Individual Portfolio

Reducing Site Waste in the Construction and Demolition Industry

Emily Rose Rees

U5812108

Systems Engineering Design

Lecturer: Chris Browne

Tutor: Ed Muthiah

The Australian National University

Table of Contents

Executive Summary.......... 3

Improving sustainability outcomes through whole-of-system design 3

The solution 3

Problem Space Analysis 4

The need for a reduction in construction and demolition waste is established, and the system and system scope is defined.

Generating Possible Solutions 5

The problem space is further explored and possible solutions classified into three groups. Mandatory waste management plans are identified as being the most promising solution.

Requirement Development and Testing.......... 6

Client requirements are identified and prioritised. These client requirements are then translated into measurable design requirements and the stakeholder who has influence over each requirement is identified. Two possible solutions are compared and the waste management plan is found to be more effective at reducing construciton and demolition waste.

Solution Integration 10

The functional flow of the current process and the process with the proposed solution integrated is analysed, The functional breakdown indicates that the solution would be relatively easy to implement as the top level functionality remains the same. The system architecture is then analysed, highlighting the flexibility of the proposed solution which allows it to better satisfy client requirements.

Future work.......... 13

Areas that could benefit from additional future invesitgation are identified.

Reflection 14

References 15

Executive Summary

This report uses a systems engineering approach to analyse potential solutions to reduce the large amount of waste generated by Australia's construction and demolition industry. The systems method includes system scoping, requirements analysis, functional analysis, system architecture and testing of the solutions, which allows for a logical and comprehensive design process. A whole-of-system approach has meant the solution is able to address the client requirements as best as possible.

Improving sustainability outcomes through whole-of-system design

Whole-of-system design fits into traditional systems engineering methodologies and works to enhance these processes. This approach is increasingly being adopted across the board as it is recognised as increasing the productivity of an engineered system and minimising both time and monetary costs incurred (Stasinopoulos, et al., 2008).

This process meant that an understanding of the system and its purpose and attributes were developed first before the solution space was systematically explored. These two phases were then followed by preliminary and detailed design and testing to ensure the proposed solution best addresses the needs and requirements established earlier.

The solution

The proposed solution is a system whereby engineering and architecture firms are required to include a site waste management plan in their technical plans and specifications in order to receive planning and building permission. The waste management plan must specify that all recyclable materials are to be recycled and all reusable materials are to be reused, either on the particular project in question or on a future project. This minimises the amount of materials directed towards landfill and reduces the amount of new materials that need to be bought. Additionally, there are a number of practical and commercial benefits to incorporating green building design, ranging from lower operating costs to increased building values and improved investment return. Further justification of the solution is given within this report.

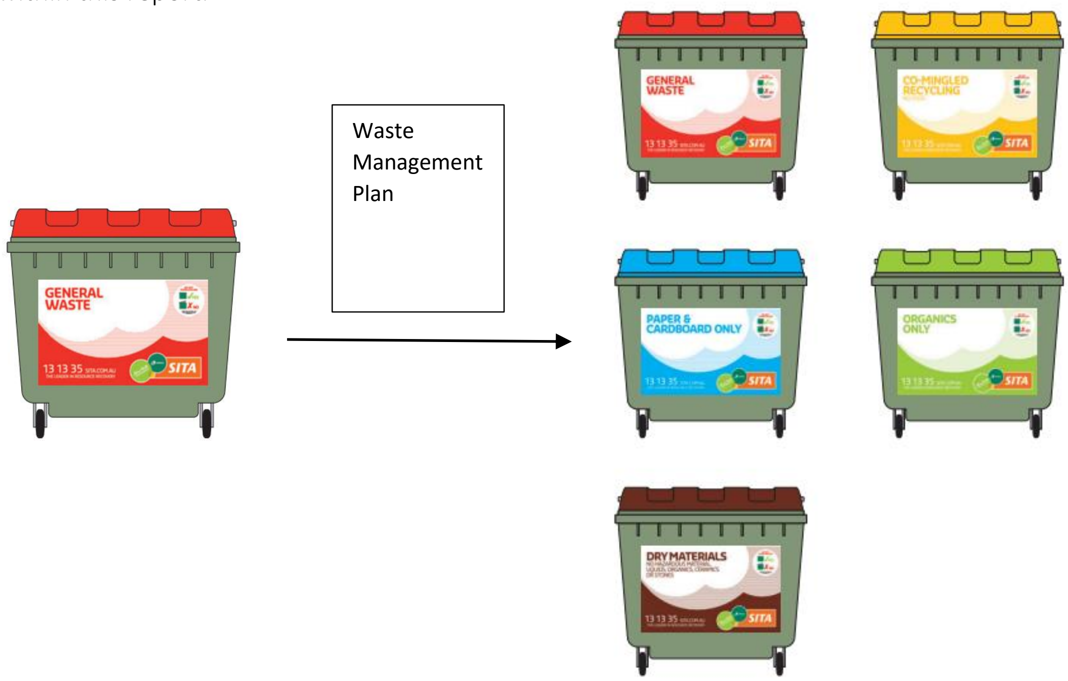

Figure 1: Graphical representation of the design solution. Images taken from (Sita, 2016)

Problem Space Analysis

As the world's population continues to grow there is an increasing demand on global resources and the environment, placing strain on a number of industries. With this increased demand comes a need for more sustainable practices. The construction and demolition industry is one of the largest generators of waste, contributing to about 40% of Australia's national waste generation (Hyder Consulting, 2011). Of the waste generated by the construction and demolition industry, approximately 45% is disposed of to landfill (Hyder Consulting, 2011).

It is evident that reducing the amount of waste generated by this industry will go a long way towards reducing Australia's total resource consumption.

Globally, there are a number of ways governments are trying to address waste management. It has been shown that training workers in waste management, purchasing machinery or equipment for waste minimisation and specifically employing waste management workers helps to promote construction and demolition waste management and reduction (Chen, et al., 2002; Osmani, et al., 2008).

Unfortunately, it is also well documented that the construction industry is resistant to change and this poses a significant barrier to waste reduction (Teo & Loosemore, 2001). Changing attitudes and behaviours of contractors and developers would be difficult and time-consuming, and wouldn't necessarily achieve the large scale reduction in waste that is required.

It has been shown in a number of papers that poor design is a major contributor to construction waste (Innes, 2004; Chandrakanthi, et al., 2002; Ekanayake & Ofori, 2000; Faniran & Caban, 1998; Bossink & Brouwers, 1996). Addressing the decisions the architects and engineers make in the design process would help reduce construction waste by designing to avoid it.

There is currently a national initiative aimed at improving the environmental efficiencies of our buildings. The Green Building Council Australia's Green Star ratings are voluntary and rate the sustainability of the design, construction, and operation of buildings, fit outs and communities (Green Building Council Australia, 2015). These ratings are based on a range of environmental impact categories, one of which is materials. The materials category includes a credit for construction and demolition waste, however, none of the credits are compulsory and the entire rating system is voluntary (Green Building Council Australia, 2013).

In the US, waste reduction and increased recycling is driven by a number of factors including government recycling mandates, higher landfill costs and a greater acceptance of recycled products (Chini, 2007). Market demands and costs associated with landfill have also driven the emergence of a number of recycling and reprocessing initiatives in Australia (Edge Environment, 2011). Government regulations have been shown to be capable of developing and fostering a regulatory environment conducive to waste reduction (Karavezyris, 2007). There is a clear opportunity for the Australian Government to introduce new legislation and industry standards to reduce national waste.

To begin to investigate a solution to this issue, the system must first be defined. *Table 1: System Boundary ChartTable 1* below has a number of variables separated into three distinct categories. Internal variables are those that are part of the system, and which the client has direct control over. External variables interact with the system but the client does not have direct control over, and excluded variables are those that might be important to consider but are being treated as outside the scope.

Table 1: System Boundary Chart

Internal	External	Excluded
• Material regulations • Engineering specifications • Architectural plans • GBCA Credit requirements • Planning and building permissions • Landfill costs	• Initial site conditions • Developers • Contractors • Materials used	• Market demand • Material costs • Recycling and reuse costs • State in which construction is carried out

Generating Possible Solutions

Improving sustainable practices in the building industry could be achieved in a number of ways. Concept generation was used to classify these approaches and identify any promising ideas worth exploring further.

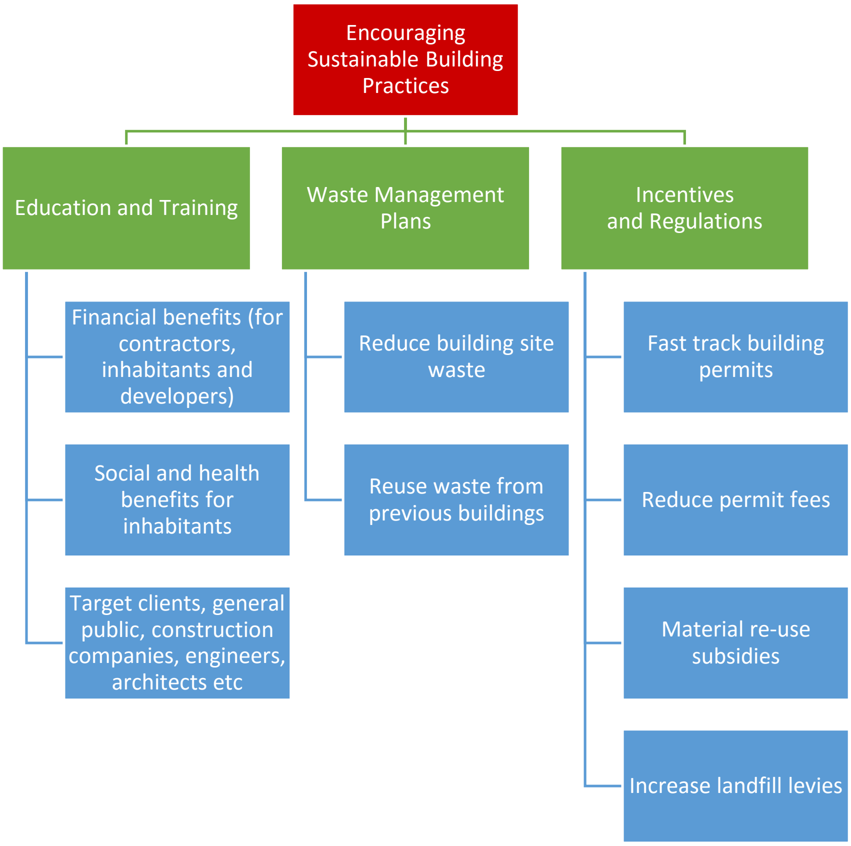

Figure 2: Concept Classification Tree used to group potential approaches to increase sustainability in the building industry

The concept classification tree (Figure 2) highlighted three overarching approaches to sustainability in the building industry; education and training, waste management plans and incentives and regulations. Education and training may be important as it would address cultural and habitual barriers to progress in the industry. However, the time cost associated with setting up training and educational programmes and the personnel requirements mean that this avenue is likely to take a long time before it would have any measurable impact.

Incentives and regulations can be an important way to quickly change behaviours in an industry. Incentives, however, don't necessarily guarantee behavioural change and changing the regulations around building permits similarly don't guarantee quality design approaches to sustainability.

Waste management plans require developments at the engineering and contractor level to have a plan for the site waste management and to implement it. Regulated waste management plans were thus identified as being the most promising potential solution to be explored in more detail.

Requirement Development and Testing

It has been shown that user centred approaches have a far greater chance of developing effective long-term solutions (Ahram, et al., 2010). It is thus crucial that client requirements for any solution are taken into account.

Four key client requirements were identified, and a pairwise analysis was conducted to establish their relative importance. For the ranking below 1 is considered the most important, and 4 the least important.

1. Reduced building site waste
2. Quality of building
3. Greater uptake of sustainable practices
4. Easy to implement

Analysis of the requirements indicates where compromises and trade-offs may be made. It is rarely ever possible to optimise all client requirements, and so assessing which are most important to the client allows for informed design decisions to be made.

Whilst the client would prefer a solution that is easy to implement, they would be willing to compromise on this if it would improve the sustainability outcomes. Additionally, the quality of the building itself is important, as this influences market behaviour and the public perception of sustainability. When sustainable buildings are of a higher quality than the industry standard this acts as a motivator for other developers and contractors to adopt sustainable practices but also increases public demand for sustainable buildings. A high-quality building is thus an important outcome and is second only to reducing building site waste. As reducing building site waste is the overall goal this is the most important outcome for the client.

The pairwise analysis indicates which requirements might be prioritised over others, but does not provide any metric by which to measure their performance or achievement. Design requirements and metrics were thus developed and can be seen in

Table 2 below.

The stakeholder who has direct influence over each requirement has also been indicated. The table indicates that it is the engineers and the architects who have the most influence over the requirements. Additionally, the most important requirement, reducing building site waste, is directly influenced by the contractors. Even though the government does not have direct influence over the majority of the requirements, both engineers and architects are bound by certain governmental regulations, and contractors are bound by their contract documents which are in part stipulated by the engineers and architects. A solution that the government can legislate would require all engineers and architects to design and build to such a solution, meaning all future constructions would have to comply.

Table 2: Technical Performance measures for each client requirement

Client Requirements	*Design Requirements*	*Metric*	*Maximise or Minimise*	*Influence*
Reduced building site waste	Percentage of waste that goes to landfill	Percentage	Minimise	Contractors
	Percentage of waste reused or recycled	Percentage	Maximise	Contractors
Easy to implement	Number of protocols/legislation that need to be written	Integer	Minimise	Government
Greater uptake of sustainable practices	Number of construction companies employing sustainable practices	Integer	Maximise	Engineers/architects
	Number of constructions using recycled materials	Integer	Maximise	Engineers/architects
Quality of building	Building value	AUD	Maximise	Engineers/architects
	Building lifespan	Years	Maximise	Engineers/architects

For the evaluation of the proposed ideas, a weighted evaluation was selected as the most appropriate method. As this project is being addressed from a cultural and behavioural change perspective, it is difficult to derive a test for its performance. As such, an evaluation process has been carried out to compare the expected outcomes with the design requirements, the results of which can be seen in

Table 3 below.

Option 1 is the idea explored above where the construction and demolition are planned with sustainability in mind. The architectural and engineering specifications are required to include a waste management plan for the reuse and recycling of materials from demolition and construction.

Option 2 is one of the ideas mentioned in the idea generation phase – reducing regulation for buildings whose plans show a strong commitment to sustainable practices. A reduction in regulation can include fast-tracking building permits and accreditation for initiatives such as Green Star.

The weighted evaluation suggests that both option one and option two would be effective at achieving the design requirements as their total weighted scores are relatively close. It also indicates that perhaps option one may be slightly more effective than option two based on the design requirements above and their weightings. As option one is easier to implement on a company by company basis and has a direct impact on waste management practices on site, this was the design chosen.

Table 3: Weighted Evaluation of the two potential solutions

			Option 1 Scores		*Option 2 Scores*	
Client Requirements	**Design Requirements**	*Weighting*	*Assigned*	*Weighted*	*Assigned*	*Weighted*
Reduced building site waste	Minimise percentage of waste going to landfill	5	5	25	3	15
Easy to implement	Minimise the number of protocols/legislation to be written	1	3	3	1	1
Greater uptake of sustainable practices	Maximise the number of constructions employing sustainable practices	3	5	15	5	15
	Maximise the number of constructions using recycled materials	3	3	9	3	9
Quality of building	Maximise building value	1	3	3	3	3
	Maximise building lifespan	3	1	3	3	9
		Totals		58		52

Legend: 5 = exceeds compliance, 3 = full compliance, 1 = partial compliance, 0 = non-compliance

Solution Integration

In order to understand the operation of the original system and how a solution might be integrated, it is necessary to understand all the processes in the original system. To accomplish this, the system was broken down into functions via a top-down methodology. Broad, top-level functions are defined first, with lower sub-level functions subsequently defined. This is illustrated in the Functional Flow Block Diagram (FFBD) shown in Figure 33 below.

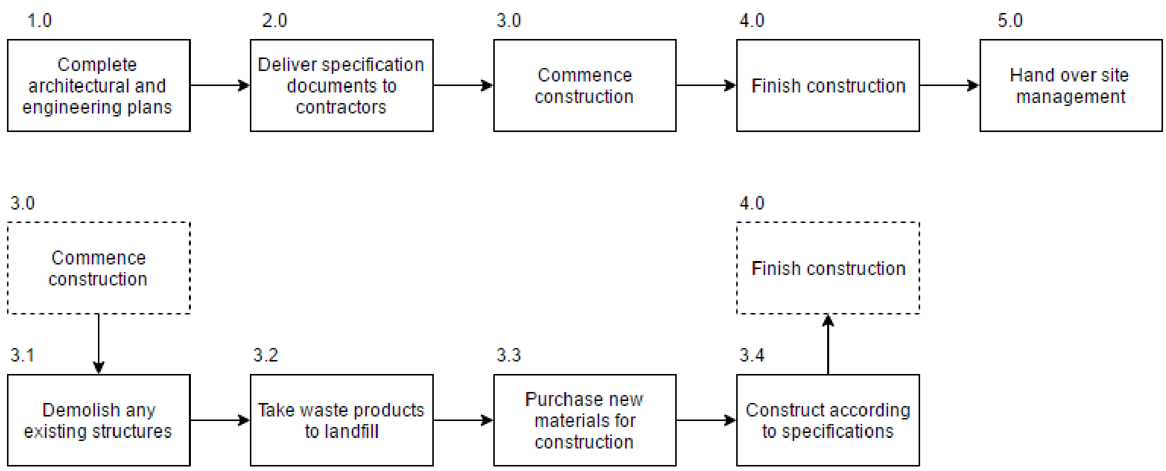

Figure 3: A Functional Flow Block Diagram (FFBD) for a typical building and construction process

The FFBD for the typical current process illustrates the linearity of the system. Waste materials from the site are taken to landfill and there is no scope for recycling or reusing materials. Additionally, it is clear that the construction and demolition process are highly influenced by the architectural and engineering plans and specifications. These areas are where the potential solution would be most effective.

An FFBD was then created for the potential solution. Figure 44 illustrates how a waste management plan would integrate with the current system. What is evident is that this solution requires the addition of another sub-level and features an '& gate', which represents multiple functions completed simultaneously. Of note is that the top-level functioning of the system remains unchanged. This means that while the sub-levels may be different, these changes would be relatively easy to implement given that the overall system does not need to change.

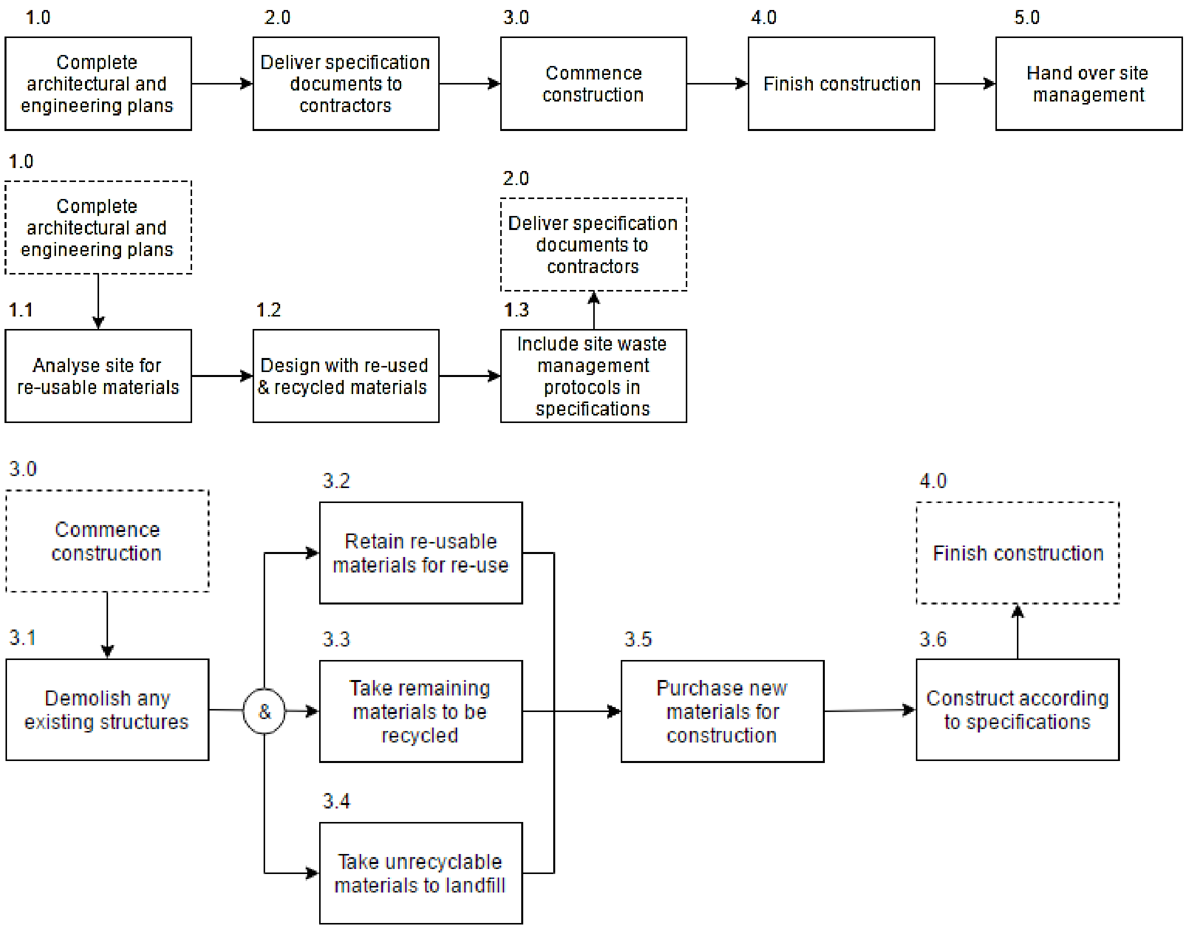

Figure 4: Functional Flow Block Diagram (FFBD) for the building and construction process with a waste management plan integrated

A subsystem interface map for the system above was then drawn. Each component of the subsystems has complex interactions with other components as can be seen in Figure 55.

The architectural plans specify the overall construction plans, including some materials which influence the engineering specifications in terms of the types of materials that can be used. Certain parts of the architectural plans may require specific properties from materials such as strength or durability, these are detailed further in the engineering specifications. The engineering specifications also dictate what information must be kept and recorded if the building is targeting a Green Star rating.

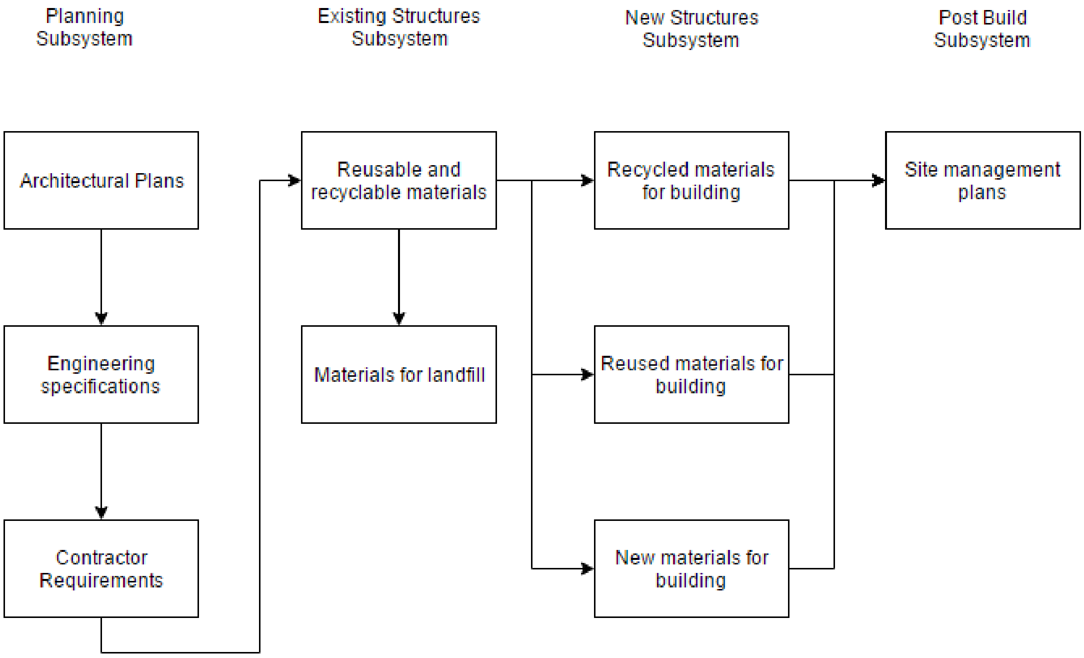

Figure 5: Subsystem Interface map for the construction and demolition process with a waste management plan integrated

The engineering specifications are turned into a set of instructions for the contractors to follow on site which dictate the materials the contractors should use, what should be kept from any existing structure needing demolition and where there may be flexibility in the choice of materials used. The contractor may also be required to keep documentation required for accreditation, and this would be part of their contractor requirements.

This marks the final component of the planning subsystem. At this stage, these plans, requirements, and specifications are all held by the contractors. The system now moves into the construction and demolition phase, and particularly into the subsystem dealing with existing structures.

At this point, the contractor would make a note of what is specified in the plans regarding reusable and recyclable materials already on site. During demolition special care would be taken not to damage these materials, and to retain reusable materials for the construction step. Any material that cannot be reused or recycled would be taken to landfill.

The composition of materials in the demolished structure directly feeds into the new structures subsystem. Reusable materials retained from the demolished structure, or from prior demolitions the contractors have performed may be used to construct the new structures. As far as possible any additional materials would be recycled, and all remaining materials would be new.

The prior life cycles of materials, their age, composition, and properties all influence how they must be maintained. As such, the various materials used in the construction will all have different maintenance requirements. With sustainable design in mind, builds are becoming more modular and durable and thus it is expected that maintenance requirements will be reducing compared to standard builds of a number of years ago. These maintenance requirements are the final component, and make up the post-build subsystem.

The system as a whole is not very modular – changing any component will have a flow on effect on the remaining components in the system. The system is, however, quite flexible as there are a number of heavily interrelated components, such as the ‘reusable and recyclable materials’ and the ‘materials for landfill’ components. Some components also overlap; the components in the planning subsystem all have a single purpose – to make it clear for the contractors exactly how to execute the demolition and construction. As such, if, for example, the architectural plans did not have detail relating to sustainability measures, these may be specified in one of the later components.

Ultimately, the most important customer requirements identified were reduced building site waste, greater uptake of sustainable practices and quality of build. These requirements are better able to be met with more flexible systems and subsystem interactions as these allow for the tailoring of the solution to each individual project.

Future work

As was mentioned in the introduction, a number of recycling and reuse initiatives have emerged due to various market demands. Further investigation should be conducted into what these initiatives specifically cater for and the potential for these to become industry standards.

The body of research considered when developing this report did not include an analysis of these initiatives. It is possible that these initiatives could contribute towards a better solution, as smaller initiatives usually respond to a direct local need, meaning there might be a greater flow on uptake of sustainable practices.

A detailed investigation into the breakdown of the materials in construction and demolition waste produced in Australia, and the specific recycling and reuse opportunities on a location basis should be produced to assist engineers and contractors in achieving the desirable outcomes. This could be integrated with the initiatives mentioned above, and incorporate them into the solution to result in a more fully developed solution.

Roll out may look like involving a few companies or firms on a pilot programme, with a quantitative and qualitative study conducted on the outcomes. This could then provide a basis for the government to implement national legislation covering all individuals and companies involved in the construction and demolition industry.

As with any solution, there is potential for certain aspects to fail. With governments agendas changing fairly regularly, passing legislation can be a lengthy process, assuming it is passed in the first place. Additionally, there is no guarantee that engineers and architects will design with waste reduction in mind. It is likely that a number would continue as they always have, and only comply with bare minimum requirements. A concrete financial impacts analysis may go a long way towards changing these behaviours if such an analysis were to conclusively demonstrate significant financial benefits to this method of design.

Even with these failure risks, the proposed solution is still highly likely to produce desirable outcomes and outcomes that are a significant improvement on the current state of affairs. If such legislation only resulted in one firm changing their practices and treatment of site waste, this would still be a significant reduction and would be likely to further influence market behaviours towards sustainable practices.

Reflection

The course and the course tools have taught me a number of different skills that I believe will be incredibly valuable going forward in my degree and in my career afterwards. The group work has meant my communication and teamwork have developed over the past semester, and our group was effective in group management and balance of work amongst members.

Throughout the individual project, I not only developed my time management skills but also learnt about how the tools could be applied and adapted to suit different systems and analysis outcomes. It was important to learn about compromises and trade-offs as these happen on every single project and being able to justify why one thing was prioritised over another is key.

The documents that were required throughout the course have also taught me a lot about professional writing and communication. I have learnt a lot more about how to tailor my work to a specific audience, and how to convey something so that it is easily understandable for the target audience. The poster session was particularly crucial for developing my understanding of these concepts, and having to stand in front of our poster and having to clearly and concisely deliver our design solution to the client, other students and tutors was a challenge, but I learnt a lot.

Finally, by completing my individual project I have further developed my research and critical thinking skills. The different analyses that were carried out all involved thinking about the problem in a different way, and it was definitely very interesting seeing all the different ways a system can be broken down to obtain a variety of information.

I found the peer review focus quite frustrating. Whilst both portfolios I reviewed were mostly complete, the quality of the work left a lot to be desired. A number of sections were incomplete, meaning it was difficult to give comments. Potentially this is a result of poor time management on the behalf of these students. The comments I received were mostly positive. While these are nice to read, they rarely help improve the quality of the work and can be damaging if the reviewer has a lower standard of quality than that of the author. There were a few constructive comments on things I could improve or do better which was really useful to read. Some of them I agreed with and implemented changes, and some I disagreed with and disregarded. Overall, I do think the peer review process is quite useful. It forces you to read the portfolio from quite a critical angle, which makes it easier to critique your own work. Seeing how other students have approached the task and implemented the tools is also interesting and can be helpful when polishing your own portfolio. Whilst the peer review system obviously has many flaws, on the few occasions when it does work, it does so quite well and can be enormously beneficial to both the reviewer and the reviewee.

References

Ahram, T. Z., Karwowski, W. & Amaba, B., 2010. User-centered systems engineering approach to design and modeling of smarter products. *System of Systems Engineering (SoSE), 5th International Conference*, June, pp. 1-6.

Bossink, B. & Brouwers, H., 1996. Construction waste: quantification and source evaluation. *Journal of Construction Engineering and Management,* 122(1), pp. 55-60.

Chandrakanthi, M., Hettiaratchi, P., Prado, B. & Ruwanpura, J., 2002. *Optimisation of the waste management for construction projects using simulation.* In: Proceedings of the 2002 Winter Simulation Conference, San Diego, pp. 1771-1777.

Chen, Z., Li, H. & Wong, C., 2002. An Application of bar-code system for reducing construction wastes. *Automation in Construction,* 11(5), pp. 521-533.

Chini, A., 2007. General issues of construction materials recycling in USA. *Portugal SB07: Sustainable Construction, Materials and Practices,* pp. 848-855.

Edge Environment, 2011. *Construction and Demolition Waste Guide - Recycling and Re-use Across the Supply Chain,* s.l.: Edge Environment.

Ekanayake, L. & Ofori, G., 2000. *Construction material waste source evaluation.* In: Proceedings of the Second Southern African Conference on Sustainable Development in the Built Environment, Pretoria, 23-25 August.

Faniran, O. & Caban, G., 1998. Minimising waste on construction project sites. *Engineering Construction and Architectural Management,* 5(2), pp. 182-188.

Green Building Council Australia, 2013. *Construction and Demolition Waste Reporting Criteria,* s.l.: GBCA.

Green Building Council Australia, 2015. *Introducing Green Star,* s.l.: GBCA.

Hyder Consulting, 2011. *Construction and Demolition Waste Status Report - management of construction and demolition waste in Australia,* s.l.: Hyder Consulting.

Innes, S., 2004. *Developing tools for designing out waste pre-site and on-site..* In: Proceedings of Minimising Construction Waste Conference: Developing Resource Efficiency and Waste Minimisation in Design and Construction, London, United Kingdom, New Civil Engineer.

Karavezyris, V., 2007. Treatment of commercial, construction and demolition waste in North Rhine-Westphalia: policy-making and operation options. *Waste Management,* 25(2), pp. 183-189.

Osmani, M., Glass, J. & Price, A., 2008. Architects' perspectives on construction waste reduction by design. *Waste Management,* 28(7), pp. 1147-1158.

Sita, 2016. *Brochures.* [Online]
Available at: http://www.sita.com.au/media/publications/1209-SITA_Rear_Lift_Brochure.pdf
[Accessed 25 April 2016].

Stasinopoulos, P., Smith, M., Hargroves, K. & Desha, C., 2008. *Whole System Design: An Integrated Approach to Sustainable Engineering.* London: Earthscan.

Teo, M. & Loosemore, M., 2001. A theory of waste behaviour in the construction industry. *Construction Management and Economics,* 19(7), pp. 741-751.