A Conceptual Framework to Investigate the Adoption of On-Site Waste Management Innovation in Australian Building Projects

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Abstract--**Building waste accounts for over half of the solid waste generated worldwide and has an environmental impact on all stages of the building process, including raw material extraction, manufacturing, transportation, construction and disposal. The recycling and re-use of Construction and Demolition (C&D) waste in Australia is currently below optimal levels and the industry faces ongoing barriers to improvement. Ideally, the industry needs to put greater attention on innovative on-site waste capture and segregation practices, including on-site processing technologies that offer significant benefits, particularly in reducing transport requirements and associated environmental impacts. In order to establish a starting point for empirical research into this topic area, this paper outlines the results of an early review of the literature about on-site waste management innovation and proposes a conceptual framework to be used to investigate the behavioral intentions influencing relevant innovation decisions in building construction projects. To interpret the behavioral dynamics of project-based organizations within the C&D waste management innovation system, a novel conceptual framework is proposed that integrates two key behavioral decision-making theories; Innovation Diffusion Theory (IDT) and Theory of Planned Behavior (TPB). The proposed conceptual framework provides a sound basis for a large scale empirical study of on-site waste management innovation adoption on Australian building projects.**

I. INTRODUCTION

Effective product, process and/or system innovation adoption on construction projects can result in improved program performance, decreases in cost and potential improvements in the quality of project outcomes [25]. In response to the challenges of environmental sustainability, global experts have called for greater investment in innovation aimed at reducing whole-of-life building energy consumption, in light of estimates that greenhouse emissions from buildings can be reduced globally by 30% at no net cost, by 2020 [16]. Similarly, the World Building Council for Sustainable Development has singled out the construction industry as critical industry where 'large and attractive opportunities' for improvement exist, given an appropriate investment in innovation [35]. Certainly within Australia, recent government policy has emphasised the need for greater innovation and environmental sustainability to align with global expectations [20].

Technological and process advances in on-site separation of Construction and Demolition (C&D) waste offer reduced contamination by capturing and segregating materials for effective processing, while on-site re-use through systematic deconstruction techniques enables greater recovery of material resources [4]. Compared to conventional C&D waste disposal methods, there is the potential for greater than 90% of building recycling to be routinely achieved if supply chain organisations give priority to waste recycling measures [6].

Despite the potential of waste management innovation, recycling and re-use of C&D waste in Australia is currently below optimal levels and the industry faces ongoing barriers to the greater re-use and recycling of C&D waste. To address this challenge, requires greater attention to innovative on-site waste capture and segregation practices and on-site processing technology that offer significant benefits, particularly in reducing transport requirements and associated environmental impacts.

Previous research has identified negative practitioner attitudes as a key barrier to C&D waste recycling and re-use [33], [37]. However, there remains little research conducted into how practitioner attitudes may influence C&D waste management behaviour from a construction project perspective. This paper is the result of the first stage of a project, involving an early literature review and development of a conceptual framework that will be used to guide the first stage of the research. This research builds upon the global literature emphasising the specific need for further research into understanding practitioner attitudes towards C&D waste re-use and recycling [33], [37]. This is an under-researched area with only three articles investigating human-related factors in C&D waste management published in construction-related journals since 2001, according to a recent meta-analysis [37]. Reluctance from project-based construction practitioners to implement waste management strategies is driven by misconceptions around the value and ownership of C&D waste recovery, 'with many contractors feeling that waste management falls outside of their core responsibilities' (p.21) [5].

The research proposed in this paper focuses on the key beliefs that underpin effective on-site C&D waste management behaviour across the supply chain. To do so, the building supply chain is conceptualised as an Open Innovation System, which is extended by applying an adapted Project Based Product Framework to define the C&D waste management context, and Innovation Diffusion Theory and Theory of Planned Behaviour to explore the decomposed beliefs and behavioural intentions of system participants and subsequent adoption behaviour within this context. The following section discusses the nature of the construction industry that is characterised by a fragmented project-based supply chain and its impact on innovation; as background to the proposed research.

II. CONSTRUCTION INNOVATION

The study of construction innovation remains an important topic for researchers, as innovation is recognised as an essential survival trait for construction organisations [10], placing greater strategic emphasis on purposefully managing innovation development [11], [29]. In light of increased global competition, construction industry firms are striving to maximise innovation opportunities which offer more effective ways to compete and secure greater market share. Despite the ever growing need to systematically capture and promote innovation opportunities within the construction market, there remain significant and well-documented barriers to innovation at the project level [3]. These barriers relate to the highly complex and unique multi-firm production model for construction project delivery. This model is characterised by a fragmented market structure, typically resulting in disjointed relationships across project networks [31]. However, it is also characterised by highly interdependent project outputs.

Under these conditions, promotion of construction innovation requires a clear understanding of key organisational barriers constraining uptake. However, construction project-based organisations face inherent difficulties in innovative knowledge sharing and benchmarking global best practice [25]. This organisational dynamic has resulted in negative perceptions towards the value of innovation despite persisting regulatory intervention. National and global innovation studies have indicated that regulation should be undertaken alongside policy responses aimed at encouraging more positive attitudes to innovation [21]. Similarly, recent sustainability management research has called for greater emphasis on improving the processes that support the introduction of sustainability technologies, not only to be driven by market demand but also mediated by the vested interests of a wide range of industry stakeholders [27]. By encouraging more positive attitudes towards innovation and addressing underlying problems of conservatism, performance improvement across the project-based construction supply chain can be achieved.

III. C&D WASTE MANAGEMENT INNOVATION

C&D waste management has received significant attention in construction and engineering literature over the last ten years e.g. [18], [30]. This research has emerged as a result of general consensus that the global construction industry generates unacceptable levels of solid waste in the consumption of natural resources, materials and energy [36]. In an aim to minimise environmental impact and increase resource efficiency of the construction industry, research attention has been directed to three key areas: C&D waste reduction, re-use and recycling [36]. C&D waste is unavoidable, but C&D waste re-use strategies offer significant potential in decreasing disposal rates, due to the minimum processing required in the recapture of embodied energy [22]. C&D waste re-use can be broadly categorised into (1) rejuvenating a material or product for a similar function in a new way [17], or (2) new-life re-use where a base material or component is reconstituted for a completely new function [8]. If the C&D waste cannot be re-used on site, recycling strategies allow the reprocessing of waste into new materials, which would otherwise be dumped to landfill [30].

At an industry level, two long-standing issues for the construction industry in Australia and other developed countries are lacklustre innovation activity coupled with environmentally unsustainable practices. For example, in Australia, the C&D waste stream produces the highest tonnage of waste in comparison to all other waste steams (Municipal Solid Waste and Commercial and Industrial Waste) comprising 18.2 million tons produced nationally in 2010-11 [15]. Of this material, mixed C&D waste represents the majority of waste that is disposed to landfill, emphasising a need to improve on-site separation/reprocessing and minimise waste contamination [7].

Innovation in on-site separation, processing and re-use of C&D waste offers significant social, economic and environmental benefits over traditional methods, including reduced transportation requirements [15]. Advances in on-site separation can reduce the contamination of building waste by capturing and segregating materials for effective processing, while on-site re-use through systematic deconstruction techniques enables greater recovery of material resources, thus reducing the embodied energy impact of buildings. Despite research attention in developing strategies to reduce, re-use and recycle C&D waste, implementation of these strategies in practice have been limited [30], [37] resulting in the need for industry practitioners to better understand how the adoption of innovative waste management practices can be improved.

IV. CONCEPTUAL FRAMEWORK

To investigate these industry-wide problems and identify how to improve waste management practice in construction, this research conceptualises the building construction industry as an Open Innovation System, the aim being to interpret the beliefs and behavioural intentions of project-based organisations towards on-site C&D *waste recycling and re-use* innovation within the building supply chain. Open Innovation System theory usefully draws attention to the key feature of modern innovation processes – their openness to external ideas in the name of creativity, innovation and growth [13]. In the context of Open Innovation, a novel conceptual framework is proposed that combines: (1) Gann and Salter's seminal Project-Based Product Framework (PBPF) [12], treating it as an Open Innovation System (OIS) in a project-based environment, as typified by the building construction industry, with; (2) Innovation Diffusion theory

(IDT) [23] and Theory of Planned Behaviour (TPB) [1], which together provide a nuanced theoretical framework for understanding innovation behaviour and decision-making by individuals and groups in building construction projects. Each of these theoretical contributions is now discussed.

Project-Based Open Innovation System (PBOIS): Gann and Salter's seminal Project-Based Product Framework (PBPF) [12] is adapted and treated as an Open Innovation System (OIS) [13], [26] to provide context for the study. This adaption accounts for the key players and dynamics associated with construction waste production and management. The relationships between stakeholders and their reliance on one another are emphasised to source external ideas for innovation. This extended framework provides a rich context in order to interpret and assess the beliefs and behavioural intentions of organisations within a project-based open innovation system. C&D waste reprocessing firms are uniquely positioned in the PBOIS; these manufacturing-based organisations interact with project-based organisations (e.g. contractors and consultants) at both the end of a building lifecycle i.e. at demolition stage (purchasing sorted C&D waste) and in design and construction stages (sale and integration of recycled materials/products). The inclusion of the C&D waste reprocessing firms adds an additional dimension to the innovation system, as they potentially act as key knowledge brokers in the diffusion of C&D waste management innovation in both design/construction and demolition/disposal stages. This is the first time the PBPF or an OIS has been used to frame the activities and participants in C&D waste management.

Innovation Diffusion Theory (IDT) and Theory of Planned Behaviour (TPB): To interpret the beliefs and behavioural intentions of project-based organisations within the C&D waste management innovation system (as defined by the PBOIS), two key behavioural decision-making theories, TPB and IDT, are employed. TPB is a well-known behavioural theory that hypothesises actual behaviour as a direct function of behavioural intention, as the weighted sum of attitudes, subjective norm and perceived behavioural control [1]. TPB is one of the most influential and commonly employed theories to explain intentions to use new technology [19]. Despite the usefulness of TPB as a foundation theory to explain behavioural intentions of construction practitioners [33], it is contended that a decomposition of attitudinal drivers is required to better understand the relationship between antecedents of intention and relationship between attitudinal structures towards innovation adoption [32]. Thus, key innovation characteristics that influence adoption attitudes drawn from IDT [23], are integrated and combined with TPB to improve its explanatory power within an innovation system context. The integration of TPB and IDT has been empirically applied in previous information technology innovation studies [28]. This is the first time this integrated model is considered to explain innovation adoption behaviour in the construction industry, and in the context of the C&D waste management innovation system.

The proposed PBOIS is shown at Figure 1. The open innovation knowledge links are represented as arrows in the model. Although the research focuses on project-based organisations, it is proposed the roles and influences of the supply network (e.g. manufacturers and waste re-processors), building clients and end users, the technical support infrastructure (e.g. research and development) and the regulatory and institutional framework (e.g. state and local government regulators) on innovation adoption decisions should also be explored.

In addition to using the PBOIS to interpret the C&D waste management context, the underlying antecedents of innovation adoption behaviour by project-based organisations are explored using an integrated IDT/TPB model (Figure 2). Variations of this integrated IDT/TPB model have been applied to explore user intentions to adopt technology in the area of information technology [28] and marketing [32].

As illustrated in Figure 2, IDT (innovation specific) contributes to the broader TPB constructs where IDT can usefully be integrated to inform the antecedents of potential adopter *attitudes*. According to the model, behavioural intention is then a function of attitude, subjective norm and perceived behavioural control. The actual behaviour of project-based stakeholders to adopt innovation is a direct function of this behavioural intention.

As a decomposition to the traditional TPB, the drivers of attitude (or a predisposition towards a behaviour) are considered through three salient innovation adoption characteristics: *relative advantage*: the degree to which innovation is perceived to have significant advantage over alternatives; *compatibility*: the degree to which innovation is perceived as being consistent with existing values, past experiences and current needs; and *complexity*: the degree to which innovation can be readily understood and applied. Subjective norms are also predictors of behavioural intentions and refer to influences of social pressure, particularly pressure applied by important people (or groups) and motivation to comply with such pressure (referred to as *normative influences*).

Finally, perceived behavioural control, as a predictor of intention, focuses on both internal and external factors that influence the perception of control over behavioural outcomes. Uniquely, the dimension of *organisational efficacy* is included as an antecedent to perceived behavioural control. Organisational efficacy can be defined as informed members' (e.g. managers) perception of the higher order functional capabilities of an organisation [34]. This is an important antecedent to perceived behavioural control in project-based organisations due to the collaborative nature of collective project outputs. Shared perceptions of conjoint capabilities across an organisation define opportunities available to perform a particular behaviour (innovation adoption). In addition to organisational efficacy, *facilitating conditions* are used as an antecedent to perceived behavioural control. This

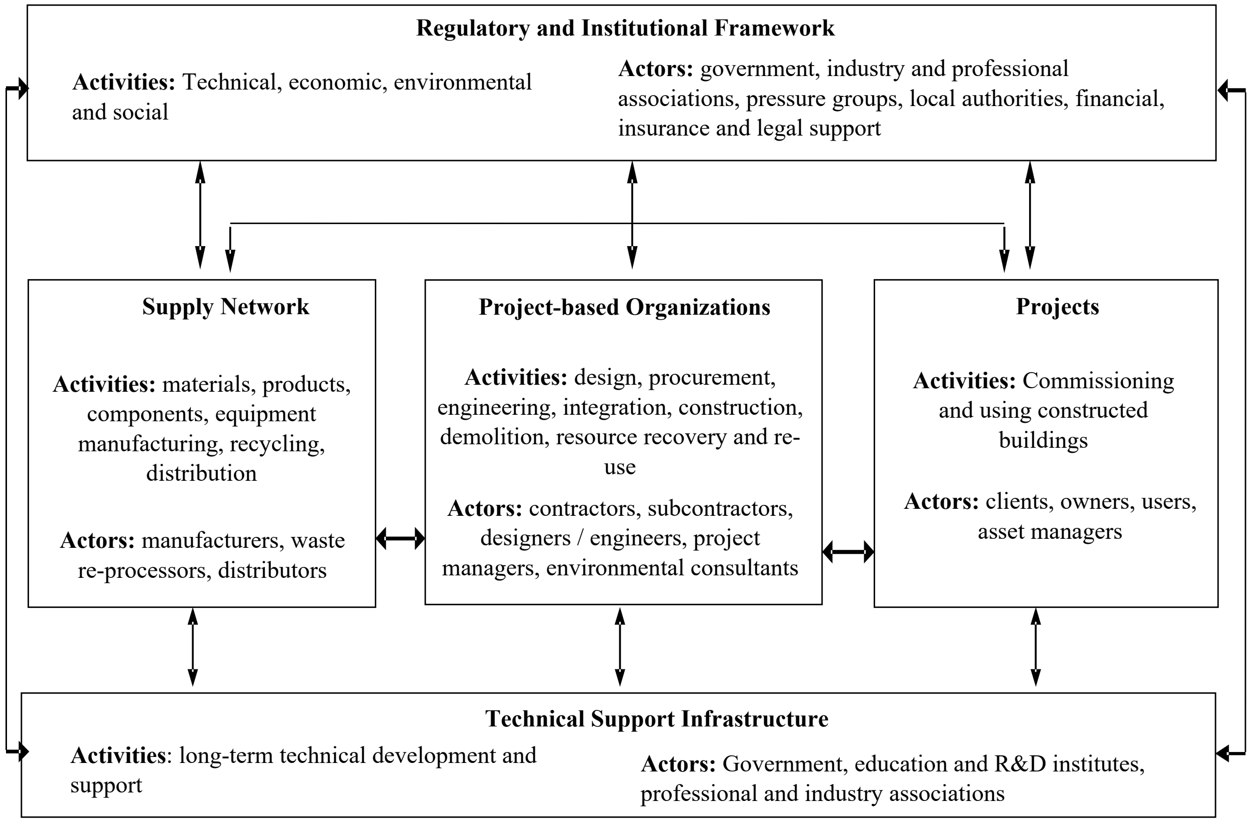

Figure 1 Project Based Open Innovation System (PBOIS), based on Gann and Salter [12]

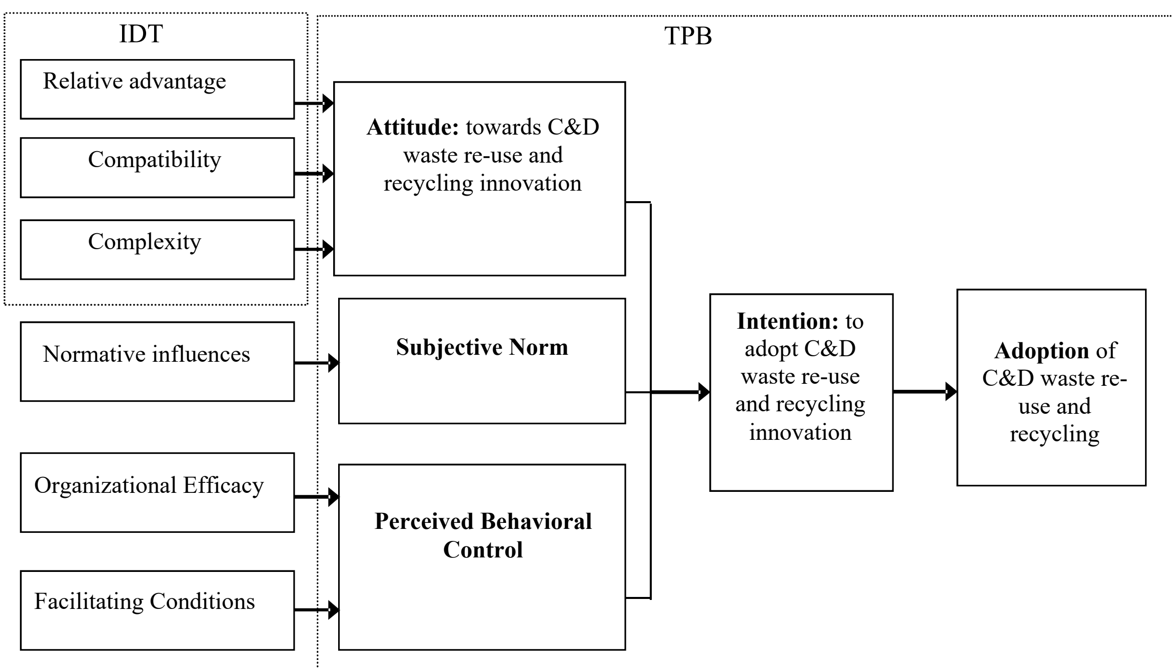

Figure 2 Innovation Diffusion Theory (IDT) and Theory of Planned Behaviour (TPB), based on Shih & Fang [28]

relates to the availability of resources to affect behaviour such as time, money or technological infrastructure, whether internally generated or defined by external factors such as government recycling incentives or regulatory influences.

V. THE PROPOSED STUDY

Drawing upon the conceptual framework presented in the previous section, future research is proposed to empirically: (1) map the Australian on-site C&D waste management innovation system and adoption behaviour; and (2) measure the behavioural intentions to adopt. Each stage is now discussed in detail.

A. Mapping of the on-site C&D waste management innovation system and adoption behaviour

There is currently no comprehensive data on the innovation system characteristics of on-site waste re-use and recycling in Australia. Research is required to provide a more refined understanding of the innovation system supporting the adoption of innovative on-site waste management initiatives. In the proposed work, on-site C&D waste management innovation can be categorised into: 1) process and technological innovations in the capture and segregation of C&D waste on-site; 2) advanced fixed or mobile on-site reprocessing technology for material and product reprocessing; or 3) new processes or technology in the on-site re-use of waste materials and components. Using the PBOIS as the conceptual frame will provide a detailed explanation of: 1) the characteristics of these innovations, 2) the interrelationships across innovation system activities and participants, and 3) current adoption behaviour including the beliefs of key stakeholders in the C&D waste management innovation system. This will also include the identification of regulatory, economic, organisational obstacles currently constraining adoption from key stakeholders' perspectives.

To do so, the researchers will conduct inductive semi-structured interviews with selected representatives across six key sectors involved in the C&D waste management stream in Australia: (1) clients, (2) managing contractors, (3) subcontractors, (4) consultants, (5) waste re-processers and (6) material manufacturers. Interviewees across these six key sectors will be purposefully selected based on their level of experience and understanding of C&D waste management practice in the building industry. The interviews will elicit salient perceptions of on-site C&D waste management behaviour (including adoption obstacles) and define the relationships across stakeholders in the supply chain, as conceptualised in Figure 1.

Taking an integrated, non-linear view of the supply chain will capture rich data about individual sector perspectives, and triangulate perspectives on innovation adoption behaviour across the six industry-stratified sectors. It is expected this will reveal the influencing stakeholder beliefs that currently constrain adoption behavior. A qualitative approach is proposed in order to explore in-depth the complex relationships and interdependencies within the innovation system. The similar use of a prior 'belief elicitation study' to guide follow-on quantitative surveying is also recommended by authors of TPB, Ajzen [2] and TPB research guidelines [9]. Content analysis is proposed to code the interview transcripts; NVivo software to classify, sort and arrange the data; and comparative techniques to draw out the most frequently occurring stakeholder perceptions which will inform the generation of measures for quantitative study of behavioural intentions to adopt.

B. Quantitative study of behavioural intentions to adopt

According to the Integrated IDT/TPB model, it is predicted that to increase adoption of on-site C&D waste management innovation, project-based organisational managers (as the decision-makers in this context) need to have a positive attitude towards the innovation, perceive support from individuals and groups around them; and control over the adoption process and outcome.

Drawing from the qualitative study results, a widespread industry survey will be conducted with senior representatives of their respective project-based organisations (as defined in Figure 1) to rate the strength of their agreement with statements about factors that may influence their decision to adopt on-site waste management innovation (including the perceived positive or negative inclination of factors impacting on adoption behaviour). Survey participants will also respond to the *likelihood* that their perceptions towards on-site waste recycling innovation would influence adoption behaviour and outcomes. Additionally, data on actual adoption will be collected and analysed as a retrospective activity measure according to the innovation characteristics.

While the PBOIS describes the context of decision-making around innovation adoption, the factors leading to those decisions are explored using TPB model. Thus, the specific attitudinal outcomes, key groups and contextual factors identified in the first stage of the fieldwork, will guide the development of survey questions. The survey questions will concern the measurement of the core TPB constructs, including intention to adopt a higher level of on-site waste management innovation, and the predictor variables of this intention. Description and rationale for the proposed questionnaire items is presented in Table 1.

It is proposed the survey sample will be randomly selected, but limited to senior managers at project level representing their respective organisations across the research population. Senior managers in construction firms can be viewed as 'key actors in a dominant coalition' and can have strong levels of autonomy in decision-making as representatives of their organisation in the project environment [24]. Therefore, the focus is on gaining insight into senior managers' 'intention to adopt' due to their significant influence on adoption decisions within a project-based organisational context.

TABLE 1 DESCRIPTION OF SURVEY CONSTRUCTS AND QUESTIONS

Construct	Question	Rationale
Business characteristics	Sector involvement/ function location of operation/ years of operation/ size of operation (employees/turnover)	Basic descriptive business characteristic data. Assess representativeness of sample to Australian sector distribution
Activity	Previous on-site waste management innovation activity	Previous behaviour as a predictor of future behaviour.
Intention and Willingness	Will firm use a higher level of on-site waste management innovation? If conditions were supportive, would firm use higher level of on-site waste management innovation?	Key outcome measure for the TPB including willingness to commit to behaviour if provided opportunity
Planning and Commitment	Commitment to and level of future plans to consider options, develop plans, put into action and commit longer term?	Additional outcome measure as 'plan of action' development as an indicator towards intentions to adopt and commitment to a behaviour
Contextualised TPB measures	Direct and Indirect measures of the underlying elements TPB constructs (contextualised from Stage 1 results):	Questions concern following TPB constructs: - **Attitudes** (IDT): likelihood of outcome, weighted by whether outcome is positive or negative in context of underling elements *Attitudes - relative advantage*: the degree to which the innovation is perceived to has significant advantage over alternatives; *Attitudes - Compatibility*: the degree to which the innovation is perceived as being consistent with existing values, past experiences and current needs; *Attitudes - Complexity*: the degree to which innovation is readily understood and the perceived complexity in application. **- Subjective Norm:** Approval of key persons/groups weighted by how much their opinion is valued (normative influences). **- Perceived Behavioral Control**: Degree of influence of contextual factors, weighted by their likelihood of occurring: *PBC - Organizational Efficacy*: degree of influence of higher order functional capabilities of an organisation and impact on innovation adoption *PBC - Facilitating Conditions:* level of availability of resources to such as time, money and degree of impact of external conditions (e.g. market)

Survey responses will be analysed to measure the impact of project-based stakeholders' attitudes, subjective norms and perceived control on innovation behavioural intentions. Thus, descriptive analysis of individual items that define the theoretical framework will provide a baseline to understand the relative impact of factors that influence respondents' decision to adopt on-site C&D waste management innovation.

Following univariate analysis of individual items, analysis of bivariate relationships will then be conducted to assess relative influence of particular factors that are perceived to impact on attitude, subjective norm and perceived behavioural control measures. Finally, multivariate analysis using structural equation modelling (based on the extended variable sets and related control factors) is proposed to indicate the efficacy of the model to explain the intentions of project-based stakeholders to adopt on-site C&D waste management innovation. The model is expected to have greater explanatory power than those currently in use, potentially advancing construction innovation theory.

VI. CONCLUSION

Building waste accounts for over half of the solid waste generated worldwide and has an environmental impact on all stages of the building process, including raw material extraction, manufacturing, transportation, construction and disposal [7].

The proposed research will build upon previous work in seeking to understand practitioner attitudes towards C&D waste re-use and recycling, and for the first time, proposes an integrated framework to explain on-site C&D waste management behaviour through an innovation system lens. It will focus on the beliefs and behavioural intentions of project-based organisations as the key actors in the adoption of on-site C&D waste management innovation.

The conceptual framework presented in this paper takes a different approach to the main construction innovation models currently offered, with emphasis on system-wide analysis of project-based innovation within the PBOIS. Existing models have tended to focus on a firm-level innovation management that has lacked explanatory power when dealing with the complexities of the traditionally fragmented project-based construction supply chain [14]. This allows the focus on a specific type of project-based innovation from an integrated system perspective, contextually tailored to the unique vertical and horizontal supply chain relationships within this system (e.g. inclusion of the waste reprocessing firms as a potentially critical knowledge link across project organisational boundaries). Drawing for the first time upon the integration of IDT and TPB as a lens to interpret the decision-making of project-based construction organisations in the PBOIS, the conceptual framework provides the foundation to derive a deeper and more finely-grained understanding of the determinants of innovation across complex construction supply chains than is currently possible, within the context C&D waste innovation.

There are formidable challenges associated with resource depletion that require greater attention to reclaiming the embodied energy of existing building stock, and decrease the energy required to construct new buildings though innovative waste management strategies. Despite significant research attention aimed at improving C&D waste management practices in construction, implementation strategies have been far from effective resulting in the unnecessary disposal of C&D waste to landfill. The future planned research will focus on the adoption of innovations that can potentially reduce the environmental impact of the Australian construction industry and re-capture the embodied energy of existing buildings and their materials through improved C&D waste innovation.

Although the conceptual framework is yet to be validated, it provides a sound basis for a large scale empirical research project of on-site waste management innovation adoption on Australian construction projects. By identifying the behavioural drivers to adoption, strategies can be proposed to improve on-site waste management practice in projects, and shed new light on the system supporting the adoption of innovative on-site waste management initiatives.

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