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Purpose of the Series

The aim of this publication is to provide an opportunity for students to publish the findings of their undergraduate or postgraduate work. Guidance on publication will be given by staff who will act as second authors. It is hoped that by providing a guided transition into the production of papers that students will be encouraged throughout their future careers to publish further papers. Guest papers are welcomed in any field relating to the Built Environment. Please contact E.A.Laycock@shu.ac.uk. A template will be provided on request.

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CONTENTS

CONSTRUCTION WASTE MANAGEMENT STRATEGIES ON LARGE RESIDENTIAL CONSTRUCTION

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Waste generation within the construction industry out strips all other waste going to landfill within the UK. Current rates of disposing of waste suggest that landfills are not the best way to solve this problem.
The research investigated site waste management strategies employed within the construction industry in a hope to understand ways in which one national house builder could improve its waste performance.
Literature suggests:
1) That focus on the construction phase of the project to limit waste can have partial success.
2) Focus given to the procurement and design stages of a development as ways to reduce the waste generation further would be a better solution
The study found overall that current waste management strategies employed showed little success.

Keywords: Site waste management plan, Construction waste, Hierarchy of waste

INTRODUCTION INTO WASTE WITHIN THE CONSTRUCTION SECTOR

Waste within construction has been identified as a source for concern with the construction industries heavy reliance on land fill as its main source for disposing of waste. Figure 1 was taken from the Department for Environment, Food and Rural affairs statistics on waste, it shows how much waste is generated by the Construction sector including construction, demolition, and excavation (C, D&E). The waste output of the UK construction industry dwarfs all other categories of waste generators, with the same theme in other developed countries such as Hong Kong, USA and Australia. These latter countries have introduced taxes and charges to try and persuade construction companies to develop more sustainable waste management policies (Poon, 2007). The negative effect of these charges is that larger construction companies have now entered into pay to

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recycle schemes with skip hire companies (Ajayi *et al.*, 2015). Along with the partnerships comes a reduced awareness of the impacts associated with poor waste management as the waste producers are distanced from the end result. The construction industry consumes larger amounts of resources due to the attitude/management of waste at site levels and the industries encouragement of a "take-make-consume-dispose" approach (Esa, Halog & Rigamonti, 2016). This is emphasized by the amount of material delivered to site which ends up as waste, Yahya & Boussabaine (2006) claim this to be up to 13% of all solid delivered to a construction site. Gavilan & Bernold (1994) identified poor waste management as being one of the main causes of waste generation, operatives' attitudes and awareness are also a key factor in waste generation as the operatives/contractor companies do not stand to lose anything for poor waste segregation.

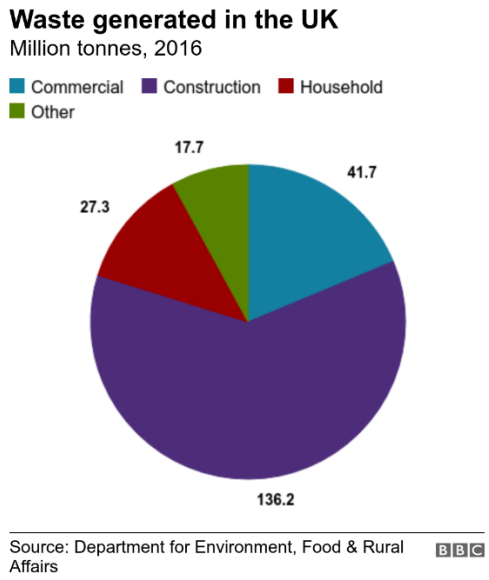

Figure 1 -Waste generated by various sectors in the UK (BBC News, 2019)

RESEARCH METHOD

This section outlines the rationale behind the chosen research method and identifies the primary data collection strategy employed

Data Collection Method

The survey collected quantitative and qualitive data from a population of 30 site managers and assistants. The use of a mixed method approach allowed the strengths of one research method to minimise the weaknesses of the other (Cresswell, 2014). The design of the survey was influenced by the issues raised within the literature review. The researcher gained further insight into these issues through the opinions of site managers within the case study organisation and particularly the North West. An information sheet and consent form were sent with the questionnaire invites.

Case study

A case study is "*a method used to understand a real-life phenomenon considering relevant contextual conditions"* (Yin, 2018). Case studies are used to answer questions

about current events, aiming to answer the "how" and "why" (Yin, 2018), before choosing a case study Tetnowski (2015) states the research question should be considered. Case study research works well with both data sets but is used more to collect qualitive data due to the fact it "*does not dictate a prescribed set of data collection and analysis methods; it works flexibly with an emerging data set and avoids methodological constraints that might result in a priori assumptions that create examiner bias*" (Tetnowski, 2015). Another advantage of the use of a case study is that it can capture the interactions between a person and a prescribed event, such as the disposal of waste when the incorrect waste skips are present. The sample site will be chosen at random from all sites failing to meet the group KPI on waste.

Sampling

To better understand the perceived drivers and barriers encountered when implementing site waste management, the entire construction department was invited to complete the questionnaire. The sample included senior site managers, site managers, assistant site managers and trainee site managers, all of which plan/enforce/police waste management on site to varying degrees. The sample was chosen due to their experience with site waste and their direct control over its production, with a research subject which can provide an insight by "virtue of experience" (Neuman, 2011).

Coding

The purpose of coding is to reduce the large number of individual answers to a few general answers, or categories which can be given a numerical code, which is then used to display the data on a graph or chart (Naoum, 2007) the code will be "open" with common themes being identified and then displayed as bar charts for further analysis.

Questionnaire design

The questionnaire is used to 'grab' large amounts of data in a passive way (Farrell, 2011). With limited time to collect data, the researcher used the questionnaire to collect data from the site managers within the North west division. The questionnaire was designed to collect the knowledge and experience of the site managers in a descriptive way. The questionnaire is structured and based upon the findings of the literature review.

Sections of the questionnaire

Section 1 – has 2 questions which gather information about the participants their and job role within the division.
Section 2 – the 4 questions in this section focus on collecting the experiences of the managers and their attitudes towards waste management on site.
Section 3 – 10 questions aimed at establishing the site managers' knowledge of site waste management across the industry and within the case study company.

Measurement scale

Section 1 – mainly quantitative data collected and presented as a nominal scale, 1 open ended question which will be coded.
Section 2 – Quantitively data collected and presented on a nominal scale
Section 3 - Quantitively data collected and presented on a nominal scale.

Pilot study
Piloting a questionnaire helps to provide clarity and validity to the design (Creswell, 2014), what may seem clear to the researcher may not be clear to participants (Farrell, 2011). The pilot study will enable the researcher to gather feedback regarding response times, question design, clarity of questions and layout of the form used.

LITERATURE REVIEW

This section reviews current literature appertaining to the construction industry in relation to government waste statistics and key academic research

Recycling

95% of all the company's construction waste is diverted from landfill and recycled; this is achieved using an offsite sorting method. Although a large amount of waste is recycled the consumption of virgin materials largely offsets the benefits to this approach. The company's reliance on offsite sorting/recycling methods has allowed the workforce - including site management - to take a lax approach to on site waste segregation. Poon, Yu & Ng (2001) conclude that the construction industry is reluctant to take up this type of onsite sorting method and that only by increasing taxes and charges or inserting terms and conditions into contracts will we get the construction industry to accept this method. Kartam *et al.* (2004) cite a number of benefits which recycling materials could offer such as (1) reducing the demand for new resources; (2) cutting down on transport and production energy cost; (3) utilizing waste which would otherwise be lost to landfill sites; (4) preserving areas of land for future urban development; and (5) improving the general state of the environment, all of which should seem enticing enough for the construction industry to buy in to.

A down fall of on-site recycling/sorting is that all waste materials require correct segregation prior to sorting, any contaminated waste would still have to go straight to landfill (Shen *et al.*, 2004) thus defeating the objective of implementing such a strategy. Management buy in from a senior level is critical if waste management strategies are to succeed, as company attitudes radiate from the top down. Senior management are also seen to be more focused on the initial costs of the set up rather than the long-term cost saving of such a method (Shen & Tam, 2002). Wang *et al.* (2010) completed a survey of construction sites in Shenzhen, China which concluded that construction operatives found better management to be a key factor of the implementation of the on-site sorting of construction waste. It should be noted that currently the company in the study runs no specific training for, or around the subject of, waste management, with the closest course being Environmental awareness which covers issues more closely associated with environmental breeches rather than waste reduction. If middle management were brought up to speed on the site waste management plan/process of the company then it could see significant savings in its waste handling charges with "*up to a 50% cost savings for waste handling charges, 15% volume reduction of waste generation prior to recycling on site, and 43% waste reduction for landfill*." (Mcdonald & Smithers, 1998).

Material re-use

Material re-use is where the discarded product is used in its current form (Ajayi *et al.*, 2015). The waste produced would require less handling once produced, for example soft timber off cuts could be used as supports or "noggins" within the next first fix. This is echoed by Saunders & Wynn (2004) who state that workers attitudes lean towards using materials more efficiently rather than sorting the waste materials afterwards. This attitude was influenced by the effect on their priced works concurring with the view of Ajayi *et al.*, (2015) that "financial gains associated with the strategies usually influence the industry professionals".

Design out waste.

The design stage is a critical part of any project, this area has a huge impact on the scale of waste within a project. If construction companies could design out waste it would remove the need to create and establish waste management strategies to treat the waste created Faniran & Caban (1998). This would seem a more logical approach than any other discussed within this research, a consensus in the literature has been reached that improper design vastly contributes to the increase in waste on construction sites (Ekanayake and Ofori, 2004).

Waste prediction tools come into use at this stage, NetWaste and DOWT-B/DOWT-CE are the main waste prediction tools used within the UK industries. NetWaste is "The NW Tool has been designed as a series of simple web pages that enable the user to enter information on their project and the materials they are intending to use and then to carry out analysis on both waste management and recycled content." ("WRAP NW Tool", 2018). Designing houses to allow the use of full materials such as designing to "gauge" when looking at brick work openings would reduce the number of cuts needed to build a house. Saunders & Wynn (2004) also point out that poor designs of projects result in excessive off cuts. The organisation has made valid attempts to combat this type of waste stream production by reducing plasterboard sizes to fit all standard ceiling heights within the company's house types this will reduce the number of off cut waste plasterboard generated per house, not only saving the company money on disposing of the waste but also the contractor because less plasterboards will be required per house.

Waste efficient procurement

Literature surrounding the subject of procurement as a way to minimise waste generation has had less focus than the construction and design processes (Ajayi *et al.* 2017). There have been a number of studies undertaken which suggest the ineffective coordination of materials procurement as a major cause of construction waste (Formoso, *et al.*, 2002). Procurement measures as a whole has remained largely unexplored within academic research. The study organisation has a sustainable waste policy which dictates criteria to the supply chain. The main aim is to gain certification to ISO14001. Material suppliers have been identified as key stakeholders within the construction industry (Ajayi, *et al.*, 2017). As a key stakeholder they play an important part in the minimalization of construction waste. Excessive materials/poorly coordinated procurement can lead to materials being poorly stored on site, risking breakages a need to order replacement

items. Ajayi *et al.,* (2015) argues that material suppliers who can deliver small quantities of materials as often as required would help reduce the problems caused by traditionally long lead times for items and the refusal to push them back in fear of missing a potential delivery date. Part of the procurement process is the delivery of materials to sites, most products are placed onto a pallet, wrapped and then sent out for delivery on a lorry. It is this process which needs to be managed, as loose items can break during the delivery to site and excessively wrapped products will inevitably add to the waste produced (Oyedele, *et al.,* 2013).

Legislation

Legislation should be used to enforce greater change within the construction industry, yet each act is used more as a nudge in the right direction and not a push. It is understandable that the Government will act accordingly with public views on the issue (Ajayi *et al.*, 2015.) and with greater awareness of issues such as climate change public opinions are changing towards more sustainable options and as such the Government may be forced to act.

Waste procedures of the Organisation

Site waste management plans are a standard protocol across all sites within the company. All sites follow the same plans and are structured to group standards. The use of colour coded skips to depict which waste stream they are used for, site signage above larger skips to remind the telehandler which skip is used for which waste stream. During all inductions on site a flip chart is used to illustrate site rules and protocol, waste segregation is covered during the site induction, this includes informing the operative of the above skips and which waste streams are allowed on site. RFI (Request for information) forms are used when a design error appears on site, these forms are critical as they allow drawing errors to be identified and addressed at group level. Site teams fill the details of the error and the drawing house type or revision and send it directly to a group contact.

Critical analysis

Waste management strategies focus on the construction and design phases of a project with a greater emphasis on construction. With little focus being given to the creation of waste and mainly dealing with waste after it is produced (Ajayi *et al.*, 2015). It has been accepted that waste will be produced, and it is how we deal with waste that is the focus, re-using waste is the preferred option within the literature, with the use of onsite recycling facilities being the ideal way to sort the materials ready for re-use, Teo & Loosemore (2001) and Poon *et al.* (2001) clearly state the barriers to onsite recycling being implemented are the demands of site space, labour and initial cost of the set up. Although operatives on site would potentially be more open to using recycled materials as opposed to having to segregate waste streams themselves (Saunders & Wynn, 2004). The design process plays a key part within the minimalization of waste generated on site, with a greater focus being put upon the process by researchers within the industry. Faniran & Caban (1998) believe that the correct design would eliminate waste and in doing so remove the need to design waste strategies. The least focus is given to the procurement of materials as stated earlier. The literature focussed on the idea that supplier/vendors are

key stake holders and should be treated so, with partnerships that benefit both parties being established such as take-back schemes. The critical nature of the policies and procedures implemented at the construction phase of a project to deal with waste was stressed. The resistance to use of modular construction as a whole throughout the residential construction industry means that the onus is put on the fixing/assembly of items on site, which leads to damage of key components due to mishandling, storage and weather. The literature sheds light on the potential benefits of all the waste management strategies and also points out the reluctance of the construction industry to adopt new ideas. A company can stand to gain financial benefits from an effective implementation of the correct waste management strategy, whilst also protecting the environment and raising its own public image (Yuan and Shen, 2011).

RESULTS

Questionnaire to site management
Section 1
Objective –

This section aimed to collect the site managers attitudes towards waste on site, what affects it and if they place a value on the running of an efficient waste management strategy.

Question 1 – Current position held.

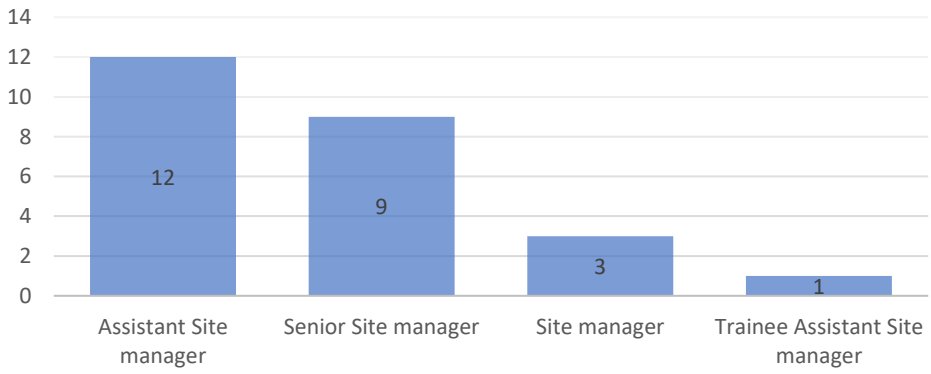

Figure 2 – Job role within the division.

Figure 2 shows the participants current job role within the North West division.

Comments –

1. This data will allow the researcher to separate the answers of senior management from those of the junior management and analyse the buy in/attitudes towards waste from both groups. This follows on from comments from Shen & Tam (2002) about management buy in from senior levels.
2. There is roughly an equal split between senior management (senior site managers 9 and site managers 3) and junior managers (assistant site managers 12, trainees assistant site managers 1).

Question 2 – What proportion of your working day is spent checking/planning/enforcing your site waste management or waste segregation policy.

Participants were offered a multiple-choice question with five options ranging from all to none of the day.

The bar chart in Figure 3 show the demographic split between senior and junior management and their answer.

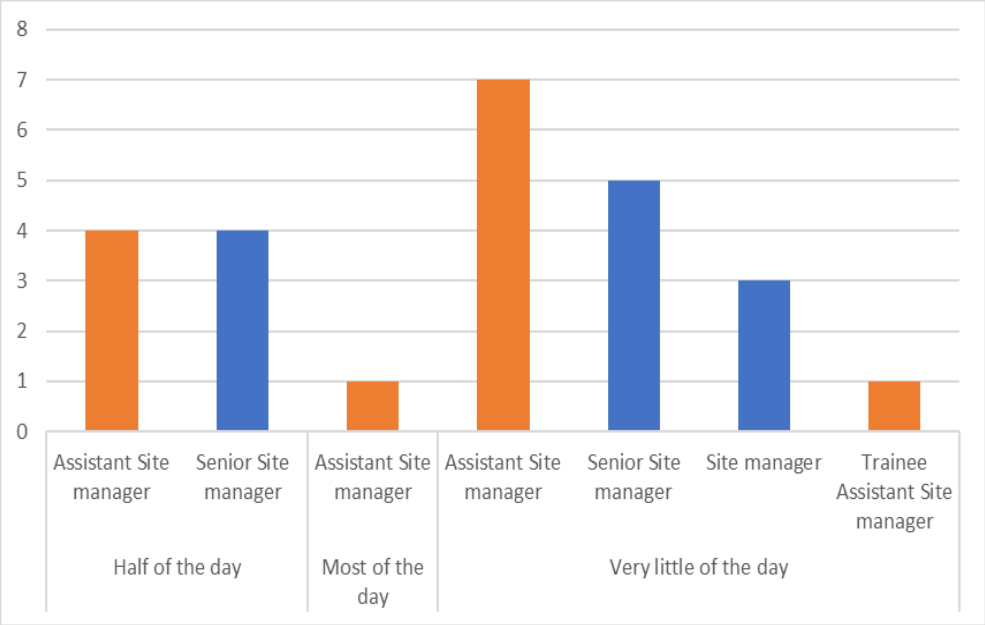

Figure 3 – Allocation of time for site waste management.

Comments –

1. Lingard, Graham & Smithers (2000) suggested that managers placed little value on site waste management. The data shown above would suggest that a high number of managers within the division spend little time on site waste management and allocate their time elsewhere.

Statistical analysis showed no significant difference between experienced managers and less experienced managers and the time priority afforded to waste management.

Question 3 - Which one of the issues below do you consider the largest influence on the performance of a site waste management programme?

Participants were offered 6 options which were management buy in, operatives' attitudes towards waste, time restraints, Equipment or facilities, production timescales and lack of accountability. These options were chosen from the literature review as some of the key factors which can hinder the success of a site waste management plan.

Figure 4 shows the factors that influence waste according to site management.

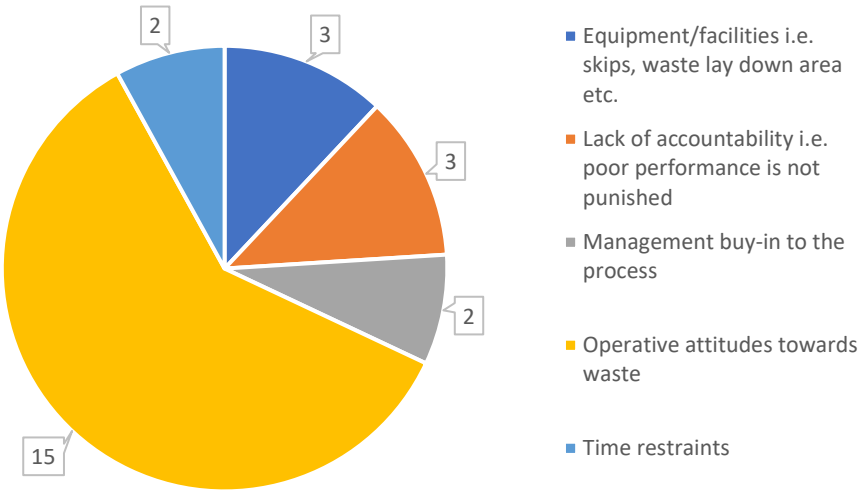

Figure 4 – Influences on waste

Comments –

1. The data would suggest that from the point of view of a management team that operatives' attitudes towards waste management are seen as having a large influence.
2. According to the data, site management spend very little time on site waste management as an activity and blames operatives for poor performance.
3. The exclusion of "other" as a viable option may have pushed participants towards choosing an answer, so could have affected the results.

Question 4 - Please expand on your answer to the above

The participants where then asked to expand on the answer they gave to question 3, a coding system was used to analyse the data from the open-ended responses.

Table 1 shows the coding used to produce Figure 5.

Comments –

1. Site managers identified that subcontractors and attitude were the largest factors to affect site waste management, these factors could be down to blame apportioning from the site management teams. With little time or value devoted to the site waste management from the site management teams (as suggested in questions 1 and 2) operatives may not be aware or policed on their actions.
2. Operatives were identified as the root cause for poor site waste management, this was discussed by Gavilan & Bernold (1994).

Table 1-Coding values

Common theme	Quantity	Code	Code cause	Quantity
Education	5	3	Internal issues (1)	14
Subcontractor/contractor	9	2	Planning (2)	12
Attitude	8	1	Investment in training (3)	5
Site team	3	2		
Time	3	1		
Pressure	3	1		

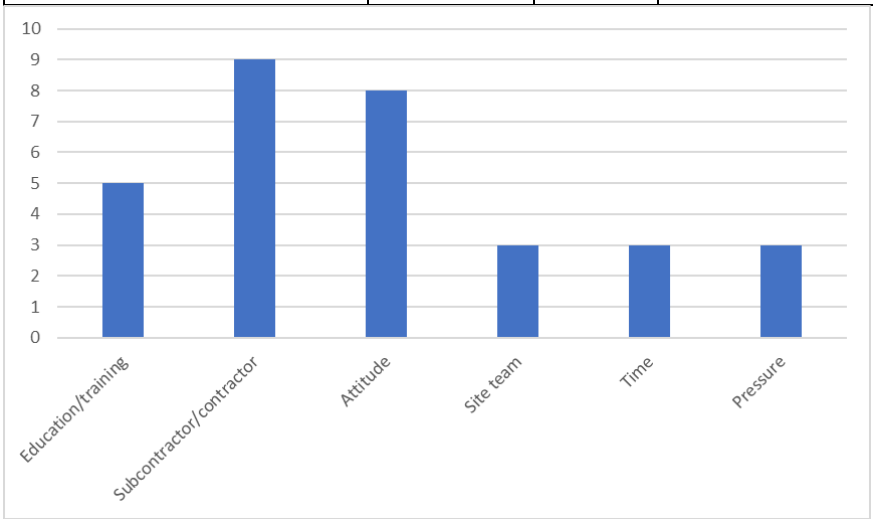

Figure 5 – Common themes for open ended question.

Question 5 - Do you consider waste segregation a priority within your daily tasks?

Participants were offered a dichotomous question with yes or no answers (Figure 6).

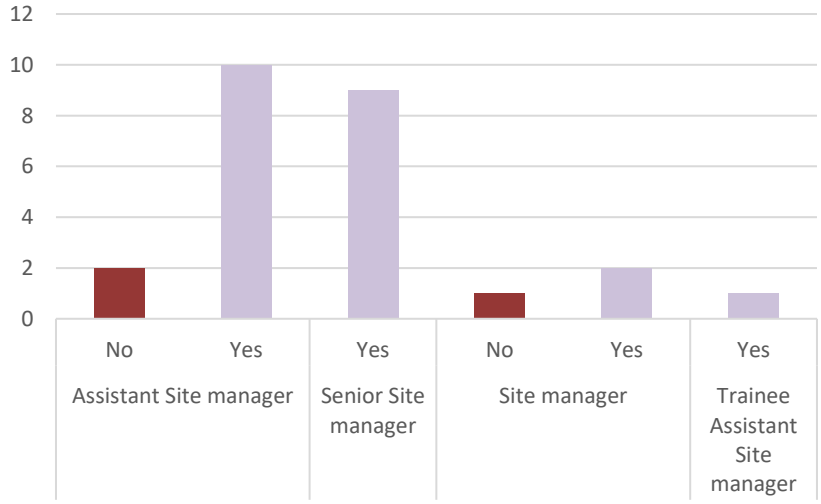

Figure 6 – Importance of waste segregation

Comments –

1. 22 site managers across the division placed site waste management amongst their priorities for the day, this attitude conflicts with the lack of time spent on it (question 2) and the figures discussed which show nearly every site within the division has not met the KPI.
2. The data suggests that there is a consensus that site waste management is a priority across the division's site management.

Statistical analysis shows that there is no significant difference between experienced managers and less experienced managers and the priority afforded to waste management within their daily routine.

Case study

Introduction

The literature demonstrated that a high percentage of all solid material delivered to sites, ends up as site waste. This is due to several factors such as storage, handling, early delivery times and movement of materials on site. The poor performance of construction sites and their site waste management strategies discussed in formed the basis of the investigation of the selected site known as 'Site alpha'. Site alpha was chosen at random from all sites failing to meet the required KPI waste target, the investigation aimed to observe site practises, operative's involvement with waste and site facilities for materials and waste.

Waste management practises on site

During a 3-month period site alpha was visited and observed by the author twice a month, will full knowledge of the site team. Site alpha had a designated waste area and compound, site signage was visible to operatives above skips (see Figure 7). The use of colour coded signs above skips is intended to help with waste segregation and all operatives are briefed on the practise upon induction to the site. it was observed that colour coded skips were in place but not being used correctly. Waste within the skip (Figure 7) was of the wrong type as the sign above the skip is for active waste and not wood, additionally pallets are not meant to be disposed of in a skip as the company runs a pallet collection scheme. Operatives were seen mixing waste within mini skips and the forklift truck driver emptied the mini skips into the 16-yard skips thus contaminating the entire waste stream. Figure 8 is another example of the contaminated waste streams on site. This skip was allocated for plaster board waste, but now contains paper, plastic, brick and wood.

Poor material storage around site accounted for a number of items becoming damaged and then being thrown away and re-ordered, something which could easily be avoided by providing the correct storage area for the materials, managing the delivery schedule of the items and treating materials with care once they arrive to site, something which both direct and indirect labour seem disengaged from. Figure 9 shows materials being poorly stacked in storage; in the picture the timber shown is a truss ladder leaning on top of cast stone cills. Both have excessive lead times and damage to delivered materials could potentially push the project back by some time. Further materials were found to be stored

incorrectly as shown in Figure 10, whereby a large number of GRP components have been stacked on top of each other next to a scaffolded plot.

Figure 7 – Waste signage

Figure 8 – waste contamination

Figure 9- material storage

Figure 10 – GRP storage

Evidence from the primary data has indicated that poor waste management strategy adherence has allowed the operatives on site to mix waste streams with little regards shown for the consequences. The research also suggests that a blasé approach from the site team towards the enforcement of such strategies has not helped the matter, with a lack of or no material call off monitoring observed with excess materials located around

the site and delivered to site on a weekly basis. Simple storage areas should be erected to store excess materials until needed, material call offs should be in line with current lead times for the products and planned to arrive just in time to minimise the period they are on site before they are fixed in place. Enforcement of the waste management strategy needs to be a main focus, site operatives require further training or education on waste streams on site, possible ways to achieve this could be to write into the contracts that tradesmen and their companies should segregate their own waste stream and if such waste streams contaminate others then the offending contractor should pick up the cost of the segregation.

CONCLUSION

Overall, the research found a heavy focus on the control of waste once it was produced, this is clear from the number of legislations created to deal with the issues of waste and not the controls needed to prevent it. The findings of both the case study and review of literature into site waste management strategies used within the construction industry indicated a lack of research into the re-use of materials and the procurement of materials as a waste management strategy. It is evident that more should be done to manage and control materials to sites, lack of management and operative buy in was highlighted in the case study and the literature review as a hinderance to any site waste management strategy, with financial partnerships or pain and gain relationships as a possible answer so that the operatives gain from correct waste management. From the analysis of the data it was unclear if the company's waste management strategies are effective, during the case study it was evident that the sample sites waste management policy wasn't working with many red flags. However, the 95% recycle rate will be maintained as all materials will be sorted off site, effectively rendering any segregation on site useless.

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SOCIAL CONFLICT IMPACT FOR PUBLIC PROJECT IN URBAN REGENERATION

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The research evaluated the impact of a social conflict on a public project which is part of an urban regeneration scheme in a complex urban and political environment. The research approach included qualitative data collection through semi-structured interviews and contrasted this with the relevant literature. Interviewees represented different roles and positions within the municipality and urban regeneration project organisation in terms of decision-making and different level of responsibility. The approach provided an opportunity to recognise different and sometimes contradicting prevailing opinions and interests within different roles of the municipality organisation and a project environment. External stakeholders significantly influence a project's performance where successful project management is not the same as a successful project. Despite its recognised importance, project managers lack empirical research for effectively engaging with communities to prevent protests.

Keywords: urban regeneration management, social conflict, stakeholder management, project management.

INTRODUCTION

This research focussed on what happens if public projects go wrong. The literature review looks at: what causes project controversies, as it is described as social conflict here, what consequences, and what solutions stakeholder management or engagement theories may suggest. Discussion points are based around literature topics and data collected from interviews. The discussion also responds to recognised components of urban regeneration process: leadership and agenda of an urban intervention, stakeholder management or engagement, motives and tactics when things go wrong, inevitable impacts on project

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viability, and capabilities to engage and make compromises to solve a conflict and protect the value of a project.

Magalhaes (2015) argues that "urban regeneration" policy aims to make a positive change to deprived areas by involving a range of stakeholder groups. Urban regeneration projects are characterised by a higher level of social and economic uncertainty as well as significantly greater political complexity, than conventional construction projects (Yu & Kwon, 2011). Additionally, socio-political risk is considered difficult to predict and social concerns are inadequately addressed in the context of the relationship built with a local community (Teo & Loosemore, 2017). The impact of external stakeholders on performance of largescale construction projects which are being implemented within a complex urban context are significant, here project managers must balance project delivery on time and budget within a defined scope that satisfies societal and commercial needs (Teo & Loosemore, 2017). Various concerns must be addressed when adopting an effective stakeholder management approach that falls within the limits of the project environment (Olander & Landin, 2008).

LITERATURE REVIEW

Urban regeneration projects are time consuming, complex and have a high uncertainty rate for completion, and a relatively high failure rate (Jung *et al.*, 2015; Yu & Kwon, 2011) and aim to improve economic, physical, social and environmental conditions (Voase, 1997; Radulescu *et al*, 2016; Konsti-Laakso & Rantala, 2018; Pastak & Kährik, 2016). The research by Lee *et al*., (2017) demonstrated that society has become a powerful group of external stakeholders and has become a critical factor for a project's viability due to an increasing awareness of social and welfare issues. There is growing interest about stakeholder management in complex projects over recent years (Nguyen *et al.* 2018). Research publications that contributed to the research topic were found across 25 different journals that indicates interdisciplinary field of research (summarised in Figure 1). Despite its recognised importance, Teo & Loosemore (2017) argue that project managers lack empirical research for effectively engaging communities and dealing with emerging protests. Construction project managers deal with communities as with a risk and liability rather than as asset and opportunity. Some authors criticise project management theory, suggesting that the term 'management' indicates intentions to 'control' communities as a risk rather than engage for mutual benefit (Teo & Loosemore, 2017). Other authors advocate a social risk management approach for identifying those affected stakeholders and mitigating social risks by taking proactive response measures during project implementation (Liu *et al*., 2016).

Definition of urban regeneration

Magalhaes (2015) argues that the definition of "urban regeneration" is not straightforward as it can mean interventions and policy intended to make a positive change to disadvantaged areas by involving a wide spectrum of different stakeholder groups. He also identifies synonymous terms adopted such as 'urban renewal,' 'urban revitalization,' or 'urban renaissance" to describe processes of intervention and policy change. Block & Paredis (2013) write about urban development projects in Belgium which are described as physical spatial interventions that act as catalysts for urban transformations. Butler (2006)

argues that urban regeneration is a process of social and spatial change of an are Yu & Kwon (2011) conclude that urban regeneration projects are characterised by a higher level of social and economic uncertainty and a significant greater political complexity than conventional construction projects.

Definition of social conflict in urban regeneration

Conflict is well understood among internal stakeholders who are contractually involved and where this can lead to a claim or dispute. Conflicts may arise among external stakeholders such as governments, residents, and third parties (NGO) or civic groups. It is also argued that Not-In-My-Backyard (NIMBY) and Please-In-My-Front-Yard (PIMFY) responses are representative cases of a potential social conflict (Lee *et al*., 2017).

Definition of external stakeholders

External stakeholders belong to public and private sectors with no legal relationship to a project (Lee *et al.*, 2017; Ninan *et al*., 2019). External stakeholders are identified as people who can affect or be affected by implementation of project (Yu *et al* 2019) and may consist of groups: third parties such as NGO's or civic groups or governments (Voase, 1997). There is a tendency that different community groups are perceived as a one homogenous group whereas in reality, external stakeholders consist of different complex groups and are multidimensional, layered, competing and often conflicting (Teo & Loosemore, 2017; Ninan, Mahalingam & Clegg, 2019; CL:AIRE, 2008). Stakeholders do not necessary fall into certain categories and final definition is complex (Ninan, Mahalingam & Clegg, 2019; Voase, 1997). Yu *et al*. (2019) argue that a significant variety of stakeholders complicates relationships due to different individual interests and creates complex relationship structures. Yu & Kwon (2011) agree that the complex relationship structure is the defining characteristic of urban regeneration project by contrasting with traditional complex construction projects. The approach to social conflict and stakeholder management varies in different literature as well as terminology adopted which differs from 'empowerment', 'stakeholder engagement' or, 'stakeholder management' to 'social risk management or control'. Stakeholders are recognised as an asset, opportunity or even a risk across different literature. Research publications of journals of urban and social sciences are more likely to adopt an engagement approach. For instance, Vanclay *et al*., (2015) write about desired participatory and engagement philosophies, when "public owns project', without using phrases such as "stakeholder management". Journals of construction or business management tend to adopt a risk management approach. The research by Teo & Loosemore (2017) suggests that construction project managers deal with communities as a risk and a liability rather than as an asset and an opportunity. Despite different approaches, stakeholder silence and satisfaction are the mainstream of those studies, and balance together complementing the area of research. Figure 1 illustrates the tendencies identified in the literature reviewed.

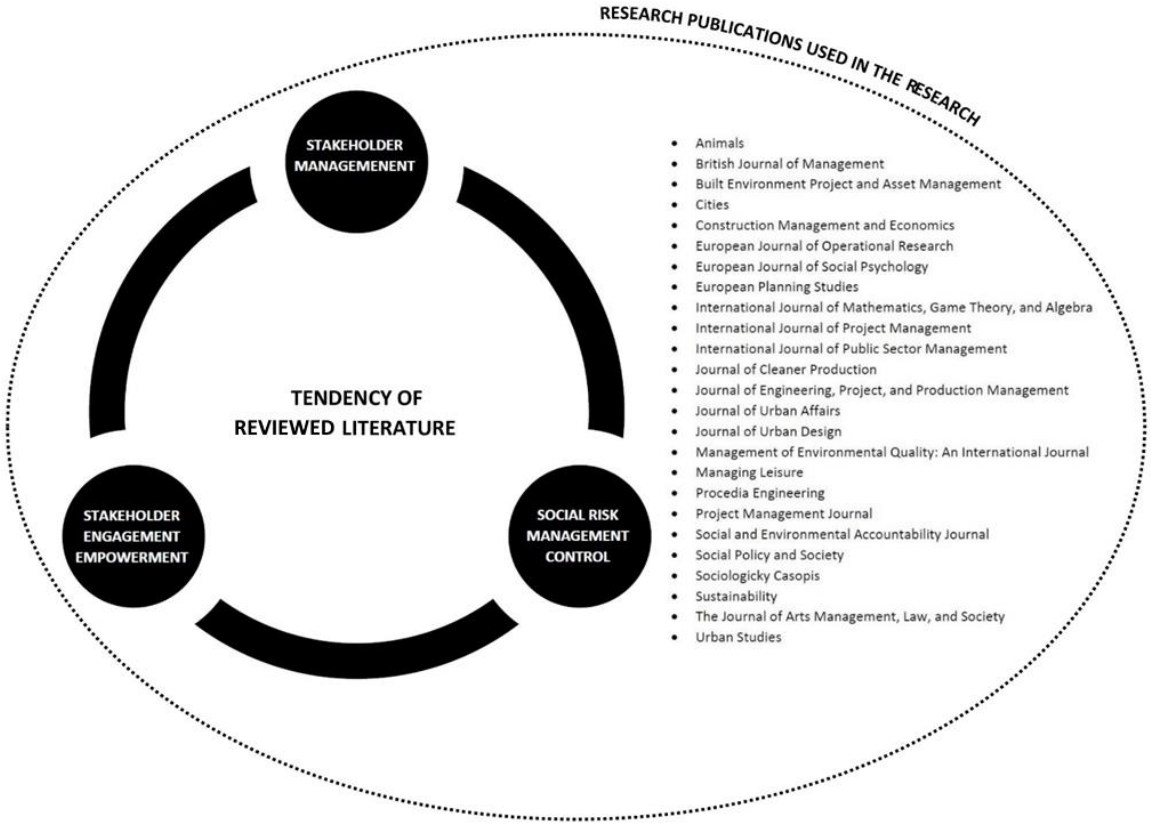

Figure 1: Journals reviewed and tendency of references within literature

Conflict causes

Lu & Wang (2017) divide conflicts into two categories: a task conflict and a relationship conflict whereas Lee *et al.* (2017) suggests that conflicts fall within three wide categories: contextual factors, project characteristics and local impacts. Conflict causes are also categorised as cognitive, environmental, economic and governmental authority factors (Lee *et al.*, 2017; Yu *et al*., 2019). Each category may also be expanded; the cognitive factors are subject to perception and value systems such as urban development and environmental conservation; environmental factors are subject to construction activity; economics factor is subject to conflict of interests and imbalance of cost and convenience; governmental authorities factor is subject to exclusion/dismissal of inhabitants' opinion and misinformation about the project (Lee *et al.*, 2017). Many findings indicate that project location together with feasibility study is a great factor (Amadi *et al*., 2018; Lee *et al.*, 2017). Pastak & Kährik (2016) argue that an improvement of local social and economic development usually is not the main project objective, but a side effect after project implementation. Therefore, several authors argue that there is lack of consensus on what constitutes sustainable urban development (Klein *et al.*, 2013; CL:AIRE, 2008). The research by Lee *et al.* (2017) has indicated the significance of the impact of social conflict at different stages: most causes of conflict originate at early stages of project cycle and evolve in the construction stage. Zwikael & Smyrk (2012) conclude that people

care about what they get or see, but also about what might have been obtained if they had chosen differently.

Tactics and motives

If communities are not engaged, they see the only option as engaging by collective action to influence decision-makers for or against a project (Voase, 1997; Teo & Loosemore, 2017; Bern, 2018; Yu *et al.*, 2019). A collective identity plays a major role in community protests by providing shared experiences such as: a community picket and attending protest events together, shared vision for fighting against the developer or government system that is perceived to be corrupt (Teo & Loosemore, 2017; Bern, 2018). The same authors also claim that such collective actions make a common language by creating cultural and symbolic artefacts. Yu *et al.*, (2019) argue that not all participating actors have the same power. The power depends on resources possessed and ability to withdraw resources from an organisation which implements project (Block & Paredis, 2013; Yang, 2014; Radulescu *et al.*, 2016). Olander & Landin (2008) argue that the public usually do not have formal power to affect decision-making but have an informal power to put pressure on more powerful stakeholders to change their position towards a project. Bern (2018) adds that stakeholders surrounding the project core are also influenced by their own independent set of stakeholders who have experience in urban regeneration. Therefore, more often there are conflicting interests among stakeholders themselves in a project (Yang, 2014). Stakeholders use political influence to gain advantage and influence project outcomes, opposition of a project may create a strong powerbase using media and politicians to gain power in a process for appealing against municipal decisions (Radulescu *et al.*, 2016; Bern, 2018). Therefore, the media becomes another stakeholder group that can be actively used by an opposition by promoting views of opponents to exert an influence over the decision-making process (Olander & Landin, 2008). Motives in relation to conflict causes suggested by the reviewed literature are summarised in Figure 2.

Consequences

A social conflict causes negative impacts on project performance as well as a social cost leading to an unsustainable project implementation (Radulescu *et al.*, 2016; Pastak & Kährik, 2016; Lee *et al.*, 2017). A project consumes resources (inputs) for producing output (Zwikael & Smyrk, 2012). Predetermined needs over resources creates a measure of value (British Standards Institute, 2000). Toor & Ogunlana (2010) suggest that conventional project measures such as cost, time, quality, scope may be directly affected but factors of safety, efficient use of resources, effectiveness, stakeholder satisfaction and needs should be appreciated as well. Toor & Ogunlana (2010) argue that successful project management and a successful project are not the same achievements. They also add that successful project management can satisfy traditional project performance measures and still deliver a failed project which does not meet objective and qualitative aspects.

Teo & Loosemore (2017) identify a perception that all social questions which might trigger a conflict, are sorted out at early planning stages of a project. This gives an illusion that no further community engagement is required once construction commences

on site. The authors also add that an engagement of stakeholders is usually perceived as a time-consuming, stressful and burdensome process which incurs additional costs. Wilson (2017) argues that conflicts can cause a loss of social licence or legitimacy and reputation among stakeholders to implement a project. The list is not definitive and only briefly indicates the most relevant consequences of social conflict emphasised by the literature.

- Undermined project final quality
- Increased project cost
- Project delay
- Project termination
- Lost project social value and legitimacy
- Damaged social capital

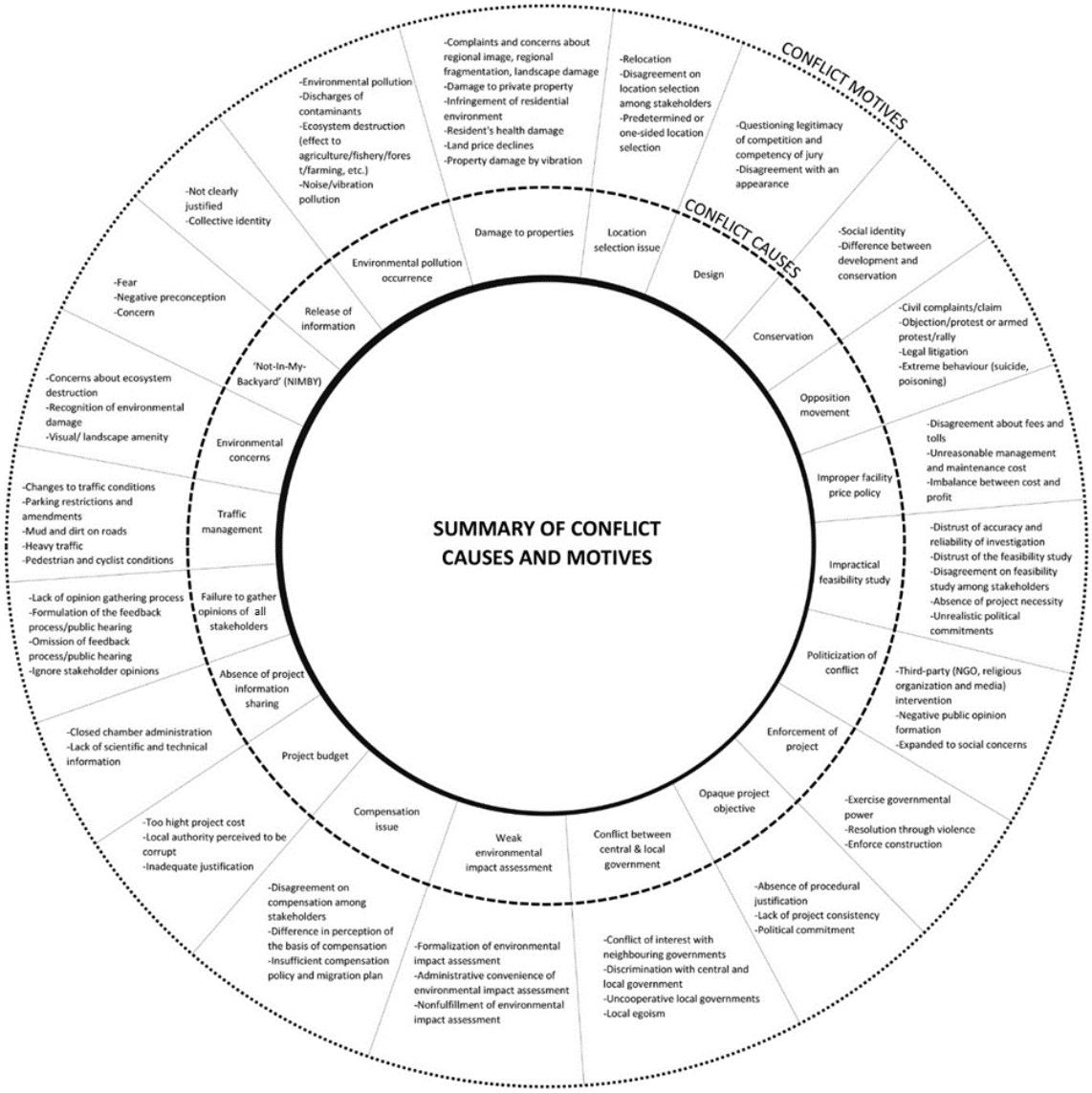

Figure 2: Summary of Conflict Causes and Motives

Countermeasures

Regeneration is based on participation and consensus among stakeholders working as partners (Radulescu *et al.*, 2016). However, Lee *et al.* (2017) argue that complex projects involve many internal and external stakeholders who complicate finding causes and solutions for a conflict. The same authors argue that stakeholder complexity brings less certainty and additional risks for successfully delivering projects. Block & Paredis (2013) concluded that more often urban decision-making is a process implemented through mixed networks of public and private actors, and less often a process within the context of formal, institutional or bureaucratic procedures. The same authors also demonstrate that most of the power is mobilised outside formal urban governance institutions. Kennedy (2011) mentions that the general public is less interested and less motivated than a business-professional community or the non-profit and public sector to participate in a discussion. Therefore, a narrow stakeholder accountability indicates that stakeholders must be motivated and organised to ensure valuable contributions (Kennedy, 2011). Stakeholders and their interests must be identified, prioritised and decisions made in relation to importance of priorities and power to react to those decisions (Maguire, Rimmer & Weston, 2013; Yang, 2014; Nguyen *et al.*, 2018). Research by Block & Paredis (2013) demonstrated that local political leaders play a creative entrepreneur role for interconnectivity, setting agendas and networking thus articulating new ideas, introducing ambitions, new discourses, connecting streams of problems, politics and policies for shaping a policy agendVanclay *et al*., (2015) argue that the top-down approach, referred to as DAD ('decide, announce, defend') or even DEAD ('decide, educate, announce and defend'), are no longer acceptable and neither effective nor sustainable, whereas MUM ('meet, understand, modify') or POP ('public owns project') are desired participatory philosophies. Several studies demonstrate the most successful engagement and empowerment methods (Enrique *et al*., 2016; Nguyen *et al.*, 2018). Summarised stakeholder engagement principles and methods identified in reviewed literature is illustrated in Figure 3.

RESEARCH METHOD

The research approach included qualitative data collection through semi-structured interviews that proved to be an effective approach as Klein Woolthuis *et al*., (2013) and Lee *et al.*, (2017) demonstrate in their research to better understand motivations, reasoning, and interests in the context of urban regeneration project implementation. Lee *et al.*, (2017) argue that social conflicts within the project environment are areas with a limited scope for quantitative analysis thus qualitative methods are more appropriate.

The research involved 6 participants: municipality officials, project manager, administration director, mayor and principal contractor who were located in the Baltic States of Northern Europe. Interviews allowed an investigation of circumstances in which conflicts arise and determination of corresponding consequences by analysing different conflict scenarios (Lee *et al.*, 2017). All participants have been involved in regeneration projects in the same city. Interviewees represent different roles and positions within the city municipality and urban regeneration project organisation in terms of decision-making and different level of responsibility. All participants were asked the same questions to explore their experience in urban regeneration. Questions were altered

to explore the individual participant's knowledge of the topic and in using this approach provided an opportunity to make participants more comfortable and able to discuss sensitive issues. Participants felt free to talk about positive and negative aspects of their experiences by sharing real-life examples. This approach provided valuable insights for this research and allowed the identification of the complex dynamics of urban regeneration process, as well as the sometimes conflicting interests.

Figure 3: Summarised Stakeholder Engagement Principles and Methods

Interview data was analysed adopting deductive coding method categorising responses into topics, which were extracted after literature review, and to subcategories, derived from interview answers. Interviewees were approached via email seeking for an initial agreement and organising suitable dates for both parties and were conducted in January 2020. Interviews were recorded using an MP3 recorder supplied by Sheffield Hallam University with permission obtained to take audio recording and notes. Handwritten

paper notes were scanned uploaded to the researcher's university account thus protecting against any sensitive data loss or disclosure.

Additional data was collected from public documents and 126 relevant articles of regional and national mediThis established additional contextual background about urban regeneration in the city areA similar approach demonstrated by Bern (2018) proved to be effective for finding the dynamic of social conflict and how it evolved. Other information related to project opposition was collected from facebook.com. Privacy of private users is a concern regarding social media thus only news feed of public pages and open groups were used. The social media data is not treated as equal to the news articles collected on features that form a record of events, but they are organised around shared news articles that can be seen as an extension of the story according to Bern (2018).

RESULTS AND DISCUSSION

This research identified dominant themes of factors that led to a social conflict and these are discussed below. However, those themes are not discrete nor definitive and there is significant complexity and interrelation.

Definition of stakeholder

Participants identified the city and its citizens, local community, municipality and city council with elected councillors as their stakeholders. It was clear that those groups have different interests and have complex relationships. The city council was identified as a stakeholder by the chief city architect, project manager and municipality specialist by indicating those positions are accountable to the city council which represents citizens and are in power to make decisions. (Municipality specialist): "The c*ity council is the major stakeholder. Also, society of city and different groups of community*." In contrast, the city mayor and administration director did not mention the city council as stakeholder. (Mayor): *"I think, community in narrow terms, who are in that particular territory, also, the community of the entire city."* The city council is a special status stakeholder that has the features of internal and external stakeholder at the same time. As a political majority representing the electorate it has legitimate power to make decisions, whereas a political minority (e.g. the opposition) representing their electorate, only has power to influence decision making and can be called an 'affected party' as it represents electorate or transfers the voice of local interest groups. Participants identified different groups of external stakeholders. However, there is a tendency that different community groups are perceived as one homogenous group (e.g. community) whereas in reality, external stakeholders consist of different complex groups and are multidimensional, layered, competing and often conflicting (Teo & Loosemore, 2017; Ninan *et al*., 2019; CL:AIRE, 2008). Ninan, *et al*., (2019). Voase (1997) argues that stakeholders do not necessarily fall into certain categories and final definition is very complex.

Perception of stakeholder management

Executive positions such as the director of principal contractor and the administration director demonstrated a risk management approach for decision making. (Administration director): "*When we deal with all external factors which could express disagreement, when all risks are managed".* Other positions that also make significant contributions to

implementation of urban regeneration projects demonstrated a stakeholder engagement approach. They talked about the importance of being democratic and diplomatic by approaching communities to ensure active participation. Participants also demonstrated that higher positions tended to be more reluctant to accept compromises than lower position. (Mayor): *"Unfortunately, I see compromises tend to deliver a negative impact for the final result of urban regeneration."* It could be explained that compromise requires more effort to achieve it and some discounts for power positions in balancing a wider spectrum of competing interests. Such practical implications correlate with the findings of the literature review, where business and construction management sources tend to adopt a risk management approach and other sources used alternative approaches. Urban regeneration requires a collective approach, mobilising and involving multiple actors and creating partnerships with local community, often the state, professional, economic, cultural and social environment (Radulescu *et al.*, 2016). This research demonstrated that participants identified different groups of external stakeholders. While the city council consists of both political majority and minority, it is not so unreasonable to state that the political minority is still a powerful stakeholder that finds opportunities and pretext to mobilise other external stakeholders and has resources and the ability to influence the decision-making as the literature suggested. Thus, not all participating actors have the same power (Yu *et al.*, 2019) and the power depends on the resources possessed and the ability to withdraw resources from the implementing organisation (Yang, 2014; Block & Paredis, 2013). Perhaps the problem is more complex than an ability to recognise, but it is more about willingness to accept the existence of such groups. Participants also argued that behind external stakeholders stands political opposition in the case of social conflict. Lee *et al.* (2017) argue that different factors such as insufficient feasibility study results ignored stakeholder's opinion and allowed 'Not-In-My-Backyard' (NIMBY) syndrome to emerge. They add that local residents raised objections and demanded additional evaluations and investigations for project feasibility and challenged the project viability. However, Olander & Landin (2008) argue that all opposition shouldn't be simply labelled as NIMBY protests - irrational obstructions should be recognised as expression of fears and needs that must be analysed and not just simply ignored.

Urban regeneration leadership

Almost all participants identified strategic political leadership as the key factor for an urban regeneration success. (Principal contractor): "*Strategic leadership is essential in urban regeneration. It should be demonstrated by the director of administration and the mayor.*" The mayor position is mostly seen as a source for a political and strategic leadership, also the administration director plays significant role. Local authority, comprising different institutional organs, required unified leadership at strategic, tactical and operational levels, while different actors demonstrated different leadership at certain levels of an organisational hierarchy. The new political leadership instigated processes which created conditions for an urban regeneration to be accomplished through 'policy windows' by setting an urban agenda and networking, as suggested by Block & Paredis (2013). The policy entrepreneurs played an important role in articulating new ideas, introducing ambitions, new discourses, connecting streams of problems, politics and policies for shaping a policy agenda and gaining social legitimacy for support through

cooperation and collective action by bringing together the interests of different stakeholders (Klein *et al.*, 2013).

Urban regeneration agenda

Project presentation and justification, particularly from the economic point of view, were emphasised by participants. Project presentation is mostly considered as an effective communication about economic, social and environmental factors. (Project manager): *"Marketing of a project's positive cultural and economic benefits and a communication from early stages outside formal project consultancy meetings."* In contrast, participants have felt that they are not capable of delivering set ideal standards effectively such as: project presentation and justification; intentional avoidance to withhold the information; legislative analysis; inaccurate initial project estimate. (Chief City Architect): *"Everyone tend to hurry for implementing the project thus some project stages and public consultancy procedures only tick boxes to make sure a procedure is performed."* (Mayor): *"Sometimes dialogue between different stakeholder groups is dishonest and process is no more than formal. Sometimes, some particular questions are being intentionally excluded from the agenda."* However, those omissions emphasised by participants are attributed to someone else in the organisation. Research by Lee *et al.* (2017) suggested that project outcomes based on political commitments lead to urgently planned project by resulting in an impractical and subjective feasibility study that did not satisfy the actual needs of external stakeholders. As identified by Block & Paredis (2013), policy entrepreneurs instigate an urban agenda and define objectives which are not always reasonable in terms of time scale and funds available. Lee *et al.* (2017) suggest that urgent project planning and implementation of projects may eliminate consideration of all factors which are important to external stakeholders. It also may result in an avoidance of revealing all information and sometimes inadequate legislative analysis as interview participants indicated. Moreover, while stakeholders tend to think beyond traditional measures of "iron triangle" criteria such as time, cost, quality; research by Toor & Ogunlana (2010) suggests that satisfaction of external stakeholder needs include not only quantitative and objective criteria but also subjective and qualitative criteria such as satisfaction towards whole project life-cycle as suggested by Musawir *et al*., (2017). The reviewed literature emphasises the importance of clear project presentation and justification. Therefore, it is important to ensure social legitimacy among the public by clearly demonstrating benefits and impact of any activity.

Recognisable social conflict drivers and motives

Few participants emphasised factors such as: inadequate feasibility study; architecture. Mostly participants emphasised factors such as: political opposition; cultural heritage. It was almost claimed that the social conflicts are mostly motivated by personal self-interest of competing individuals. (Municipality specialist): *"There we always have a group of community which claims that defends a public interest, but if you look deeper, they only protect their own personal beliefs and local interest ignoring a wider city context."* The administration director and the mayor interpreted a political opposition as a burden rather than an active partner. They also claimed that people's personal interests are interlinked with political interests. (Administration director): *"A political party may be interested about a project, which is elected by people and have different people as members who are*

citizens." Power positions such as administration director or especially mayor, viewed the political movement personally as a direct threat to their power position. Such facts also explain why the city council is not called a stakeholder by them as mentioned previously, thus the city council as stakeholder is excluded from the stakeholder list when opposition to the project is active and is not beneficial to project viability. As reviewed literature suggests, disagreement about cultural heritage protection escalates further debates on two contradicting factors - contemporary architectural appearance and conservation (Bern, 2018). Marginalisation of external stakeholders is the main reason causing opposition (Amadi *et al*., 2018; Pastak & Kährik, 2016). There is recognition that one political group promoting a project always attracts criticism from a rival political group of supporting soft needs rather than hard (Voase, 1997). Furthermore, participants claimed that self-personal interests prevail, and every project is evaluated through peoples' personal perspective. Participants also indicated that people care how they will be impacted by project implementation. In contrast, participants recognise different stakeholders with conflicting interests and understand prerogative function to balance different interests and deliver public services. However, opposition of some projects mentioned by participants was marginalised. Also, participants argued that a protest voice of external stakeholders is influenced by actions of political opposition. In addition, interview data demonstrates that those in power positions are reluctant to make compromises as projects tend to be urgently planned because of political agendas and due to time limits when bidding for funding opportunities. Therefore, socio-political risks are the most unpredictable risks that construction projects face in an urban regeneration context (Teo & Loosemore, 2017). It is suggested that decisions about the project are made without analysing the consequences of the decision on different stakeholders, meaning that project managers are unprepared for conflicts and have no plan how to resolve them (Olander & Landin, 2008). Community concerns can spill-over into other project phases such as construction by creating conditions for protest and collective actions (Teo & Loosemore, 2017).

Recognisable tactics and moves by the opposing side

Participants mostly emphasised factors such as: manipulation, blemish on political opponents, misleading facts about project. A mobilisation of opposing stakeholders and collaboration with opposition members in city council was interpreted as intention to blemish political opponents, but not to seek recognition as a stakeholder group. (Municipality director): *"Mismanagement of information is a significant project risk. I mean occasions when articles by press provides misleading or inaccurate information about the project."* Participants claimed that sometimes misleading information appears in a form of opinion during public discussion, with the intention of influencing decision making. Urban regeneration projects get special attention from the media which becomes an active platform for external stakeholders to amplify their voice, as demonstrated in research by Bern (2018). Sometimes published articles challenge the project and the official position of municipality, as well as its justification of the project and legitimacy of decisions (Bern, 2018). Interview participants interpreted such actions as a manipulation and spread of misleading facts by opponents. However, many of the reviewed press articles indicated that opponents of the project made their own judgements and evaluations based on information published by the municipality. Participants viewed

this as an intentional means to avoid revealing all information; and judgements and evaluations by external stakeholders were still based on the quality and amount of information provided by the municipality, where the lack of information may result in misinterpretations. Moreover, reviewed literature suggests that sometimes conflicts bring significant controversies from political, pressure groups, media and local community members and attract more powerful actors (Mok, Shen & Yang, 2015; Bern, 2018). When communities are not actively engaged with, they see collective action as the only option to engage and influence decision-makers for or against a project (Teo & Loosemore, 2017; Voase, 1997; Yu *et al*., 2019; Bern, 2018). The public usually do not have a formal power to affect decision-making so use informal power to put pressure on the more powerful stakeholders to alter their position towards a project (Olander & Landin, 2008).

Impact of social conflict scenarios

Participants emphasised factors such as: lost funding opportunity; increased project cost; project termination. Few participants noticed that usually consequences are unpredictable. (Project Manager): *"Usually we have a project delay. […] more chances are that a project can be terminated at early stages, less likely if budget is agreed."* It is recognised that the lost funding opportunity mostly led to project termination caused by delays when deadlines set by financial bodies were breached. Moreover, the majority of urban regeneration projects were expected to be funded from European Structural and Investment Funds 2014-2020 which set strict deadlines for providing project applications. Participants considered time as an important resource and argued that delays may increase a project cost. While external stakeholders evaluate visible and tangible progress provided to citizens, participants emphasised that project delays also undermine people's expectations due to prolonged periods of waiting the result. Missing deadlines due to a project delay can be one of the main concerns from their point of view and the main reason causing a project cancellation. Conflicts with or resistance of the public can negatively affect or even kill the project (Mok *et al*., 2015). Furthermore, most causes of conflict originate at early stages of the project cycle and evolve in the construction stage (Lee *et al.*, 2017). Participants also mentioned that initial estimates are sometimes intentionally lower to gain political support from the council which may be strict on budget control. Here, entrepreneurial project managers expect to find alternative sources of funding later in a process (Klein *et al.*, 2013). Such behaviour also explains factors raised by the city mayor and political leader about the presence of dishonesty within the internal organisational structure. This links with the idea that socio-political risks in urban regeneration construction projects are highly unpredictable (Teo & Loosemore, 2017).

Community engagement

Most participants emphasised building early relationships as an important factor for community engagement and project success. Participants emphasised factors such as equal, honest and simplistic communication as a required condition for achieving an effective presentation and justification of a project. (Project Manager): *"Groups of community must be reached through different engagement activities such as informal public events for creating a feeling of project ownership."* In contrast, participants recognised ineffective engagement practises such as: poor communication; passive participation; technocratic communication. Also, some participants emphasised issues

when the wrong aspects of a project were communicated. Poor communication was both the absence of communication and the intentional avoidance of sharing all information. Passive participation is recognised as a problem that stops effective community engagement. Honest and equal communication is recognised as important, but at the same time participants admit that they have a record of poor communication and manifestations of dishonest communication practices. Such conditions do not create a sense of equality and prevent engagement. Participants demonstrated lack of knowledge about stakeholder analysis, whereas they emphasised that poor communication and a technocratic approach leads to a passive participation of external stakeholders. Since the public is less interested and motivated than the private or public sector to participate in a discussion, the public must be motivated and organised to ensure valuable contributions (Kennedy, 2011). While the local authority demonstrated an awareness of community engagement, they lacked good practice examples for analysing and engaging external stakeholders. Moreover, technocratic communication is related to formal consultancy procedures rather than active participation and active engagement. An inclusion of multiple stakeholders is essential for building a bottom-up collaboration and creating a feeling of project ownership (Amadi *et al*., 2018). However, a project can be realised if support is available from the most powerful stakeholders (Klein Woolthuis *et al*. 2013; Heath *et al*., 2017). In contrast, the top-down approach is referred as DAD ('decide, announce, defend') or even DEAD ('decide, educate, announce and defend') that are no longer acceptable and not effective or sustainable, whereas MUM ('meet, understand, modify') or POP ('public owns project') are desired participatory philosophies (Vanclay *et al*., 2015).

CONCLUSIONS

The perception of separate participants was contrasted with literature in relation to the urban regeneration environment. Different conflict causes interrelate and overlap between each other and become a reason for another cause to appear, creating an interrelated chain of causes controlling the conflict process. Interviewees demonstrated the complexity and uncertainty of the urban regeneration process, where the project is implemented in the complex socio-political context. The research indicated that the social conflict is mostly caused due to ineffective identification of powerful and interested external stakeholders and inability to engage those stakeholders, eventually causing dissatisfaction of external stakeholders' needs. The project objectives are most likely to be unreasonable and fail to identify true needs if relevant stakeholders are misrepresented and disengaged. The social legitimacy is no less important than the legal legitimacy thus both components are vital for the viability and success of urban regeneration. It is important that external stakeholders are treated as equal partners and they can recognise that their expectations are satisfied.

The roots of the social conflict can be recognised at the outset of the project. If no mitigation actions are taken for those small signs of dissatisfaction, it eventually evolves to social conflict. The control and the progress of the project become more unpredictable as the conflict progresses. Therefore, proactive actions are necessary at an early stage and compromises are inevitable. Those compromises may seem to be expensive for political and highest positions in the organisation, while municipality officials have a challenge to balance between conflicting interests within the organisation at the same time as dealing

with conflicting external stakeholders. However, without those compromises, there will be more expenses later. The social conflict creates unsustainable communities, as there is lack of clear definition of sustainable development. Predetermined needs over resources creates a measure of value (British Standards Institute, 2000) but this value is lost when stakeholders are dissatisfied and outcomes not achieved. When needs are misrepresented, the resources used for satisfying those needs are wasted and the final value is questionable. Further research could be carried out for investigating impact of unofficial networks of external stakeholders within different social media "bubbles" on complex regeneration projects.

ACKNOWLEDGEMENTS

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A REVIEW OF ULTRASONIC VELOCITY TESTING AND OTHER TECHNIQUES TO EVALUATE DETERIORATION OF NATURAL STONE

Lauren-Mae Crofts[5] **and Elizabeth Laycock**[6]

Lauren-Mae Crofts studied BSc (Hons) Building Surveying at Sheffield Hallam University and graduated in 2020 with First Class Honours. This work was undertaken while at Derbyshire County Council. She now works as a Building Surveyor at Concertus Design and Property Consultants Limited. Professor Elizabeth Laycock is a member of staff at Sheffield Hallam University who supervised the dissertation.

The review was undertaken as part of the final year dissertation in order to evaluate the viability of ultrasonic velocity testing as a non-destructive method of monitoring deterioration, further to weathering tests. Examination of the literature demonstrates how various fundamental properties such as porosity and density, influence P-wave velocity behaviour and how differences in test conditions affect the level of deterioration observed. The research proposed is presented here to illustrate the intended investigation, however the university laboratory was closed down as part of the Covid-19 spread prevention measures in March 2020 which prevented this from taking place. In lieu of this an extended literature review was developed which is summarised in this paper. It was determined that salt crystallisation and frost action are major causes of damage to buildings through their weathering processes with salt being seen as the most damaging mechanism. Previous studies have shown that P-wave velocity has a negative linear relationship with porosity but a positive linear relationship with density and uniaxial compressive strength. Both P-wave velocity and uniaxial compressive strength in weathering tests decreased from their initial values while porosity increased in the form of new cracks and fractures. This is the mechanism by which a decrease in P-wave velocity may determine a decrease in uniaxial compressive strength linked to internal decay.

Keywords: ultrasonic velocity, non-destructive, weathering tests, deterioration

INTRODUCTION

"The assessment of the intensity of stone deterioration is an essential aim for preservation and conservation purposes" Ahmad *et al.* (2012, cited Siegesmond *et al.*

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2002). Frost and soluble salts are main weathering agents which affect building stones used in the UK, such as limestone and sandstone (Doran and Cather, 2014). However, there is an issue with understanding and monitoring decay and compressive strength within masonry when subject to weathering agents due to difficulties in observing the internal matrix (Viles, 2012). Consequently, the purpose of this study is to evaluate the viability of ultrasonic velocity testing as a non-destructive method of monitoring stone deterioration when subject to freeze thaw and salt decay. In turn, through researching the effect of compressive strength and direct transmission of ultrasonic velocity, correlations may be developed to aid implementation of maintenance strategies for stone-built structures.

RESEARCH METHODOLOGY PROPOSED

Laboratory testing was undertaken to evaluate the theories identified within the literature review and draw conclusion on the research aims and objectives.
To provide a level of control and confidence in the primary data, the specimens within each set (e.g., limestone specimens and sandstone specimens) were sourced from the same quarry, for example all the sandstone samples were collected from a quarry in Derbyshire. This ensured the few samples that were to be used for mercury porosimetry and SEM referencing, reflected the cohort as close as possible.
All testing was conducted at Sheffield Hallam University. However, due to Covid-19 the university closed on 20th March 2020 and primary data collection was halted. A summary of the test methodologies and standards that were proposed to be adopted can be viewed in Table 1.

Test	**Standard and purpose**	Number of specimens (per stone set)	Specimen size
Compressive strength	BS EN 1926:2006 – Determination of uniaxial compressive strength (BSI, 2006a). To determine the failure load of the specimens, before and after various levels of decay.	42nr	50mm x 50mm x 50mm cubes
Salt Crystallisation (RILEM)	Specimen size and test conditions using RILEM AS.2 & Test V.2 as reference [as discussed in Lubelli *et al.* (2018), were incorporated into the research methodology. The purpose of the test was to subject specimens of known open porosity to a decay mechanism and assess ultrasonic velocity through the stones before, during and after testing.	9nr	50mm x 50mm x 100mm prisms

Salt Crystallisation (BS EN 12370)	BS EN 12370: 2019 – Determination of resistance to salt crystallisation (BSI, 2019b). Lubelli *et al.* (2018) describes the British Standard as an aggressive test method. This was to be used as a reference for an additional salt crystallisation test, utilising spare cube specimens used to generate more rapid data	12nr	50mm x 50mm x 50mm cubes
Freeze-thaw	BS EN 12371:2010 – Determination of frost resistance (BSI, 2010). Test was to subject specimens of known open porosity to frost decay and assess ultrasonic velocity through the stone before, during and after testing.	12nr	50mm x 50mm x 50mm cubes
Open porosity, apparent density & water absorption	BS EN 1936:2006 - Determination of real density and apparent density (BSI, 2006b), and of total and open porosity and BS EN 13755:2008 Determination of water absorption at atmospheric pressure (BSI, 2008) were used as a refence for sample size and test conditions. The purpose of the tests was to obtain control data including open porosity, apparent density and water absorption. Also, to enable specimen allocation to decay tests and aid the analysis of primary data.	42nr	Both cubes and prisms of sizes previously outlined
Sound speed propagation	BS EN 14579:2004 – Determination of sound speed propagation (BSI, 2004) and the Proceq Pundit - PL 200 manual guide was used as a reference for the ultrasonic velocity methodology. The purpose of the test was to identify and analyse if correlations can be developed between P-wave velocity (Vp) and other measured properties before, during and after specimens are subject to decay mechanisms.	42nr	Both cubes and prisms of sizes previously outlined
Mercury porosimetry	No specific standard for reference. The purpose of this test was to determine quantifiable aspects of the porous nature of the stones such as pore diameter and pore volume	3nr	-
SEM	BS EN 12407:2019 – Petrographic examination (BSI, 2019c) was proposed to be used as a reference for methodology, technical terms and analysis of petrographic samples. The purpose of the test was to clarify the classification / geological nature of each type of stone tested.	3nr	-

Table 1: Testing Standards and Purpose

Laboratory Procedures

Laboratory testing was conducted in accordance with the relevant British, European and International Standards as a benchmark for specimen selection and methodology.

The following flow charts (Figures 1 – 3) illustrate a plan of work for the tests proposed to be conducted within the university labs.

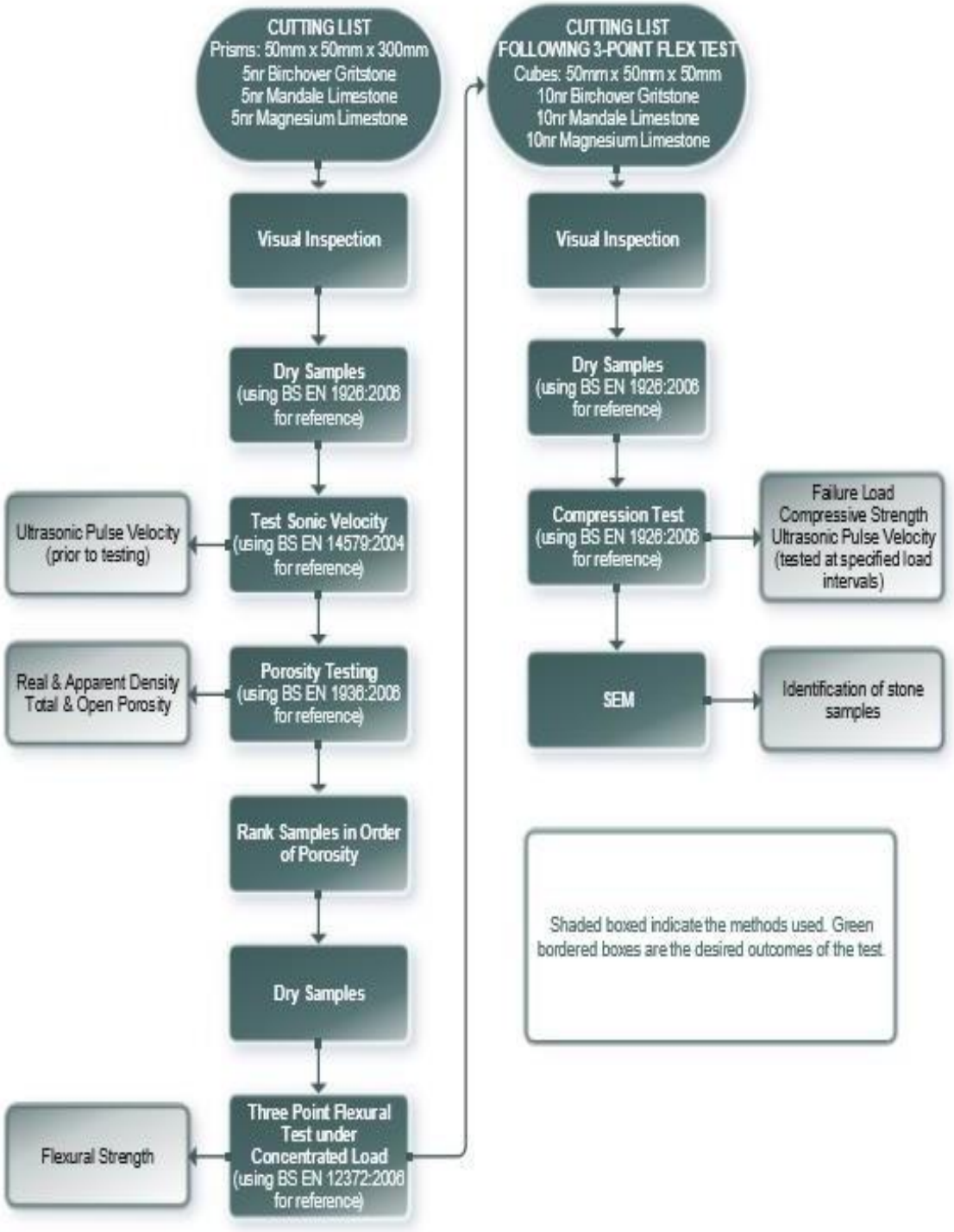

Figure 1: Control Data Collection Methodology

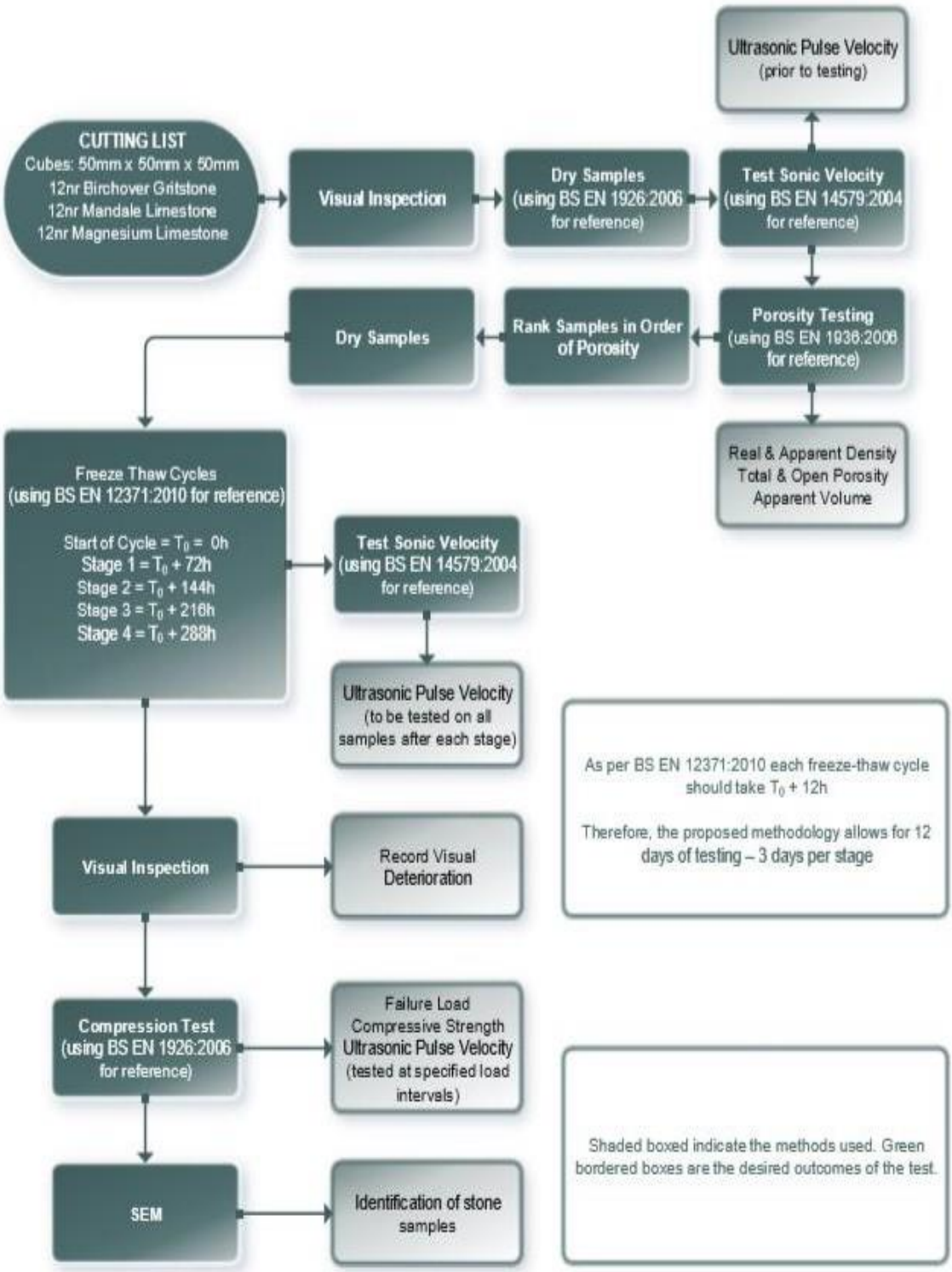

Figure 2: Freeze-Thaw Methodology

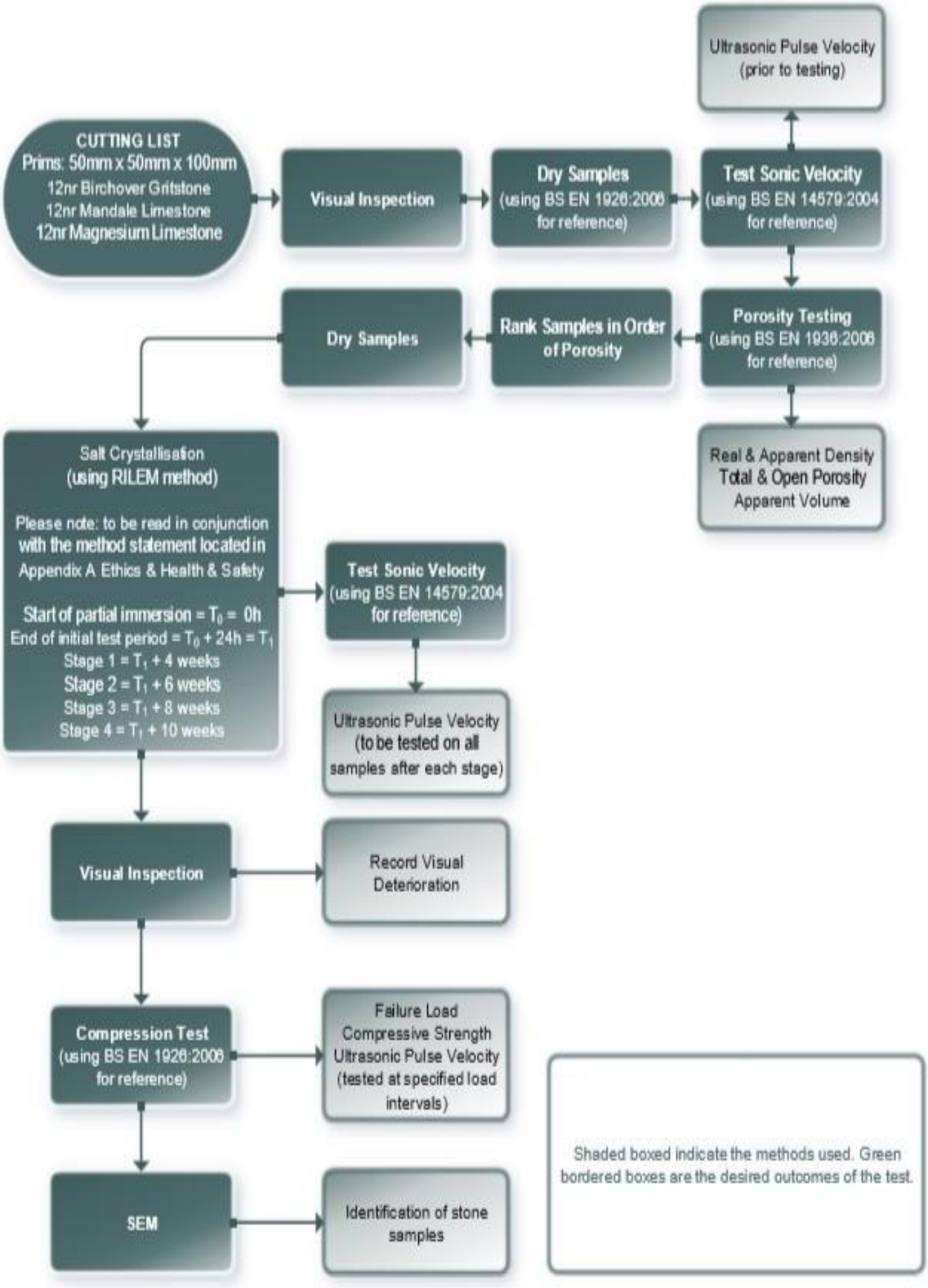

Figure 3: Salt Crystallisation Methodology

Open Porosity, Apparent Density and Water Absorption Methodology

BS EN 1936:2006 was used as reference for open porosity and apparent density, whereas BS EN 13755:2008 was used as a reference to calculate water absorption of each specimen. The principal of these tests is to establish a set of baseline data before the application of decay mechanisms, and after to assess if there is a change in open porosity. Data may also be correlated with ultrasonic velocity readings.

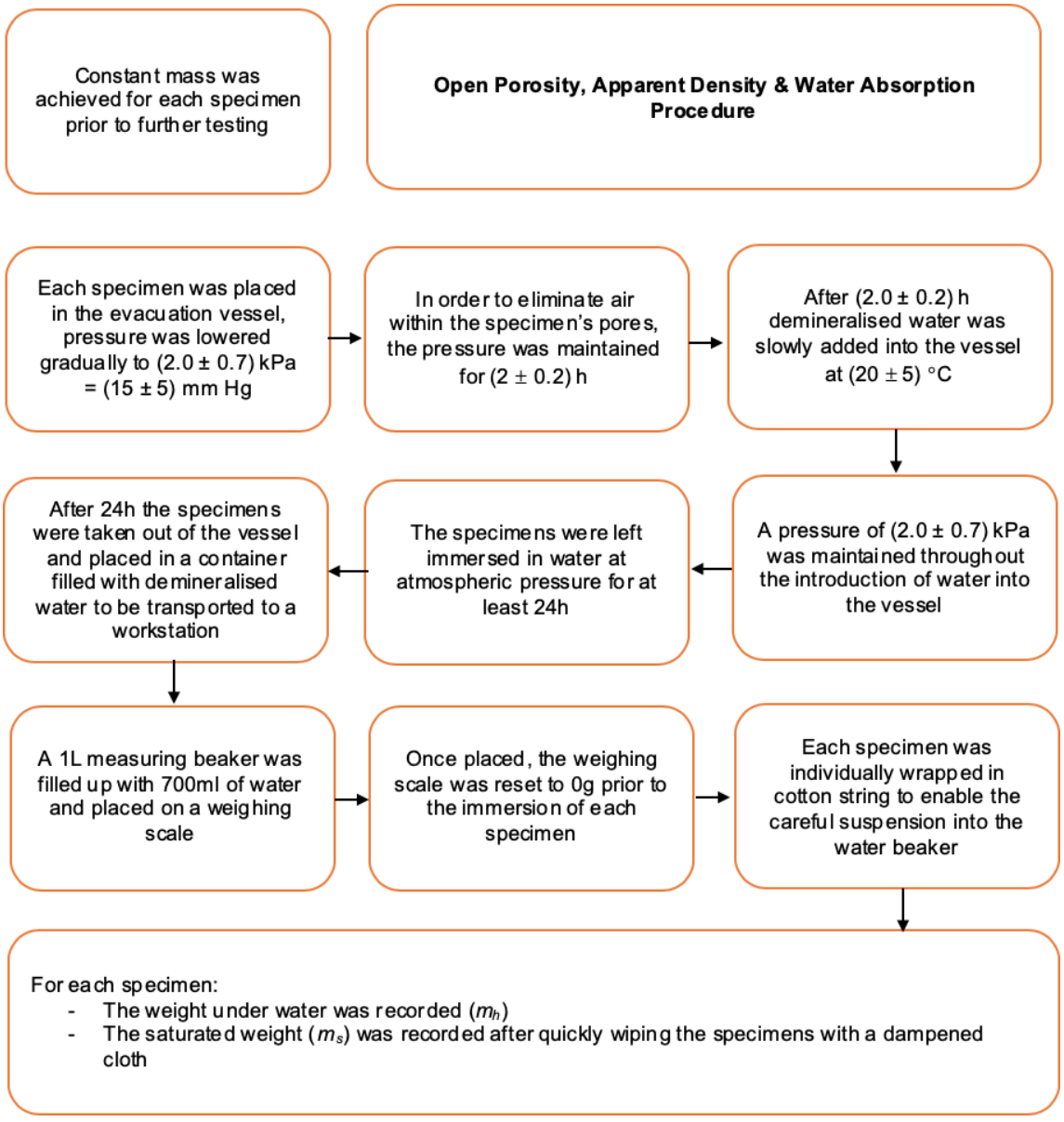

Figure 4: Open Porosity, Apparent Density & Water Absorption Procedure

Ultrasonic Velocity Methodology

It was proposed P-wave velocity (V_p) readings were to be taken before and after weathering testing. Both dry and saturated data was to be collected and the t-test applied to determine if there is a significant difference in results.

Preparation: Prior to testing, it became apparent the speed of the P-waves largely fluctuated with the pressure applied to either side of the specimen. Therefore, a custom frame was produced (Figure 5) to eliminate bias, human error and to standardise the test procedure. This ensured the only pressure applied on the transmitter was the weight of the specimen and receiver.

Procedure Prior to testing, the transducers were zeroed to increase accuracy. This involved input of the calibration value (25.4μs) stated on the calibration rod. The transducers and calibration rod were placed into the custom frame and zeroing was started on the touchscreen. This function was complete when "*zeroing succeeded*" appeared.

1. For each specimen thereafter, couplant was applied to the transducers to reduce the loss of signal. The equipment was then set-up as per Figure 5.
2. Pulse velocity was selected as the test result unit. The distance between transducers was also set for each specimen type: 0.05m (cubes) & 0.1m (prims).
3. As the transmission of signal began, a stopwatch was started. Every three seconds the velocity was recorded up to nine seconds.
4. An average V_p for each specimen and direction of travel was calculated.

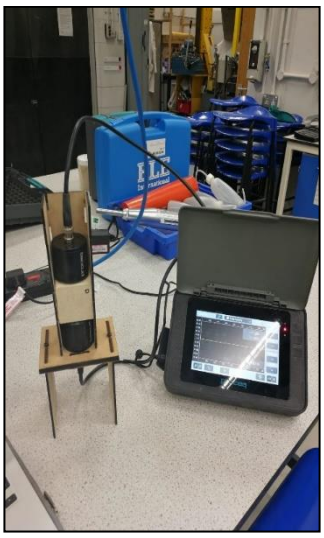

Figure 5: Ultrasonic Velocity Equipment Set-Up Using Proceq Pundit PL-200

Freeze-Thaw Methodology

BS EN 12371 prescribes each cycle to consist of a 6h freezing period followed by 6h thawing period during which the specimens are immersed in water. However, each cycle within this study consists of 0.5h spray and drain ($\geq +5℃ \leq +20℃$), 6.5h freezing ($\leq -8℃ \geq -12℃$) and 6h thawing period ($\geq +5℃ \leq +20℃$) to replicate BS 12371 as close as possible. This is due to the automatic freezing cabinet incorporating a spray function, also allowing the freezing cabinet to chill to required temperature.

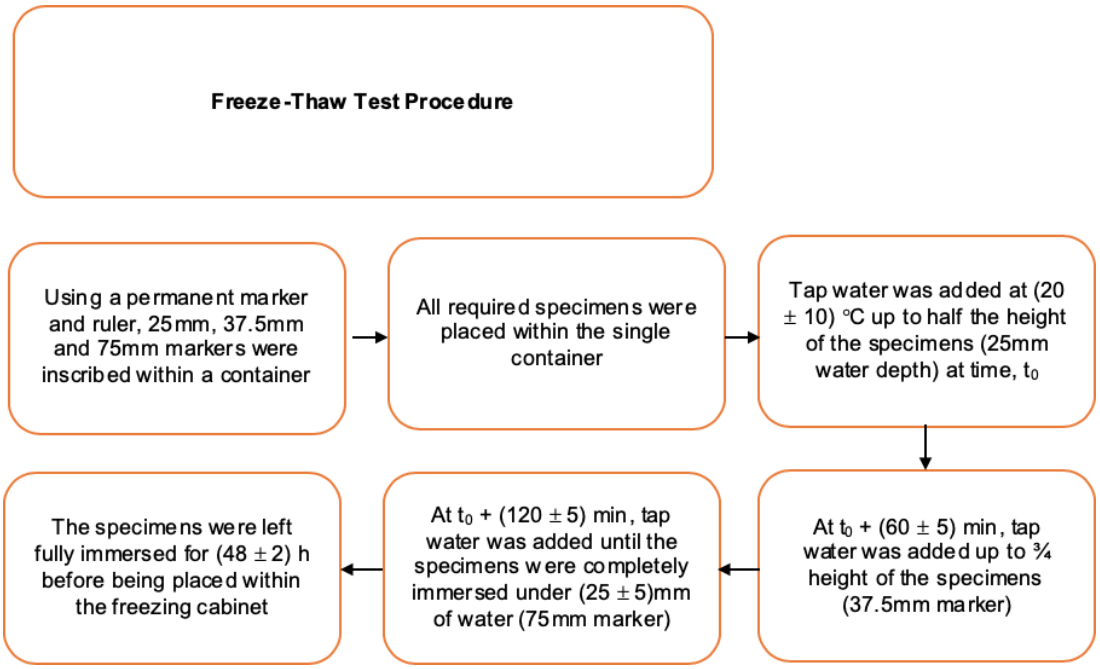

Figure 6: Freeze-Thaw Procedure

Salt Crystallisation Methodology (RILEM)

The principal of this test was to subject the prism specimens to partial immersion in saline solution to monitor deterioration through capillary rise. RILEM (1980) Test V.2 – crystallisation test by partial immersion procedure (1980) was used as reference.

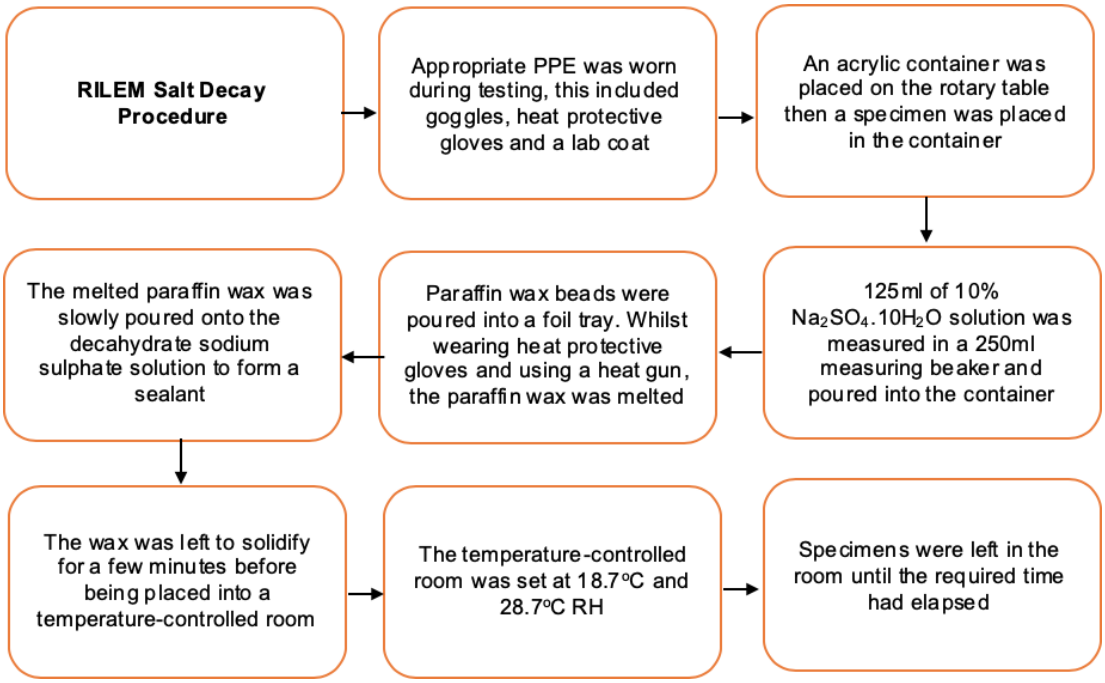

Figure 7: Salt Crystallisation Procedure

Data Collection

The following flowchart (Figure 8) illustrates how the tests interact with each other to achieve the study aims and objectives. Tests which are highlighted in RED were not conducted at all, whereas tests outlined in ORANGE were started but not completed due to COVID-19 measures.

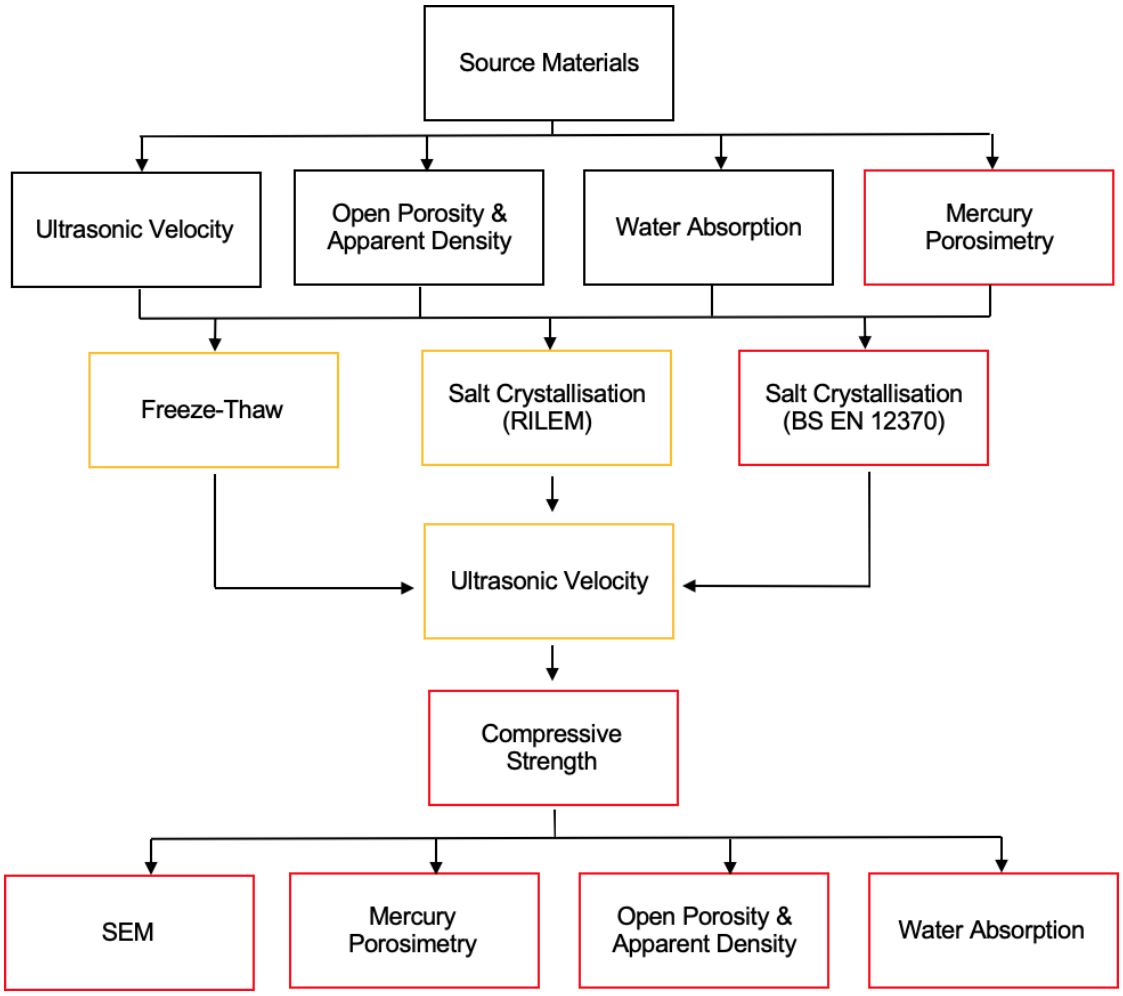

Figure 8: Testing Flowchart Illustrating Completed Tasks

EXTENDED LITERATURE REVIEW INTO THE RELATIONSHIPS BETWEEN DECAY MECHANISMS AND P-WAVE VELOCITY

Due to Covid-19 university closures there was limited primary data to analyse, therefore an extended literature review was compiled in line with the study aims and objectives. This is presented below.

Introduction

Sonic pulse velocity testing is amongst the most widely used non-destructive investigation methods for masonry (Binda, Saisi and Tiraboschi, 2001). Ultrasonic techniques can be employed to determine various mechanical properties of limestone and

sandstone structures. Manning, Ramos and Fernandes (2014) and Binda *et al.* (2001) agree speed propagation tests aim to evaluate the following:

- Consistency;
- The presence of cracks, voids and joints;
- Deterioration through detecting change in physical characteristics.

Consequently, through a non-intrusive approach to surveying, methods of masonry repair or replacement can be evaluated to support the conservation of architectural heritage and implementation of maintenance strategy.

The Geological Nature of Stone

Studies identified within Miller and Stewart's (n.d.) research proposal on the relationship between sonic velocity and density in sedimentary rocks reveal lithology (the physical characteristics of rocks) can influence V_p correlations when plotted against a variety of fundamental properties. Furthermore, Parent *et al.* (2015) suggests materials such as limestone and sandstone have differing mechanical properties due to heterogeneity and diversity of the quarries where each stone type originates.

Deterioration Mechanisms

Doran and Cather (2014, p.203) explain weathering agents, chemical and physical structure are the three main mechanisms which affect stone degradation. However, Marshall, Worthing, Heath and Dann (2014) suggest the most significant factor which affects the durability of stone is pore structure. This determines the level of water and salts that can pass through stone, leading to deterioration via the decay mechanisms stated above. Consequently, it is stressed by Benavente (2011) pore size and pore network is the most important parameter with regards to the evaluation of stone deterioration.
Smith and Viles (2006 cited Leary,1983) in suggesting that limestone with a large network of finer pores is less durable than stones with larger pores. Marshall *et al.* (2014) explains a vast network of small pores leads to a high level of capillary action but a relatively low level of evaporation; thus, is more likely to suffer damage via salt and/or frost attack. Alternatively, stones consisting of larger pores transport more water and salts into the capillary structure, however, can accommodate the increasing pressures induced from decay mechanisms.

Salt Crystallisation

It is recognised by Godts, Hayen and De Clercq (2016) a major cause of deterioration to porous buildings is salt crystallisation. Although Viles (2012) articulates it is a complex cause of decay and there remains much to be understood about the mechanism through theoretical work and experimentation. Nevertheless, Espinosa, Franke and Deckelmann (2007) agree a vast number of heritage buildings are substantially damaged due to salts growing within the pore network. In turn, this exerts mechanical stress on the confining pore walls and generates pressure leading to internal decay and microcracking (Desarnaud, Bonn and Shahidzadeh, 2016). Often, salt crystallisation is initially diagnosed through the presence of efflorescence (Viles, 2012); a white staining of soluble salts on the surface as masonry dries - shown in Figure 9 (Marshall *et al.*, 2014, p.165). Furthermore, efflorescence usually causes minimal damage as the salts are crystallising

on the surface instead of within confined pores states Viles (2012); this is otherwise known as subflorescence.
Conversely La Russa *et al.* (2013) disputes, salt efflorescence from a macroscopic viewpoint can inflict particularly aggressive damage due to a loss of material via flaking and erosion. However, once soluble salts have penetrated into the pore network, crucial parameters such as supersaturation, climatic conditions and porosity can accelerate the subflorescence process. Figure 10 illustrates sodium chloride crystal formation within a sandstone pore further to salt resistance testing; pressure exerted on the quartz grains have the potential to cause microcracking as shown on the upper quartz grain.

The Effects of Fluctuating Climatic Conditions

Rodriguez-Navarro and Doehne (1999) concluded damage induced by salt crystallisation is largely due to "*solution properties*" and "*evaporation rates*", such as the type of salt dissolved within solutions and climatic conditions. An important mechanism which depends upon wetting, temperature and relative humidity fluctuations is dissolution-recrystallisation cycles (Flatt *et al.*, 2017). The general principal includes the dissolution or deliquescence of salts in solution before being dried, consequently dissolving out finer salt crystals and inhibiting the growth of remaining crystals during the cooling period. Furthermore, saline solutions can be transported throughout the pore network and re-crystallise in multiple locations following variations in temperature and relative humidity. Flatt *et al.* (2017) explains, in practice salts can be found dissolved in animal excrement, agriculture and atmospheric pollution (such as acid rain / sulphuric acid) which can wash into the ground and be transported into the material via capillary rise. On the other hand, salts can be dissolved within water vapour in the air (deliquescence). This occurs when: relative humidity of the air $>$ equilibrium relative humidity of the saturated salt solution. Moreover, it is also recognised chemical mechanics and kinetics are dominant factors which assist the explanation of crystallisation patterns and substrate damage.

The Behaviour of Various Salts

Flatt *et al.* (2017) and Lubelli *et al.* (2018) agree most laboratory experiments outline the testing of single salts, commonly sodium sulphate due to its aggressive nature. Often, sodium chloride is used as a substitute, although it is agreed to be much less damaging by various literature. This is evidenced within the most widely used test standard, BS EN 12370 (BSI, 2019b), which prescribes the use of 14% sodium sulphate, although Lubelli *et al.* (2018) highlights results may not truly reflect the damage observed in practice. Research concluded sodium sulphate was the most destructive salt in the weathering of stone Lubelli *et al.* (2018 cited Goudie, Cooke and Evans, 1970) and Cooke (1979) who used saturated solutions to test the durability of sandstone. In addition, Rodriguez-Navarro and Doehne (1999) also conducted further research into micro and macroscale salt weathering experiments to compare the growth of mirabilite and halite crystallisation patterns. Results showed decahydrate sodium sulphate was strongly affected by relative humidity of more than 50% and, subflorescence was formed at constant temperature and relative humidity (RH). Conversely, sodium chloride grew efflorescence at constant conditions, although RH had lesser effect during macroscale experiments (partial immersion in salt solution). In turn, lower RH led to higher levels of evaporation and

supersaturation, which may be described as a *"thermodynamic driving force… of which the energy may produce damaging mechanical work"* (Flatt *et al.*, 2017, p.109).

Frost Weathering

In addition to salt induced decay, "*frost weathering… [is also] a major physical deterioration process*" (Ruedrich, Kirchner & Siegesmund, 2010). BS EN 12371 (BSI, 2010) is the most commonly used standard test to check the frost resistance of natural stone. Generally, frost resistance tests incorporate a period freezing followed by a period of thawing (often where specimens are immersed in water). Ruedrich *et al.* (2010) state this type of test typically comprises of 30 to 50 freeze-thaw cycles although, further to experimental research it was concluded most stone specimens don't show signs of decay until 50 freeze-thaw cycles. Conversely, research undertaken by Walbert, Eslami, Beaucour, Bourges and Noumowe (2015) on three French limestones revealed the degree of deterioration varied on a macroscopic scale. Figure 11 shows the level of damage caused to the stone specimens after a varied number of freeze-thaw cycles. Whilst some specimens decayed after 30 to 50 cycles, other stones only started to deteriorate at 320 cycles. It was discussed the level of frost resistance is related to mechanical properties, pore size and distribution.

Comparing Petrological Characteristics of Secondary Data

Throughout the extended literature review several experimental studies on the effects of accelerated weathering tests on selected sandstones and travertine specimens are reviewed. Concu, De Nicolo & Valdes (2014) and Parent *et al.* (2015) previously suggested the typical matrix and fundamental properties of a stone are influenced by the diversity of the quarry where each stone specimen originates. Therefore, the research articles have been selected due similarities in sampling area across Iran and Turkey. Jamshidi, Nikudel, Khamehchiyan, Zalooli & Yeganehfar (2017) and Akin and Özsan (2010) study variations of travertine whilst Ghobadi and Babazadeh (2014) and Momeni, Khanlari, Heidari, Bagheri and Bazvand (2015) decay specimens of sandstone and Alvand monzogranite, respectively.

The Building Research Establishment (2008) outlined the porosity of limestone to range between 1% – 40%, likewise the average porosity (n) of travertine before testing was 3.48% with values ranging between 0.47% - 6.65% and a standard deviation (SD) of $\pm$0.61%. However, the average porosity for Group A yellow travertines ($n < 5\%$) was 4% with a SD of $\pm$0.55% and the average porosity for Group B ($n > 5\%$) was 6.25% with a SD of $\pm$0.88%. Additionally, porosity and dry density data of sandstone and granite specimens are compared in Table 2 below. Although the values derived from Ghobadi and Babazadeh's (2014) tests may be within scope of expected data, it should be noted the effective porosity range is largely varied for specimens quarried from the same areIn turn, this may have an effect on the results gathered from the respective study.

Type of Stone Specimen	Researchers	Dry Density (kg/m^3)		Effective Porosity (%)	
		Range	Average (SD)	Range	Average (SD)
Alvand Monzogranite	Momeni *et al.* (2015)	2670 -2690	2680 (-)	1.02 -1.50	1.28 (-)
Sandstone	Ghobadi and Babazadeh (2014)	2006 -2590	2400 (±0.07)	1.06 –11.56	6.04 (±0.9)
Typical sandstone values	BRE (2008)	2000 -2600	-	0.6 - 26	-

Table 2: Comparison of Engineering Properties Between Research Studies

It may be assumed yellow travertine specimens contain more connected voids thus permitting increased permeability. Adopting Benavente's (2011) theory of pore size and network, it is suggested yellow travertine specimens will allow a higher level of water and salts into the pore network during accelerated weathering tests, potentially leading to a higher level of decay. However, as the size of pores is unknown it is unclear whether high porosity reflects either a high level of capillary action or evaporation (Leary, 1983 cited in Smith and Viles, 2006).

Accelerated Weathering Tests

To monitor the resistance to salt weathering of each stone specimen, each study adopted the use of sodium sulphate and referred to the standard test method EN 12370. The only deviation from the testing standard was Akin and Özsan (2010) which undertook tests in accordance with RILEM (1980). Nevertheless, the specimens were also immersed in 14% sodium sulphate solution and dried at 105°C ± 3°C. The following flowchart demonstrates the level of aggressiveness of the methodologies implemented by each research article.

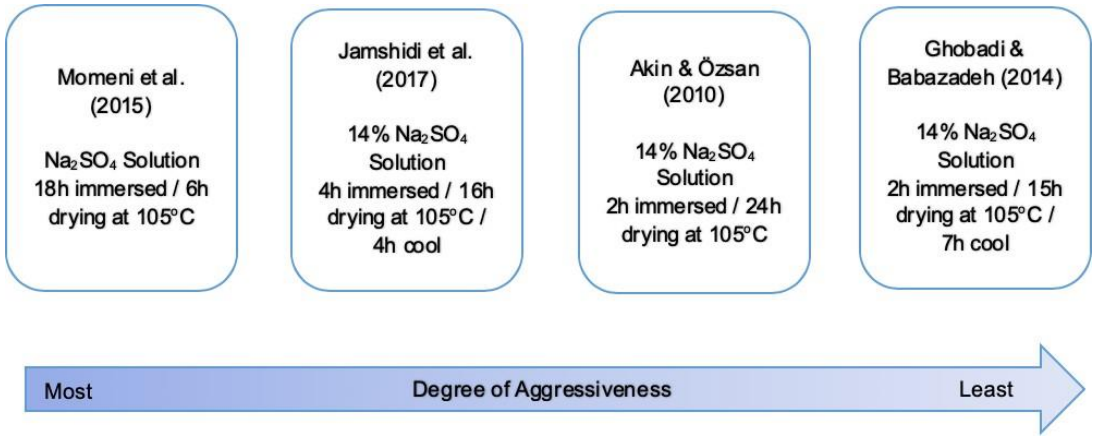

Figure 10: Level of Aggressiveness of Accelerated Salt Weathering Tests

Equally, the freezing-thawing cycles reflect a similar order of aggressive test procedures utilised by each of the studies. This is illustrated in Figure 11.

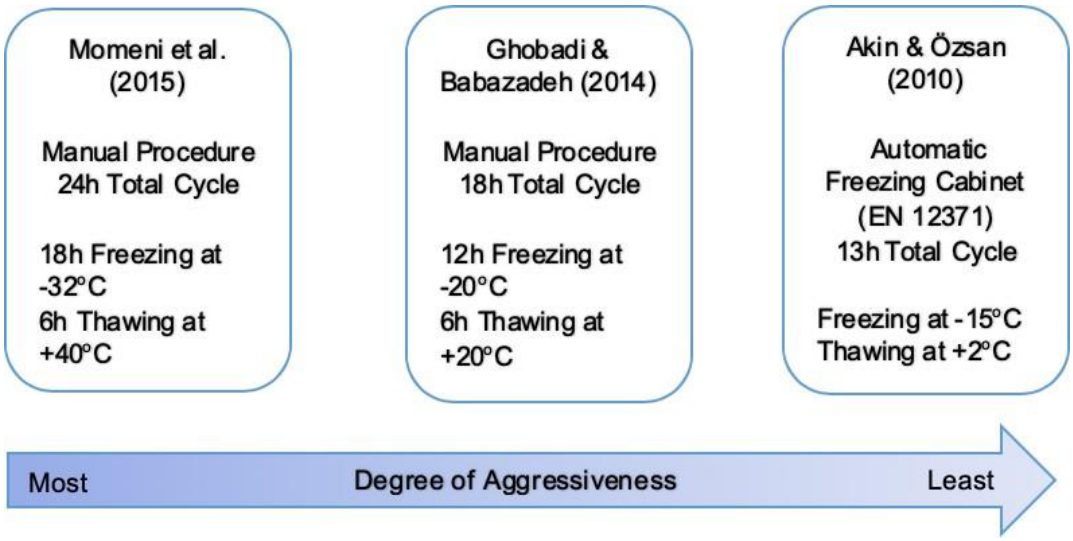

Figure 11: Level of Aggressiveness of Accelerated Frost Weathering Tests

Data Analysis Prior to Testing

Prior to testing, initial porosity, density, uniaxial compressive strength and P-wave velocity data was collated by each of the studies. This enables baseline correlations to be established and fluctuations in data can be monitored against reference points. Momeni *et al.* (2015) only provided average data, therefore figures could not be extrapolated into linear equations for correlation and statistical analysis purposes. In addition, Ghobadi and Babazadeh (2014) collected dry and saturated P-wave velocity data, however before both these sets of results could be analysed the t-test was performed to verify if there is a significant difference in the velocity readings. The calculated value of *t* is 0.31 suggests there is no significant difference between the dry and saturated readings and can be used to establish initial correlations.

First, strong **negative correlations** are ascertained between **density and porosity** and **P-wave velocity and porosity**; further to calculating their respective Pearson product-moment correlation coefficient's (r). Furthermore, it is also evidenced within Akin and Özsan's (2010) study, both density and V_p decreases as effective porosity increases in value. Density can be denoted as $\rho = \frac{m}{v}$, therefore if mass is constant or equal to 1, volume must decrease for an increase in density (inverse relationship). Consequently, the internal matrix of the stone would be more compact, and grains / minerals would be closer together thus fewer void spaces within the material. In turn, decreasing the level of water that can pass through the pore network and permitting a lower porosity value (Martynenko, 2008, p.1497).

Equally, **P-wave velocity and density** have a significant relationship and a **strong positive correlation**. Speed / velocity can be expressed as $s = \frac{\Delta d}{\Delta t}$ where d can be assumed as a constant for the specimens. In order for velocity to increase, time taken for the p-waves to travel through the material must decrease. This suggests P-waves travel slower through air within voids and if there are more voids present due to a decrease in

density. The correlation between density and V_p for sandstone data is further verified by Miller and Stewart (n.d., p.264).

The following hypothesis can be proposed: *A lower V_p reflects a higher level of decay.*

Moreover, **P-wave velocity** and **uniaxial compressive strength** also have a **strong positive linear relationship** with a correlation coefficient of $r = 0.92$ for Ghobadi and Babazadeh's (2014) sandstone specimens and $r = 0.97$ for the travertine specimens. Majstorović, Gugoric, Lutovac, Negovanović and Crnogorac (2019) agree lower P-wave values correspond with lower UCS values. This supports the proposed hypothesis as it is assumed UCS decreases with the number of weathering cycles.

Salt Weathering Data Analysis

Subsequent to the specimens being subject to accelerated salt weathering tests, Akin and Özsan (2010) established the dry and saturated weights of the yellow travertine samples were not considerably altered. Throughout testing, only a 1% total weight increase was noted. Although, fractures were observed parallel to the lamination axis and decreases in weight were detected after initial cracking. Likewise, the total dry density of the granite specimens was not particularly affected; a reduction of 0.06gr/cm^3 or 2.2% was calculated. On the other hand, most of Ghobadi's and Babazadeh's (2014) sandstone specimens also illustrated minimal change in weight / density, however specimens labelled S, S1 and Tr demonstrated a significant weight increase of 30.98%, 45.38% & 48.6%, respectively. In light of these results, Ghobadi and Babazadeh (2014) did not pursue investigation of these specimens. Akin and Özsan (2010) agree with Espinosa *et al.* (2007) and La Russa (2013) that fluctuations in weight are largely caused by an accumulation of salt crystals within the pores further to the dissolution-recrystallisation process. In addition, if weight is presumed constant throughout the weathering cycles, it may be assumed V_p is mostly influenced by porosity as suggested by Marshall *et al.* (2014) and Benavente (2011).

In turn, the porosity (%) of the Alvand Monzogranite specimens gradually increases until cycle 30 and then sharply increases by 4.68% between cycles 30 and 35. Through investigating the density of cracks within rocks via microscopic analysis (Ding and Song (2016) cited Ferrero and Marini, 2001) in recognised a correlation between an increase in porosity and the development of new fractures and cracks. Moreover, it is noted UCS also rapidly decreases from 107.2MPa to 9.8MPa throughout the 35 cycles and evidences UCS decreases as a material deteriorates.

Conversely, the porosity behaviour demonstrated in Momeni *et al.* (2015) study is not wholly reflected in the yellow travertine data (see Figures 15 & 16). For both Group A ($n < 5\%$) and Group B ($n > 5\%$), porosity initially decreases rapidly until the 10th cycle is reached, then porosity sharply increases. Data also shows the final porosity figure for Group A exceeds the mean initial value, thus a total % increase is achieved as found with the granite specimens. However, Group B specimens did not attain their original porosity value after the salt decay cycles and Akin and Özsan (2010) suggest this is due to smaller pore size.

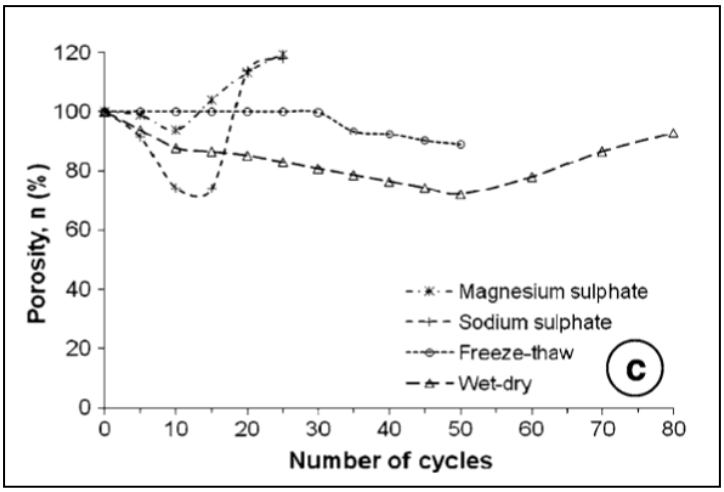

Figure 12: Variations in Porosity of Group A Yellow Travertine Specimens via Salt Weathering (Akin & Özsan, 2010, p.107)

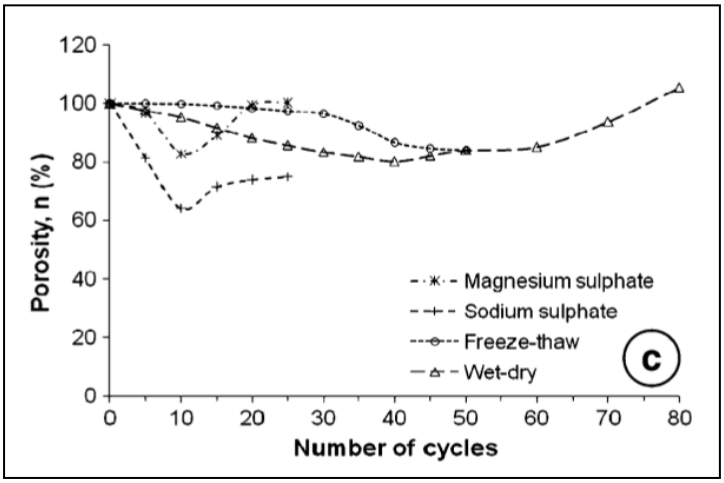

Figure 12: Variations in Porosity of Group B Travertine Specimens via Salt Weathering (Akin & Özsan, 2010, p.108)

Akin and Özsan (2010) agree with Ferrero and Marini (2001) cited in Ding and Song (2016) that a variation in porosity reflects internal damage such as the development of new fractures. The initial fall in porosity is largely due to the formation of salts within pores and reducing void capacity, whereas the rapid increase follows observation of the first fractures. Thus, porosity of the yellow travertine specimens echoes internal decay.

Moreover, all four studies saw UCS gradually decrease across the salt weathering cycles. Values ranged considerably between the various stone types with an average % loss in UCS for travertine of 22% compared with the granite specimens that were most adversely affected with an average loss of 86% over 30 cycles. This suggests granite is the least durable stone when subject to Na_2SO_4 cycles, however as previously identified, the weathering test undertaken by Momeni *et al.* (2015) was the most aggressive and it is likely this fundamentally influenced the results. The UCS data obtained evidences the

expected pattern of results. It was determined UCS has a significant inverse relationship with porosity therefore as increased porosity is observed throughout the cycles it is anticipated UCS decreases. Consequently, V_p also decreased overall from initial figures. However, only Akin and Özsan's (2010) Group A specimens and Ghobadi and Babazadeh's (2014) sandstone specimens showed a constant reduction in V_p throughout the cycles. Conversely, Jamshidi *et al.* (2017) and Momeni *et al.* (2015) data demonstrates an initial spike in V_p during the first $10 - 15$ cycles before gradually reducing. Literature explored within this study supports the data retrieved from the travertine and granite specimens. Initially the increase in V_p is likely due to an accumulation in salt crystals within the pores of the specimens thus decreasing the porosity (Akin and Özsan, 2010; Martynenko, 2008; Espinosa *et al.* 2007). Furthermore, due to dissolution and re-crystallisation cycles and the formation of new cracks, it is expected porosity increases and V_p decreases (Ferrero and Marini, 2001 cited in Ding and Song, 2016).

Overall, the data analysed ratifies the validity of the initial correlations. Nevertheless, there appears to be discrepancy within initial cycle datYellow travertine was the only stone type to behave in the predicted manner during first 15 cycles for both porosity and V_p.

Freeze Thaw Data Analysis

Comparable to the salt weathering tests, density and water absorption remained consistent throughout the freeze-thaw cycles. A total average weight loss of 0.5%, 1.1% and 0.7% was recorded for the yellow travertine, sandstone and granite specimens, respectively. Yildirim and Ekinci (2012) suggest weight loss as a result of freeze thaw cycles could be due to the spalling of the materials surface and corners which is likely to occur initially in samples characterised with a high porosity and loose internal structure. Thus, S and S_1 sandstone specimens were most adversely affected by the freeze thaw cycles. Their initial porosities of 11.56% and 11.13% encountered 4.1% and 2.18% weight loss after 15 cycles compared with an average porosity of 4.5% and SD of 2.8% for the remaining sandstones that were reduced in weight by a mean of 0.28% and SD of 0.27%. Moreover, all the specimens analysed exhibited a gradual decrease in V_p throughout the frost resistance cycles, V_p of the granite specimens reduced by 8.5% over 300 cycles whereas the sandstone specimens decreased by 10.2% over 60 cycles. Likewise, the UCS of the sandstone specimens was reduced the most by 17.5% following 60 cycles in comparison with the granite specimens which only decreased by 18.7% after 300 cycles; despite Momeni *et al.* (2015) adopting a more aggressive procedure. In addition, the average porosity of the Alvand monzogranite was initially 1.28% and 6.04% for the sandstone. Therefore, as a strong negative linear relationship was established between porosity and both V_p and UCS, it can be understood why sandstone specimens experienced a significant decrease in these parameters.

Further to analysis of volume expansion theory and linear growth pressure following the redistribution process of soluble solutions, Ruedrich *et al.* (2010), Desarnaud *et al.* (2016) and Marshall *et al.* (2014) agree the durability of natural building stones is largely dependent on pore space. An assessment of data within the literature review indicates

resistance against crystallisation processes can be predicted, however long-term data retrieval is required to evaluate a significant difference in V_p and UCS; especially for higher density rocks such as granite.

CONCLUSIONS

It can be concluded establishing the origin, relative mass, density and porosity of stone samples is significant when undertaking V_p tests, it was suggested by Concu *et al.* (2014) these parameters have varying effects on V_p. In addition, literature further explained the importance of pore structure on the durability of stones subject to weathering cycles.

Primarily, it is understood (Viles, 2012; Binda *et al.*, 2001 & Manning *et al.*, 2014) V_p is widely used within the construction industry to non-intrusively monitor masonry although, it was identified observing the internal matrix has its issues. Godts *et al.* (2016) suggested salt crystallisation is a major cause of deterioration to buildings, whilst Ruedrich *et al.* (2010) also explained another damaging weathering process is frost action. Both mechanisms rely on solution to be transported through the pore network and deposited within voids to inhibit the growth of salt and ice crystals. In turn, subjecting the confining pore walls to mechanical stress leading to cracking and fractures.

Travertine and granite specimens demonstrated an initial spike in V_p during the first 15 salt cycles, whereas yellow travertine and sandstone showed a constant decline. It was discussed within the literature an accumulation of salt crystals within pores may have caused the initial spike due to a reduction in porosity; it is suggested V_p has a strong negative correlation with porosity. However, this does not necessarily explain why a gradual decrease in V_p was observed in Akin and Özsan (2010) and Ghobadi and Babazadeh's (2014) studies due to similarities between the specimen's properties (e.g., Travertine and Yellow Travertine). It may be the case that because their tests were not as aggressive (as suggested in Figure 13), fewer salt crystals were formed in the same number of cycles. Similarly, a gradual decline in V_p was seen throughout the freeze-thaw cycles. However as previously explained, frost action was the least aggressive mechanism. This would support the previous theory that fewer salt and ice crystals were formed thus porosity was not compromised. In addition, the relative humidity of the salt weathering test in each study was not stated. Rodriguez-Navarro and Doehne (1999) explained RH > 50% has a strong effect on decahydrate sodium sulphate, therefore the travertine and sandstone specimens may have been subject to a higher RH during testing which inhibited the rapid growth of subflorescence.

Consequently, through analysis of secondary data, initial correlations and relationships between fundamental properties could be developed. The following negative linear relationships were established before testing:

1. Density v. Porosity;
2. P-Wave Velocity v. Porosity;
3. Uniaxial Compressive Strength v. Porosity.

Subsequently, the following positive linear correlations were suggested:

4. P-Wave Velocity v. Density;

5. P-Wave Velocity v. Uniaxial Compressive Strength.

Thus, the hypothesis: a lower V_p reflects a higher level of decay was proposed.

It was developed that porosity generally increased with the number of weathering cycles, whereas UCS was reduced. Ferrero and Marini (2001) cited in Ding and Song (2016) recognised porosity increased with the development of new cracks and fractures. In turn, as UCS declined with the number of weathering cycles, a reduction in Vp was also observed. Subsequently, this suggests the hypothesis is proven and it may be assumed if V_p decreases from its initial value, it is likely the material has lost uniaxial compressive strength and deteriorated. To conclude, the level of deterioration of each weathering mechanism is dependent upon the stone's fundamental properties, mainly porosity and density. It can be suggested the internal matrix of stones does influence the behaviour of P-wave velocity.

As a result of this study, it is recommended further research is undertaken to investigate how the orientation of ultrasonic transducers (through-direct transmission vs. pulse-echo direct transmission) effects V_p correlations. Furthermore, Ghobadi and Babazadeh's (2014) study incorporated dry and saturated V_p data which enabled the comparison of variation in the readings. Further to performing the t-test, it was concluded there was no significant difference between the values. This suggests adverse weather conditions should not affect V_p readings if ultrasonic testing methods are adopted in the field. However, it must be appreciated this assumption is based on one set of data and additional investigative research is suggested to explore the theory.

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