# WASTED ... AGAIN

*Or how to understand waste as a data problem and aiming to address the reduction of waste as a computational challenge*

M. HANK HAEUSLER[1], ANDREW BUTLER[2],
NICOLE GARDNER[3], SAMAD SEPASGOZAR[4] and SHAN PAN[5]
[1,3]*UNSW / Computational Design*
[1,3]*{m.haeusler|n.gardner}@unsw.edu.au*
[2]*Cox Architecture Sydney*
[2]*andrew.butler@cox.com.au*
[4]*UNSW / Construction Management*
[4]*Sepas@unsw.edu.au*
[5]*UNSW / Information Systems and Technology Management*
[5]*shan.pan@unsw.edu.au*

**Abstract.** The global construction industry is the single largest consumer of materials on the planet. Of that material consumption anywhere between 10-20% will end up in landfills as waste. Currently, there are three approaches to tackle this problem - reduce, reuse, and recycle. Concentrating purely on the challenge of reducing waste this research aims to address the problem of waste in the construction industry by addressing it in the preliminary design stage. It does so by asking the research question if computational design offers opportunities towards lean construction or to achieve Zero Waste by understanding waste as a data management challenge. For our research materials are specified in databases outlining geometrical and quantitative information either in material supplier databases (homepage) or in architecture and construction databases via Revit or Grasshopper. Consequently, one can collect via web scraping, investigate via databases, inspect and compare via Grasshopper and Python these databases to understand if one can transform data into information towards material use and consequently into knowledge on waste production and reduction. This investigation, its proposed hypothesis, methodology, implications, significance, and evaluation are presented in the paper.

**Keywords.** Construction industry; waste reduction; databases; web scraping; computational design.

## 1. Background and motivation

Rapid growth in construction activities in Australia in recent years has led to increased generation of construction and demolition (C&D) waste (Shooshtarian

*PROJECTIONS, Proceedings of the 26th International Conference of the Association for Computer-Aided Architectural Design Research in Asia (CAADRIA) 2021*, Volume 1, 371-380. © 2021 and published by the Association for Computer-Aided Architectural Design Research in Asia (CAADRIA), Hong Kong.

et. al, 2019). Ibid. argues that, according to the latest statistics (NWR, 2018), about 20.4 Mt of C&D waste was generated across Australia during 2017- 2018. That is equal to 30.5% of the total waste generated, from which 33% is disposed of in landfills. With the existing rate of migration and population growth (ABS, 2018), it is expected that C&D waste generation will continue to grow steadily in the coming years. To give a general background the paper wants to present a few figures in order to give the research a sense of the magnitude of the problem. The Australian Bureau of Statistics (ABS, 2020) lists in 2020 recent report with a reference period for the 2018-19 financial year that Australia generated 75.8 million tonnes of solid waste in 2018-19, which was a 10% increase over the last two years (since 2016-17). Over half of all waste was sent for recycling (38.5 million tonnes), while 27% was sent to landfill for disposal (20.5 million tonnes). Sectors generating the most waste were:

- Manufacturing: 12.8 million tonnes (16.9%)
- Construction: 12.7 million tonnes (16.8%)
- Households: 12.4 million tonnes (16.3%)
- Electricity, gas and water services: 10.9 million tonnes (14.4%)

Showcasing that construction waste in the above-cited years ranks higher as a waste producer than households. In providing industry insights the same report states that construction with its 16.8% contribution of total waste has with masonry materials (8 million tonnes) the largest supply (35%) of all masonry material waste. The construction industry has spent AUS$2 billion on waste services and the construction waste increased by 22% since 2016-17. With these figures in mind, construction waste is further classified by the EPA (2020) who provides information for demolition and excavation companies, builders, contractors, project managers, and property developers. Ibid. states that construction and demolition activities can generate a wide range of different waste materials. This waste is not just rubbish and unwanted material, but based on type, the construction debris is classified into excavation debris, roadwork debris, demolition debris, and complex debris (CDRecycler, 2020).

- **Excavation debris** is further segmented as vegetable soil, soil, sand, gravel, rock, and clay.
- **Roadwork debris** includes debris generated by activities such as construction, demolition, and renovation of roads, railroads, airports, and runways. This includes concrete, broken asphalt, paving stone, sand, pebble, railway traverse, and ballast.
- **Construction debris** generated by the building and demolition of industrial and residential buildings, hospitals and schools such as concrete with iron, concrete without iron, roofing, tiles, bricks, wood, stucco, gypsum and ceramic are included in demolition debris.
- **Complex debris** such as plastics, metals, ceramic, paper, and cartons are considered separately.

For our research we concentrate solely on (3) construction debris with an extension to (4) complex debris, as (1) excavation debris not necessarily is harmful in landfills, and its reduction is not covered in the research, similar to (2) roadwork debris. In terms of material, construction debris is segregated into wood, metal, shingles, asphalt brick and concrete (ABC) debris, packaging debris, ceramics, gypsum, plastic, and others.

- **Wood waste** includes plywood, manufactured wood, painted wood, pallets and crates, and treated wood.
- **Metal waste** includes ferrous and nonferrous metals.
- **ABC debris** includes asphalt, bricks, concretes and composites.
- Toilets, sinks, and tiles are included in **ceramic debris**.
- Plastic pipe, vinyl siding, and other plastics are considered **plastic waste**.

The outlook on waste is dire as the volume of construction waste generated worldwide every year, according to a report from Construction Waste Market (2016) will nearly double to 2.2. billion tons by the year 2025 confirming the importance to address this research.

Literature on addressing waste in the construction industry lists the following. The Australian Government suggests three approaches to minimising waste as the three ‘Rs’ of waste minimisation: reduce, reuse, recycle (YourHome, 2020).

- **Reduce** consumption of resources by building smaller houses that are better designed for your needs. This is the most effective way to conserve precious resources for use by future generations and reduce waste. It also lowers costs. Improve the accuracy of your ordering so that materials are not wasted nor sit around a site for long periods where they can become damaged.
- **Reuse** existing buildings and materials in order to reduce demand for resources, lower waste volumes, and save money. A lot of energy and resources go into the materials used to construct a home and due to the mixed nature of these materials most end up in landfills. The following graph shows that the emissions from the energy of the materials required to construct a typical house are nearly equal to the emissions from the energy required to heat or cool that house over a typical 50-year life. Consider renovating an existing house, rather than demolishing the old and building from scratch as very little of the demolished house is recycled or reused.
- **Recycle** resources that are leftover or have reached the end of their useful life. This reduces the demand for new materials and lowers the volume of waste going to landfills. Use materials with high recycled content to create a market for recycled resources. It raises the price paid by recyclers for recovered resources and increases the viability of recycling.

In computational design research investigating waste as a data management challenge, we concentrate on the first point to reduce waste. This is further motivated also computational designers primarily work in offices in design, documentation, and communication stages of a building where they are in a position to reduce waste in design or documentation and not on construction sites. Further one can argue that any waste not produced contributes to the solution of reducing waste. Hence the following source (United Rental, 2018) suggests the 8 Ways to Reduce Construction Waste (only the first three are listed due to their relevance for this research).

- Reduce construction mistakes

- Order the right amount of materials
- Get the right-size materials for the job

Yet while a reduction of waste is arguably a topic worth pursuing given the above-stated problem, research that investigated if and how architects can prevent waste production paints a dire picture. When investigating *'Architects' perspectives on construction waste reduction by design'* (Osmani et al., 2006, 2008) the author's research revealed that waste management is not a priority in the design process. Additionally, their research unveiled that architects seemed to take the view that waste is mainly produced during site operations and rarely generated during the design stages; however, about one-third of construction waste could essentially arise from design decisions (Ibid.). The authors conducted a questionnaire survey based on specific and interrelated organisational waste minimisation issues conducted with architects and contractors and revealed that very few attempts are made to reduce waste during the design process. On the other hand, the results show that contractors are pursuing a more proactive approach to manage on-site waste production through the development of environmental and waste management policies. The results reveal that poorly defined responsibilities are leading to confusion regarding who should control and monitor waste management. Both architects and contractors are constrained by internal and external factors, such as 'waste accepted as inevitable' and lack of interest from clients (Ibid.).

## 2. Research Question, objectives and outcomes

Research in Computational Design as a discipline following pragmatist concepts (Gardner et al., 2019) suggests that computational design research offers the opportunity to use and apply new methods and tools to 'old problem'. Through the literature review above we have identified waste in the construction industry as one 'old problem' suitable to pursue through a computational lens. Hence asking the core research question of waste can be understood and investigated as a data management challenge and consequently assists in understanding better how much waste is produced in the design phase and if waste can be reduced.

**Objectives.** As part of this research the paper aims to introduce a different way of thinking about waste. In the work presented the researchers thought about buildings, their designs, and their materials as series of databases, starting and applying seven observations. (1) Architecture is made out of industrial designed products (i.e. plasterboards) that companies manufacture and sell; (2) Industrial design products are often only partially used to build a building - some of them are turned into Waste; (3) EACH product is defined as data through their dimensions, material, costs, carbon footprint, etc.; (4) Data that defines these products are stored in a database (Excel / REST framework online); (5) Architects define through their drawings which product is used, in which quantity, and if the single object is used in its whole or only in parts (no waste/waste per item). BIM families defining elements used for walls, facades, floors; (6) IF databases in (4) and (5) exists one, therefore, compare both databases to identify waste. If this assumption is correct one would be able to understand how much waste is produced during design, and (7) This could allow the establishment of a WASTE BUDGET during the design phase (ignoring the reuse of offcuts).

**Outcomes.** The research project presents a proof of concept study in which we used web/HTML scraping to source products data from suppliers homepages (over 1400 products over one week trial), stored in REST frameworks, and connected these with GH scripts defining the geometry (residential/commercial floor plan, facades, and roof) and allowing an optimisation of the geometry towards using products as a whole while at the same time understanding how much waste will be produced as a consequence of design, in the first five minutes of design.

## 3. Methodology

The research project was conducted as part of a 2nd-year course at the Bachelor of Computational Design at the University of New South Wales, Sydney in engaging students in setting up data structures and writing robust interoperable code in Grasshopper and Python. The project applied action research methodology (Sein et. al, 2011) to create a frame that focuses, informs, and guides the work undertaken to ensure that the previously stated aims are met, and the questions sufficiently answered. The research project applied the concept of 'Upstreaming Information' as a main theoretical framework, arguing that information as digitised data exist within a current or past project (i.e BIM data) and outside a project (i.e data on homepages such as planning regulation or environmental). While these data can exist in various stages of a design project at a current stage we aim to 'upstream' them to the 'first five minutes of design'. This is motivated and influenced by the 'MacLeamy curve' developed in 2004, as discussed by Daniel Davis in blog and Ph.D. (2020). The MacLeamy curve outlines, according to Davis (Ibid.), "a pretty self-evident observation that architectural projects become more difficult to change the more developed it becomes". Consequently, the curve visualises the ability to impact a project and the cost of design changes during the duration of a project from predesign to construction. The idea of 'Upstreaming' argues that one can take digitised information and move them up and down across different stages in a linear progression of a construction project (predesign to construction). While there is various digitised information that has the potential to be 'upstreamed' in this research we concentrate on material information to reduce waste in the first five minutes of the design process. In order to do so, we needed to source data using Web/HTML scraping, storing data in a REST (Representational State Transfer) framework, and linking the stored data to a Grasshopper model. All concepts explained in the following.

## 4. Literature Review

Other than the previously discussed literature review outlining the current thinking and research on waste in the construction industry the paper briefly aims to introduce the following technical concepts which provided a base for the investigation.

**Web or HTML scraping** is a technique or term used to describe the use of a program or algorithm to extract and process large amounts of data from the web. As the internet hosts arguably the greatest source of information many disciplines such as data science, business intelligence, or other forms of investigative reporting benefit from collecting and parsing raw data from websites. In the case of the research, we argued that nearly all material suppliers for the construction industry will offer their products on websites. Hence information about this product such as data through their dimensions, material, costs, the carbon footprint can be accessed as raw data via web scraping. In our research, we used 'Beautiful Soup' a Python library for parsing structured data (Realpython, 2020). Beautiful Soup allows you to interact with HTML in a similar way to how you would interact with a web page using developer tools. Beautiful Soup exposes a couple of intuitive functions you can use to explore the HTML you received. Following the tutorials, on realpython.com (Realpython, 2020b) the research team builds a web scraper that fetches Software Developer job listings from the 'Monster' job aggregator site (2020). Our web scraper parsed the HTML to pick out the relevant pieces of information and filter that content for specific words (in our case material information). When inspecting our data source, we explored the website, decipher the Information in URLs, and inspect the Site Using Developer Tools. This was followed by the second part in which scraped HTML Content From a Page (we used mainly Bunning's homepage, Bunnings is a large Australian hardware store which sells most building products used for small scale residential developments, yet went as well to other producers such as tile manufacturer) using Python. Here we were getting the site's HTML code into our Python script so we could interact with it, using Python's 'requests' (2020b) library. Depending on the website type one would face either static HTML content. In this scenario, the server that hosts the site sends back HTML documents that already contain all the data you'll get to see as a user. Alternatively, a hidden website contains information that's hidden behind a login or dynamic websites where the server might not send back any HTML at all. For ease, we mainly targeted static websites. The third and last task was then to parse HTML Code with Beautiful Soup to parse lengthy code responses with Beautiful Soup to make it more accessible and pick out the data we were interested in.

A **Representational state transfer (REST)** is a software architectural style that defines a set of constraints to be used for creating Web services. Web services that conform to the REST architectural style, called RESTful Web services, provide interoperability between computer systems on the internet. In our research, we used Django REST (2020) framework, a powerful and flexible toolkit for building Web APIs.

**Postman Collaboration platform.** In order to collaborate as a team we used 'Postman' (2020) a collaboration platform for API development. Postman is a popular API client that makes it easy for developers to create, share, test, and document APIs. Via Postman users can create and save HTTP/s requests needed in the case of the research to combine various material information. When copying a URL into Postman and run a sent one can see the source code and returns information to the user. When linking this to a database one can write requests into Postman to list various components useful for the later task. This enabled us to generate a joint database. Making a 'Post' request allows us to feed data into the joint database. All information is stored in a joint Google sheet which was overtime populated with ~1500 material/product information within one week (the duration of a specific task in class) from various suppliers offering building products.

## 5. Project

The proof of concept research project was conducted as part of class CODE2120 - Building Data course as the Bachelor of Computational Design in mid-2020. As part of a ten-week course, students were given the above in Chapter 2. Research Question, Objectives, and Outcomes listed seven observations to address in three assignments. Please see the following URLs with Video clips of student works showcasing work in the assignments:

- Scarlett Rogers - www.youtube.com/watch?v=cOFqCnC3qSQ&feature=youtu.be
- Luka Jovanovic - www.youtube.com/watch?v=130RGnbON0A&feature=youtu.be
- Eddie Azzi - www.youtube.com/watch?v=KSOOlyf2xKQ&feature=youtu.be

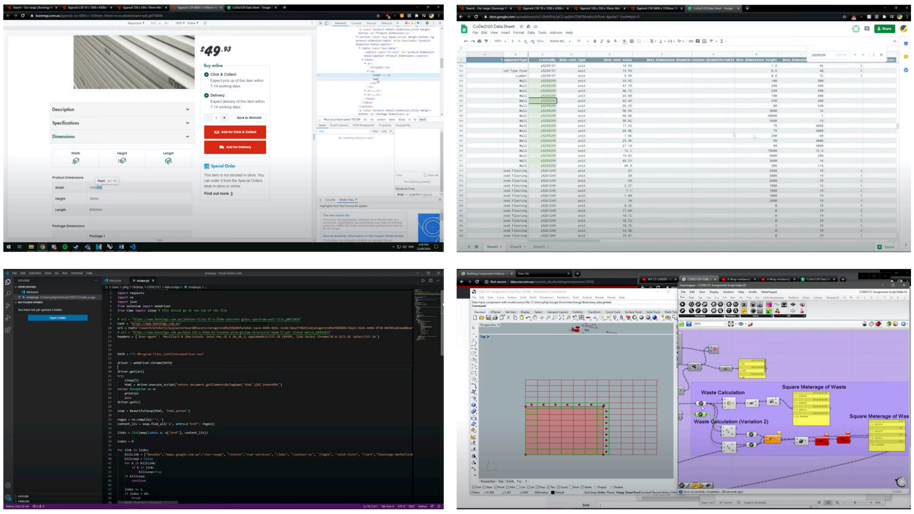

Figure 1. Screenshots from Video Eddie Azzi - HTML-scraped homepage (top/left), Google database (top/right), pythonscript (bottom/left), and grasshopper script (bottom/right).

**Assignment 1: Understanding operability** Here we outlined to students that building material data are stored in various online databases that sell products such as Bunnings Warehouse (a large Australian supplier of building material) and many others with information about dimension and many more. In this first assignment, students were asked to identify database systems for Building material data and sourced, scraped, stored them in the order as listed in the literature review. During the exercise, students learned how to set up databases and define agreed formats in how data are sorted and listed.

**Assignment 2: Automating tasks in architectural workflows** By the end of the first assignment students have established a database for the materials (with dimensions and other information). This information now needs to be brought together with architectural geometry. As outlined above in Observation 5 architects define through their drawings which product is used, in which quantity, and if the single object is used in its whole or only in parts (no waste/waste per item). Here, and this is simplified - if one draws the floor plan of a room and the room is surrounded by walls defined via a BIM family with i.e plasterboards our script is able to do the following calculation. If the wall is 5100mm long and the plasterboard would come in a length of 1250mm then one would require 5 plasterboards with a total length of 6250mm of which one only uses 5100mm and 1150mm would become waste. Ignoring the fact that one can use the left-over plasterboard elsewhere for the moment the design has produced significant waste with 18.4% of the material going to landfill. When moving the wall by 100mm one could use exactly 4 plasterboards and create 0% waste. This calculation is easily done in this example but harder on a whole building - but not for a computer. In the following task, students were asked to script a shape (L, S, T, U, I shape) so the computer knows what shape the presented one is either clockwise or counter-clockwise shapes. This is essential to do in the following advanced tree manipulation in Grasshopper.

**Assignment 3: Waste in construction** The last task asked students to combine the material database and the Grasshopper models to return a calculation similar as the one outlined when talking about the plaster board. Naturally, as this was done computationally one could do the calculation on as all walls on each floor of a building and get a result.

## 6. Evaluation, conclusion and next steps

In evaluating the above-listed method of extracting information using web scraping, storing jointly collected data in one database, and connecting this database with grasshopper models one can conclude the above as success. Students were able to draw a simple building outline ((L, S, T, U, I shape) with parametric heights representing design stages in a 1:200 scale, the Grasshopper script generated a simplified floorplan (walls and room purpose) and the python script returned quantities of the selected material used and waste produced for each building outline. Given the limited timeframe of ten weeks for the experiment while learning Beautiful Soup, Django, Postman amongst others from scratch and using students as developers for the experiment one can clearly state that the presented approach has seeds worthwhile further development. The Python scripts could estimate the amount of waste produced and communicate to designers in an early design stage the quantity of waste. If nothing else a script like this might raise much-needed attention onto the topic - which too often ignored as research by Osmani et al (2006, 2008) has proven. Yet the presented research has obviously room for improvements and the presented research understands itself as a position paper aiming to raise attention in the CAAD community to the issue of waste in the construction industry and that one can contribute in addressing the problem through computational skills. The results motivated the team to continue the research and we are planning to investigate:

- **Developing a tool for waste reduction.** As currently we only have a proof of concept script the first step is in developing a robust tool based on Python and/or C languages that will be hosted on the Giraffe Technology platform (2020). We envision that future users can model rooms as the smallest item in the AEC industry on Giraffe and the platform will send our tool geometry information we can process, connect with to material and BIM database and return a result. Yet other steps are needed as well.
- **Extracting information out of BIM.** In 2.1 Objectives we state that architects define the characteristics of walls, floors, or ceilings via BIM families and that these families contain information that needed to be linked to an extended material database as the one explained above. Hence future research will be conducted to understand the data structure of BIM families to (i) allow the future user to upload their RFA (family) files and RFT (family template), (ii) storing material-related information in a separate database to match with the material database. In parallel, we are already working on Natural Language Processing (NLP) as we assume that each BIM user names its families and products differently and NLP has, in our research so far, proven to be successful.
- **Extending material database.** While our proof of concept was able to collect ˜1500 material via web scraping, we are planning to extend this exercise to source five to six-figure numbers of material concentrating first on products used in Australia.
- **Experiments in machine learning and multi-objective optimisation.** While we know how much waste one might produce, we do not offer yet a solution to the problem. Hence research will be undertaken to investigate how a machine can offer design solutions that reduce waste. The focus here can be on a solution that reduces waste on specific material types i.e with high embodied carbon or materials that are not biodegradable to name but two examples.
- **AI-enabled mentoring on waste.** How and when in the design process is the human informed by the machine on waste? What interaction happens, how is the information communicated, how does the human react and act upon receiving the information?

We hope to address these questions and topics for future research to reduce waste in the construction industry in the first five minutes of design.

## References


"Construction Waste Market" : 2016. Available from Construction Waste Market: Global Industry Analysis, Size, Share, Growth, Trends and Forecast 2017-2025<https://www.transparencymarketresearch.com/construction-waste-market.html> (accessed 09. December 2020).

"NWR" : 2018. Available from Australian National Waste Report 2018. Department of the Environment and Energy<https://www.environment.gov.au/protection/waste/publications/national-waste-reports/2018> (accessed 09. December 2020).

"ABS" : 2018. Available from Australian Demographic Statistics. In: STATISTICS, A. B. O. (ed.). ENVIRONMENT AND COMMUNICATIONS REFERENCES COMMITTEE 2018. Never waste a crisis: the waste and recycling industry in Australia. In: SENATE, T. (ed.). Commonwealth of Australia 2018.<https://www.aph.gov.au/Parliamentary_Business/Committees/Senate/Environment_and_Communications/WasteandRecycling/Report> (accessed 09. December 2020).

"United Rental" : 2018. Available from 8 Ways to Reduce Construction Waste<https://www.unitedrentals.com/project-uptime/expertise/8-ways-reduce-construction-waste#/> (accessed 09. December 2020).

"Postman" : 2020. Available from Collaboration platform for API development<https://www.postman.com/> (accessed 09. December 2020).

"Monster" : 2020. Available from Software Developer Job Listing<https://www.monster.com/jobs/search/?q=Software-Developer> (accessed 09. December 2020).

"ABS" : 2020. Available from Waste Account Australia Experimental Estimates<https://www.abs.gov.au/statistics/environment/environmental-management/waste-account-australia-experimental-estimates/latest-release> (accessed 09. December 2020).

"EPA" : 2020. Available from Waste / Industrial Waste / Construction Demolition<https://www.epa.nsw.gov.au/your-environment/waste/industrial-waste/construction-demolition> (accessed 09. December 2020).

"CDRecycler" : 2020. Available from Global Volume Construction Demolition Waste<https://www.cdrecycler.com/article/global-volume-construction-demolition-waste/> (accessed 09. December 2020).

"Realpython" : 2020. Available from Beautiful Soup Web Scraper Python<https://realpython.com/beautiful-soup-web-scraper-python/> (accessed 09. December 2020).

"YourHome" : 2020. Available from Waste Minimisation<https://www.yourhome.gov.au/materials/waste-minimisation> (accessed 09. December 2020).

"UN SDGs" : 2020. Available from UN Sustainability Development Goals<https://www.un.org/sustainabledevelopment/sustainable-consumption-production/> (accessed 09. December 2020).

"Django" : 2020. Available from Django Rest Framework<https://www.django-rest-framework.org/> (accessed 09. December 2020).

"Giraffe Technology platform" : 2020. Available from Giraffe is a json editor with map of world to model and an app store to upload tools<https://www.giraffe.build/> (accessed 09. December 2020).

"Mirvac" : 2020. Available from Mirvac releases its plan for zero waste<https://www.mirvac.com/about/news-and-media/mirvac-releases-its-plan-for-zero-waste#> (accessed 09. December 2020).

"Davis" : 2020. Available from Daniel Davis Blog - Macleamy curve<https://www.danieldavis.com/macleamy/> (accessed 09. December 2020).

"Realpython" : 2020b. Available from Python requests<https://realpython.com/python-requests/> (accessed 09. December 2020).

Gardner, N. and Haeusler, M. H. 2019, Introduction: Computational Design - From Promise to Practice, *in* N. L. Gardner, M. H. Haeusler and Y. Zavoleas (eds.), *Computational Design: From Promise to Practice*, avedition, Ludwigsburg, Germany, 7-15.

Osmani, J., Glass, J. and Price, A. D. F.: 2006, Architect and contractor attitudes to waste minimisation, *Proceedings of the Institution of Civil Engineers - Waste and Resource Management*, **159**(2), 65-72.

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

Sein, M., Henfridsson, O., Purao, S., Rossi, M. and Lindgren, R.: 2011, Action Design Research, *MIS Quarterly*, **35**(1), 37-56.

Shooshtarian, S., Maqsood, T., Khalfan, M., Wong, P. and Yang, R.: 2019, Construction and Demolition Waste Management in Australia: Review of Differences in Jurisdictional Regulatory Frameworks, *CIB World Building Congress 2019*, Hong Kong SAR, China, 1-11.