Plastic Minimisation in Construction: A Pilot Study identifying and quantifying the composition of C&D plastic in construction waste

Linda Kestle[*], German Hernandez[2], Terri-Ann Berry[3] , Joanne Low[4] and Shannon Wallis[5]

[1] *Unitec Institute of Technology, Auckland, New Zealand. email: lkestle @unitec.ac.nz*
[2] *Unitec Institute of Technology, Auckland, New Zealand email: hhernandez@unitec.ac.nz*
[3] *Unitec Institute of Technology, Auckland, New Zealand email: tberry@unitec.ac.nz*
[4] *Unitec Institute of Technology, Auckland, New Zealand email: jlow@unitec.ac.nz*
[5] *Unitec Institute of Technology, Auckland, New Zealand email: swallis@unitec.ac.nz*

**Corresponding author*

Abstract

Construction and demolition (C&D) waste contributes at least 10,000 tonnes of plastic to landfills in Auckland annually. The growing use of plastic in the packaging of building materials, the use of polystyrene and products such as building wrap are contributing to this landfill stream. Most construction waste is not sorted on construction sites, with C&D waste often being co-mingled. This funded research is an exploratory study being undertaken as a pilot project over 12-18 months by academics with three industry partners (a commercial construction company (Naylor Love), a leading building materials' supplier (Mitre 10), and a large recycling company (Green Gorilla), to undertake a comprehensive waste audit analysis of plastic waste, and workplace incentivisation for source separation of waste. The research grant was awarded to Unitec Institute of Technology by the Auckland City Council in December 2019. To date, the research team (principal investigator assisted by another senior researcher and two research assistants, a plastics technician, and an industrial chemist), has audited and recently analysed the first of two rounds of the plastics' recycling bags that were located at three of the construction company's project sites. Mitre 10 and Green Gorilla are providing the research project with statistical data related to the products being supplied and recycled to and from the three project sites. The main aim of the collaborative pilot research project was to investigate how to identify and quantify the composition of C&D plastic in construction waste going to landfill. As the pilot research project concludes later in 2021, the results to date are preliminary, yet positive. The findings demonstrate the value-added results of this collaborative academic and industry partnership, and the commitment to making a real difference that Naylor Love, and Mitre10 in particular have achieved, for minimising plastic and plastic wastes on their projects, and influencing clients customers and other players in the construction industry.

Keywords
C&D, Construction sites, landfill diversion, pilot project, plastics

Introduction

The growing use of plastic in the packaging of building materials, the use of polystyrene and products such as building wrap are contributing further to the landfill stream (Geyer et al.2017). Unlike countries such as the UK, most construction waste in New Zealand is not sorted on-site, and construction and demolition (C&D) waste is often co-mingled (Low et al. 2020). Minimal analysis on the recoverability of plastics has been evidenced or published yet, and in addition,

knowledge about both the diversion potential, and the potential economic value of plastic waste still needs to be further investigated (Häkkinen et al., 2019). Research undertaken in New Zealand to date has not disaggregated the various types of C&D plastics and assessed them for recycling potential. Therefore this particular research was a new waste minimisation pilot study initiative funded by a grant from the Auckland City Council's relatively new Waste Minimisation Innovation Fund (Auckland Council, 2021). The aim was to conduct an exploratory study to identify and audit the types of plastic waste generated from three construction sites in Auckland, New Zealand. All three project sites were being managed by the same commercial sector construction company (Naylor Love) in Auckland, who in collaboration with fellow members (who were academic researchers), in the Sustainable Business Network (SBN) organisation, wanted to investigate the varying types of plastics on construction sites and ways in which they might be diverted from landfill now and in the future.

Another aim of the funded research was to also work with C&D and construction supply chain building supplies' providers to identify issues and opportunities for reducing or reusing or recycling plastics at source, as projects progress and complete (NZ Government, 2019). Identification (and to some extent the volumetric quantification) of the composition of the C&D plastic waste stream from the construction sites, was generated from differing stages of the various construction projects. The origins of plastic wastes were determined for each involved stage of construction, to potentially enable plastic reduction prior to arrival on site (at supplier level). Options for reuse and recycling were examined, as well as any significant barriers to effective waste management on active construction sites, which may hinder future reductions in plastic waste types and volumes to landfill.

Literature Review

The three Rs of waste management (reduce, reuse and recycle) are fundamental to managing the amount of C&D (construction and demolition) waste diverted to landfill. *Reduction* of waste involves making good planning and design decisions to reduce the amount of C&D waste produced. *Reuse* of existing products for use in a new building or construction project. C&D waste sent to landfill has direct environmental (soil and groundwater leaching), social (odour; loss of amenity value), and financial (cost of disposal) implications, as well as indirect and/or additional costs due to the additional packaging of products, when being delivered to sites by manufacturers, suppliers and distibutors. In New Zealand, C&D waste sent to landfills has been steadily increasing, and is not subject to a substantial landfill levy as yet, thus reducing the impetus for reuse and recycling activities (BRANZ, 2020). There are many different opportunities to reduce waste in the construction industry but none of them are sufficient to create a truly circular economy. Ideally, the construction of a new building would first consider how much new-build waste can be designed out through careful planning for incoming materials (Yu et al., 2021).

A variety of methods have been employed to quantify C&D wastes generated on construction sites. Llatas (2011), adopted an estimation model based on waste factors obtained from the European Waste List, whereas González Pericot (2011), analysed waste container delivery notes against waste densities, and linked these to a construction stage to generate a 'descriptive evolution' of the waste generated. Further, González Pericot et al. (2014), described specific training and team incentives for site workers focussed on C&D waste segregation, combined with analyses of waste contractor delivery notes to estimate quantities. Waste which is unavoidably produced in the C&D industry can be recovered to reuse and recycle before entering landfill, and reuse of materials is preferred as it tends to use less energy for processing

and has a lower cost than recycling according to Yuan and Shen, (2011). The current waste pathway for buildings tends to be linear -with a mantra of "take-make-dispose", with little priority given to waste management, (Osmani et al., 2008; Andrews, 2015; Osmani and Villoria-Sáez, 2019). The hierarchy of waste management puts reduction as the top priority for waste minimisation, followed by reuse, recycle, and finally landfill disposal (Yuan and Shen, 2011). Reduction in the use of raw virgin materials can occur mainly during the design stage of construction and should be supported by a sustainable procurement strategy. Reuse of waste during construction and the recycling of residual waste in the final construction stages also provide opportunities for waste minimisation (Low et al, 2020).

The relatively low production cost of plastics however means there has been little economic incentive to develop plastics recovery from C&D waste. Plastics are synthetic organic polymers predominantly derived from fossil hydrocarbons (Geyer et al., 2017), and are typically light, versatile and cheap to purchase, but can cause significant environmental harm (Häkkinen et al., 2019). According to Geyer et al., (2017), the building and construction sector consumes 69% of the global production of polyvinyl chloride (PVC) products, and 19% of all non-fibre plastics. In addition, other forms of plastics commonly used in the construction industry include polyethylene (PE), polypropylene (PP), expandable polystyrene (EPS) and polyurethane (PU).

Plastic use in the construction industry can be categorized as either *direct* or *indirect.* For example - construction materials containing plastics, (e.g. insulation, damp-proofing, flooring, roofing, windows and laminated surfaces), building service installations (e.g. pipes and cabling), surface treatments (e.g. paints, varnishes, sealants, glues and resins), covers and tarpaulins are used during the construction process and are considered *direct use* plastics. Plastics used for packaging of construction materials (e.g. foils and moisture barriers, expandable polystyrene (EPS), polypropylene (PP) sacks) only serve their purpose during the transport and storage of those materials and are considered *indirect use* plastics.

A recent study by Kamaruddin et al., (2017), has demonstrated that some plastics generated from the construction sector can successfully be recycled into new household/commercial products, for example, PVC tiles, pipe fittings, hose inner cores, carpet fibres and clear film for packaging. Plastic waste has potential recycling applications in the construction industry, such as cement binders and aggregates, or used as a base and sub-base for road construction, and insulation materials, (Awoyera & Adesina, 2020). However, there are considerable barriers to reuse and recycling, which include health and safety considerations, material contamination, and the need for staff education and training of on-site waste management (Low et al., 2020).

There is also a need for improved understanding of the composition and origins of plastic C&D waste, to identify opportunities for better waste management including advancing the development of reuse and recycling solutions. Whilst previous studies have performed in-depth surveys and analysis of wastes generated for all major material types across typical construction sites, it is believed that this particular pilot study is the first to consider the spectrum of plastic types used in construction, and their descriptive evolution from source to end use. Further options for reuse and recycling were examined by Kamaruddin et al., (2017), as well as the significant barriers to effective waste management on active construction sites which may impact future reductions in plastic waste generation.

Research Methodology

The funded research was an exploratory study undertaken as a pilot project over 12-18 months by a project team of a principal investigator (PI), another senior researcher, two research assistants, a plastics' technician, a chemist; and from industry –a large privately owned commercial construction company, a leading building materials' supplier, and a large recycling company. The commercial construction company specialises in vertical construction, including industrial, retail, education, commercial and residential buildings, and was wanting to minimise waste, increase diversion of waste- especially plastics-from landfill, and make a real waste diversion difference on their project sites. The leading building materials' supplier also had a focus on plastic minimisation regarding materials from source, and reducing supply chain delivery packaging to customers.The academic–industry partnered team wanted to undertake a comprehensive pilot study conducting a waste audit analysis of plastic waste on a series of commercial builds, and help develop Naylor Love's workplace incentivisation with staff for source waste reduction, and/or separation of waste on site, at Mitre 10's supply yards, and at Green Gorilla's recycling centre.

The main aim was to identify the different types and sources of plastic waste generated during construction, and to track the destination of these wastes. Plastic waste was collected from three of the construction company partner's different construction sites across Auckland during 2020, and the two waste audits were carried out with the assistance and cooperation of the three other partner companies: Naylor Love, Mitre 10, and Green Gorilla.

All of the construction sites audited involved a mix of demolition/partial rebuild or completely new construction plastic waste. Waste collections were undertaken over two timelines - Phase 1 was carried out between February and March 2020, while Phase 2 was carried out between May and October 2020. Both of these phases were cut short and/or significantly impacted timing wise, due to Level 4 and Level 3, Covid 19 total lockdowns in the Auckland region.

A construction manager at each site ensured that all construction staff retained any plastic waste materials used and stored them in dedicated containers, which were provided (and later collected) by the waste management company or the construction company. The construction managers also ensured that the construction stage and source of material was recorded for each waste container. This enabled a descriptive evolution of each stage of the generation of waste during the construction work, and the overall audit process.

Plastic waste materials were categorised as either (P) Protection of Building works, (W) Product Wrapped Plastic, or (C) Plastic construction Components, and the waste audit analysis of the plastic waste was undertaken using a Fourier Transform Infrared (FTIR) Spectrometer as it provided precise, high-quality results for even the smallest plastic waste samples. Refer Figures 1 and 2.

There were a few early limitations to the pilot study realized however, when the bags for 'plastics only waste' (supplied by the leading recycling company to the construction company sites) were being incorrectly used for plastic and co-mingled with general waste. Hence the decision to involve the academic institution to design and later fabricate purpose-made reusable bins for onsite collection of plastics, and for other specific waste bins as well .

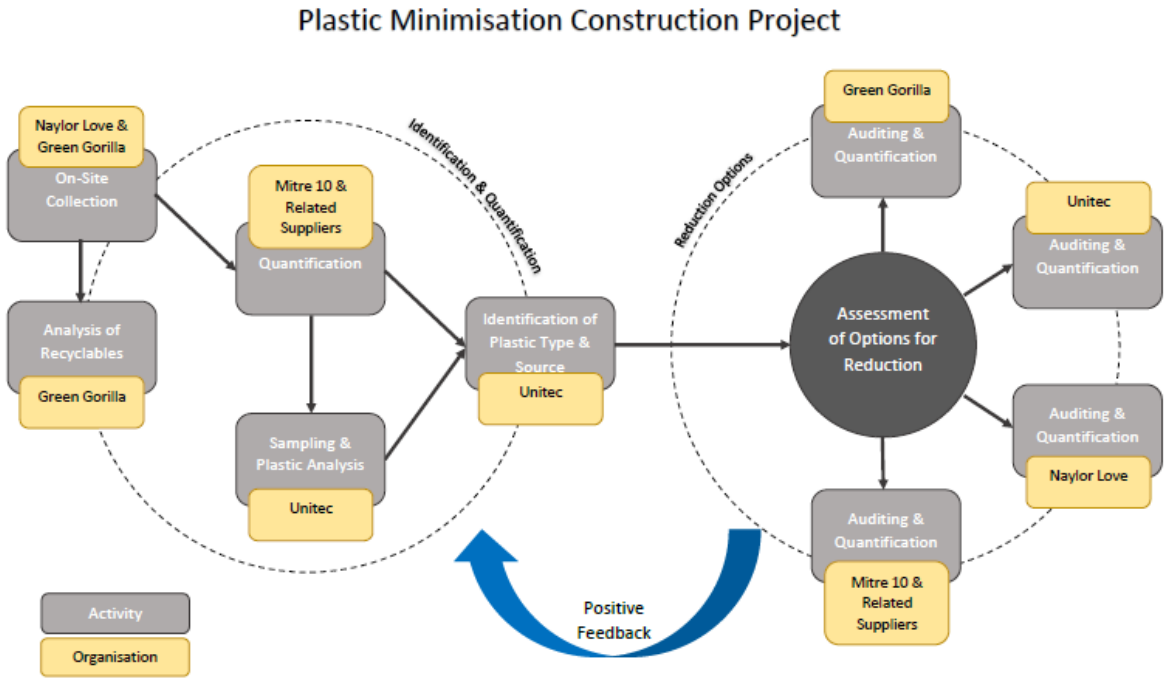


Figure 1: The Research Project Team Tasks Flowchart

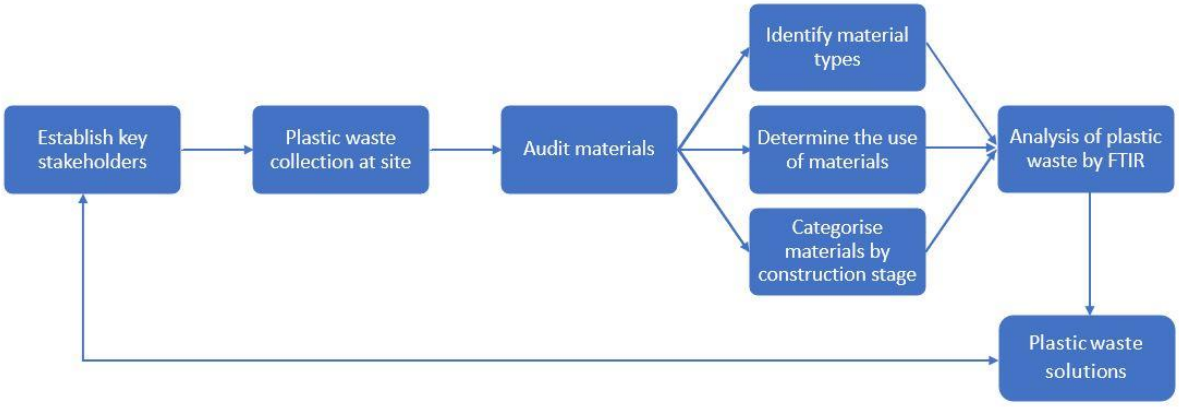


Figure 2: The Plastic Waste Audit Process

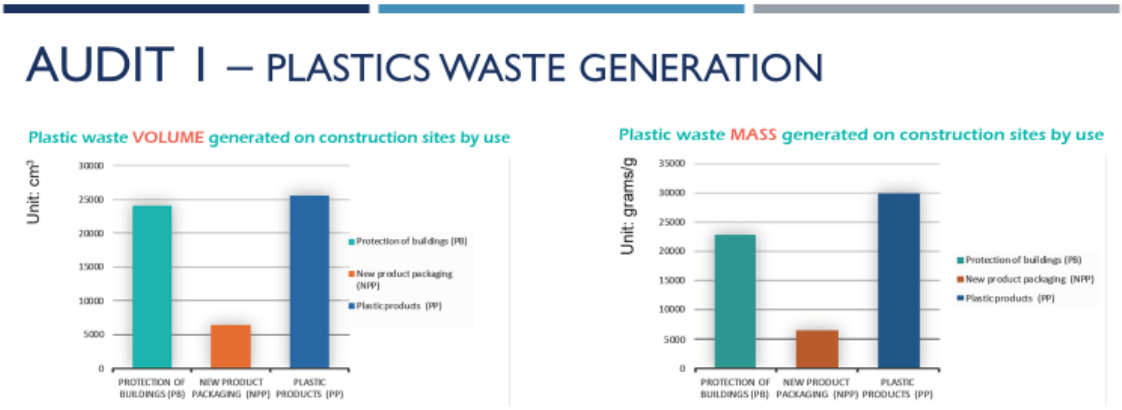
4. Findings and Discussion

The majority of plastic waste analysed was obtained during the *services and cladding* stage (99%). Plastics for building protection formed the majority (69%) of the plastic waste during the *demolition* stage, with packaging plastics contributing 30%. Waste generated during the *foundations and framing* stage comprised packaging plastics exclusively. Interestingly, construction plastics were the greatest contributors (53% by mass) to plastic waste generated during the *services and cladding* stage, with building protection and packaging plastics each contributing similar amounts at 23% and 24% respectively, (refer Figures 3 and 4).

Findings suggested that the generation rate of product packaging plastics, based on project floor area, was calculated to be 0.0019 kg/m^2, whereas González Pericot et al. (2014) found that the

majority of packaging plastics were generated during the *exterior and weatherproofing* stage and *services and cladding* stage, with a significantly higher generation rate of 0.53 kg/m^2. The current study only analysed plastic wastes across specific stages of each site, not the entire project, which may explain this difference. Other potential factors may include inaccuracies in reporting due to a lack of waste separation, on-site training and staff behaviours; the difference in building types (commercial or residential) involving different amounts of packaging; different construction methods, and differing packaging standards in New Zealand and Spain.

Across all of the samples collected, the three categories of: construction; building protection and packaging were fairly evenly represented. PE (polyethylene) was the most common plastic waste in the collected samples from the three build stages, followed by PVC (polyvinylchloride) being the next most common. As a result of there being so much co-mingling in the plastics-only bins on the sites, which was disappointing, the decision was taken by the research team to restrict the Audit 2 analysis to the 'types' of plastics rather than trying to compare the range of plastics by mass or by volume. Training on-site staff is an ongoing process by the construction managers and supply chain organisation(s), but hindered at times by a seemingly regular flow in and out of transitional employees in these skill shortage times.



Plastic waste quantification

Type of Plastic	Total Volume (m^3)	Total Mass (kg)
PE	4.6×10^{-2}	43.1
PP	7.36×10^{-4}	0.67
PVC	1.4×10^{-2}	19.1
PA	5.07×10^{-4}	0.67
Total	6.1×10^{-2}	63.5

Figure 3 Plastic waste generation and quantification on the three construction sites

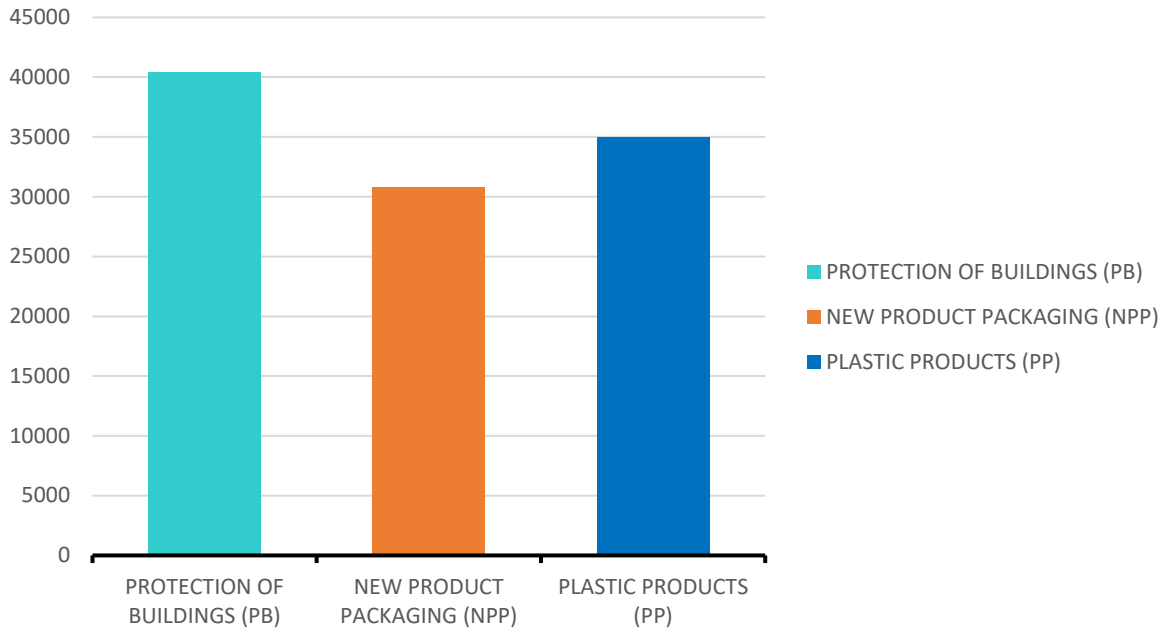


Figure 4: Determination of mass and dominant uses in AUDIT 2 of plastic waste on the three construction sites

4.1 Other outcomes from this research pilot study

The Materials' Supplier on the academic- industry partnered team stated that:

"We are sending excessive amounts of plastic to customers who either do not know how to refuse the plastic covers – or thought it normal practice to have plastic packaging. In a twelve month during 2020, an option was offered on the online customer portal by the building materials' supplier (Mitre10), to choose whether ordered materials were to be wrapped and packaged in plastic, or not- The resultant preference by customers was that an amazing 97% of orders were supplied unwrapped on request, and only 3% were supplied wrapped."

The Construction Company on the academic-industry partnered team – believed that the following key industry impacts occurred during the pilot study to date, being:

- The design and trial of permanent plastic collection bins,
- Training and information posters on waste management and separation processes, and why - for all on and off-site construction and supply chain company staff (refer Figure 5 below).

Importantly, strong connnections and relationships between the academic-industry partnered team members have been built, with new and ongoing waste management and landfill diversion project possibilities forming as well, this year. In late April 2021 - a symposium - 'Building Out Waste' was organised in Auckland by the Sustainable Business Network, which highlighted the latest practical innovations, industry updates and inspiration from current case-studies to tackle waste in the C&D sector. The academic-industry partnered team were all in attendance, and were asked to make an informal presentation of some of the early highlights of the plastics minimisation pilot study.

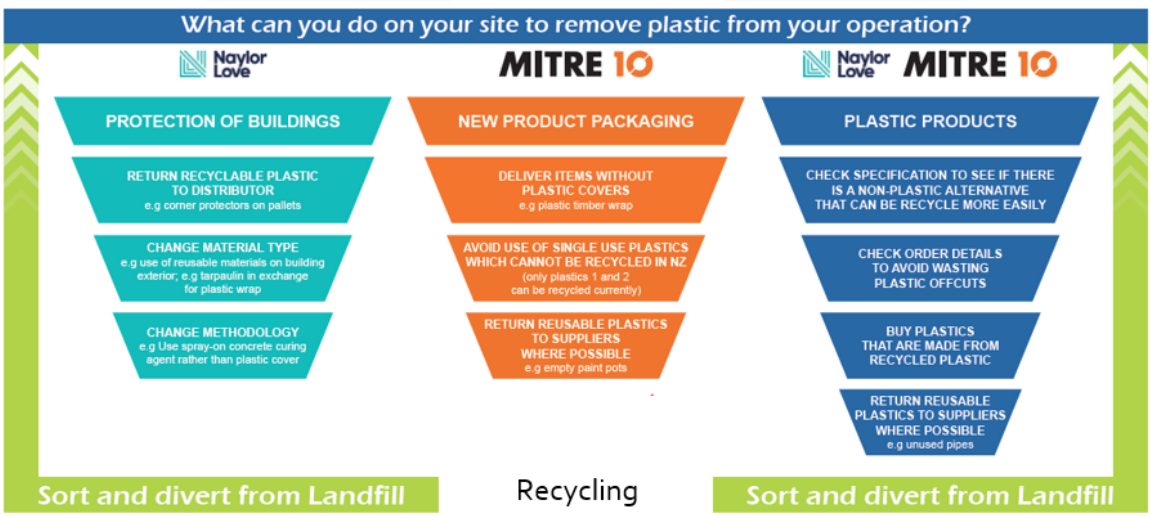


Figure 5: Poster prepared for training purposes by the construction company in collaboration with others in the pilot study project team

In addition and very recently in 2021–two significant and direct impacts of this collaborative academic - industry research have emerged. Firstly, a series of sponsored reusable tarpaulins have been designed and launched, and are in use by the construction company to avoid/mitigate the use of plastic packaging of materials (timber in particular) from the supply source to their construction sites (refer Figure 6 below). Secondly, the academic-industry partnered team won the highly commended Tamaki Makaurau (Auckland) Community Collaboration Zero Waste Award on 29 July 2021 for this academic- industry partnered pilot research, and the notable impacts being evidenced in the city's C&D sector.What has also been obvious is the influence and impacts a team of industry partners and academic researchers can achieve in a small way initially, through shared networking, getting the word out there via various media, construction companies and materials producers, and suppliers in particular. As a result, this pilot study could and is already leading to further innovations and increased levels of landfill diversion of plastics being realized.

Figure 6: Tarpaulins now in use from July 2021 for timber and materials delivery to the construction company's sites

Conclusion and recommendations

The practical implications of the pilot study as already noted has included the following :

-have established the predominant types of plastics whether packaging, building protection or products, and the scientific nature of the dominant plastics found during the two audits on the three pilot study construction sites,

- the production of training and information posters on waste management and separation processes, and why its important - for all on-site and off-site construction and supply chain company staff,

- the design and recent trial of permanent plastic collection bins rather than the usual bags,

- newly launched reusable tarpaulins for timber deliveries to Naylor Love's construction sites,

The rationale and aims of this pilot study have been met, exceeded and expanded as momentum grew over the last eighteen months in the pilot study team members and related networks. All this despite co-mingled wastes at times as well as earlier noted and the limitations of the L4, and L3 Covid total lockdowns, closing down construction sites and supplier operations for several months in 2020.

From the current findings, it is recommended that a future research project will involve examining a single commercial scale construction project, across all of the construction stages till completion. This approach would provide a more diverse yet in-depth level of comparative data, that could assist in demonstrating the connections between every construction stage, and the associated plastic waste types, predominances and quantities by volume and/or by mass. The 'take-back' of plastic materials /products produced by the original manufacturers' is another important area of investigative research work that a few companies are implementing here, with the aim of minimising plastic waste, recovering the plastic products to be recycled and diverting plastics from landfills.

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