers, an RFID system can discriminate among several tags that may be within range of the RFID reader and yet read them simultaneously.

RFID tags come in two types:

- Passive – is solely powered by the incoming electromagnetic waves generated by the RFID reader, triggering a signal that is captured by the tag's antenna.
- Active – contain their own internal power source (a long life battery), permitting increased propagation range by the tag which emits a signal to the RFID reader (e.g. these tags can include devices such as GPS, temperature and humidity sensors).

For most prefabricated construction requirements, passive tags are thought to be the best way to go, given a mix of cost versus functionality requirements.

Where does RFID work best as a value proposition?

The value proposition of RFID technology is principally a matter of perspective concerning an organisation's openness to digital technology, the importance of continuous information flows, and the structure of the supply chains involved. For instance, perspectives from the research underpinning this Guide varied widely but three identifiable types of information were found to commonly exist:

- Product information (i.e. product characteristics relating to physical features, sustainability, quality, and compliance)
- Process dynamic information (i.e. active decision support of production/logistics/construction process management)
- Feedback during the service life of the end product (i.e. potential for information pertaining to building operation, inspection, durability and maintenance)

To build aggregated value along the full length of these combined stages, there needs to be demand/desire to replace existing systems with more efficient ones. Tags also need to be introduced early in the above processes in order to retain information lineage throughout.

Those involved in medium to large scale production-to-project-to-ownership operations appear to obtain the best benefits from RFID technology, more so than small and isolated construction projects, especially where using minimal prefabricated elements. Further, the degree of fragmentation typically in construction supply chains means that where there are only small and/or individual benefits at each link in the supply chain, there exists insufficient impetus to foster a strong value proposition for RFID technology unless driven by strong customer needs. The value proposition tends to be more obvious where there is an inclination towards integration across supply chain participants and a need to deal with process complexity.

Specific examples of this include:

1. *Large scale and vertically integrated supply chains:* The value proposition is strongest where an individual company spanning multiple links in the supply chain extends from incoming material logistics, to factory production, to inventory control, to site operations.

2. *Logistics between large and closely linked supply chain companies that work in an ongoing and integrated way:* This seems to be most readily implemented where *en masse* supply of materials or building elements are involved.

3. *Large scale internal logistics:* This simply relates to internally dedicated tracking systems within the likes of large-scale fabrication companies that deal with repetitious processes and products on a significant economy of scale.

Designing an RFID system suited to Prefabricated Timber Construction

In designing an RFID system suited to prefabricated timber construction, there is a need for the technology to deal with two different environments including factory and construction site contexts. Technology must be chosen accordingly and an initial issue with regard to this, is the choice between three categorically different RFID solutions including: Low Frequency (LF), High Frequency (HF), and Ultra-High Frequency (UHF) technologies. In general, UHF tends to offer the best option given the mix of issues involved.

As mentioned, stapled-on paper labels tend to represent a common and low-cost form of tag, that is relatively unaffected by exposure to weather onsite. These should be large enough for printed information (such as branding, ID numbers, barcodes etc) to be physically readable and should allow room for stapling to take place in a way that will not damage the printed information and the inbuilt chip.

Figure 4: RFID Label stapled to CLT panel (Source: Strongbuild P/L)

Care also needs to be taken in locating tags – especially if near metallic materials which can significantly reduce reading accuracy. There are also limits in read range when the signal must pass through multiple materials.

Handheld readers represent the cheapest entry point for the hardware required – most involve on-board screens but dongles attached to smart phone are also increasingly possible. Even so, handheld readers obviously require manual operation – hence meaning workers must be engaged for such tasks as part of their skill set and must spend time taking the required readings, thus reducing automation and retaining a degree of labour cost. Such tasks also represent a significant departure from normal site duties and so cultural mindsets must change and training should be provided, in order to ensure appropriate levels of technology uptake. Fixed readers (including dedicated gate readers) are more expensive but have the advantage of providing increased automation in reading tags, and therefore decreased worker involvement in day-to-day reading operations.

Detailed Design for Field Usage

The detailed design of RFID systems is largely driven by the scope of benefits sought by the organisations involved. Key areas may include:

- Avoiding wasted time arising from delivery logistics, especially finding panels quickly and efficiently in-process.
- Identifying potential points in the factory, to onsite processes that could add value and remove wasted work effort.
- Defining when and where to read or write to the RFID system in the field. Among other things, this includes:
    - Pulling down panel information from shipping manifests

- Pulling down panel information from a "panelisation model" of the building project, which may be derived from a Building Information Model (BIM) of the building
- Time and date stamping to show that an assembly has passed through defined process locations to determine throughput and productivity
- Determining how to structure and display readings for practical purposes and for various levels of interest (factory or site personnel, internal management information, and external parties)
- Determining what information should be stored
- Determining operating characteristics such as the placement, scalability and performance of the RFID system.

A Model Production-to Construction Process

A model process that addresses many of the above items – especially process related items - is shown in **Figure 5**. It identifies designated reading locations that span from incoming feedstock material, to production of both frames and mass timber panel elements, to storage, and then site related processes.

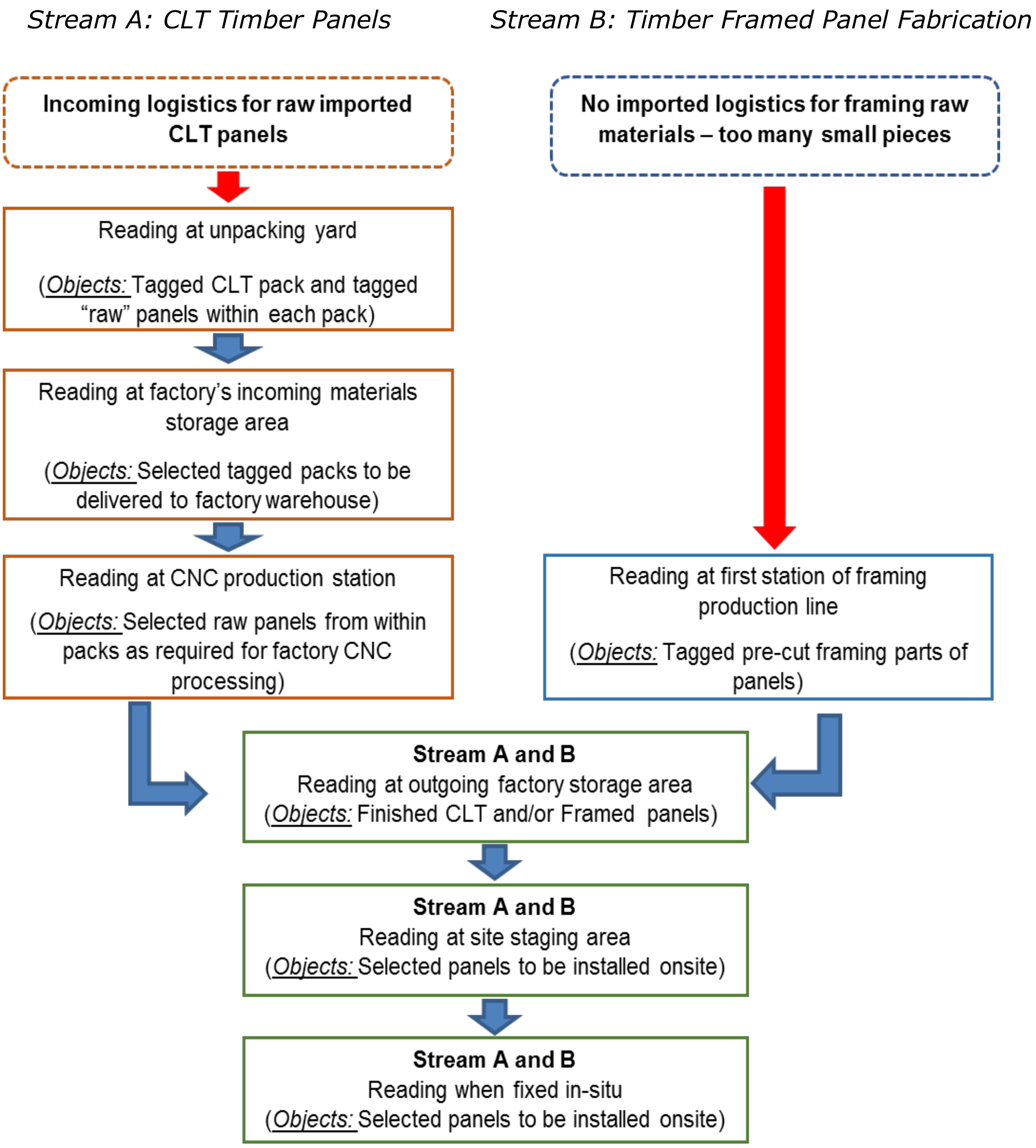

Figure 5: Overview of RFID reading locations for CLT (Stream A) and Framing fabrication (Stream B) applied to vertically integrated production-to-construction processes

Linking RFID with BIM

In undertaking the process shown in Figure 5, it is useful to tag finished panels with an ID number that can be traced to the BIM model for the project. This specifically means generating an ID number for each and every panel in a way that can be traced to the panelisation model of the building, which is typically a more detailed model developed from the 3D architectural model of the building.

The panelisation model not only provides a "file-to-factory" approach that is useful for driving CNC machines (for making CLT panels) and computerised production lines (for making timber framed elements), but can also be used to assist site operations in planning deliveries and in helping workers install panels according to a planned sequence.

To facilitate this, a data export is typically possible from the panelisation model that lists each and every panel in a tabulated spreadsheet format as shown in Figure 6. This can be used to obtain panel identification numbers that can be fed into the RFID software platform for printing onto individual tags which are eventually stapled onto each panel.

No. production list	Group	Sub group	Name	Material	Quantity	Real height	Real width	Real Length	Comment	User2	User3	User4	User5	User6	User7	User8	User9	User10
						[mm]	[mm]	[mm]										
178	02 - LEVEL 02 FLOOR	F - 0001	BBS Fichte	BBS Fichte	1	140	1250	3141	CLT 140/5s	Floor	Falz 56 | 28	NH-C	NH-C		5s	beidseitig gehobelt	Double Hole & Loop	
179	02 - LEVEL 02 FLOOR	F - 0001	BBS Fichte	BBS Fichte	1	140	1250	2244	CLT 140/5s	Floor	Falz 56 | 28	NH-C	NH-C		5s	beidseitig gehobelt	Double Hole & Loop	
180	02 - LEVEL 02 FLOOR	F - 0001	BBS Fichte	BBS Fichte	1	140	384	2219	CLT 140/5s	Floor	Falz 56 | 28	NH-C	NH-C		5s	beidseitig gehobelt	Double Hole & Loop	
181	02 - LEVEL 02 FLOOR	F - 0001	BBS Fichte	BBS Fichte	1	100	1250	2269	CLT 100/5s	Floor	Falz 56 | 28	NH-C	NH-C		5s	beidseitig gehobelt	Double Hole & Loop	
182	02 - LEVEL 02 FLOOR	F - 0001	BBS Fichte	BBS Fichte	1	100	1250	2269	CLT 100/5s	Floor	Falz 56 | 28	NH-C	NH-C		5s	beidseitig gehobelt	Double Hole & Loop	
183	02 - LEVEL 02 FLOOR	F - 0001	BBS Fichte	BBS Fichte	1	100	1250	2216	CLT 100/5s	Floor	Falz 56 | 28	NH-C	NH-C		5s	beidseitig gehobelt	Double Hole & Loop	
184	02 - LEVEL 02 FLOOR	F - 0001	BBS Fichte	BBS Fichte	1	100	1250	2216	CLT 100/5s	Floor	Falz 56 | 28	NH-C	NH-C		5s	beidseitig gehobelt	Double Hole & Loop	
185	02 - LEVEL 02 FLOOR	F - 0001	BBS Fichte	BBS Fichte	1	100	1250	2289	CLT 100/5s	Floor	Falz 56 | 28	NH-C	NH-C		5s	beidseitig gehobelt	Double Hole & Loop	
186	02 - LEVEL 02 FLOOR	F - 0001	BBS Fichte	BBS Fichte	1	100	1250	3089	CLT 100/5s	Floor	Falz 56 | 28	NH-C	NH-C		5s	beidseitig gehobelt	Double Hole & Loop	
187	02 - LEVEL 02 FLOOR	F - 0001	BBS Fichte	BBS Fichte	1	100	1250	3069	CLT 100/5s	Floor	Falz 56 | 28	NH-C	NH-C		5s	beidseitig gehobelt	Double Hole & Loop	
188	02 - LEVEL 02 FLOOR	F - 0001	BBS Fichte	BBS Fichte	1	100	1250	3069	CLT 100/5s	Floor	Falz 56 | 28	NH-C	NH-C		5s	beidseitig gehobelt	Double Hole & Loop	
189	02 - LEVEL 02 FLOOR	F - 0001	BBS Fichte	BBS Fichte	1	100	783	3069	CLT 100/5s	Floor	Falz 56 | 28	NH-C	NH-C		5s	beidseitig gehobelt	Double Hole & Loop	
190	02 - LEVEL 02 FLOOR	F - 0001	BBS Fichte	BBS Fichte	1	100	1250	3069	CLT 100/5s	Floor	Falz 56 | 28	NH-C	NH-C		5s	beidseitig gehobelt	Double Hole & Loop	
191	02 - LEVEL 02 FLOOR	F - 0001	BBS Fichte	BBS Fichte	1	100	1250	2812	CLT 100/5s	Floor	Falz 56 | 28	NH-C	NH-C		5s	beidseitig gehobelt	Double Hole & Loop	
192	02 - LEVEL 02 FLOOR	F - 0001	BBS Fichte	BBS Fichte	1	100	1250	2812	CLT 100/5s	Floor	Falz 56 | 28	NH-C	NH-C		5s	beidseitig gehobelt	Double Hole & Loop	
193	02 - LEVEL 02 FLOOR	F - 0001	BBS Fichte	BBS Fichte	1	100	1250	2812	CLT 100/5s	Floor	Falz 56 | 28	NH-C	NH-C		5s	beidseitig gehobelt	Double Hole & Loop	
194	02 - LEVEL 02 FLOOR	F - 0001	BBS Fichte	BBS Fichte	1	100	1250	2812	CLT 100/5s	Floor	Falz 56 | 28	NH-C	NH-C		5s	beidseitig gehobelt	Double Hole & Loop	
198	02 - LEVEL 02 FLOOR	F - 0001	BBS Fichte	BBS Fichte	1	100	80	2812	CLT 100/5s	Floor	Falz 56 | 28	NH-C	NH-C		5s	beidseitig gehobelt	No Lifting System	
201	03 - LEVEL 02 WALLS	W - 2001	BBS Fichte	BBS Fichte	1	140	686	3080	140-5s BBS 125	Wall	Falz 56 | 28	NH-C	NH-C		5s	beidseitig gehobelt	Hebeschlaufe	
203	03 - LEVEL 02 WALLS	W - 2002	BBS Fichte	BBS Fichte	1	140	836	2860	140-5s BBS 125	Wall	Falz 56 | 28	NH-C	NH-C		5s	beidseitig gehobelt	Hebeschlaufe	
206	03 - LEVEL 02 WALLS	W - 2004	BBS Fichte	BBS Fichte	1	160	1250	3060	160-5s BBS 125	Wall	Falz 56 | 28	NH-C	NH-C		5s	beidseitig gehobelt	Hebeschlaufe	
207	03 - LEVEL 02 WALLS	W - 2004	BBS Fichte	BBS Fichte	1	160	1173	3060	160-5s BBS 125	Wall	Falz 56 | 28	NH-C	NH-C		5s	beidseitig gehobelt	Hebeschlaufe	
208	03 - LEVEL 02 WALLS	W - 2005	BBS Fichte	BBS Fichte	1	160	507	3060	160-5s BBS 125	Wall	Falz 56 | 28	NH-C	NH-C		5s	beidseitig gehobelt	Hebeschlaufe	
209	03 - LEVEL 02 WALLS	W - 2006	BBS Fichte	BBS Fichte	1	160	338	2820	160-5s BBS 125	Wall	Falz 56 | 28	NH-C	NH-C		5s	beidseitig gehobelt	Hebeschlaufe	
210	03 - LEVEL 02 WALLS	W - 2006	BBS Fichte	BBS Fichte	1	160	1250	3080	160-5s BBS 125	Wall	Falz 56 | 28	NH-C	NH-C		5s	beidseitig gehobelt	Hebeschlaufe	
211	03 - LEVEL 02 WALLS	W - 2006	BBS Fichte	BBS Fichte	1	160	629	1415	160-5s BBS 125	Wall	Falz 56 | 28	NH-C	NH-C		5s	beidseitig gehobelt	Hebeschlaufe	
212	03 - LEVEL 02 WALLS	W - 2006	BBS Fichte	BBS Fichte	1	160	924	3080	160-5s BBS 125	Wall	Falz 56 | 28	NH-C	NH-C		5s	beidseitig gehobelt	Hebeschlaufe	
213	03 - LEVEL 02 WALLS	W - 2008	BBS Fichte	BBS Fichte	1	140	259	3060	140-5s BBS 125	Wall	Falz 56 | 28	NH-C	NH-C		5s	beidseitig gehobelt	Hebeschlaufe	

Figure 6: Panel data in spreadsheet format (as taken from the BIM panelisation model)

In addition, the panelisation model typically allows PDF drawings to be created in 2D for each panel, as shown in Figure 7. These drawings contain a QR code identifier which can be linked to the RFID tag via the common panel number– hence providing a relatively simple means of linking a panel drawing with a tag attached to a physical panel. It represents a simple way that can help site personnel compile delivery lists and delivery sequences by simply cutting and pasting QR codes into lists. Such lists can then be sent to the factory in a way that can be readily used by the likes of the storeman in using their RFID reader to find panels in storage areas or elsewhere in the factory.

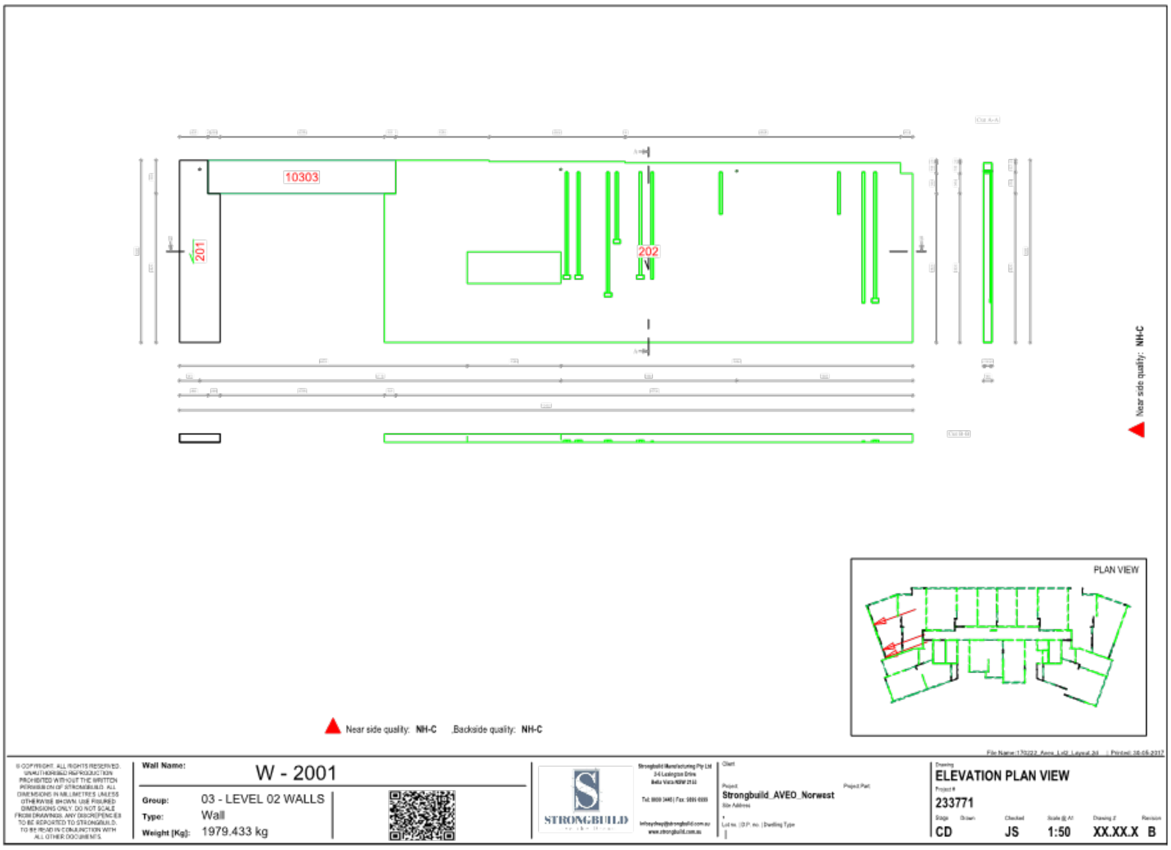

Figure 7: 2D panel drawing with QR code for linking to RFID tags

Wish List for Information held on tags

As mentioned previously, RFID tags have a limited degree of on-board memory and whilst this imposes restrictions, the advent of increased memory may in the future, allow increased core information to be deployed from cloud-based storage to residing on tags. This assists site workers, compliance inspectors, sustainability auditors, facilities managers and others who may not have easy access to information on the cloud database. Of note, a menu of potential data where there may be an argument for storing on the on-tag memory, as distinct from on-cloud memory, could include physical features of the object such as:

a) Size: thickness, length, width, and volume
b) Area: gross area and net area (with windows, doors, openings included/deducted)
c) Construction type: framed or mass timber
d) Dominant material type: timber species, CLT GLT, LVL, plywood, oriented strand board
e) Design density (kg/m^3)
f) Special characteristics: # of lamellas, lamella thickness
g) Stress grade
h) Surface finish grade: industrial, industrial &finished, finished both sides
i) Adhesive type (for engineered timber materials)
j) Surface coatings
k) Main connectors
l) Termite/fungal treatment

Other information which would require greater memory and perhaps less achievable in the short term includes:

- Construction drawing details
- Safety information
- Inspection certificates/certification
- on-site installation sequences, lifting plan,
- fixing details, propping layout, bracing layout
- photographic evidence of (now) hidden construction i.e. covered by subsequent layers of construction

Conclusions

RFID technology essentially concerns accessible real time information flows that stay with a given product or object (in this case, prefabricated timber panels) throughout a defined process. It provides time and date stamping at given locations. It provides product tracking and a degree of stored information held on the RFID tag. Read and write capability makes it possible to update information on the tag – such as the progressive inclusion of inspection certificates. The reader does not need a direct line of sight to the tag which means it can potentially read through minor overlying construction materials, albeit that metal layers pose problems to reading accuracy, as does wet reading environments. These features plus the ability to build-in a degree of smart technology, are the main features that differentiate it from the likes of bar code and QR code technology. The basic need for tracking objects (irrespective of the specific technology being used) is unlikely to change, so the underlying purpose of RFID technology has long term usefulness to prefabricated timber construction. Increasingly, this will utilise automated processes (using fixed readers) where standardised processes, such as in factory environments are possible. Handheld readers offer greater flexibility as may occur onsite. The ubiquitous use of common handheld smartphones – in the future - may aid this and extend usage scenarios significantly.

Whilst used commonly in many industries, RFID application to construction is relatively new and currently limited. Here, five distinct value adding stages of RFID application exist including:

- incoming delivery logistics,
- factory production of panels,
- outgoing delivery logistics,
- onsite installation
- third parties who may inspect the finished construction work

The main areas of interest for prefabricated timber assemblies include:

- Speeding information flows on the location of assemblies onsite i.e. tags on panels can potentially be linked to digital drawings or BIMs to know where panels go onsite or perhaps the order in which they should be placed
- Providing safety information on tags about safe handling processes.
- Making work ready planning possible and then potentially linking this with the contractor's planning and time scheduling software
- Providing real time information on the progress of fabrication and installation including measuring the percentage of plan complete, and release of deliveries to site.
- Details on the types of materials used in a panel in terms of environmental certification, chain of custody and waste management requirements.