School of Public Health

Developing a Validated Tool to Identify Asbestos-Containing Materials in Domestic Settings in the Western Australian Community

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This thesis is presented for the Degree of
Doctor of Philosophy
of
Curtin University

June 2018

Declaration

To the best of my knowledge and belief this thesis contains no material previously published by any other person except where due acknowledgment has been made.

This thesis contains no material which has been accepted for the award of any other degree or diploma in any university.

The research presented and reported in this thesis was conducted in accordance with the National Health and Medical Research Council National Statement on Ethical Conduct in Human Research (2007) – updated March 2014. The proposed research study received human research ethics approval from the Curtin University Human Research Ethics Committee (EC00262), Approval Number RDHS-89-15.

Signature: ………………………………..

Date: 18 June 2018

Abstract

Background: Asbestos-containing materials (ACMs) were used extensively in Australian residential settings throughout much of the 20th century. Despite the Australian Government enforcing a prohibition on the importation, manufacture, and use of asbestos products from 31 December 2003, exposure can still occur when individuals repair, renovate or demolish older buildings containing *in situ* asbestos. However, many Australians lack the knowledge and confidence to identify ACM despite its ubiquity in the residential environment. Furthermore, we currently do not know the amount, most common types, and current condition of *in situ* ACM remaining in Australian residential settings.

Aims: Therefore, this project aimed to: 1) design and develop a mobile phone application (app) to assist with identifying *in situ* ACM; 2) test the app on a sample of Western Australian homes; and 3) use the app in a cross-sectional study to collect data on the current prevalence and condition of *in situ* asbestos remaining in Western Australian and other Australian residential settings. To achieve this, the project consisted of three key phases.

Phase One: The ACM Check app was designed and developed by a multidisciplinary team to methodically guide users, such as householders, home renovators, and tradespeople, through a visual inspection of the inside and outside of the house where key materials that may contain asbestos could be located. The app identifies potential ACMs, prioritises the materials for remediation or removal based on their condition and potential for disturbance, and produces a summary report for each screened house.

Phase Two: Before ACM Check was released to the public, a study was conducted to test the accuracy of the app in identifying *in situ* ACM, and to evaluate the functionality and potential impact of the app on participants. Forty participants were recruited who owned a home built pre-1990 in the metropolitan area of Perth, Western Australia (WA). Each participant completed ACM Check on their home and the results were compared to onsite inspections conducted by an experienced environmental consultant. Based on Cohen's kappa statistic, there was fair (e.g., $\kappa=0.304$ for interior flooring) to substantial (e.g., $\kappa=0.918$ for fencing) agreement between the two methods when categorising specific materials as positive or negative for asbestos. Participants took a cautious approach towards assessing the condition and potential for disturbance of ACMs, and they tended towards selecting more severe ratings compared to the consultant. Feedback suggests that the app is visually appealing and easy to use, navigate, and complete. The follow-up questionnaire indicated that ACM Check may raise people's awareness of residential sources of asbestos, and that completing the app may lead to users taking preventative actions to protect household occupants from exposure to asbestos.

Phase Three: The app was released to the public and used as the data collection tool in a cross-sectional study. Of the 461 houses assessed, 377 (81.7%) houses contained a total of 1,266 *in situ* materials that were categorised as positive for asbestos by the app. The data collected using ACM Check showed that the majority of *in situ* ACMs were located outside the home (70%), and the most prevalent *in situ* ACMs included the following: flat asbestos-cement sheeting used as the backing board to electrical meter box (51% of homes), flat asbestos-cement sheeting used for eaves (44% of homes), and corrugated asbestos-cement sheet fencing (34% of homes). In particular, the data highlighted that asbestos-cement sheet fencing was much more prevalent in the WA residential environment compared to other Australian jurisdictions (50.7% vs. 9.2%, respectively). One in five ACMs across all Australian jurisdictions were rated by users as being in ‘poor’ (14.8%) or ‘very poor’ (5.3%) condition. While the majority of ACMs were categorised as ‘very low’ or ‘low’ priority for action, 5.5% of all ACMs were considered to be of ‘high’ priority.

Conclusions: This thesis shows that a specifically designed app, ACM Check, can be used by a range of community members to collect data on the presence, current condition, and potential for disturbance of *in situ* asbestos in Australian residential settings. This is the first such app to be developed and trialled in this population, and to the best of our knowledge, in any population internationally. Mobile phone apps offer a platform to help increase people’s awareness of possible health hazards found in the residential environment, such as asbestos, while also being used to collect data for public and environmental health research.

Acknowledgements

There are numerous people and organisations who I wish to acknowledge for making this a reality. Firstly, my deep gratitude goes to my exceptional supervisors, Associate Professor Alison Reid and John Curtin Distinguished Professor Lin Fritschi. Thank you for providing me with the opportunity to undertake a PhD – something that I never thought I would be able to do. I am incredibly grateful for all of your time, effort, feedback, guidance, and positivity over the years. More broadly, I would like to extend the thanks to the past and present members of the Occupational Epidemiology Team at the School of Public Health, Curtin University who always showed interest in my project and were an endless source of encouragement.

Secondly, I am indebted to Dr James White of Reach HPI who not only handled the technical development and management of ACM Check throughout this project, but also went the extra mile in assisting me in whatever way he could. This undertaking would not have been possible without his time and commitment.

I want to take the opportunity to thank the Environmental Health Directorate, Western Australian Department of Health for funding the project. In particular, I wish to thank Dr Peter Franklin, Dave Peckitt (ret.), and John Howell (ret.) of the Environmental Health Hazards Unit for their assistance with the formative design and development of ACM Check. In addition, I wish to thank Dave for sharing his years of experience regarding asbestos identification as well as for his assistance during Phase Two.

Thanks are extended to the Asbestos Safety and Eradication Agency for the additional funding and, specifically, to Merrin Hambley for being supportive of what we were trying to achieve.

Additionally, I wish to thank the team at Cancer Council WA: Sharnae Zanotti, Melissa Ledger, Elise Wareing, Nicole Biagioni, and Michelle Jongenelis. Their invaluable feedback during the development phase, and their promotion of ACM Check when it was released to the public, are greatly appreciated.

Of course, thanks are extended to all of the individuals and organisations who contributed to this project in various capacities, whether it was providing feedback during development, beta testing the app, participating in the validation or community studies, promoting the app or our research, or downloading and completing ACM Check. These contributions allowed me to complete this program of research, and for that, I am grateful.

Finally, I would like to acknowledge the endless love and support of my Fiancé, Mel. Thank you for all that you do!

Statement of Contribution of Others

The School of Public Health at Curtin University provided the research environment that supported the PhD candidate to undertake this research. The PhD candidate was the co-investigator of the project and active in designing the methodology and intervention, undertaking recruitment, implementing the intervention program, and data collection and analysis. The PhD candidate was responsible for writing all publications presented as part of the thesis, with input from co-authors. Details are provided below.

- **Associate Professor Alison Reid** contributed as PhD supervisor and provided close and ongoing support and involvement with the research project. Associate Professor Reid participated in the study design, read drafts and suggested improvements for all publications.

- **Professor Lin Fritschi** contributed as PhD co-supervisor and provided ongoing support and involvement with the study. Professor Fritschi also participated in the study design, read drafts and suggested improvements for all publications.

- **Dr James White** contributed as a collaborator who performed a paid contracting role in the technical development and management of the mobile phone app, ACM Check. Dr White also contributed as co-author and read drafts and suggested improvements for the publication presented in Chapter 3.

Appendix A: Co-Author Statements provides signed statements from the Co-Authors endorsing the contribution of the PhD Candidate to publications included as part of this thesis.

List of Publications

Published

Govorko, M. H., Fritschi, L., White, J., & Reid, A. (2017). Identifying asbestos-containing materials in homes: Design and development of the ACM Check mobile phone app. *JMIR Formative Research, 1*(1), e7. doi:10.2196/formative.8370

Govorko, M. H., Fritschi, L., & Reid, A. (2018). Accuracy of a mobile app to identify suspect asbestos-containing material in Australian residential settings. *Journal of Occupational and Environmental Hygiene*, 1-21. doi:10.1080/15459624.2018.1475743 (Accepted author version posted online: 14 May 2018)

Planned for publication

Govorko, M. H., Fritschi, L., & Reid, A. (2018). Using a mobile phone app to identify and assess remaining stocks of *in situ* asbestos in Australian residential settings. Unpublished.

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Abbreviations and Definitions

ACM(s): asbestos-containing material(s)

ACT: Australian Capital Territory

AMR: Australian Mesothelioma Registry

App: application

ARD(s): asbestos-related disease(s)

ASCC: Australian Safety and Compensation Council

ASEA: Asbestos Safety and Eradication Agency

CDC: Centers for Disease Control and Prevention

DIY: do-it-yourself

DoH: Department of Health

EHD: Environmental Health Directorate

EHO(s): Environmental Health Officer(s)

enHealth: Environmental Health Standing Committee

IARC: International Agency for Research on Cancer

ISO: International Organization for Standardization

NAER: National Asbestos Exposure Register

NATA: National Association of Testing Authorities

NOHSC: National Occupational Health and Safety Commission (now Safe Work Australia)

NSW: New South Wales

NTP: National Toxicology Program

OR: odds ratio

OS: operating system

PLM: Polarised Light Microscopy

RR: relative risk

SA: South Australia

UK: United Kingdom

US EPA: United States Environmental Protection Agency

US: United States of America

WA: Western Australia

WHO: World Health Organization

Chapter 1: Introduction and Overview

1.1. Background

The term "asbestos" refers to a group of naturally occurring fibrous silicate minerals that have several favourable physical and chemical properties including high tensile strength, durability, and fire resistance. Asbestos was used throughout the greater part of the 20th century in industrialised countries, including Australia, Canada, United States (US), United Kingdom (UK), Italy, and other parts of Western Europe, and was incorporated in over 3000 commercial applications.

Globally, Australia was the country that consumed the highest amount of asbestos on a per capita basis during the 1950s and 1960s (Lin et al., 2007; Takahashi et al., 1999). In Australia, asbestos was mined as early as the 1880s and asbestos cement products were manufactured from the 1920s and continued till the late 1980s (Environmental Health Standing Committee [enHealth], 2013). During that time, every capital city in Australia had at least one asbestos cement manufacturing plant (Gray, Carey, & Reid, 2016). The asbestos cement manufacturing industry accounted for 60% of all production (i.e., mining of raw asbestos) and 90% of all consumption of asbestos fibres in Australia (Australian Safety and Compensation Council [ASCC], 2008b; Leigh & Driscoll, 2003). By 1954, Australia was the fourth highest gross consumer of asbestos cement products globally, only behind the US, UK, and France (Leigh & Driscoll, 2003). Up until the 1960s, 25% of new Australian homes were clad with asbestos cement products. In the state of New South Wales alone, 70,000 homes were built with asbestos cement between 1945 and 1954 (Leigh & Driscoll, 2003). It is currently estimated that one third of all Australian homes contain asbestos products and it is highly likely that all homes built before the mid-1980s contain at least some asbestos-containing materials (ACMs; enHealth, 2013). In residential settings, ACMs are commonly found in the external and internal wall cladding, eaves, ceilings, fences, and outbuildings.

However, during the period when asbestos was being used widely, it became clear that asbestos exposure can result in the development of diseases, including malignant mesothelioma, lung cancer, and asbestosis (collectively termed "asbestos-related diseases" or ARDs). As a direct consequence of past national consumption, Australia now has one of the highest incidence rates of malignant mesothelioma in the world at 2.5 new cases per 100,000 population (Australian Mesothelioma Registry, 2017). The number of incident malignant mesothelioma cases in Australia increased from 156 in 1982 to 700 in 2016. Western Australia (WA) continues to have the highest age-standardised incidence rates of malignant mesothelioma of any state or territory in Australia at 4.5 new cases per 100,000 population. This high rate is related to its substantial history of crocidolite asbestos mining and extensive production and use of ACMs (Australian Mesothelioma Registry, 2017; Leigh & Driscoll, 2003; Musk, de Klerk, & Brims, 2017). Two epidemics of ARDs have been recognised, namely the "first wave" (from mining of asbestos and production of ACMs) and the "second wave" (from use of ACMs by builders, ship workers, etc.).

Because of the health effects of asbestos, in Australia, the production of crocidolite ceased in 1967 followed by the cessation of amosite use in 1984 while chrysotile was phased out between 1981 and 1987. The use of new ACMs in residential settings ceased in the late 1980s. As of 31 December 2003, a complete national ban was put in place prohibiting the importation, manufacturing, processing, sale, storage and re-use of all types of asbestos and ACMs (enHealth, 2005).

However, the prohibition does not extend to ACMs that were *in situ* prior to this date. Therefore, a large reservoir of *in situ* asbestos exists in the residential environment and is a lasting toxic legacy of Australia's high levels of consumption during the previous century. Exposure to asbestos in Australia, and in other countries who have banned asbestos, is now predominantly from the maintenance, renovation, and demolition of buildings with *in situ* ACMs (Mazurek, Syamlal, Wood, Hendricks, & Weston, 2017; National Institute for Occupational Safety and Health [NIOSH], 2011; Sen, 2015). These exposures are often referred to as "third wave" exposures and are expected to contribute to the future burden of malignant mesothelioma. In particular, a Western Australian study by Olsen et al. (2011) documented that the number of malignant mesothelioma cases related to renovation and maintenance activities in and around the house has significantly increased over the last ten years and predicted that it will continue to rise. More specifically, home renovators comprised the largest proportion of non-occupationally exposed malignant mesothelioma cases for both men and women, accounting for 87 of the 195 cases of mesothelioma associated with non-occupational asbestos exposure (Olsen et al., 2011).

Primary prevention is key for ARDs, especially as there is no recognised safe level of exposure to asbestos. Despite the ubiquity of ACMs in Australian homes, previous studies have reported low levels of awareness, knowledge, and confidence when it comes to identifying asbestos and correctly managing the risks. A key reason for this is that ACMs are difficult to identify because of the large and varied uses of asbestos in residential settings. This is exacerbated by the similarities in visual features between certain older ACMs and the newer asbestos-free materials, which makes it difficult for the untrained individual to distinguish between ACMs and non-ACMs. Therefore, it has been established that greater practical information and guidance is needed on how to identify ACMs and how to correctly manage the risks (Asbestos Safety and Eradication Agency [ASEA], 2014).

A potential method to improve identification and raise awareness of residential sources of asbestos is through the use of specifically designed and developed mobile applications ("apps"), which have risen in prominence over the last decade alongside the growth of smartphones and tablet computers. There were over 16.7 million estimated smartphone users in Australia during 2017 (Statista, 2018) with 88% of Australians over 18 years of age owning a smartphone (Drumm, White, Swiegers, & Davey, 2017); the number of smartphone users is projected to increase to 17.35 million in 2018 through to 19.3 million in 2022 (Statista, 2018). As such, mobile apps offer a platform with the power to reach a large audience, especially when they are made available for free on the major operating systems (OS), and can be used without internet connection once they have been downloaded. However, there are no apps available in Australia – and to the best of our knowledge, internationally – that target the identification of *in situ* asbestos in the residential environment.

1.2. Research Design

The overall design of this project involved creating an asbestos identification and assessment questionnaire with a scoring algorithm; professionally developing a mobile phone app for this questionnaire; pilot testing and validating the app on a sample of WA homes; and, conducting a prevalence survey using the app to collect data on *in situ* asbestos located inside and outside WA and other Australian state and territory residential settings.

More specifically, this research project consisted of three main phases each with its own specific aim and series of objectives. Each phase builds on top of the previous phase. The phases include:

- Phase One: App design and development
- Phase Two: Validation and pilot study of the app
- Phase Three: Community survey of asbestos in Australian residential settings

1.3. Aims and Objectives

The primary aim of this research project was to develop, validate, and implement a mobile phone application ("app") that aids in the identification and assessment of *in situ* ACMs in Western Australian residential settings and demonstrate its use in the Australian population. To achieve the primary aim, the research project comprised three phases, each with a specific aim and a set of corresponding objectives (Table 1).

Table 1 Specific aims and objectives of the research project

Aim 1: To develop a mobile phone app that can be used to identify and then assess the condition of *in situ* ACMs in residential settings. The app was created to do the following:	
1.1	To identify *in situ* ACMs inside and outside the home
1.2	To describe the condition of the ACMs
1.3	To collect data regarding the amount, type, and condition of ACMs in and around residential settings
1.4	To direct users to further resources that assist in the safe management of ACMs
Aim 2: To pilot test and validate the app on a sample of homes built pre-1990 in Perth, WA.	
2.1	To validate the accuracy of the app in identifying *in situ* ACMs located inside and outside of homes compared with onsite inspections conducted by an experienced environmental consultant
2.2	To pilot test the condition assessment of ACMs using the app compared to the results of an experienced environmental consultant
2.3	To evaluate the usability and flow of the app (i.e., its functionality)
2.4	To investigate if completion of the app resulted in knowledge seeking or changes to participants' behaviour (i.e., its potential impact)
Aim 3: To demonstrate the ability of the app to estimate current patterns of domestic sources of asbestos in a community.	
3.1	To demonstrate that the app can be used to estimate the number of houses with potential/identified *in situ* asbestos, the sources of asbestos, and the condition of the ACMs

1.4. Significance

There are several key reasons why this project was undertaken. There are no curative treatments currently available for malignant mesothelioma, asbestosis, or lung cancer. Furthermore, there is no safe threshold level of exposure where inhalation of asbestos fibres does not increase an individual's risk of developing mesothelioma. Therefore, preventing asbestos exposure is of primary importance. National bans on the importation, manufacturing and use of asbestos are necessary to reduce, but not sufficient to eliminate, the burden of ARDs in a given country or region. A principal reason for this is the continued risk of exposure from *in situ* ACMs in the built environment. This is the case in Australia where the importation and use of asbestos was prohibited in 2003, but the prohibition does not require the removal of *in situ* asbestos. As a consequence, individuals (such as tradespeople, DIY home renovators, and household occupants) continue to be exposed to asbestos during repair, maintenance, and renovation activities or during demolition of older houses that contain asbestos products.

Awareness and knowledge of asbestos in the residential environment is key for those who are at risk of exposure. However, *in situ* ACM is difficult to identify for the untrained individual, and previous surveys have reported that many Australians have a low level of confidence when it comes to identifying asbestos, assessing the risks, and then managing the risks safely (ASEA, 2014; EY Sweeney, 2016). As such, the Australian Government's Asbestos Safety and Eradication Agency (ASEA) highlighted in their *National Strategic Plan for Asbestos Awareness and Management 2013-2018* that there is a need for increased community awareness about the risks of asbestos, development of measures to assist with the identification of *in situ* ACMs in the residential sector, and research looking at "practical and implementable approaches to prevent exposure to asbestos" (ASEA, 2013, p. 2).

Finally, the current stocks of ACM remaining in the Australian residential sector as well as their current condition are unknown; hence there is a need to gain an improved understanding of the amount, location, and condition of ACMs in the residential environment (ASEA, 2017b). A mobile phone app has the potential to assist in this task.

At the commencement of this project there were no free mobile phone apps that assisted community members in screening a residential premises for the presence of ACM. Therefore, developing, testing, and implementing a specifically designed mobile app can simultaneously address two major needs: helping community members to identify residential sources of asbestos whilst also collecting data on its presence and condition for public health research.

1.5. Outline of the Thesis

This thesis is presented in the form of two published papers, one paper prepared for publication, and two additional chapters describing the results of the study, together with introductory, literature review and concluding chapters. The thesis is structured as follows:

Chapter One has introduced the thesis and given an overview of the research design, aims and objectives, and significance of the study.

Chapter Two contains a review of the literature with regards to asbestos, and a brief summary of its health effects. This chapter concentrates on exposure pathways, *in situ* ACMs in the Australian residential environment, and current awareness in the community of asbestos in residential settings. This discussion is followed by a review of the emergence of mobile phone apps and how they can be utilised for health promotion and research. Finally, a discussion of the gaps in current knowledge is presented.

Chapter Three outlines the multiple steps involved in designing and developing the mobile phone app, ACM Check, and describes the different components making up the app. This chapter was published in the JMIR Formative Research (see Appendix D: Published Papers).

Chapter Four presents the validation study that was conducted to test the accuracy of ACM Check in identifying *in situ* asbestos located inside and outside of homes in metropolitan Perth, WA. It describes the strength of agreement between the results obtained from ACM Check compared to the results obtained from onsite inspections conducted by an experienced environmental consultant. This chapter was published in the Journal of Occupational and Environmental Hygiene (see Appendix D: Published Papers).

Chapter Five describes the current condition of *in situ* ACMs assessed by participants of the validation study using ACM Check and compares their results with the environmental consultant's assessments.

Chapter Six discusses the results of the feedback and follow-up questionnaires that were completed by participants of the validation study in Phase Two of this project. This chapter also includes a discussion of the changes to ACM Check based on participant feedback made prior to the app being released to the public and used in Phase Three.

Chapter Seven presents the methods, results and discussion of the community survey that was conducted using ACM Check as the data collection tool. It describes the most common *in situ* ACMs and their current condition. This chapter is planned for publication.

Chapter Eight synthesises the major findings of the research project, discusses the strengths and limitations of the project, and provides recommendations for future research.

Appendices included are the questionnaires, recruitment materials, participant information and consent forms, and the ethics approval letters.

Chapter 2: Literature Review

This review briefly describes the mineralogy of asbestos and summarises the health risks of asbestos inhalation. The chapter concentrates on exposure pathways, the history of asbestos consumption in Australia, *in situ* asbestos-containing materials (ACMs) in the Australian residential environment, and current awareness in the community of asbestos in residential settings. It is followed by a discussion of the emergence of smartphones and mobile apps and how they can be utilised for health promotion and research. The review is concluded with a summary of the gaps in current knowledge.

2.1. Asbestos Mineralogy

2.1.1. Terminology and Classification

Asbestos is a generic term referring to a family of naturally occurring, fibrous silicate minerals, which have a specific crystalline structure and chemical composition (Craighead, Gibbs, & Pooley, 2008; Henderson & Leigh, 2011; Sporn, 2011). The term "asbestos" is derived from the Greek term for "inextinguishable," "unquenchable" (Henderson & Leigh, 2011) or "indestructible" (Craighead et al., 2008) and can be traced back to Greek philosophers use of the words "amiantos" and "asvestos" (Ross et al., 2008). To reflect the fibres' ability to resist fire, Greek philosophers used the term *amiantus* meaning "undefiled" (Alleman & Mossman, 1997). Whereas the Latin term *asbestinon* was first used by Pliny the Elder in the first-century and translates to "unquenchable" (Alleman & Mossman, 1997). Furthermore, what we now call asbestos has previously been referred to as "Salamander Cotton" and "Salamander's Wool," whilst alchemists during the Medieval period labelled the mineral "Salamander Stone," which refers to a mythical animal believed to have fireproof characteristics (Sporn, 2011).

There are two primary subfamilies of asbestos minerals, made of six minerals of particular importance. The serpentine category consists of only a single member, chrysotile (white asbestos), its name being derived from the Greek word *chrysos* (gold) and *tilos* (fibre). In contrast, the amphibole category contains the commercially used amphiboles crocidolite (blue asbestos) and amosite (brown asbestos) as well as actinolite, anthophyllite, and tremolite (Henderson & Leigh, 2011; Wagner & Lemen, 2008).

2.1.2. Mineralogical Features

The amphibole and serpentine groups have significant differences in chemical composition and chemical structure as well as differing geologic occurrences. This is despite these minerals generally being classified and regulated together as "asbestos." These variances result in differing fibre structures, dimensions, and biopersistence. In turn, these lead to noticeable differences amongst the fibre types in regards to their relative potency and ability to cause disease in humans (Sporn, 2011).

Although fibrous crystals of minerals are somewhat common in nature, the formation of asbestiform minerals is rare (Ross et al., 2008). Although the asbestiform minerals share a distinctive set of physiochemical properties, each type of fibre can be distinguished from the next based on their differing chemical compositions and structures (Ross et al., 2008). For instance, chrysotile fibres are curly and have a tendency to matt together whilst amphibole fibres are straight and needle-like with an ability to split longitudinally (Craighead et al., 2008; Henderson & Leigh, 2011).

In addition, serpentine asbestos (i.e., chrysotile) is considerably different in terms of its mineralogy compared to those in the amphibole subfamily, which share particular crystal features. For instance, chrysotile tends to exist in the air as loosely adherent clumps or bundles of fibres, as opposed to single fibres, as is the case for amphiboles. This feature of chrysotile markedly influences the aerodynamic properties of the material in the environment as well as its respirability. It is for this reason (amphiboles affinity to occur singly whilst airborne) that amphiboles can be readily transported deep into the lungs after inhalation. Furthermore, the asbestos fibre types differ with respect to their size ranges when airborne and in lung airways (Craighead et al., 2008).

2.1.3. Key Physicochemical Characteristics

The group of six main asbestos minerals share a number of physical and chemical properties that are ideal for industrial use including that they (1) have high tensile strength and flexibility, (2) are a long fibrous shape, (3) are resistant to corrosion from acids and bases/alkalis, (4) have low thermal and electrical conductivity (i.e., ideal insulating properties), (5) have high mechanical thermal stability (resistance to fire), and (6) high absorbency (Henderson & Leigh, 2011; Ross et al., 2008). Furthermore, asbestos fibres are fine and are insoluble in both water and organic solvents which means they may be spun and woven into textiles as well as incorporated into a wide range of other types of materials (Sporn, 2011). However, the chrysotile and amphiboles are sufficiently different to have result in different commercial applications.

2.2. History of Asbestos Consumption in Australia: Mining, Production and Consumption

Due to its physicochemical properties, asbestos has been referred to as the “magic mineral” and was incorporated into approximately 3000 to 4000 different commercial products (Henderson & Leigh, 2011; Selikoff, Churg, & Hammond, 1964). These products ranged from insulating and fire resistant material used in ships, locomotives, power stations, and commercial buildings, and insulation covering boilers, furnaces, ovens and steam pipes; chrysotile in brake linings and gaskets; chrysotile in textiles used for the production of insulating and fire resistant suits, blankets, and rope; in asbestos filters in gas masks; through to a wide-range of asbestos cement products (Henderson & Leigh, 2011). Moreover, asbestos has been used for well over 2000 years with its first documented uses being in the manufacture of pottery in Finland around 2500 BC (Sporn, 2011). However, it wasn't until the late 19th century that demand steeply rose for asbestos due to its usefulness in industrial and commercial applications (Ross et al., 2008), with many industrialized countries, including Australia, beginning to mine raw asbestos and produce ACMs.

2.2.1. Mining and Production

Asbestos was first mined in Australia in the 1880s with amphibole at Jones' Creek, New South Wales (NSW), and serpentine at Anderson's Creek, Tasmania (Henderson & Leigh, 2011; Leigh & Driscoll, 2003). In 1916, crocidolite was first mined at Robertstown located in South Australia (SA). During this time asbestos production gradually increased and, until 1939, greater amounts of chrysotile than amphiboles were mined (Henderson & Leigh, 2011). Crocidolite then dominated asbestos production in Australia once mining commenced at Wittenoom, WA in 1937, and it continued to dominate production until the mine was closed in 1966 (Henderson & Leigh, 2011; Musk et al., 1992). From 1943 onwards, production rapidly increased and peaked at 11,000 tons of crocidolite per annum from 1957 until its closure (Musk et al., 1992). Asbestos production declined to pre-1952 levels in Australia as a consequence of the mining operations ending at Wittenoom in 1966 (ASCC, 2008b). From 1967 exports began to decline as did imports of chrysotile. Chrysotile continued to be mined at Baryulgil, NSW, and from 1971, it began to be mined at Woodsreef, NSW with exports increasing in conjunction with production at the mine. New South Wales produced the largest tonnages of chrysotile in Australia and continued to mine it up until 1983 when the Woodsreef mine ceased production due to the dry milling plant being unable to meet dust control regulations (Henderson & Leigh, 2011).

Due to a decrease in world demand for asbestos in conjunction with the increased costs of operating the Woodsreef mine, Australian production of asbestos declined in 1981 and ceased in 1983. Between 1880 and 1983, a total of 740,293 tonnes of asbestos was produced in Australia that comprised of 583,491 tonnes (78.82%) of chrysotile, 155,874 tonnes (21.06%) of crocidolite, and 927 tonnes (0.13%) of amosite (Leigh & Driscoll, 2003).

In addition to this, a large quantity of raw asbestos was imported into Australia beginning as early as 1929. Approximately half as much crocidolite and close to twice as much chrysotile asbestos was imported into Australia than was mined locally. The greater majority of imported asbestos was chrysotile from Canada followed by crocidolite and amosite imports from South Africa (Henderson & Leigh, 2011). From 1929 through to 1983, a combined total of approximately 1.5 million tonnes of raw asbestos was imported into Australia (Leigh & Driscoll, 2003). Along with the production and importation of raw asbestos, a wide range of manufactured asbestos products were also imported into Australia from the US, UK, Japan, and the Federal Republic of Germany (Musk & de Klerk, 2004).

2.2.2. Consumption

Globally, Australia was the country that consumed the highest amount of asbestos per capita during the 1950s and 1960s (Lin et al., 2007; Takahashi et al., 1999). Furthermore, Australia ranked fourth in the world by 1954 in regards to total amount of asbestos cement products consumed and was only behind the US, UK, and France (Leigh & Driscoll, 2003). The overall trend of asbestos consumption in Australia was that it greatly increased post-World War II to a peak in the 1970s before rapidly declining in the 1980s (Leigh & Driscoll, 2003; Riley & McNab, 2016).

Apparent consumption in Australia can be determined by summing the amount of asbestos produced and imported into Australia and subtracting the amount exported from Australia (Donovan & Pickin, 2016; Leigh & Driscoll, 2003). Based on data obtained from the Bureau of Mineral Resources, Australia produced a total of 740,293 tonnes, imported 1.6 million tonnes and exported 455,031 tonnes of asbestos between 1880 and 1985 (Leigh & Driscoll, 2003). This gives an apparent national consumption of 1,888,036 tonnes of asbestos (Leigh & Driscoll, 2003) that peaked at approximately 70,000 tonnes per year in 1975 (Musk & de Klerk, 2004).

Donovan and Pickin (2016) used data from the British Geological Survey, which provides detailed records beginning in 1920 through to 2003 concerning the annual quantity of asbestos consumed in Australia. This data set showed Australian asbestos consumption as beginning in 1921, steadily increasing from the 1930s, peaking in 1975 at 93,000 tonnes, and then rapidly declining to 2000 tonnes consumed in 1999 through to no asbestos being consumed in 2003 (Figure 1; Donovan & Pickin, 2016).

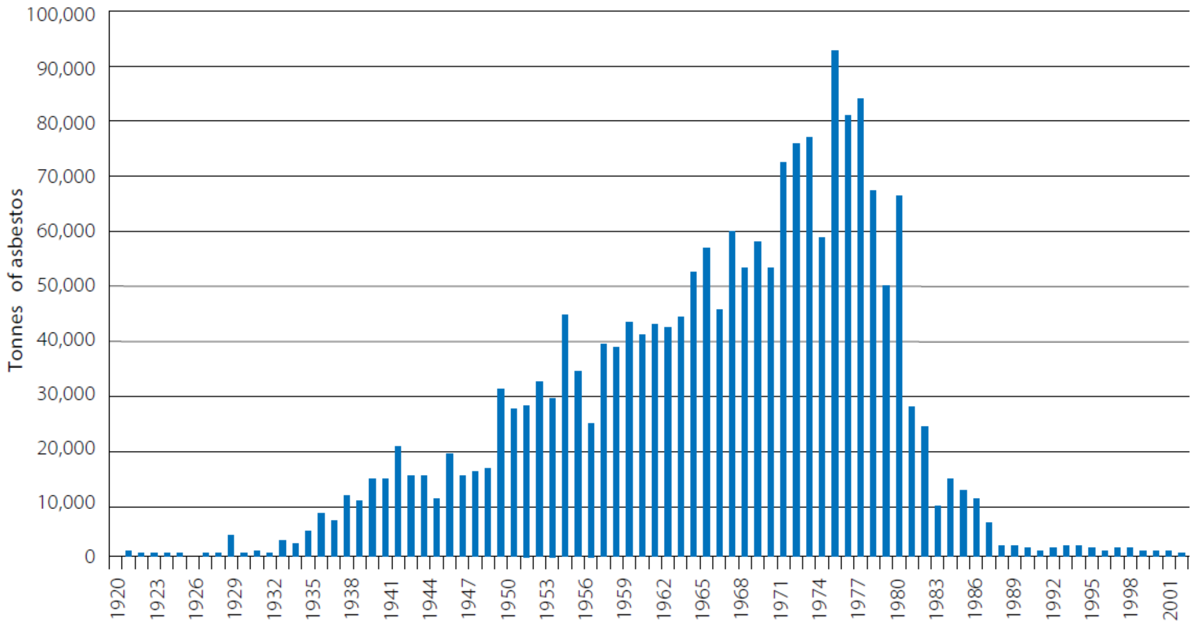

Figure 1 Apparent consumption of asbestos in Australia 1920-2003. Adapted from "An Australian stocks and flows model for asbestos," by S. Donovan and J. Pickin, 2016, *Waste Management & Research, 34,* p. 1082. Copyright 2016 by the authors.

The production of crocidolite ceased in 1967 followed by the cessation of amosite use in 1984 whilst chrysotile was phased out between 1981 and 1987. In 2004, a total ban on asbestos use of any type, including a prohibition on the importation, manufacturing, processing, sale, storage and re-use of asbestos and ACMs was implemented in Australia by the then National Occupational Health and Safety Commission (NOHSC).

2.2.3. Australian Asbestos Cement Manufacturing Industry

The asbestos cement manufacturing industry accounted for 60% of all production (i.e., mining of raw asbestos) and 90% of all consumption of asbestos fibres in Australia (ASCC, 2008b; Leigh & Driscoll, 2003). By 1954, Australia was the fourth highest gross consumer of asbestos cement products globally, behind the US, UK, and France (Leigh & Driscoll, 2003). Furthermore, every capital city in Australia had at least one asbestos cement manufacturing plant (Gray et al., 2016). In WA specifically, asbestos cement products were widely manufactured between 1921 and 1987 (Healthy WA, 2017). The majority of asbestos consumed in Australia was used in the manufacturing of cement sheets used in commercial and residential buildings and cement water and sewerage pipes (Figure 2; Donovan & Pickin, 2016).

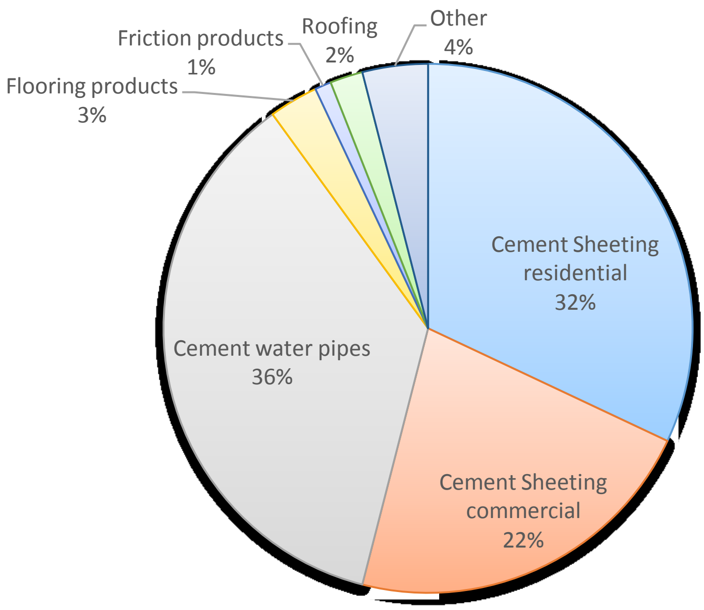

Figure 2 Amount (percentage) of asbestos consumed in each product group from 1920 to 2003. Adapted from "An Australian stocks and flows model for asbestos," by S. Donovan and J. Pickin, 2016, *Waste Management & Research, 34,* p. 1083. Copyright 2016 by the authors.

However, there is a lack of data regarding the annual allocation of asbestos to the different product groups during the years of asbestos product manufacturing, with only small amounts of information being found by Donovan and Pickin (2016). From the 1930s to the end of the 1970s, 40% of the asbestos consumed each decade by the cement manufacturing industry went into the construction of asbestos cement water pipes. Over this same period, it has been estimated that 52% of the asbestos consumed each decade went into the manufacturing of asbestos cement sheeting of which 31% was for domestic use and 21% for commercial use. Three percent of asbestos consumed went into flooring products and two per cent into roofing products (Figure 2). These proportions changed in the 1980s when cement water pipes were no longer manufactured. Over half (51%) the asbestos consumed during the 1980s went towards the manufacturing of cement sheeting for domestic use whilst five per cent went into flooring products and three per cent into roofing products (Donovan & Pickin, 2016).

In Australia, there were three principal manufacturers of asbestos cement building materials, including Colonial Sugar Refining, Wunderlich, and James Hardie & Co., and they predominantly used chrysotile with smaller quantities of crocidolite and amosite also being used in their products (ASEA, 2017b; enHealth, 2013). All three types of asbestos were used in the asbestos cement manufacturing industry from around 1940 till the late 1960s. Crocidolite was the first of the asbestos fibres to be phased out of use in this industry, with use ceasing in the late 1960s, while amosite continued to be used till around 1983. Chrysotile was phased out between 1981 and 1987 (ASCC, 2008b; Leigh &

Driscoll, 2003). Despite the phase out, a significant proportion of the asbestos cement manufacturing industry's output remains in service today in older Australian residential settings where it continues to be a source of asbestos exposure.

2.3. Asbestos Exposure and Health Risks

2.3.1. Inhalation of Asbestos Fibres and Health Risks

The primary routes of exposure to asbestos are inhalation and ingestion (International Agency for Research on Cancer [IARC], 2012). The health risks associated with fibre exposures are mainly determined by (1) the fibre's physical dimensions, which influences how deep the fibres can penetrate and deposit within the lung, and (2) their biopersistence, which is their ability to cumulate within the body and resist clearance from the body (Attanoos & Gibbs, 2013; Craighead & Gibbs, 2008; Craighead et al., 2008; IARC, 2012; National Toxicology Program [NTP], 2016). More specifically, a high aspect ratio (length to width ratio), a low fibre diameter, the respirability of the fibres, the number ('dose') of respirable fibres compared to the absolute fibre mass, and a higher biopersistence are considered important factors in the development of asbestos-related diseases (ASCC, 2008a).

There are distinct physicochemical differences between amphibole and chrysotile asbestos, as described above, and these underpin the differences in their biological toxicities (Attanoos & Gibbs, 2013). For example, compared to chrysotile, the amphibole forms of asbestos are significantly more durable after being inhaled and can persist within the respiratory tract for long periods of time. Moreover, their half-life in the human body can be measured in decades. In contrast to amphiboles, chrysotile's half-life can be measured in terms of weeks or months (ASCC, 2008a; Craighead et al., 2008).

2.3.2. Health Effects of Asbestos Inhalation

Asbestosis, benign pleural disease (including pleural plaques, diffuse pleural thickening, and benign pleural effusion), lung cancer and malignant mesothelioma are diseases and conditions related to asbestos exposure, and are collectively referred to as 'asbestos-related diseases' (ARDs; Wagner & Lemen, 2008). Furthermore, asbestos exposure has been associated with other non-malignant diseases such as autoimmune diseases (Pfau et al., 2014) and retroperitoneal fibrosis (Uibu et al., 2004). In addition, the International Agency for Research on Cancer has stated that there is currently sufficient evidence that asbestos inhalation also causes cancer of the larynx and ovary (IARC, 2012; World Health Organization [WHO], 2014) and that there is evidence of positive associations for cancer of the pharynx, stomach, colon, and rectum (IARC, 2012).

ARDs have emerged as a global public health issue (Collegium Ramazzini, 2016). Numerous publications have reported strong correlations between the past national consumption of asbestos and the incidence of ARD (Lin et al., 2007; Park et al., 2011; Takahashi et al., 1999; Tossavainen, 2004). These analyses provide evidence that an increase in the use of asbestos will result in an increase in future cases of ARDs (Stayner et al., 2013). At the present time, occupational exposure to asbestos is estimated to cause approximately 107,000 deaths per annum around the world (Collegium Ramazzini, 2016; WHO, 2014). This is comprised of an estimated 41,000 deaths from lung cancer (Pruss-Ustun, Vickers, Haefliger, & Bertollini, 2011), 43,000 (Driscoll et al., 2005b) – 59,000 deaths from mesothelioma (Pruss-Ustun et al., 2011), and 7,000 (Driscoll et al., 2005a) – 24,000 (GBD 2013 Mortality and Causes of Death Collaborators, 2015) deaths from asbestosis. Furthermore, the burden of ARDs is likely to be underestimated as opposed to overestimated due to being under diagnosed and underreported, especially in industrializing countries (Collegium Ramazzini, 2016). Moreover, it has been estimated that there are two to four times the number of deaths due to asbestos-related lung cancer as there are due to mesothelioma (McCormack, Peto, Byrnes, Straif, & Boffetta, 2012; Soeberg, Vallance, Keena, Takahashi, & Leigh, 2018). Despite this, mesothelioma statistics are commonly used as a measure of ARD burden in a community due to the difficulties in attributing lung cancer deaths to asbestos exposure given the disease's multiple causes.

Mesothelioma is a form of invasive cancer that occurs in the mesothelial cells, most often of the pleural and peritoneal cavities and sporadically in the tunica vaginalis (93%, 6.4%, and 0.3% of cases in Australia, respectively), and it is universally fatal (Australian Mesothelioma Registry, 2017; Marinaccio et al., 2015; Musk et al., 2017; Robinson, Musk, & Lake, 2005). Although specific prognosis for mesothelioma patients can vary widely (Brims et al., 2016), the median survival time from diagnosis is often between nine and 12 months for individuals with pleural mesothelioma and six months for individuals diagnosed with peritoneal mesothelioma (Musk et al., 2011). Epidemiological studies have reported no significant difference in mesothelioma risk between current smokers and lifetime non-smokers (Rake et al., 2009). While latency periods of approximately 15 years have been documented, the time between onset of disease and time since first exposure to asbestos is usually 20-40 years but can be as long as 50 years (Berry et al., 2012; Lanphear & Buncher, 1992; Leigh & Driscoll, 2003). No cure is available for mesothelioma (Musk et al., 2017) and there is little evidence of benefits to quality of life or increased survival despite the availability of several different treatment options (Sen, 2015).

Although it is recognised that all forms of asbestos are carcinogenic to humans, amphiboles are considered to be more potent (IARC, 2012; NTP, 2016). For example, Hodgson and Darnton (2000) reported that the amphiboles, amosite and crocidolite, are approximately 100 and 500 times as potent as chrysotile, respectively, in regards to the different fibres ability to induce mesothelioma. Similarly, Berman and Crump (2008) reported that chrysotile was between 0 and 1/200th as potent as amphibole forms regarding their ability to cause mesothelioma. Nevertheless, there is currently no safe threshold level of exposure at which exposure to asbestos fibres does not increase an individual's risk of an ARD (Collegium Ramazzini, 2016; IARC, 2012).

The adverse health effects of asbestos exposure have been known for over a century (Lee & Selikoff, 1979). Asbestosis, a form of pneumoconiosis characterised by diffuse interstitial fibrosis of the lungs that is a direct result of inhaling asbestos fibres (Attanoos & Gibbs, 2013; Lazarus & Philip, 2011; Wagner, 1997) was first reported in 1899; although, the term 'asbestosis' was not introduced until the 1920s (Cooke, 1927). The role of asbestos dust inhalation in the development of "a serious type of fibrosis of the lungs" was further established by Merewether and Price (1930). The reporting of the first case of lung cancer in a person with asbestosis is credited to Lynch and Smith (1935). However, the relationship between asbestos, lung cancer and the presence of asbestosis was then disputed before being firmly established by Doll (1955) in a seminal paper that posited that lung cancer was a specific industrial hazard for asbestos workers. Since then, asbestos exposure has been associated with all lung cancer cell types (Becklake, Bagatin, & Neder, 2007).

Soon after, the first evidence of a causal link between asbestos and malignant mesothelioma was documented by Wagner, Sleggs, and Marchand (1960) who investigated 33 individuals with pleural malignant mesothelioma who were exposed to asbestos occupationally and environmentally in a crocidolite mining district located in the north west of Cape Province, South Africa. Following this, a number of reports and studies were published citing cases of pleural and peritoneal mesotheliomas related to asbestos exposure in other industrialised countries including Western Australia (McNulty, 1962), Great Britain (Newhouse & Thompson, 1965), and the US (Selikoff, Churg, & Hammond, 1965). Together, these epidemiologic studies supported the conclusion that mesothelioma is an important complication of asbestos exposure in addition to the other known asbestos-related diseases, including lung cancer and asbestosis.

Since then mesothelioma has been referred to as "the sentinel disease for asbestos exposure" (Armstrong & Driscoll, 2016, p. 2). Mesothelioma rarely develops in individuals who have not been exposed to asbestos in the past (Musk et al., 2017). It is clear mesothelioma is a global public health issue (Odgerel et al., 2017) and the recent trend in this cancer has been referred to as a "pandemic" (Collegium Ramazzini, 2016; Stayner, Welch, & Lemen, 2013). This pandemic of mesothelioma and other ARDs shows some indications of abating in the industrialized world, but it is growing in the developing world (Stayner et al., 2013). The most recent analysis estimates that there are approximately 38, 388 deaths attributed to mesothelioma each year worldwide (Odgerel et al., 2017). However, the diagnosis of mesothelioma remains difficult and it is still likely that cases are underreported (Lemen, 2016).

Around the world, cases of mesothelioma are more frequently reported among men than women (Australian Mesothelioma Registry, 2017; Health and Safety Executive, 2017; Leigh & Driscoll, 2003; Lemen, 2016; Marinaccio et al., 2015; Mazurek et al., 2017; McElvenny, Darnton, Price, & Hodgson, 2005; Zhao et al., 2017). Approximately 80-85% of identified mesothelioma deaths occur in males, which reflects exposure patterns throughout much of the 20th century when men were generally more heavily exposed in occupational settings.

Evidence suggests that no safe threshold level exists where asbestos exposure does not increase mesothelioma risk (Hillerdal, 1999; Hodgson & Darnton, 2000; IARC, 2012). In the absence of exposure to asbestos, it has been hypothesized that the background incidence rate is in the order of one to two cases per million person-years, although some scientists estimate that it is much less (Hillerdal, 1999; Leigh & Driscoll, 2003; McDonald & McDonald, 1996; Robinson et al., 2005).

2.3.3. Mesothelioma in Australia: Current Trends

The incidence of mesothelioma began to rise in Australia during the 1960s. However, peak levels of mesothelioma in Australia have only now been reached because of the long latency between asbestos exposure and the onset of disease (mean latency of 30-40 years; Musk et al., 2017). For a number of years Australia had the highest national per capita incidence rate of malignant mesothelioma in the world, which is associated with Australia's history of a high consumption of asbestos during the 20th Century (Leigh & Driscoll, 2003). The number of incident mesothelioma cases per year in Australia has increased from 156 in 1982 to 700 in 2016 with the highest number of new cases occurring in 2014 (n=756). Of the 700 cases of mesothelioma diagnosed in 2016, 559 (79.9%) were males and 141 (20.1%) were females and the ages of the cases ranged from 21 to 95 years (Australian Mesothelioma Registry, 2017).

The overall age-standardised mesothelioma incidence rates in Australia have increased from 1.1 new cases per 100,000 person-years in 1983 to 2.5 new cases per 100,000 person-years in 2016 (Australian Mesothelioma Registry, 2017). However, the incidence rate varies by sex, with rates for males being close to five times that for females, as well as by state (see Table 2). Western Australia continues to have the highest age-standardised incidence rates of any Australian state or territory with 4.5 new cases of mesothelioma per 100,000 person-years (see Table 2; Australian Mesothelioma Registry, 2017; Leigh & Driscoll, 2003). Furthermore, WA reportedly had the second highest incidence rates of mesothelioma in the world and was only behind the Genoa Province, Italy (4.7 vs. 5.8 per 100,000, respectively; Bianchi & Bianchi, 2007). This is associated with the mining of crocidolite at Wittenoom Gorge in the state's North West between 1937 and 1966 as well as the state's extensive use of asbestos cement and other asbestos products during the 20th century (Musk et al., 2017; Musk et al., 1992).

Table 2 Age-standardised incidence rates of mesothelioma in Australia by sex and state or territory for 2016

	Incidence rate per 100,000 population*								
	NSW	Vic	Qld	**WA**	SA	Tas	ACT	NT	Total
Males	4.8	3.4	3.5	**9.3**	2.7	0.8	5.2	-	4.2
Females	1.0	0.9	0.7	**1.7**	0.9	0.3	0.5	-	0.9
Total	2.7	2.0	2.0	**4.5**	1.9	0.5	2.7	-	2.5

**Directly age-standardised using the 2001 Australian standard population*

Note. Adapted from *Australian Mesothelioma Registry 6th Annual Report: Mesothelioma in Australia 2016* (p. 4), by Australian Mesothelioma Registry, 2017, Canberra, ACT: Australian Institute of Health and Welfare. Copyright 2017 by the author.

Researchers believe that the peak in the overall number of cases and age-standardised incidence rates from mesothelioma have most likely been reached in Australia (Armstrong & Driscoll, 2016; Musk et al., 2017; Soeberg et al., 2016).

2.4. Exposure Pathways: The Third Wave of Exposure

"Every asbestos fiber that is mined . . . repeatedly exposes many individuals during its lifecycle from mining and extraction of asbestos-containing rock to manufacturing of asbestos-containing products (ACP), and further during use, repair, demolition and abatement of ACP." Collegium Ramazzini (2016, p. 87)

Exposure to asbestos and the subsequent development of asbestos-related diseases can be described as occurring in three waves since the beginning of the industrial era (Landrigan, 1991). The first wave of individuals exposed to asbestos included workers mining, milling, and transporting raw asbestos, as well as factory workers involved in the manufacturing of raw asbestos into asbestos-cement products (Armstrong & Driscoll, 2016; Musk et al., 2017). The second wave involved workers who used asbestos-containing products, such as asbestos-cement and insulation, in industry and included contractors, tradesmen and labourers (Armstrong & Driscoll, 2016; Musk et al., 2017). These occupational exposures to raw asbestos and ACMs continue to be the predominant cause of malignant mesothelioma and other asbestos-related diseases today (Health and Safety Executive, 2017; Lacourt et al., 2014; Mazurek et al., 2017; Muruganandan et al., 2017; Olsen et al., 2011). However, there is a third wave of exposure that stems from occupational and non-occupational exposure related to the disturbance of ACM whilst living, repairing, renovating or demolishing an older building with ACM present, and also includes environmental exposure cases from naturally occurring asbestos (Armstrong & Driscoll, 2016; Musk et al., 2017; Riley & McNab, 2016). It is this third wave of exposure to *in situ* asbestos in the home or workplace that is emerging as a significant contributor to the burden of asbestos-related disease.

Notably, in WA, there has been an increasing proportion of mesothelioma cases since 1980 that are not connected to occupational asbestos exposure (Musk, Olsen, Alfonso, Peters, & Franklin, 2015). For instance, Olsen et al. (2011) reported 195 cases of mesothelioma associated with non-occupational asbestos exposure out of 1,631 (1,408 males, 223 females) cases diagnosed in WA between 1960 and December 2008. Of these, 87 cases were attributed to asbestos exposure that occurred during DIY home renovations and maintenance. Since the first case associated with renovations was registered in 1981, there has been an upward trend in the number and incidence rates of these cases in both men and women. Between 2005 and 2008 specifically, mesothelioma was associated with home renovation and maintenance activity in 8.4% of male cases and 35.7% of female cases. As such, home renovators form the largest group of all non-occupational cases. A further increase in cases of mesothelioma attributable to home renovations is expected as a direct result of the widespread distribution of asbestos cement products throughout Western Australian homes in combination with the long latency period between exposure to asbestos fibres and the diagnosis of mesothelioma (Olsen et al., 2011).

This trend is expected to continue, not only in WA, but Australia-wide. Riley and McNab (2016) projected that between the years 2015 and 2100, 19,427 cases of mesothelioma will be diagnosed in Australia. Of these projected cases, 42% (n=8,163) were attributed to third wave exposures. Cases attributed to waves one and two were projected to have peaked in 2013, and to decline from this point onwards. In contrast, cases attributed to the third wave are projected to remain significant for a longer period of time; they will reach a projected peak of 212 diagnosed cases in 2021. Furthermore, the authors estimated that third wave exposures will result in approximately 200 cases of mesothelioma each year for the next 20 years and will account for the majority of new cases of mesothelioma from 2050 onwards (Riley & McNab, 2016).

2.4.1. Exposure to *In Situ* ACM in the Built Environment

In previous decades, concern in the industrialised world was primarily for exposures occurring in the occupational environment (first and second waves), but asbestos exposure has been greatly reduced or even eliminated in many industrial operations. However, there are hundreds of different types of ACMs that are used around the world and that are fixed in place (Noonan, 2017). These ACMs can contain chrysotile, crocidolite and/or amosite in various combinations and quantities (generally 5-20% by weight) and were used for such purposes as exterior and interior wall cladding, roofing, soffit lining, ceilings, flooring, fencing, and insulation. Despite 63 countries having currently banned the use of ACMs (Pira, Donato, Maida, & Discalzi, 2018), asbestos exposure continues to occur (either occupationally or non-occupationally) due to asbestos that remains present in buildings as a legacy of past use (Collegium Ramazzini, 2010; Noonan, 2017; Stayner et al., 2013). In countries such as Australia, the UK, and the US, one of the largest concerns is the active disturbance of ACMs in older buildings (Noonan, 2017; Sen, 2015). Individuals, such as tradespeople/workers, Do-It-Yourself (DIY) home renovators, or household occupants, can be exposed to significant levels of airborne fibres when ACMs are disturbed during maintenance operations, renovations, removal or demolition work (Mazurek et al., 2017; Noonan, 2017; Sen, 2015). For instance, in the US alone, the US Centers for Disease Control and Prevention (CDC) estimate that there are currently 1.3 million construction and industry workers who are being exposed to asbestos during work involving the maintenance, renovation or demolition of old homes, schools and buildings that contain asbestos (CDC, 2009; Lemen, 2016; Mazurek et al., 2017).

There is the possibility of exposure, and potentially of relatively high exposure, whenever there is damage to any machine or construction that contains asbestos (Hillerdal, 1999). In particular, a significant number of asbestos fibres can be released if the activity involves the use of power tools for cutting, drilling, grinding, sanding, and/or sawing (Keyes, Ewing, Hays, Longo, & Millette, 1994). Activities that may place home renovators, workers, or household occupants at increased risk of exposure to asbestos fibres include such things as lifting or tearing up linoleum or vinyl sheet flooring; sanding asbestos-cement sheeting used for eaves, ceilings or interior and exterior walls in preparation for painting; replacing asbestos-cement sheets in bathrooms and other wet areas; installing, repairing, replacing or removing asbestos-cement panels used for fencing and/or outbuildings, such as garden sheds or car ports; and creating “sleep-outs” by enclosing verandas (Olsen et al., 2011).

More specifically, DIY home renovations are activities undertaken by the homeowners or occupants themselves as opposed to enlisting the services of a paid contractor or tradesperson. This covers a broad range of work and encompasses such things as plumbing, painting, demolition of walls, and replacing fence panels and flooring (Gray et al., 2016). DIY home renovations are a common activity undertaken by Australian homeowners. For instance, 24% of homeowners in NSW who responded to a mail out questionnaire indicated they were a DIY renovator (Park, Yates, Hyland, & Johnson, 2013).

A recent investigation was undertaken to quantify the release of, and exposure to, asbestos fibres during DIY renovations involving the removal or disturbance of asbestos cement sheeting. Personal exposure measurements were recorded that would be considered unacceptable in current occupational settings in Australia (i.e., above 0.02 fibres/ml) when completing tasks in poorly ventilated areas, whilst using power tools, and when breaking the asbestos cement sheeting prior to the fragments being bagged (ASEA, 2016a).

Considering home renovation is a common activity undertaken in Australia in conjunction with the past national consumption of asbestos, the risk of asbestos exposure from *in situ* ACMs in the built environment is a growing concern (ASEA, 2017b; Musk et al., 2017; Olsen et al., 2011).

2.4.2. Prevalence of Asbestos Exposure in the Australian Residential Environment

It is clear that a significant number of people continue to be exposed to asbestos that remains *in situ* even decades after the enforcement of asbestos bans. However, there are currently no reliable global estimates of the number of people who are exposed to asbestos fibres either environmentally or domestically (Ferrante, Mirabelli, Tunesi, Terracini, & Magnani, 2016). In Australia, information regarding asbestos exposure in non-occupational settings not only comes from historical exposure assessments and projections of diagnosed mesothelioma patients, but also through surveys of the general public and exposure registries.

A survey conducted in New South Wales during 2008 aimed to investigate self-reported non-occupational asbestos exposure occurring as a result of home renovation activities. A questionnaire was mailed to 10,000 adults aged over 18 years old who were randomly selected from the NSW electoral roll. A total of 3,612 completed questionnaires were returned of which 1,597 respondents reported home renovations. Of the 1,597 respondents, 858 (53.7%) were self-reported DIY renovators. Asbestos exposure was reported for 61.4% (n=527/858) of these DIY renovators. Over one-third of the DIY renovators reported that their partners had been exposed during renovation activities (n=337/858; 39.3%), with close to a quarter (n=196/858; 22.8%) reporting that their children had also been exposed. The most common type of exposure was from asbestos cement ("fibro") sheeting (n=508/527; 96.4%; Park et al., 2013).

In addition, 16.2% (n=584/3,612) of all participants stated that their current home contained asbestos with 28.2% (n=1,010/3,612) of participants indicating that they did not know if their house contained asbestos or not. Of concern, respiratory protection was worn on a regular basis by only 12% of respondents, whilst just over a quarter (28.4%) used it occasionally (Park et al., 2013). Park et al. (2013) concluded that self-reported asbestos exposure as a result of home renovation activities was common in NSW.

Another source of information pertaining to asbestos exposure is the National Asbestos Exposure Register (NAER). The NAER, established by the Australian Government in 2014 and managed by the ASEA, aims “to record the details of members of the community who think they have been exposed to asbestos” (ASEA, n.s.). The NAER collects information via manual and electronic questionnaires regarding such things as age, gender, whether asbestos exposure was occupational or non-occupational, age range at first exposure, decade in which first exposure occurred, and the frequency of exposure (or time period over which exposure occurred; ASEA, 2016b).

For the period 1st July 2016 to 30th June 2017 there was a total of 1,770 questionnaires completed by Australian residents. Of these, the majority (76.95%) was male. Of the 1,770 individuals reporting exposure to asbestos, 1,235 (69.77%) reported occupational exposure (occurring at the workplace) whilst 535 (30.1%) reported asbestos exposure occurring in non-occupational settings. More specifically, non-occupational exposures were further categorised by 285 (16.1% of total) counts of reported exposure occurring in residential settings, 101 (5.71%) occurring in school or educational settings, with the remainder split between environmental/domestic (n=88; 4.97%) and other settings (n=61; 3.45%). Respondents who reported exposure in the workplace were most often workers in the construction industry (n=213/1,052; 20.25%) followed by electricians (n=177/1,052; 16.83%; ASEA, 2017a).

Overall, the duration of exposure was most often for six months or less (n=524/1,770; 29.60%). More specifically, for the 285 respondents reporting residential exposure, nearly one-third (n=93/285; 32.63%) were exposed to asbestos for five or more years with the next highest duration of exposure being for six months or less (n=83/285; 29.12%). Slightly over 10% of respondents indicated that they were exposed once (n=33/285; 11.58%) in a residential setting (ASEA, 2017a).

The largest number of responses were from WA residents (n=491/1,770; 27.74%) even though the population of WA is only the fourth largest of any Australian state or territory (WA makes up 10.5% of the Australian population). This may indicate the current level of community concern considering the past patterns of asbestos use and consumption in WA, which is home to the Wittenoom mine, and used a large amount of ACMs during the 20th century (ASEA, 2017a).

Although respondents could leave free text comments, no further details were collected regarding the specific activities undertaken that resulted in asbestos exposure and prompted registration and completion of the questionnaire.

In summary, we currently have a poor understanding of general population exposure to *in situ* ACMs. Additionally, we do not know how many Australians are currently exposed to asbestos in the residential environment. However, *in situ* ACMs will continue to be an exposure pathway, particularly when products can be easily disturbed through common human activity such as home renovations (Noonan, 2017). One of the challenges to understanding how many Australians are currently exposed to *in situ* ACMs is related to the diverse uses of asbestos in the residential environment and the difficulties people have trying to identify specific ACMs. These challenges also make it difficult to assess the link between ARDs and the presence of ACMs in residential settings.

2.4.3. Asbestos-Related Disease and Exposure to Residential Asbestos-Containing Materials

Despite ACMs being prevalent in residential settings and being possible sources of asbestos exposure, there are limited studies linking an increased risk of ARDs with the presence of *in situ* asbestos in the living environment. These studies have focussed on assessing the risk of mesothelioma due to difficulties quantifying the asbestos-related lung cancer burden and attributing lung cancers to specific sources of asbestos exposure. Furthermore, only a few studies have focussed on evaluating mesothelioma risk associated with non-occupational asbestos exposures, such as household or neighbourhood exposures.

Ferrante et al. (2016) conducted a population-based case-control study that included pleural mesothelioma cases diagnosed between 1 January 2001 and 30 June 2006 in Casale Monferrato, Italy. Ferrante et al. (2016) reported a sharp increase in the risk of pleural mesothelioma with cumulative exposure and this relationship was observed even at low and very low levels of exposure. Notably, a significantly increased risk of pleural mesothelioma was associated with having an asbestos cement roof (OR=2.4; 95% CI 1.4-4.2) or having asbestos cement buildings close to the house, such as in the garden or courtyard (OR=1.9; 95% CI 1.2-3.2). Currently, no other studies that have evaluated the risk associated with the presence of asbestos cement materials in or around residential settings have reported similar findings (Ferrante et al., 2016).

Korda et al. (2017) conducted a whole-population cohort study that included all residents of the Australian Capital Territory (ACT) from November 1, 1983 to December 31, 2013. A total of 285 mesothelioma cases were recorded over the study period, of which 7 (2%) individuals (all male) had lived in a residence containing loose-fill asbestos insulation (largely containing amosite and some crocidolite) prior to their diagnosis. Korda et al. (2017) reported that males who had ever lived in a residence containing loose-fill asbestos insulation had an incidence of mesothelioma two and a half times higher than those who had not (SIR 2.54; 95% CI 1.02-5.24).

A recent meta-analysis by Marsh et al. (2017) looked at the risk of pleural mesothelioma among people exposed non-occupationally to asbestos and included 18 studies (four ecological studies, 10 case-control studies, and four cohort studies) published between 1967 and 2016 that covered 12 countries. A total of 665 cases were included in their meta-analysis. Using random effects modelling, the estimates were combined and provided an overall meta relative risk (meta RR) of 5.9 (95% CI 4.4-8.7). More specifically, the meta RR was 5.4 (95% CI 2.6-11.2) for household exposures, which included para-occupational exposures, exposures relating to installation, removal, repair, or degradation of ACMs, and the use of asbestos-containing tools and products in the home. The meta RR was 6.9 (95% CI 4.2-11.4) for neighbourhood exposures, which related to outdoor air pollution such as exposure from erosion of asbestos-containing building materials, industrial emissions, or natural outcroppings (Marsh et al., 2017). No meta RR was calculated specifically for mesothelioma risk associated with the presence or disturbance of residential ACMs.

In contrast to the above findings, Rake et al. (2009) conducted a large population-based case-control study in Britain that showed no excess cases of mesothelioma attributed to any type of DIY activity (OR=0.7; 95% CI 0.4-1.2) regardless of possible asbestos exposure or frequency. Furthermore, there was no significantly increased risk of mesothelioma associated with the type of housing, such as high rise, council or former council, prefab, or having any asbestos in the building (Rake et al., 2009).

At the present, there is only weak epidemiological evidence for the health effects of passive exposure in houses containing asbestos (Goldberg & Luce, 2009). Furthermore, there is currently inadequate data to calculate a direct estimate of the global burden of cancer attributable to non-occupational asbestos exposure (Goldberg & Luce, 2009). Given the continued presence of residential ACMs in countries where their use is banned, there is a need to further evaluate the implications of *in situ* ACM on mesothelioma and other ARD risk (Ferrante et al., 2016; Noonan, 2017).

2.5. Asbestos in the Residential Environment

Although Australia manufactured asbestos cement products as early as the 1920s, ACMs were most frequently installed in residential settings between the mid-1940s and the late 1980s (enHealth, 2013). For instance, in the post-World War II period in Australia, 25% of all new houses built up until the 1960s were clad with asbestos cement; 70,000 asbestos cement houses were built in New South Wales alone between 1945 and 1954 (ASCC, 2008). As a general rule it is considered *highly likely* that an Australian house contains some form of asbestos if it was built before the mid-1980s, *likely* to contain asbestos if it was built between the mid-1980s and 1990, and *unlikely* to contain asbestos if it was built after 1990 (enHealth, 2013). The types of asbestos products installed in residential settings weren't limited to asbestos cement cladding; there was a wide variety of ACMs that were produced and installed in a range of locations throughout the residential environment.

2.5.1. Asbestos-Containing Materials used in Residential Settings

Two broad categories of ACM can be found throughout the residential environment: bonded and friable (see Figure 3; enHealth, 2005, 2013). Bonded ACM contains asbestos fibres that are bound tightly into a cement matrix (i.e., Portland Cement) or other bonding agent, such as asphalt or polyvinylchloride (US Environmental Protection Agency, 1990). These products are typically rigid and solid (Queensland Government, 2013). In Australian residential settings, bonded ACM was used for roof sheeting and capping, guttering, shingles gables, eaves/soffit linings, flues and water pipes, disconnector trap surrounds, flat or weatherboard style wall sheeting (exterior and interior wall cladding), imitation brick cladding, zelemite backing boards to electrical meter boxes and switchboards, fencing, car ports, sheds and outbuildings, telecommunications pits, and some window putty (Queensland Government, 2013).

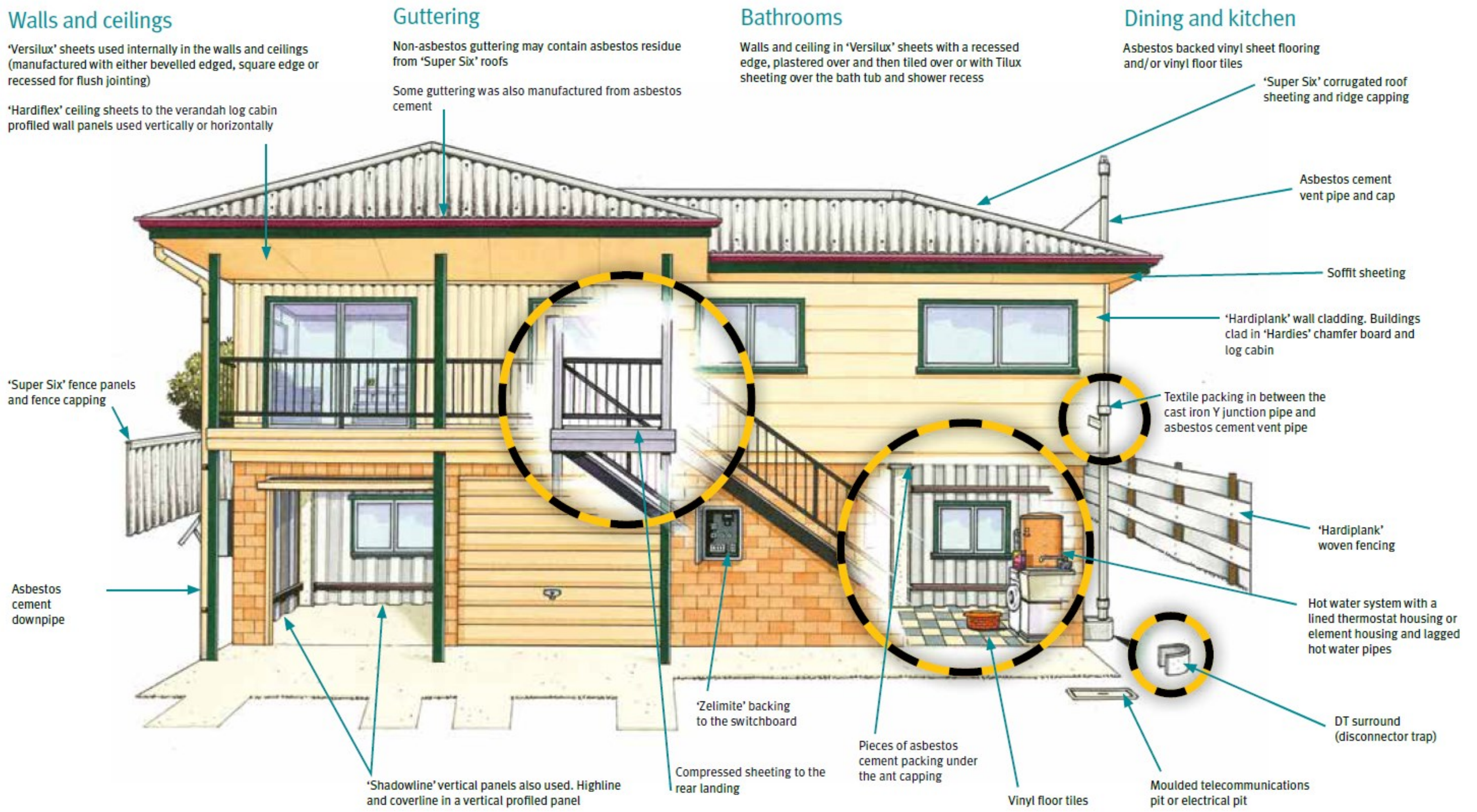

Figure 3 Common locations of materials containing asbestos in a house: Example of a house built in the 1970s. Reprinted from "Asbestos: A guide for minor renovation," by Queensland Government, 2013, p. 24. Copyright 2013 by the author.

Most of the *in situ* ACM remaining in the Australian built environment is bonded (Gray et al., 2016). However, bonded ACMs are considered as friable when the matrix/bonding agent is severely deteriorated and more readily releases asbestos fibres (ASCC, 2008a). Friable ACM is commonly defined as “any material containing more than one percent asbestos…that, when dry, can be crumbled, pulverised or reduced to powder by hand pressure” (US Environmental Protection Agency, 1990, p. 6). These materials can contain up to 100% raw asbestos and can be turned to dust and released into the air with very light pressure (Queensland Government, 2013). As such, these products are more hazardous and pose a much greater risk to health than do bonded ACMs. Friable ACMs were predominantly used in commercial and industrial settings for insulation, sound proofing, and fire proofing (Queensland Government, 2013). However, small amounts of friable ACM were also used in residential settings for insulation on hot-water systems, pipe lagging, and in old domestic heaters and stoves; in textured paint; backing materials on sheet vinyl flooring and in carpet underlay; in plaster and brick sealants; and inside fireplaces (enHealth, 2013; Queensland Government, 2013).

2.5.2. Asbestos Content of Different Product Groups

Asbestos cement building materials, such as asbestos cement walls and corrugated asbestos cement sheeting used for roofing and fencing, were manufactured using chrysotile, amosite, and/or crocidolite fibres in differing proportions. They were used due to their extremely high tensile strength, their low weight, insulating properties, and fire resistance (Henderson & Leigh, 2011; NTP, 2016). The use of crocidolite and amosite in combination with chrysotile is useful for adding specific properties, including rigidity. Nevertheless, chrysotile was the most widely used form of asbestos in industry due to being the most adaptable, and therefore accounted for up to 95% of global consumption (NTP, 2016).

Different manufacturers used slightly different mixes and proportions of asbestos fibre types. Furthermore, the same manufacturer occasionally altered their own products over time (Donovan & Pickin, 2016). There are various estimates that are available of the asbestos content of asbestos cement sheeting used in domestic and commercial buildings (Donovan & Pickin, 2016). For concrete-like products manufactured in the US, the asbestos content by weight ranges from 12 to 50%, with the binding agent typically being Portland Cement (US Environmental Protection Agency, 1990). Asbestos cement products manufactured in the UK mainly contained 10 to 15% raw asbestos by weight, but some products contained up to 40% (UK Department of Environment Transport and Regions, 1999). In Australia, asbestos cement products generally contain between five and 20 per cent asbestos by weight (Queensland Government, 2013). Asbestos cement sheeting (also referred to as ‘AC sheeting,’ ‘Fibrolite’ or ‘Fibro’) manufactured and used in Australia usually consist of approximately 90% Portland Cement and 10-15% asbestos fibre. However, the percentage of asbestos fibre by weight was reduced to 3-5% when its use was being phased out in Australia during the late 1980s (enHealth, 2005). Although some asbestos cement product manufacturers in Australia, such as Wunderlich Ltd., used up to 20% crocidolite in their mixture, chrysotile was the preferred fibre for manufacturing asbestos cement products with much of it being imported from Canada. This was because the use of crocidolite imported from South Africa could lead to blemishes in many of the manufactured products, due to the iron content of the crocidolite fibres (Raggatt, 1946). As such, chrysotile was predominantly used with amosite (up until around 1983) and crocidolite (up until the late 1960s) being used in smaller quantities (enHealth, 2013).

With regards to flooring products, the percentage of asbestos used broadly depends on the specific product. The most common use of asbestos flooring in Australia appears to have been vinyl flooring (Donovan & Pickin, 2016). Vinyl tiles and vinyl sheet flooring, introduced in the 1950s, generally contained between 8 and 30% asbestos. These tiles could be glued directly to the floor, sometimes with asbestos-containing adhesives, or could have an insulating layer under the tiles, known as floor backing which could contain up to 100% asbestos (Queensland Government, 2013; US Environmental Protection Agency, 1990).

2.5.3. Current Prevalence of ACM in the Australian Residential Sector

Despite the detailed records on the mass of asbestos consumed in Australia, Donovan and Pickin (2016) highlighted that there is sparse information regarding the subsequent dispersal of ACMs into the built environment following production. Moreover, there is a paucity of data about where the asbestos went, how much asbestos remains *in situ* in the built environment, and how much of this is being removed each year (Donovan & Pickin, 2016).

A survey of over 500 residential premises in the Australian Capital Territory (ACT) in 2005 found that over 95% of the laboratory-confirmed ACMs were types of bonded asbestos cement sheeting. Furthermore, over 90% of ACMs located in residential settings were found in external areas (i.e., eaves and external lining/cladding) or in internal wet areas (i.e., bathrooms and laundries). The majority of ACM occupied areas of less than $10m^2$ with large areas of ACM (greater than $20m^2$) being found predominantly in external locations. Sheeting and roofing products undoubtedly make up the largest proportion of ACMs in the residential sector in the ACT (ACT Asbestos Task Force, 2005), and the ASCC (2008a) believe that this is likely to be similar in the other Australian states and territories.

Gray et al. (2016) conducted a study that aimed to identify the possible sources of current and future exposure to asbestos arising from the built environment. They telephone interviewed local government environmental health officers (n=18), asbestos removalists (n=25), and asbestos assessors (n=3) throughout Australia to gather information about the most common scenarios the participants encountered regarding asbestos exposure in the built environment. The most common non-friable ACMs encountered by these professionals included asbestos cement sheeting used for fencing, roofing, internal and external wall cladding, as well as vinyl floor tiles. A respondent reported that, on average, anywhere from $1m^2$ to approximately $100m^2$ of asbestos product could be contained within domestic houses. Furthermore, residential properties could contain upward of four tons of asbestos roofing. Friable ACMs found in residential properties are less common (compared to non-friable ACMs), but can be located behind kitchen stoves, as insulation around pipes, and as electrical millboard. The removalists interviewed believed that removal work in Australia may continue for decades due to the large quantities of asbestos left across residential, industrial and public premises (Gray et al., 2016).

A model developed by Donovan and Pickin (2016) estimated the asbestos stock remaining in the Australian built environment. Asbestos stocks were estimated to have reached their maximum between 1980 and 1986 with a peak of 10.5 million tonnes in 1981. As of 2016, it is estimated that 44% (4.5 million tonnes) of the asbestos consumed in Australia remains in use (Donovan & Pickin, 2016). However, this estimate provides a gross estimate of the total remaining stock of asbestos and does not provide information regarding the specific locations where *in situ* ACM remains – at a geographical level (i.e., in what areas of the state/country) and at the individual household level.

It was further highlighted in the *National Asbestos Profile for Australia* that there are several data deficiencies, in particular, "there is no comprehensive data on the amount of in-situ asbestos, its location and condition and the impact this has on the management of asbestos in Australia" (ASEA, 2017b). As such, there is clearly a need for further research to collect up-to-date data about the most common ACMs that remain in the Australian residential environment, the percentage of housing impacted and the current condition of these materials.

2.5.4. Condition of Asbestos-Containing Materials and Risk of Exposure to Asbestos Fibres

The physical integrity of *in situ* ACMs can be altered by aging and/or a range of physical, chemical, and biological processes. The surfaces of asbestos cement products can corrode and weather due to being constantly exposed to atmospheric pollutants and meteorologic influences such as wind, frost, sunshine and acid rain (Spurny, 1989). Other processes that can affect ACMs include temperature changes, moisture and humidity, water leaching, salt scaling, acid attack/carbonation, sulphate attack, mosses and lichens, abrasions, and fire damage.

The most susceptible ACMs are those used in roofing materials, which can show noticeable signs of weathering and release fibres within 15 years, although all exterior ACMs are susceptible to the effects of weathering (ASCC, 2008a; Brown, 1987; Spurny, 1989). Furthermore, asbestos cement sheets are prone to harden with age via the hydration of the cement matrix and the sheets tend to become more brittle with natural weathering (enHealth, 2005). Weathering and corrosion can affect both uncoated and coated (i.e., painted) asbestos cement sheets.

Once the cement matrix of the surface material has been destroyed, a thin layer of free (unbound) and weakly bonded asbestos fibres can form. It is then possible for the free and weakly bound asbestos fibres to be dispersed via wind into the ambient air. Additionally, the fibres can be washed away from the surface by rainwater, which can transport them into other parts of the environment, in particular, soil and groundwater (Spurny, 1989).

Another factor in the condition of ACMs is the presence of biological growth, including moss, lichen, or fungal growth, which can occur on the surface of exterior asbestos cement products, such as unpainted roofing, and is a particular problem in sheltered settings. These growths can lead to surface deterioration and dissolution as well as possibly causing the surface to slightly soften (ASCC, 2008a; enHealth, 2005).

2.5.4.1. Risk of Exposure Associated with Condition

The extent to which ACMs contribute to the ambient air concentration of asbestos fibres will be influenced by the type and condition of the material (enHealth, 2005). Asbestos fibres only pose a health risk when they are inhaled. ACMs that are in a non-friable state, left undisturbed, and are in good condition pose a very low risk of exposure for individuals in the vicinity due to the asbestos fibres being bound tightly to the bonding agent (i.e., cement matrix). Conversely, if an ACM has become severely damaged, deteriorated or friable due to aging, weathering and/or corrosion, or the material is disturbed through activity, then asbestos fibres can be released into the air and will increase the risk of asbestos exposure via inhalation (ASCC, 2008a; enHealth, 2013). Therefore, qualitative assessment of the condition of materials and their potential to release fibres is an important component of the exposure assessment of *in situ* ACMs (enHealth, 2005).

Spurny (1989) investigated asbestos fibre emissions from weathered and corroded asbestos cement products on buildings in Germany. Spurny (1989) concluded that the number of asbestos fibres emitted from the asbestos cement products increased with increasing exposure to the polluted atmosphere, was higher for uncoated than for painted products, and higher during dry weather periods than after rain. Furthermore, asbestos fibre concentrations (200 to 1200 fibres >5µm/m^3)

have been measured in surrounding areas of houses with corroded and weathered asbestos cement products, which present "a non-negligible source of ambient air asbestos" (Spurny, 1989, p. 111). These concentrations suggest an additional health risk for occupants of houses containing ACMs and potentially for the general population (Spurny, 1989).

A literature review was conducted by the ASCC (2008a) looking at the extent to which the processes of weathering and/or corrosion impact the release of asbestos fibres from *in situ* ACMs. The majority of studies reviewed were conducted outside of Australia and observations mostly related to asbestos cement sheeting and roofing products. However, these were still deemed to be relevant to Australia's use of ACM. The ASCC (2008a) concluded that the "release of asbestos fibres is exceedingly small" (p.17) from non-friable ACMs and that the ambient air concentrations of asbestos fibres reported in the reviewed literature were well below regulatory authority guidelines. Moreover, release of asbestos fibres from weathered but non-friable ACMs, such as asbestos cement sheeting, was very small in comparison to other human activities that disturb ACMs, such as renovation and demolition work (ASCC, 2008a).

Gray et al. (2016) reported that there was disagreement among the interviewed asbestos removalists regarding the risks of asbestos exposure occurring from weathering ACMs. Some (n=6) removalists believed there was no health risk from such exposure due to the durability of asbestos products and the small numbers of fibre that would be released as a result of weathering (Gray et al., 2016). With the continued difference of opinion, it is evident that further research needs to be conducted that focuses on the risk of exposure associated with weathered and/or corroded ACMs present in the residential environment. This was also highlighted by Armstrong and Driscoll (2016) who recently posed a series of key research questions that need answering in order to further our understanding of third wave exposures in Australia and included "What are typical asbestos exposures from living in, or using, standard structures with asbestos in situ?" and "What additional asbestos exposures arise from deterioration of asbestos-containing materials in standard structures with asbestos in situ?" (p. 4).

2.5.4.2. Current Condition of In Situ ACMs

Currently, there is very little data pertaining to the current condition of *in situ* ACMs remaining in the Australian residential environment. Broadly speaking, the ASCC (2008a) stated that the release of high levels of asbestos fibres from ACMs due to aging, weathering and/or corroding does not appear to be a common event nor does it occur in the majority of circumstances. A large-scale survey conducted by the ACT Government's Asbestos Task Force in 2005 aimed to assess the extent and impact of asbestos in the ACT, which included inspections of over 500 residential premises. It was reported that, in general, asbestos cement products were in good condition and the potential to release asbestos fibres was minimal for approximately 90% of all confirmed ACMs in residential buildings. More specifically, these ACMs were assessed as only presenting a potential hazard during renovations or refurbishments. Asbestos products in an unstable condition (e.g., highly weathered asbestos cement roof sheeting) were a rare occurrence (ACT Asbestos Task Force, 2005; URS Australia Pty Ltd, 2005).

In the study by Gray et al. (2016), there was overall agreement between the environmental health officers (EHOs) and asbestos removalists who were interviewed that the greater majority of *in situ* ACM still present in the built environment was currently in "a reasonably stable condition." However, all asbestos removalists stated that they had encountered asbestos-containing products that were in poor condition and likely to release asbestos fibres either monthly, weekly or daily. A number of removalists mentioned that the majority of ACMs in poor condition were located in commercial or industrial buildings. Nevertheless, there were removalists and EHOs who remarked that domestic and commercial asbestos cement roofs in their jurisdiction had begun to weather and become friable. In addition to roofing, the interviewees reported that weathering was affecting fencing, eaves, and exterior walls (Gray et al., 2016).

At the present time there are no other published data available regarding the current condition of *in situ* ACMs located in Australian residential settings. There is a need to collect data and continually monitor the condition of *in situ* ACMs in the residential sector in light of the paucity of survey data and the age (aging) of the remaining ACMs.

2.6. Asbestos Awareness, Knowledge and Concerns in Australia

Despite the prevalence of and risks associated with deteriorating and disturbing ACM, many individuals lack knowledge or awareness about the potential sources and locations of asbestos in residential settings. For instance, in a postal survey conducted in New South Wales during 2008, 28.2% (n=1,020/3,612) of respondents did not know if their house contained asbestos or not (Park et al., 2013). This is exacerbated by the difficulties in identifying *in situ* asbestos and compounded by the large and varied uses of asbestos prior to its phase out. In order to identify what segments of the community to target in primary prevention efforts and asbestos education campaigns, it is necessary to investigate people's current awareness and knowledge of and attitudes towards asbestos. Therefore, the Australian Government's Asbestos Safety and Eradication Agency commissioned a series of asbestos awareness surveys.

2.6.1. Awareness, Knowledge and Attitudes to Residential Asbestos in Australia

The first asbestos awareness survey commissioned by ASEA was conducted in 2014 in order to provide a benchmark of asbestos awareness in Australia and to describe Australians' attitudes and behaviours towards asbestos. Participants included tradespeople (n=401), DIY home renovators (n=824), real estate agents/landlords (n=122), and the general public (n=1,015) from across Australia (ASEA, 2014).

The survey found that most Australians understand the importance of being informed about asbestos and its potential dangers. In particular, 94% of tradespeople and 87% of DIY home renovators thought it was 'important' or 'very important' to be knowledgeable about asbestos and its associated dangers while a slightly lower percentage of the general public (76%) responding similarly. Although the majority of respondents recognised the importance of the asbestos issue, only 61% of DIY home renovators and 53% of the general public reported that they felt they were informed. Moreover, approximately 20% of tradespeople thought their knowledge of asbestos was only at a moderate level or below (ASEA, 2014).

The survey also found that, in general, there was a very low level of confidence among respondents regarding their ability to identify ACMs; 55% of the general public and 39% of DIY home renovators indicated they were 'not very confident' or 'not at all confident' in their ability. Furthering this sentiment, 44% of the general public and 30% of DIY home renovators agreed with the statement "I wouldn't have a clue what types of materials contain asbestos." While nearly three-quarters of tradespeople (72%) indicated they were confident identifying potentially dangerous situations where there was risk of asbestos exposure, only a low percentage of DIY home renovators (35%) and the general public (21%) responded similarly (ASEA, 2014).

A high percentage (92%) of respondents agreed that they took "asbestos and its dangers very seriously" and the majority (64-72%) also agreed that "asbestos is very common in Australian buildings." Approximately four in five of all respondents considered that "even a small exposure to asbestos can be very dangerous," with nine in ten believing that individuals undertaking renovations should be "very mindful of asbestos" (ASEA, 2014, p. 32). Despite respondents acknowledging the dangers of asbestos, there were much fewer individuals (50%) who indicated that they knew how to protect themselves from asbestos exposure (ASEA, 2014).

Between 10% (general public) and 20% (landlords and real estate agents) of Australians believed they needed further information on asbestos and its potential dangers. Additionally, of those who believed they needed more information, four in ten tradespeople and members of the general public indicated that they needed more practical information about identifying asbestos and ACMs, and 25% wanted general information and guidelines (ASEA, 2014).

In 2016, ASEA conducted a second survey to provide an updated assessment of the community's attitudes towards asbestos and to compare the results with the 2014 survey. A similar sample was recruited as the 2014 survey with a total of 2505 respondents from around Australia including tradespeople (n=402), DIY home renovators (n=848), real estate agents and landlords (n=130), and the general public (n=1,125; EY Sweeney, 2016).

Compared to the first survey in 2014, the importance of being knowledgeable remained at 76% for the general public. However, their self-reported level of knowledge of asbestos and its dangers was slightly less in 2016 compared with 2014 (49% vs. 53%, respectively). Younger generations (i.e., under 30 years of age) reported a lower level of knowledge compared to older generations (i.e., over 50 years of age) with 41% compared to 62%, respectively, feeling that they were knowledgeable (EY Sweeney, 2016).

In contrast to the general public, there was continuous importance placed on being knowledgeable about asbestos among tradespeople. More specifically, there was an increase in the percentage of tradespeople who indicated that "I am concerned about potentially being exposed to asbestos" (58% in 2014 vs. 65% in 2016). However, only 55% of tradespeople claimed to have sufficient training to identify and manage asbestos at work whilst close to one-third (32%) thought they would benefit from further asbestos training (EY Sweeney, 2016).

One of the main concerns arising from the 2016 survey is that the largest declines in asbestos awareness and desirable attitudes towards asbestos were in DIY home renovators. This is particularly concerning given that ASEA consider this segment of the Australian population to be at high risk of exposure. For example, asbestos removal was required in close to a quarter of home renovations conducted during the previous two years; but half the home renovators did not seek a professional asbestos assessment. Notably, there was a decline among DIY home renovators regarding their self-reported level of knowledge (67% in 2014 compared to 53% in 2016 felt knowledgeable) as well the importance they placed on knowledge of asbestos and its dangers (87% in 2014 compared to 78% in 2016 felt knowledge was important). Along similar lines, DIY home renovators and the general public were less willing to pay for specialist advice if they were unsure if a material contained asbestos with the general public declining from 87% in 2014 to 78% in 2016 and DIY home renovators declining from 88% in 2014 to 80% in 2016 (EY Sweeney, 2016).

Although the majority of landlords and real estate agents surveyed thought it was important to be knowledgeable about asbestos and its dangers (80% in 2014 and 77% in 2016), only three in five felt they were knowledgeable (58% in 2014 and 59% in 2016). Furthermore, the feeling of responsibility among real estate agents and landlords has notably declined between 2014 and 2016 with fewer respondents agreeing or strongly agreeing with the following statements: "I have a duty of care to tenants regarding informing them of asbestos where present" (84% vs. 73%, respectively); and "I understand my legal obligations in relation to asbestos when dealing with clients or tenants" (60% vs. 53%, respectively; EY Sweeney, 2016).

The results from both asbestos awareness surveys clearly indicate that there are large segments of the Australian population who lack awareness and knowledge about asbestos and its associated dangers. The majority of Australians agree about the dangers of asbestos exposure, but too many have no confidence identifying ACMs or risky situations. It is evident that many Australians require practical information to help them identify ACMs so that they do not expose themselves, their family or colleagues to asbestos. In particular, future awareness and education campaigns need to target younger generations of Australians (i.e., those below the age of 30), especially in the higher risk segments of the population such as tradespeople or DIY renovators, so that inadvertent asbestos exposure is prevented.

2.6.2. Current Exposure Concerns in Australia

In addition to the asbestos awareness surveys commissioned by ASEA, there have been studies conducted that have focused on identifying current and future public health risks arising from asbestos exposure in the community.

In 2011, the Western Australian Department of Health (DoH) undertook a survey of Local Government Environmental Health Officers (EHOs) across WA "to identify patterns of public health risk from asbestos that may need to be better managed" (p.2). In addition, they obtained comments from WorkSafe WA, WA Department of Environment and Conservation, and the WA DOH Environmental Health Hazards Unit. The survey was in response to the problems associated with the removal of ACM and the demolition of older buildings in residential and public areas (Department of Health, 2011).

A total of 28 out of the 140 Local Governments responded (12 Perth Metropolitan Councils; 16 Regional WA Councils). In the approximately 18 months prior to the administration of the survey, respondents reported that they had received a total of 762 complaints (metropolitan: n=534; 70%) in relation to the management of asbestos within their jurisdictions, but reporting rates varied substantially between councils. The numbers of reported complaints were comparable between the different categories including demolitions, removals, dumping and other activities, when analysed at a state-wide level. However, when separated into metropolitan and regional councils, regional councils had comparatively fewer demolition-related complaints and more 'other' concerns than metropolitan councils (Department of Health, 2011). This may be due to there being more demolition-related activities in metropolitan areas compared to regional areas of WA or because there is a higher prevalence of older housing in poor condition. However, one respondent based in regional WA stated that they "expect concerns to increase with ageing (deteriorating) asbestos products and the communities 'awareness' of asbestos" (Department of Health, 2011, p. 4).

The most common complaints dealt with by EHOs were associated with "poor demolition practices," "incorrect removal and handling practices" and "illegal disposal of asbestos" (Department of Health, 2011, p. 4). Similar to the findings of ASEA's asbestos awareness survey, the EHOs observed that the majority of people are currently aware of the hazards related to asbestos, but there is a significant level of uncertainty in the community regarding how to handle and correctly dispose of ACM (Department of Health, 2011).

Issues related to asbestos removals, demolitions, and asbestos dumping were found to make up a substantial proportion of Local Government EHOs' workload and this load is increasing due to the age and deterioration of *in situ* ACMs in the built environment and continuing infill development (i.e., the development of vacant or underused land within existing urban areas) in residential areas (Department of Health, 2011).

In a more recent study, there was consensus among asbestos assessors, asbestos removalists, and EHOs throughout Australia that a significant amount of asbestos remains *in situ* in the Australian built environment (Gray et al., 2016). The main sources identified as potentially contributing to current and future asbestos exposures in the built environment were from asbestos-containing roofs and fences, DIY home renovations, unsafe asbestos removal practices, and illegal dumping. The EHOs and removalists held concerns that home renovation television programmes, which inspired watchers to carry out their own DIY projects, did not adequately warn of the risks of asbestos exposure. Furthermore, an EHO noted that governments interfered less with asbestos in residential settings as compared to the heavily regulated workplaces, and that homeowners were themselves legally allowed to remove and dispose of certain amounts of asbestos (Gray et al., 2016).

The results from the ASEA surveys in 2014 and 2016 indicate that there has been a decline in renovations occurring on residential buildings built pre-1990, which are the houses that have the highest likelihood of containing ACM (EY Sweeney, 2016). Nevertheless, it is evident that DIY renovations, either contracted or uncontracted, remain common and important activities in Australia. In 2016 it was estimated that 8.4 million (62%) of the 13.6 million home owners in Australia conducted some form of home renovation (Roy Morgan, 2017). In the 2016 ASEA survey, 31% of the DIY renovators surveyed reported they undertook renovations on or in a house built before 1990 (EY Sweeney, 2016). Asbestos needed to be removed in one in five recent renovations, and in about a third of these, the householder undertook the removal themselves. The number of people exposed to asbestos may be higher as more than half of the DIY renovators did not do any risk assessment for the presence of ACMs (EY Sweeney, 2016).

DIY home renovations are most often undertaken by younger people who are least knowledgeable about asbestos and who place a lower importance on asbestos exposure compared to people in the older generations (EY Sweeney, 2016). Therefore, there is a clear need to raise awareness and educate DIY home renovators who work on older homes and are placing themselves and others in potentially hazardous situations. The research on awareness, knowledge and attitudes shows that there is a need for primary prevention strategies that can help improve community members' knowledge of how to identify ACM in the home and raise their awareness of the potential dangers of incorrect handling practices. A promising platform to deliver such information is that of mobile phone applications.

2.7. Mobile Apps in Health Research

2.7.1. Smartphones and Apps

Smartphones are mobile devices with internet connectivity and the ability to perform advanced computing functions (White, 2011). Since their introduction in 2007 the global use of smartphones reached 2.32 billion users in 2017 and is projected to reach 2.87 billion users by 2020 (Statista, 2017b). It is forecast that 66% of individuals in 52 countries will own a smartphone in 2018 (Zenith, 2017). Smartphone ownership among adults is between 80% and 90% in Western Europe and Asia Pacific (Drumm et al., 2017; Zenith, 2017).

Tablet computers are another category of smart mobile device. However, global market penetration of tablets is much less than smartphones; ownership among adults across 52 countries was 18.7% in 2017 (Zenith, 2017). The trend in penetration varies widely by country, with penetration being low in China (4.8%), and is declining in some countries (e.g. Thailand), while it is highest in the Netherlands (74%). Australia has one of the strongest markets for tablets (66%; Zenith, 2017).

The growth of smart devices is expected to continue. By 2021, it is projected that there will be 1.5 mobile devices per capita globally (11.6 billion mobile devices), of which 74.7% will be smart devices

(Cisco, 2017). Furthermore, the primary method of accessing the internet for the majority of users is currently via mobile devices, which will be responsible for 73% of time spent using the internet in 2018 (Zenith, 2017).

Alongside the introduction and growth of smartphones came the ‘app,’ which is short for ‘application’ (program). An app is a small, self-contained piece of software that is coded to perform a specific and limited set of functions and is usually optimized to run on one or more mobile devices (Boulos, Brewer, Karimkhani, Buller, & Dellavalle, 2014; Statista, 2017a; White, 2011). Mobile apps were originally developed and provided as tools for productivity and information retrieval, including e-mail, calendar, and weather information. But due to the availability of developer tools and the demand from users, the market for mobile apps serving a diverse range of uses has rapidly expanded (Statista, 2017a). Some of the benefits and limitations of mobile apps are summarised in Box 1.

Box 1 Benefits and limitations of mobile device apps

Benefits

- **Versatility** – apps cover a wide range of topics, interests and activities including tools, photo, video players and editors, social networking, communication, games, and music
- **Ubiquity and accessibility** – distribution through an app store provides a much larger capacity to reach potential app users as opposed to only having it on a company or app developer’s website
- **Device optimisation** – apps can be optimized to take into account device screen size and resolution to improve the appearance of displayed data
- **Internet connectivity** – apps can be developed to function partly or completely without internet connection, which can be beneficial for users in rural areas with less internet access

Limitations

- **Quality of information** – no guarantee that information provided is of high quality, from credible sources, or evidence-based
- **Lack of “discoverability”** – apps can be hard to discover due to the large number of apps available for each OS
- **Costs** – may be free or require payment to use

Mobile apps are usually accessed or made available through an app store (or app marketplace), which can be considered to be a digital distribution centre, and are most often operated by the owners of the mobile operating system (OS) (Dogtiev, 2018; Statista, 2017a). These online app stores allow users to browse the different categories of apps, view specific information about each app including its ratings and reviews, and then download and install the app, which can be free or at a cost. The two most popular app stores worldwide are Google Play (Android OS), and Apple's App Store (iOS), which offer 2.8 million and 2.2 million apps, respectively (Statista, 2017a). To highlight the ubiquity and reach of apps, globally, there were 149.3 billion mobile app downloads in 2016 alone, and this is forecast to reach 352.9 billion in 2021 (Statista, 2017a).

2.7.2. Smartphone and Tablet Usage in Australia

Australia is one of the leading global adopters of smartphones and tablets; close to nine in ten Australians over 18 years of age own a smartphone and two-thirds own a tablet computer (Drumm et al., 2017; Zenith, 2017). It is estimated that there are 17.35 million smartphone users in 2018 (70% of the total Australian population; Statista, 2018).

As part of a 2017 mobile phone usage survey in 33 countries, a nationally representative sample of 2000 Australians between 18 and 75 years of age were surveyed (Drumm et al., 2017). Nearly 90% of Australians over 18 years of age own a smartphone, just behind Norway, Netherlands, Ireland, and Luxembourg, which have exceeded a penetration rate of 90%. Apple and Samsung devices continue to hold the majority of the market share; 41% of Australian smartphone owners currently use an Apple device and 34% use a Samsung device (Drumm et al., 2017). Furthermore, 59% of Australian households had access to a tablet device in 2015 (Drumm & Swiegers, 2015). Smartphone usage was highest in younger Australians although it was over 75% in all adult age groups, including those over 65 years of age (Drumm et al., 2017).

2.7.3. Apps and Health Research: An Avenue for Asbestos Awareness and Exposure Prevention

Smartphones are increasingly being seen as important workplace tools as workers and businesses take advantage of the devices (Drumm et al., 2017). This is particularly true for the field of public health. Mobile devices and apps offer great opportunities for public health research due to their increasing accessibility, user-friendliness, and attractive design (Olff, 2015). The expansion of mobile devices and apps into public health research and practice has led to the field of mobile health or "mHealth." Although no standardised definition of mHealth has been established, the WHO Global Observatory for eHealth (2011) refers to it as "medical and public health practice supported by mobile devices, such as mobile phones, patient monitoring devices, personal digital assistants (PDAs), and other wireless devices” (p. 6).

Mobile health apps can be developed and used to provide access to relevant information, to help individuals self-identify symptoms, to be a screening and assessment tool, to help users manage their own mental and physical health and wellbeing, and to encourage people to seek help from relevant professionals (Olff, 2015). mHealth apps have been developed for an incredibly large range of health issues: screening and assessment tools for traumatic stress (Olff, 2015), breastfeeding support (B. K. White et al., 2016), self-management of diabetes (Brzan, Rotman, Pajnkihar, & Klanjsek, 2016), asthma research (Chan et al., 2017), screening for depression (BinDhim et al., 2016), melanoma prevention (Brinker et al., 2017) and sun safety (Rodrigues, Sniehotta, Birch-Machin, Olivier, & Araújo-Soares, 2017).

mHealth apps offer a new platform for environmental and occupational health practice and research. In the US, the National Institute for Occupational Safety and Health (NIOSH) has developed and released a suite of work-related mobile apps, such as Heat Safety Tool, Ladder Safety, Sound Level Meter App, and the NIOSH Pocket Guide to Chemical Hazards (NIOSH, 2017). For example, the Heat Safety Tool allows workers to calculate the heat index for a given worksite and then provides a risk level and recommended protective measures based on the heat index.

Apps have also been developed and used to target environmental health issues, such as environmental noise pollution (Murphy & King, 2016a, 2016b) and monitoring atmospheric environmental hazards (i.e., air pollution, airborne allergens, and severe weather events; Johnston et al., 2018). Specifically, there are multiple apps on the iOS and Android platforms that can be used as sound level meters (Murphy & King, 2016b), and research has investigated how data collected via these apps can be integrated into strategic noise mapping processes (Murphy & King, 2016a). In Australia, the AirRater app was developed to improve the quality of life for individuals who have asthma, allergic rhinitis, and other conditions influenced by air temperature, pollen, and smoke. This is achieved through integrating near real-time environmental conditions (i.e., particle ($PM_{2.5}$), pollen, and weather monitoring data) with an individual’s health symptom data in order to generate custom notifications. Users indicated that AirRater increased their awareness of the environment and how it impacted their health as well led them to take action to reduce exposure (Johnston et al., 2018). The aforementioned examples demonstrate how mobile technology and specifically designed apps can be used as a means to address and monitor different types of environmental and occupational hazards.

Countries which have banned or phased out the use of asbestos need to focus on eliminating ARDs through continued vigilance and control of exposures occurring from *in situ* asbestos in the built environment (Stayner et al., 2013). These countries could utilize mobile technology to do this. An app that screens for asbestos can be a tool with the potential to enable users to approach the issue and take the first step toward prevention, action, or remediation. Furthermore, the app could double as a data collection tool for research purposes whereby consenting users share their data on the presence (or absence), type, and condition of *in situ* ACMs at the residential premises.

As discussed in section 2.6, many Australians do not know where asbestos can be found in their home, when ACMs were installed or used in residential settings, what features to look for, and how to safely manage the potential risks arising from any activity disturbing *in situ* asbestos. The portability of smartphones and tablets makes specifically designed apps an ideal platform for delivering information or a guided inspection that can help users to identify ACMs and assess the potential risk of asbestos exposure. Furthermore, the portability makes it ideal for accurate responses to questions concerning the appearance of potential ACMs as the device can be held next to the material being inspected with the user being aided with accompanying photos. Administering this type of questionnaire would be impractical and unwieldy using the traditional methods, such as pen and paper, telephone, or even web-based (computer desktop) questionnaires. However, no mobile apps are freely available in Australia, or elsewhere, that can be used to screen residential premises for *in situ* ACM.

In addition, such an app could be useful for a diverse range of people and contexts such as safety-conscious home owners and occupants, DIY home renovators, prospective home buyers, real estate agents, EHOs serving their local government, and tradespeople working in residential settings. Furthermore, mobile apps can be an effective way to reach and serve a large section of the population who have limited access to qualified and/or licensed professionals such as those who live in regional centres or areas where the nearest qualified and/or licensed professional could be hundreds of kilometres away. Thus such an app can potentially address unmet environmental health needs by increasing community members' awareness and knowledge of asbestos in residential settings and potentially preventing exposure.

Of course, mobile apps used for health research are not without their challenges and limitations. For instance, mHealth apps need to be specifically designed so that they target a clear and specific health issue and to ensure that they provide high quality information from reputable sources. Secondly, they need to have a high degree of usability. Apps for health research need to be user-friendly while also collecting relevant, reliable and valid scientific data. A third challenge is validity. Not only do apps need to be tested so that technical issues can be fixed, such as coding errors, but also tested against a "gold standard" or other valid and reliable measure(s) or method(s) to ensure that data are accurate. A fourth challenge of using apps for health research is market competition given that there is a vast range of competing mobile health apps. As such, it is important that the user directly benefits from using the app as well as the researchers and agencies who get access to and use of the data. Finally, an important consideration when designing an app to be used in health research is ethics. mHealth apps need to have correct procedures in place to conform to the requirements of human research ethics committees regarding the collection of data for research purposes, for example, obtaining the users' informed consent prior to participation.

2.8. Gaps in Our Knowledge

"The highest priority in reducing ARDs is primary prevention; that is, banning asbestos use in countries where it remains legal and preventing exposure to *in situ* sources in all countries with historical asbestos use." Collegium Ramazzini (2016, p. 89)

Controlling exposures is key to prevention (Becklake et al., 2007). With no curative treatments for any of the ARDs being presently available, eliminating the epidemic of ARDs will require continued awareness and elimination of exposures to *in situ* ACMs in the built environment (Jamrozik, de Klerk, & Musk, 2011; Stayner et al., 2013). In order to avoid and eliminate exposure during maintenance, renovations, removal and demolitions, it is important to identify and document *in situ* ACMs in buildings (Collegium Ramazzini, 2016).

However, it is difficult to accurately identify asbestos in the residential environment without appropriate laboratory testing to confirm the presence or absence of asbestos. It is not simple or easy for untrained individuals to identify suspect ACMs because they cannot rely on features such as colour or texture to indicate if asbestos fibres are present. Sampling and laboratory identification is not always practicable (e.g., ACM is *in situ* and in good condition), safe, or affordable for the general public. Although DIY home renovators, tradespeople and other community members appear to acknowledge the dangers of asbestos, there is still a critical need to provide practical information and guidance on how to identify ACM and how to correctly manage the risks (ASEA, 2014).

As highlighted by Donovan and Pickin (2016), there is little data pertaining to the subsequent distribution of asbestos-containing products into the built environment once they were imported into or manufactured in Australia. Despite knowing the total amount of asbestos Australia consumed prior to it being banned, we have much less knowledge about where ACMs went and how much of the material remains in the residential environment. As a result of these knowledge gaps, one of the primary recommendations for further research arising from the *National Asbestos Profile for Australia* was that “there is an identified need for more research to gain a better understanding of the amount and location of ACMs in the residential sector”(ASEA, 2017b, p. 39). Also essential is knowledge of the extent of deterioration of *in situ* asbestos. Considerable work needs to be done to extend our knowledge of where asbestos is located and what condition the ACM is in so that appropriate decisions can be made regarding either its prioritised removal or its containment.

Increasing public awareness and education is a key component of asbestos risk management. A solution to address these knowledge gaps is to develop, test and implement a free, accurate, easy to use, safe, and accessible tool that can be used to screen residential settings for the presence of potential ACMs. Mobile phone applications are one platform to deliver such a resource to home owners, DIY home renovators, tradespeople, and the general public in Australia. Moreover, a specifically designed mobile phone app can be both a strategy to assist in the primary prevention of asbestos exposure through increasing the users’ awareness of *in situ* asbestos products while at the same time being a tool to collect data from users on the types and condition of ACM remaining in Australian residential settings.

Box 2 Key knowledge gaps pertinent to this research project

Current Information Gaps

- Do not know the amount of *in situ* ACM remaining in the Australian residential environment
- Do not know the most common types of ACM and where they are located within Australian residential settings
- Do not know the current condition and level of deterioration of ACMs remaining in Australian residential settings

Chapter 3: Identifying Asbestos-Containing Materials in Homes: Design and Development of the ACM Check Mobile Phone App[1]

3.1. Abstract

Background: Asbestos-containing materials (ACMs) can still be found in many homes in Australia and other countries. ACMs present a health risk when they are damaged or disturbed, such as during do-it-yourself home renovations. However, community members lack knowledge and awareness about asbestos identification and its safe management in residential settings.

Objective: The objective of our study was to describe the process of developing a mobile phone app, ACM Check, which incorporates a questionnaire designed to identify and assess ACMs located in residential settings.

Methods: A multidisciplinary team was involved in the formative development and creation of the mobile phone app. The formative development process comprised 6 steps: defining the scope of the app; conducting a comprehensive desktop review; drafting and revising the content, questionnaire, conditional branching rules, and scoring algorithms; obtaining expert input; manually pretesting the questionnaire; and formulating a final content document to be provided to the software development company. We then constructed ACM Check on the iOS platform for use in a validation study, and then updated the app, replicated it on Android, and released it to the public.

Results: The ACM Check app identifies potential ACMs, prioritizes the materials based on their condition and likelihood of disturbance, and generates a summary report for each house assessed.

Conclusions: ACM Check is an initiative to raise community members' awareness of asbestos in the residential environment and also serves as a data collection tool for epidemiologic research. It can potentially be modified for implementation in other countries or used as the basis for the assessment of other occupational or environmental hazards.

3.2. Introduction

Asbestos is the term given to a family of naturally occurring fibrous silicates that have been used in a wide variety of building materials, commonly referred to as asbestos-containing materials (ACMs)

[1] This chapter has been published in: Govorko, M. H., Fritschi, L., White, J., & Reid, A. (2017). Identifying asbestos-containing materials in homes: Design and development of the ACM Check mobile phone app. *JMIR Formative Research, 1*(1), e7. doi:10.2196/formative.8370 (see Appendix D: Published Papers)

(Henderson & Leigh, 2011). Australia was the highest per capita consumer of ACMs in the world during the mid-20th century (Leigh & Driscoll, 2003). Many of these ACMs were asbestos cement products, such as flat and corrugated asbestos cement sheeting, in which the asbestos fibres were bonded to a base material. These products were installed in residential settings between the mid-1940s and the late 1980s (enHealth, 2013). Until the 1960s, approximately 25% of all new Australian homes were clad with asbestos cement products (Leigh & Driscoll, 2003), and it is likely that almost all houses built before 1990 contain some form of asbestos (enHealth, 2013). All forms of asbestos have been classified as carcinogenic (IARC, 2012), and a prohibition was declared on all new uses of asbestos in Australia in 2004. However, the prohibition does not extend to ACMs that were in place prior to the date the prohibition was enforced (enHealth, 2005). As a result, a large amount of asbestos is still present in the residential environment.

However, identifying ACMs is difficult, and householders lack knowledge and awareness regarding the identification of ACMs in and around the home and how to safely manage these materials to prevent exposure to asbestos fibres (ASEA, 2014). Identifying in situ ACMs is complicated by the large and varied uses of asbestos prior to its phase out. This is exacerbated by the similarities in visual features between certain older ACMs and the newer asbestos-free materials, which makes distinguishing between ACMs and non-ACMs complicated for the untrained individual. An Australian asbestos awareness survey conducted in 2014 found that participants' confidence in their ability to identify ACMs was low, particularly among do-it-yourself (DIY) home renovators and the general public (ASEA, 2014). The survey established that greater practical information and guidance were needed on how to identify ACMs and how to correctly manage the risks (ASEA, 2014).

ACMs present a health risk when they are in poor condition due to damage, deterioration, or weathering, or when they are disturbed. For instance, a significant number of asbestos fibres can be released into the air when working with asbestos cement sheeting in houses, eaves, fences, or sheds, especially when using power tools for cutting, drilling, grinding, sanding, or sawing (ASEA, 2016a; Keyes et al., 1994). This may particularly be a problem for DIY home renovators if they do not take appropriate precautions when dealing with potential ACMs.

In Australia, smartphones are owned by approximately 80% of people over the age of 18 years, with the majority of the market being held by Apple (41%) and Samsung (32%; Drumm & Swiegers, 2015). Because asbestos identification requires close-up visual inspection of the features of various types of materials that are spread throughout different locations around the property, their high level of portability makes smartphones and tablets an ideal platform to administer an app targeting asbestos identification. Mobile apps have been developed and used to target other environmental health issues, such as air quality (Liu et al., 2017), noise monitoring (Murphy & King, 2016a), and sun safety and melanoma prevention (Brinker et al., 2017; Rodrigues et al., 2017). However, no mobile apps are freely available in Australia that can be used to screen the residential property for the presence of in situ asbestos. Therefore, household occupants need to turn to an environmental consultant, asbestos inspector, industrial hygienist, or other qualified professional, which can be costly to the home owner. Similar to mobile apps that can be used as early-stage screening tools such as for prostate cancer (Pereira-Azevedo, Osório, Fraga, & Roobol, 2017) or depression (BinDhim et al., 2016), a mobile app that screens for asbestos can be a tool that empowers users to approach the issue and take the first step toward prevention, action, or remediation.

The aim of this paper is to describe the design and development of the mobile app ACM Check (short for Asbestos-Containing Material Check). ACM Check is an initiative to raise community members' awareness of asbestos in the home environment and also serves as a data collection tool for epidemiologic research.

3.3. Methods

The development of ACM Check was approved by the Human Research Ethics Committee (RDHS-89-15) of Curtin University, Perth, Australia (Appendix C: Ethics Approval and Amendments).

3.3.1. The Multidisciplinary Research and Development Team

We developed ACM Check in a collaborative partnership involving occupational epidemiologists and a doctoral student in public health and epidemiology from the School of Public Health, Curtin University; scientific health officers and toxicologists from a state environmental health agency (Environmental Health Directorate, Western Australia Department of Health, Perth); and a health promotion software development company (Reach HPI, Perth). Following advice from previous health promotion-based and researcher-led app development projects (Becker et al., 2014; Murray et al., 2016; White, White, Giglia, & Tawia, 2016), we involved the software developer early on in the process due to the need for specialized development skills when developing native mobile apps (versus other communication technologies, such as text messaging or websites). We engaged the software development company to provide guidance surrounding the technical aspects of mobile app development and to bring expertise in the field of graphic design, user interface design, and user experience design.

3.3.2. Development Process

The development of the app was an iterative process that occurred in 2 broad phases: formative development, followed by creation of the mobile app. The formative development process comprised the following steps: planning and defining the scope of the app; conducting a comprehensive desktop review; drafting and revising the content, questionnaire, conditional branching rules, and scoring algorithms; obtaining expert consultation and input; manually pretesting the questionnaire; and formulating a final content document, which was provided to the software development company.

3.3.2.1. Phase 1: Formative Development

In the first stage of the formative development process, we defined the scope and aim of the app. We clarified the target end users, the rationale for development, the functions we wanted to include, the data outputs we wanted to generate, and how these aims would be achieved (Table 3).

Table 3 Scope of ACM Check.

Key Factor	Parameters of ACM[a] Check
Problem	Difficulties visually identifying ACMs in residential settings
	Lack of awareness among DIY[b] renovators
Target audience	Householders, particularly DIY renovators
	Local government environmental health officers
	Tradespeople working in the residential sector
Setting	Residential settings in Western Australia, which excludes commercial, industrial, and waste sites
Objectives	Identify *in situ* ACMs inside and outside homes
	Assess current condition and likelihood of disturbing the ACMs
	Direct users to further resources that assist in the safe management of asbestos
	Collect questionnaire data regarding the amount, type, and condition of ACMs
Method	Conduct a self-administered questionnaire using automated conditional branching (if-then rules) and an additive scoring algorithm for priority assessment
	Generate a summary report for each completed home inspection
	Provide links to relevant information, resources, and contacts
Significance	Increase users' awareness of asbestos in the residential environment
	Inform relevant governmental and nongovernmental agencies about the current amount and condition of ACMs in Western Australian households

[a]ACM: asbestos-containing material

[b]DIY: do-it-yourself

We undertook a comprehensive desktop review of scientific peer-reviewed journal articles obtained from online databases, including PubMed, ProQuest, and ScienceDirect, and gray literature obtained from Australian government and non-government websites, such as the Asbestos Safety and Eradication Agency and state health department websites, prior to drafting the content for the app. We also reviewed the reference lists of the publications for additional relevant literature. Search terms were "asbestos" OR "asbestos-containing materials" AND "identification," "survey," "questionnaire," "assessment," "material assessment," "exposure assessment," "risk assessment," and "condition assessment." Documents published by the Australian federal and state government health authorities were the primary basis of the background information used in the app. We also searched for examples of different ways to assess the condition and exposure potential of ACMs in residential or occupational settings.

We held meetings with the development team to help define the scope of the app and determine what areas or materials are likely to be of most significance in the community. We sought input from 9 further experts and stakeholders outside of the development team after we had made some revisions of the content and questionnaire, including local government environmental health officers, environmental consultants, and asbestos removalists.

We pretested the questionnaire using pen and paper to test the practicality of the questions and instructions, to test the flow of the conditional branching (if-then rules), and to assess the scoring algorithms. The outputs, such as probabilities of each key material containing asbestos and its overall rating, were calculated manually at the completion of each trial. The pretesting also provided approximations for the time it would take to complete the inspection and questionnaire once it was in the digital format. We revised and finalized the questions, conditional branching, scoring algorithms, and content of ACM Check based on these manual trials and expert reviews.

3.3.2.2. Phase 2: Creation of the Mobile Application

We provided the final questionnaire and content to the software development company. ACM Check was initially developed for the iOS platform (Apple Inc). Developing the app first for one platform, then refining it before building the app for other platforms, is an efficient approach that minimizes the cost of iterating multiple versions (White et al., 2016). We chose the iOS platform for the initial version due to the smaller number of devices for testing, and the fact that Apple had the largest market share in Australia at the time of initial development (Drumm & Swiegers, 2015). After the initial build, we used TestFlight (Apple Inc) for iOS to beta test and debug ACM Check.

We then trialed the iOS version of ACM Check on a sample of metropolitan homes in Perth, Western Australia. We obtained user feedback to further improve the accuracy, functionality, and usefulness of the app before releasing it to the public. The iOS version of ACM Check was modified based on user feedback before being replicated and developed for Android (Google Inc). We released ACM Check to the public via the App Store (Apple Inc) and Google Play (Google Inc) in June 2017.

3.4. Results

The app delivers a self-administered, structured questionnaire that is supplemented with easy-to-follow instructions and images of ACMs. There are three modules that make up the questionnaire. The first module collects data on user and housing information, including state of residence, user description (e.g., community member, householder, or DIY renovator; local government environmental health officer; or tradesperson working in residential settings), residential post code, period of house construction, type of dwelling, and number and age category of occupants. The second and third modules aim to identify potential ACMs located outside and inside the home, respectively. To do this, the questionnaire methodically guides the user through a visual inspection of locations around the house where key materials that may contain asbestos could be located. The outside locations inspected include the exterior walls and gable ends, eaves or soffit linings, roofing, gutters, downpipes, electrical meter box, fencing, and outbuildings. The inside locations inspected include the interior walls, cupboards and backsplashes, ceilings, flooring, and heater flues.

3.4.1. Questionnaire Design

The ACM Check questionnaire is a computerized, self-administered questionnaire that uses conditional branching ("skip logic") to assign each screened material a probability of containing asbestos, and subsequently to assign each potential ACM a priority level for action or remediation. The answers of the completed sections and modules are linked using if-then rules. For example, *if* the house was built before 1985 *then* it is highly likely to have ACM present. This feature results in a custom pathway being created through the questionnaire. Consequently, users are automatically navigated through the questionnaire in an efficient manner so that they do not need to read and answer all of the questions (Norman, 2001).

3.4.2. Screening for Asbestos-Containing Materials

The app uses multiple-choice questions to assess each location inside or outside the house (Figure 4). The information necessary for the visual identification of ACMs includes (1) the age of the house, (2) its renovation history, (3) the location or use of the ACM, and (4) visual features specific to each type of material.

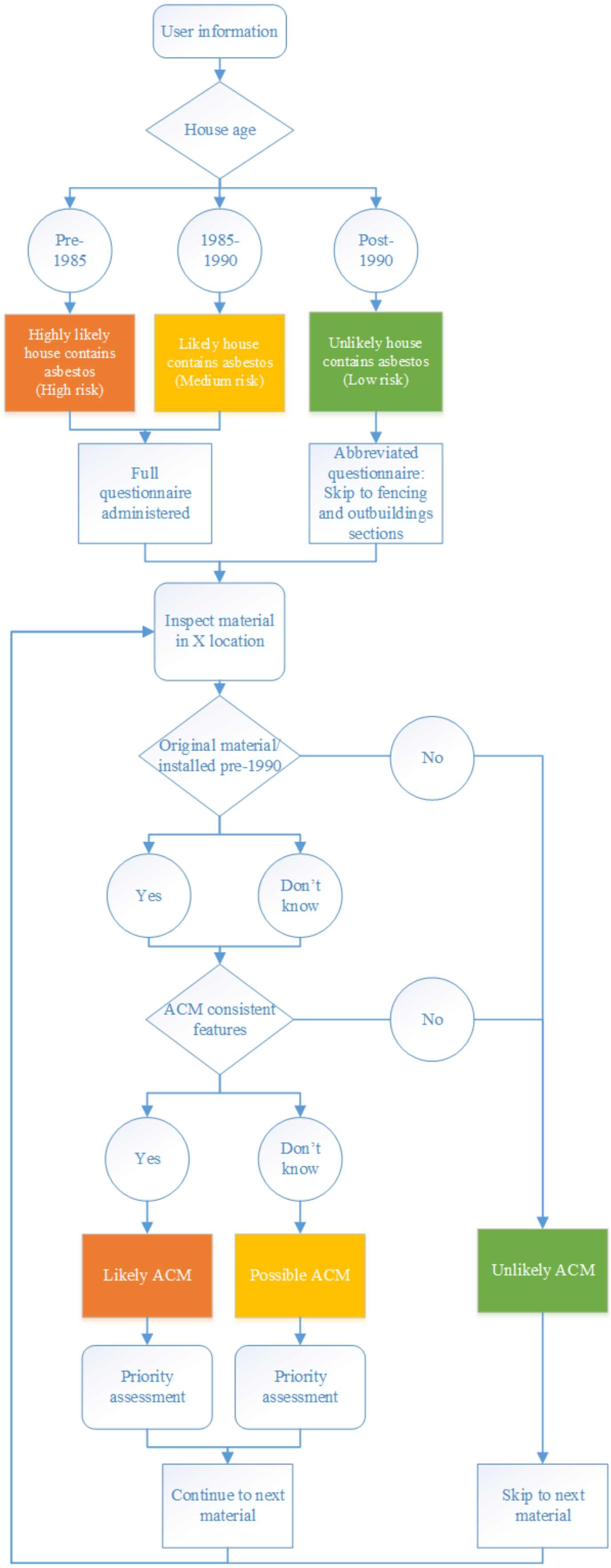

Figure 4 Process flow chart showing the key factors used in the ACM Check app to determine the probability that asbestos is present in a material or location

The age of the house is relevant because, in Australia, asbestos was phased out of residential building products that were manufactured in the years leading up to 1987 (Healthy WA, 2017). However, builders or tradespeople may have had stockpiles of ACMs in their warehouses or trade centres that were used beyond that date. Therefore, we used a conservative cut-off date of 1990 in the app. More specifically, we used 3 categories for the probability that a house contains asbestos based on the age of the house to best reflect the years in which ACM use was phased out of residential buildings (Figure 4). We adapted these categories from rankings used by the Environmental Health Standing Committee (2013). The answer to this question also determines whether the full questionnaire or only sections of it will be administered to the user. If the house was built after 1990 (the date ACMs ceased to be installed in new housing), then an abbreviated questionnaire is administered that only asks questions relating to outside materials, such as fences or outbuildings, that could be present from earlier developments (Figure 4).

For pre-1990 homes, ACMs may have been replaced with non-ACMs. Therefore, each material screened in the app has a question relating to date of installation or its renovation history.

The final factor in screening for the likelihood of a material containing asbestos is to inspect the visual features. Although some ACMs appear visually identical to non-ACMs, other materials can have distinct visual features that indicate whether they are likely to contain asbestos.

Based on the user's answers to questions regarding these four factors, each material or location inspected is automatically designated as one of four probabilities of containing asbestos: not applicable, unlikely ACM, possible ACM, or likely ACM. The designation of not applicable is used only for those materials or locations that are not present inside or outside of the home as indicated by the user. For example, not all properties have an outbuilding or a permanent internal heater, so when these are not present they are designated not applicable. The designation of possible ACM is used to highlight the situations where it is more difficult to confirm or rule out the probability that a material contains asbestos. This can be due to difficulties in visual identification, such as a lack of visual characteristics that distinguish ACM from non-ACM, or lack of information on the year of installation or the renovation history. For instance, if a user indicates they have eaves made of cement sheeting with joiner strips, but they do not know if they were installed before 1990 or replaced after 1990, then those eaves are designated as possible ACM.

3.4.3. Priority Assessment of Possible and Likely Asbestos-Containing Material

The mere presence of in situ ACMs in or around the home does not necessarily mean individuals are inhaling or being exposed to asbestos fibres, or that they are at an increased risk of developing an asbestos-related disease. Two key variables that need to be considered when looking at the risk of asbestos exposure in the residential environment are the current condition of the ACM and the likelihood of disturbing the ACM. For instance, an asbestos cement product that is in good condition and left undisturbed is associated with a minimal risk of asbestos exposure and presents a negligible health risk (enHealth, 2005). In contrast, an asbestos cement product in poor condition or that is accidentally or deliberately disturbed can result in dispersal of asbestos fibres into the air and is associated with a greater risk of exposure (enHealth, 2005). Therefore, a priority assessment that incorporates these two factors is triggered for each material that is designated a probability of possible or likely ACM.

The current condition is based on the degree to which the ACM shows signs of weathering, deterioration, or physical damage, such as surface marks, scratches, cracks, splits, breakages, or water damage, and on how friable it is; that is, how easily the material crumbles. There are two questions pertaining to the material's condition: a qualitative and a quantitative assessment. The qualitative question has four possible outcomes: "good," "fair," "poor," and "very poor." Descriptive text accompanies each option to help the user select the most appropriate answer. Additionally, the user is asked a quantitative question, which has the user rate the material on a scale of one (very poor) to ten (very good).

The likelihood of disturbance refers to the probability of the ACM being damaged or disturbed in the near future. This reflects the chances of asbestos fibres being released from the material and made airborne, which subsequently increases the risk of their inhalation by occupants in their vicinity. ACMs can be disturbed for a variety of reasons, including through access, use, repair, or renovation and maintenance activities. The likelihood of disturbance is also presented as a multiple-choice question with the user having to select one of four answers: "unlikely," "somewhat likely," "likely," or "highly likely," which are accompanied by descriptive text.

The answers to the questions on qualitative condition and likelihood of disturbance are assigned numerical values, which are then summed to provide an overall rating to the ACM, expressed as a priority level (Figure 5). The priority level, either "very low," "low," "medium," or "high" priority, indicates which ACMs are of most concern to that property with respect to the potential risk of asbestos exposure and which ACMs require remediation. For example, an ACM assigned as high priority should be given greater attention by the user and has a greater risk of releasing asbestos fibres than an ACM that is given a very low priority.

Current Condition (Qualitative)	Unlikely	Somewhat Likely	Likely	Highly Likely
Very Poor	Medium	Medium	High	High
Poor	Low	Medium	Medium	High
Fair	Very Low	Low	Medium	Medium
Good	Very Low	Very Low	Low	Medium

Likelihood of Disturbance

Figure 5 Risk matrix used to give a priority level for action or remediation to each possible or likely asbestos-containing material

3.4.4. Summary Report

A summary report is generated after the inspection has been completed, which shows the user the probability of each material assessed containing asbestos, its current condition, the likelihood of disturbance, and the priority level for each possible or likely ACM (see Appendix E: Summary Report Generated by ACM Check). Depending on the priority level, a general recommendation is provided for each ACM. These range in severity, from “Monitor and no immediate action necessary,” “Monitor and minor maintenance and repair,” and “Removal and replacement should be a priority. Major repair activity should be considered as a secondary and temporary action,” through to “Consult an asbestos professional for removal, disposal and replacement of the ACM.” These recommendations are presented in table format alongside the corresponding and color-coded priority level. Furthermore, each recommendation is accompanied by a description and links to further relevant resources where possible.

All summary reports are stored in the ACM Check Reports tab on the home screen for quick reference (Figure 6). This allows users to complete the app on multiple homes, which is useful for owners of multiple properties or individuals who work in multiple residential settings.

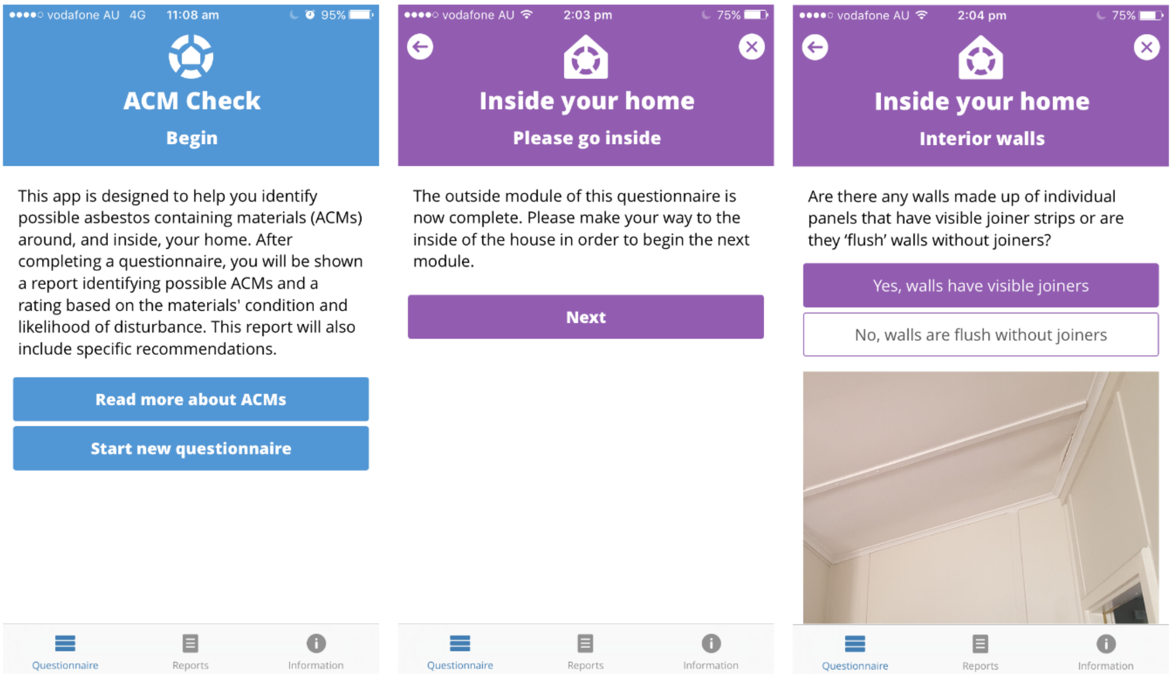

Figure 6 Screenshots of the home screen and questionnaire from the ACM Check app

3.5. Discussion

ACM Check is a screening tool designed to identify and assess the condition of potential ACMs in situ in residential settings. The app directs users to further information from reputable authorities pertaining to asbestos and its safe management. ACM Check can also be used as a data collection tool for researchers working with relevant governmental and nongovernmental agencies to map the presence and condition of ACMs in the built environment. Furthermore, ACM Check is freely available to use to assist with asbestos identification and to raise awareness about the hazards of asbestos exposure.

In situ asbestos is an ongoing problem in Australia despite being phased out of residential building products during the 1980s. ACM Check offers a free, quick, and easy-to-follow solution that will aid in the prevention of exposure to in situ asbestos in the residential environment. ACM Check is, to our knowledge, the first and only mobile app available on the market that guides users through a visual inspection of the home from beginning to end in a systematic manner. To motivate people to use the app, ACM Check was promoted via live interviews on community radio stations, as well as through social media and Web posts by various not-for-profit organizations that target asbestos-related disease prevention and awareness. Furthermore, ACM Check was promoted on trade union and occupational health and safety-related websites to encourage workers to download and use the app.

The app could be adapted for use in other countries where ACMs were used in residential settings. The questions and rules are likely to need careful modification if this tool is to be adopted for use in another country with a history of asbestos use that is different from that in Australia. For instance, different countries may have phased out asbestos in different years (if applicable); have different regulations and prohibitions pertaining to asbestos use; and have different profiles, types, and frequencies of ACMs used in homes. Regardless, ACM Check offers a model that could be easily modified to accommodate country-specific variables. Similarly, ACM Check could be expanded or modified to target asbestos in occupational settings, or used as a roadmap for new apps targeting the identification of other occupational hazards.

3.5.1. Limitations

ACM Check does not replace or eliminate the need for consultation with an asbestos professional. ACM Check attempts to capture the main sources and locations where ACMs are likely to be present in residential settings. However, it is impossible to capture all scenarios and materials that could contain asbestos in the residential environment due to the large and diverse uses of asbestos in the past (Henderson & Leigh, 2011). Therefore, there is the potential that the app misses a particular use of an ACM and fails to direct the user to assess important products that contain asbestos at the home. A further limitation is that untrained users may have difficulty assessing the likelihood of disturbance in certain settings, such as external ACMs that cover large areas.

3.5.2. Conclusion

ACMs are difficult for the untrained eye to identify in the built environment, but to prevent exposure to asbestos, identification is necessary. As a multidisciplinary team, we designed and developed a practical and easy-to-use mobile app, ACM Check, to screen for in situ ACMs in the residential environment. ACM Check forms part of a primary prevention strategy aimed at minimizing users’ risk of exposure to asbestos fibres in the residential environment while doubling as a scientific data collection tool. This technology could be modified to raise awareness among the broader community about other environmental health issues.

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Chapter 4: Accuracy of a Mobile App to Identify Suspect Asbestos-Containing Material in Australian Residential Settings[2]

4.1. Abstract

In situ asbestos in the built environment is a remaining source of exposure in countries that have prohibited the manufacture and use of asbestos. However, it is difficult to identify *in situ* asbestos-containing material in residential settings. The objective of this study was to evaluate the accuracy of the mobile phone application ("app"), ACM Check, in identifying *in situ* asbestos located inside and outside of homes compared with onsite inspections conducted by an experienced environmental consultant. A cross-sectional study was undertaken that involved participants completing ACM Check on their homes built pre-1990 and located throughout metropolitan Perth, Western Australia, and an onsite inspection conducted at each home by an environmental consultant. Cohen's kappa statistic was calculated to evaluate the strength of agreement between the two methods. The 40 houses sampled were built between 1898 and 1988 with a median year of 1966. Thirty eight (95%) homes had at least one type of material categorized as positive for asbestos by both ACM Check and the environmental consultant (κ=1.00). Agreement between the two methods differed when categorizing specific materials as positive or negative for asbestos with substantial agreement for fencing (κ=0.918), outbuilding walls (κ=0.844), backing board to electrical meter box (κ=0.826), exterior wall cladding (κ=0.771), and interior walls (κ=0.754), and fair agreement for outbuilding roofs (κ=0.375), and interior flooring (κ=0.304). ACM Check is a tool that can be used by tradespeople, home renovators, and householders to screen residential settings for the presence of *in situ* asbestos-containing material. Mobile phone apps have the potential to be developed or modified for use in other countries to help users identify asbestos and reduce their risk of asbestos exposure.

4.2. Introduction

Asbestos is a commercial term encompassing a variety of naturally occurring fibrous silicate minerals that can provide high tensile strength when added to other materials (e.g., cement), have insulating properties, are flexible, and resistant to heat and chemical corrosion (Craighead & Gibbs, 2008; Henderson & Leigh, 2011). As a result there was widespread usage of asbestos throughout much of the 20th century in industrialized countries, such as Australia, Great Britain, United States, and large

[2] This is an Author's Original Manuscript of an article published by Taylor & Francis Group in the ***Journal of Occupational and Environmental Hygiene*** **on 14 May 2018,** available online**:** www.tandfonline.com/10.1080/15459624.2018.1475743 (see Appendix D: Published Papers)

parts of Europe. Asbestos was largely used in the manufacture of building materials, particularly in cement products and insulation. These asbestos-containing materials (ACMs) can still be found *in situ* throughout the built environment despite many industrialized countries subsequently prohibiting the importation and use of asbestos. Exposure to *in situ* asbestos in the built environment, such as when people repair, renovate or demolish older buildings that contain asbestos, is one of the remaining sources of exposure and is of growing concern (Armstrong & Driscoll, 2016; Australian Mesothelioma Registry, 2017; Gray et al., 2016; Mazurek et al., 2017; Noonan, 2017; Olsen et al., 2011; Park et al., 2013).

Australia is a case in point. Australia was the highest consumer of asbestos on a per capita basis during the mid-20th century (Leigh & Driscoll, 2003), and it is likely that almost all Australian households built prior to 1990 contain some form of asbestos (enHealth, 2013). As such, it is important to raise people's awareness and knowledge of where ACMs can be located in the residential environment in order to prevent inadvertent asbestos exposure arising from these sources. However, asbestos cement products are notoriously difficult to identify and many home-owners have a low level of confidence when it comes to identifying ACMs in and around the home (ASEA, 2014; Park et al., 2013). This is complicated by the diverse range of ACMs that can be present in residential settings and the lack of knowledge regarding the distinguishing features between materials that do or do not contain asbestos.

To address this problem we developed a mobile phone application ("app"), "ACM Check," which is completed by users to assess the inside and outside of the home for the presence of *in situ* ACM (Govorko, Fritschi, White, & Reid, 2017). Before the app was released to the public, it was necessary to test its accuracy in identifying *in situ* ACM. Therefore, the aim of the present study was to evaluate the identification of *in situ* ACMs by comparing ACM Check with the results from onsite inspections conducted by an experienced environmental consultant.

4.3. Methods

4.3.1. Study Design

A cross-sectional study was conducted between August 2016 and February 2017 that involved (1) participants downloading and completing ACM Check, (2) an onsite inspection and sample collection by an environmental consultant, and (3) laboratory analysis of the samples. The study was approved by Curtin University's Human Research Ethics Committee (RDHS-89-15; Appendix C: Ethics Approval and Amendments).

4.3.2. Sample and Recruitment

A recruitment flyer was circulated through investigator contacts and email distribution lists in Western Australia (WA) as well as an advertisement broadcast on a local community radio station. The recruitment flyer outlined the study and included a link to an online registration form that incorporated questions addressing the inclusion and exclusion criteria.

The participant's inclusion criteria were: aged 18 years of age or over; spoke English; owned a home constructed pre-1990 located in a metropolitan area of Perth; and had access to an iOS Device (iPhone, iPod Touch, iPad mini or an iPad) running iOS version 8 or newer. Individuals residing in rental properties and government funded housing were excluded from this study due to the complexities of consent regarding destructive sampling of *in situ* ACM on the premises. Registrants were screened for eligibility and eligible registrants were emailed a Participant Information Sheet and Consent Form. Participation in the study did not occur until after informed consent was obtained.

4.3.3. Identification of Suspect ACM using a Mobile App

ACM Check is a mobile phone app designed as a screening tool to identify and assess the condition of *in situ* ACMs located in residential settings. A detailed description of the design and development of ACM Check has been published elsewhere (Govorko et al., 2017). ACM Check administers a questionnaire that guides the user through a step by step inspection of 14 key locations inside and outside of the home (Table 4). The questionnaire consists of three modules including a user and general household information module (7 items), an outside module (24 items), and an inside module (13 items). Areas inspected for ACM include the exterior walls, eaves/soffit lining, roofing, gutters, downpipes, electrical meter box, fencing, outbuilding walls and roofing, interior walls and splash backs, ceilings, flooring, and heater flues. Questions are asked about the age of the house, renovation history, and key visual features of the building materials present. The questions are supplemented with simple instructions and photographic examples of ACMs to assist the user in completing the inspection. Based on the answers, ACM Check automatically assigns each material/category one of four probabilities of containing asbestos ("not applicable," "unlikely," "possible," or "likely" ACM). The user is prompted to assess the condition and likelihood of disturbance for any materials that are classified as "possible" or "likely" ACM. At the completion of the inspection, a report is automatically generated within the app that shows the user a summary of the results and provides general recommendations about how to manage any ACMs. The key outcome variables for which data were collected through ACM Check include: (1) probability of being an ACM for each material/category; (2) a current condition rating ("very poor," "poor," "fair," or "good") for each "possible" or "likely" ACM;

and, (3) a likelihood of disturbance rating (“unlikely,” “somewhat likely,” “likely” or “highly likely”) for each “possible” or “likely” ACM.

For this study, participants were invited to download ACM Check onto their iOS device using a beta testing app called TestFlight. This app allowed us to control who had access to ACM Check and to track its use. Participants were instructed to complete the ACM Check questionnaire once on their property. The questionnaire had 47 individual questions; however, not all questions were answered by all users as unnecessary items were automatically skipped based on the conditional branching rules. Furthermore, three questions on the current condition and likelihood of disturbance were repeated for each material/category classified as “possible” or “likely” ACM. At the completion of the questionnaire, all answers and results were transmitted to a secure, password protected internet database hosted on a remote server.

Table 4 The 14 locations inspected for asbestos-containing material using ACM Check

Location	Type of Material
Outside Module	
Exterior walls	Flat asbestos cement sheet cladding (aka "Fibrolite" or "Fibro")
	Imitation brick cladding
Eaves/Soffit lining	Flat asbestos cement sheeting
Roof	Corrugated asbestos cement sheeting
Gutters	Asbestos cement gutter lining
Downpipes	Asbestos cement piping
Electrical meter box	Flat asbestos cement sheeting used as a backing board (aka "Zelemite" or "Bakelite")
Fence	Corrugated asbestos cement sheeting (aka "Super Six")
	Asbestos cement capping
Outbuilding walls	Flat asbestos cement sheeting
Outbuilding roofs	Corrugated asbestos cement sheeting
Inside Module	
Interior walls and splash backs	Flat asbestos cement sheeting
Wall tile backing	Asbestos mastic/adhesive
Ceiling	Flat asbestos cement sheeting
Floor	Linoleum and vinyl sheet flooring
Heater (affixed/permanent)	Asbestos cement flue pipe

4.3.4. Onsite Inspection

An onsite inspection to identify and assess ACM was conducted at each property by an experienced environmental consultant after the app had been completed by the householder. The consultant was approved by both the Asbestos Safety and Eradication Agency and WorkSafe (Western Australia) as a competent person to conduct inspections for asbestos (Safe Work Australia, 2016). All inspections followed a template to ensure that the 14 key locations/categories included in ACM Check (Table 4) were also assessed by the consultant. The consultant was blinded to the answers collected using ACM Check.

4.3.5. Statistical Analysis

To determine the level of agreement between ACM Check and the environmental consultant's assessments in regard to the presence or absence of *in situ* asbestos, Cohen's kappa statistic was calculated for each of the following variables: any ACM present on the property, any ACM present outside the house, any ACM present inside the house, all inspected materials combined, and for each of the 14 specific materials, such as for the external wall cladding, eaves, and fencing. The probability of asbestos rating was initially collected as a polytomous variable with response options including "not applicable," "unlikely," "possible," and "likely." However, the probability that a material contained asbestos was recoded into a dichotomous variable for statistical analysis with "not applicable" and "unlikely" responses coded as "negative" and "possible" and "likely" responses coded as "positive." Sensitivity was the proportion of all materials categorized as positive for asbestos based on the environmental consultant's qualitative assessments that the app indicated were positive for asbestos. Specificity was the proportion of all materials negative for asbestos based on the environmental consultant's qualitative assessment that the app indicated were negative for asbestos. Therefore, a material categorized as positive by the app but negative by the consultant is referred to as "false positive" and a material categorized as negative by the app but positive by the consultant is referred to as "false negative."

A p-value of < 0.05 was considered statistically significant in all tests. All statistical analyses were completed in IBM SPSS Statistics for Windows, Version 24 (IBM Corp., Armonk, NY, USA).

4.3.6. Sample Collection and Analysis

Samples of materials, both suspected ACM and non-ACM, were collected by the consultant and sent for laboratory analysis. Samples were only collected if it was safe, the homeowner provided verbal consent, and sampling did not deface the material. Therefore, the sampling of materials was non-random. In addition, materials suspected to be non-ACM by the consultant were occasionally sampled for confirmation if it was a material that was visually similar to known ACMs. All samples were collected in accordance with the recommended sampling protocol (Safe Work Australia, 2016).

Samples were analyzed at a National Association of Testing Authorities accredited laboratory. The method of asbestos identification was a qualitative identification of fibre type in bulk samples using Stereo Microscope Examination and Polarised Light Microscopy (PLM), which included Dispersion Staining. Asbestos identification was in accordance with the Australian Standard (AS4964-2004). The techniques did not quantify the amount of asbestos present in the bulk samples. The results were reported using the descriptive terms 'chrysotile asbestos detected,' 'amosite asbestos detected,' 'crocidolite asbestos detected,' 'no asbestos detected,' 'organic fibres detected,' and 'synthetic mineral fibres detected.'

The samples analyzed in the laboratory were compared to both qualitative methods. Cohen's kappa statistics were calculated to determine the level of agreement between the samples analyzed in the laboratory and (1) the consultant's opinion, and (2) the ACM Check results. Due to the small sample size of materials analyzed in the laboratory, kappa values could not be calculated for specific materials/locations but only overall.

4.4. Results

A total of 60 individuals registered to participate in the study, of whom 54 were eligible. Of these, 47 provided written consent to participate, and 41 downloaded and completed ACM Check on their property. A total of 40 inspections were then completed by the environmental consultant, with one property being excluded due to demolition and asbestos removal work commencing before the inspection date (Figure 7). Thirty-two samples were collected from 23 properties.

The 40 houses ranged in year of construction from 1898 through to 1988 with a median year of 1966 (interquartile range, IQR 1942-1976). Of the 40 houses, the majority were separate houses (n=38; 95%). The houses were distributed throughout the Perth metropolitan region.

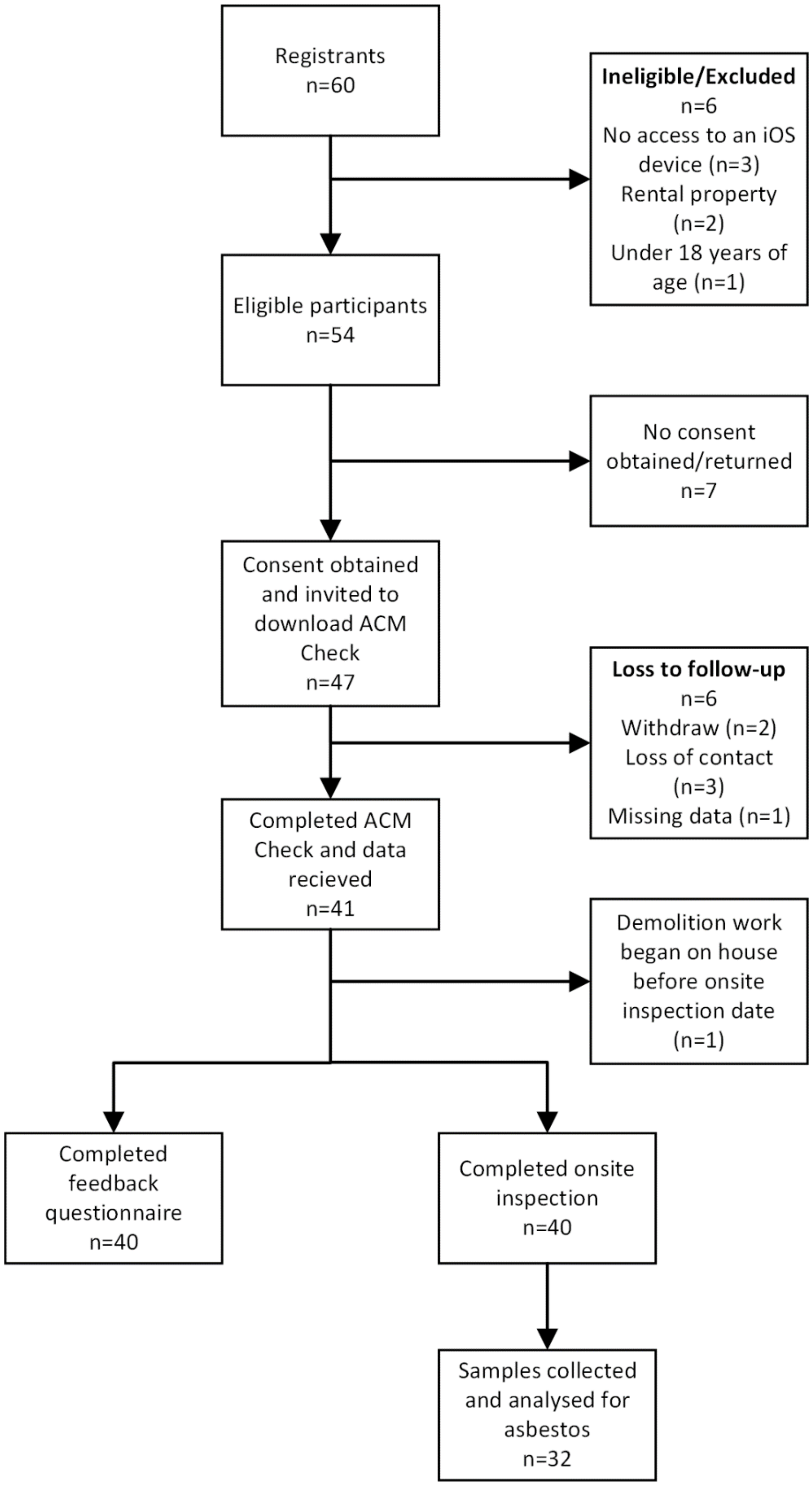

Figure 7 Flowchart showing participant recruitment and stages of data collection

4.4.1. Agreement between Laboratory Analysis and the Consultant and ACM Check

A total of 32 bulk samples from 23 houses covering eight categories of materials were collected for laboratory analysis. Of these, 30 (94%) were collected from outdoor locations (including exterior wall cladding, eaves/garage ceiling, backing board to electrical meter box, fencing, fence capping, and outbuilding wall) and two (6%) from indoor locations (including interior walls and linoleum flooring). Three samples were excluded because they were taken from debris that was stored beside a shed, and therefore were not classified as *in situ* asbestos. Two samples of cement sheet fencing were excluded due to the consultant sampling twice from the same fence on two occasions. The most frequently sampled material was corrugated cement sheet fencing (n=11), cement fence capping (n=4), and flat cement sheeting used for eaves/garage ceiling (n=4).

Of the 27 samples, the consultant classified 22 as ACMs while the laboratory analysis found that 19 samples were positive for asbestos with most (n=17) having both chrysotile and amosite asbestos fibres detected. There was substantial agreement between the consultant's opinion and the laboratory analysis ($\kappa=0.701$, $p<0.05$). The three cases where there was disagreement included two samples taken from eaves/garage ceiling, and one taken from a fence.

Of the 27 samples, ACM Check categorized 25 materials as being positive for ACMs (see Supplemental Materials Table 7). There was a fair strength of agreement between the app and laboratory analysis ($\kappa=0.319$, $p<0.05$) with ACM Check having high sensitivity (100%) but low specificity (25%). False positives were one interior floor sample, two fence samples, and three samples taken from the eaves/garage ceiling.

4.4.2. Agreement between Consultant and ACM Check

Of the 40 houses included, 38 (95%) had at least one type of ACM that was identified qualitatively as positive by both the environmental consultant and ACM Check (Table 5). Thirty seven homes (92.5%) had at least one type of material located outside that was categorized as positive for asbestos by both methods. Overall, there was perfect agreement between ACM Check and the consultant's inspection for categorizing the house as having any *in situ* asbestos present on the property (category: anywhere in Table 4) and as having any *in situ* asbestos present outside.

There was only fair agreement between the two methods when categorizing the home as having any *in situ* asbestos present inside ($\kappa=0.318$, $p=0.013$). ACM Check identified 25 (62.5%) homes as positive whilst the consultant identified 12 (30%) homes. This discrepancy was primarily due to ACM Check overestimating wall tile backing as being positive for asbestos (n=21 false positives). After excluding wall tile backing from the analysis, the number of houses categorized as having at least one ACM located inside by ACM Check was reduced from 25 (62.5%) to 13 (32.5%) and the agreement between the two methods increased to moderate strength (κ=0.593, p<0.001). Both ACM Check and the consultant categorized nine homes (22.5%) as having at least one type of material that was positive for asbestos located inside with an additional three homes being judged as positive by the consultant only (false negatives) whilst there were four homes judged as positive by ACM Check only (false positives; Table 5).

Table 5 Properties categorised as positive or negative for asbestos anywhere, outside, and inside the house (N=40)

Category	**Environmental Consultant assessment**	**ACM Check assessment**		**Kappa (κ)**
		Positive	**Negative**	
Anywhere	Positive	38 (95%)	0	1.00
	Negative	0	2 (5%)	
Outside	Positive	37 (92.5%)	0	1.00
	Negative	0	3 (7.5%)	
Inside	Positive	11 (27.5%)	1 (2.5%)	.318
	Negative	14 (35%)	14 (35%)	
Anywhere other than wall tile backing	Positive	37 (92.5%)	1 (2.5%)	.787
	Negative	0	2 (5%)	
Inside other than wall tile backing	Positive	9 (22.5%)	3 (7.5%)	.593
	Negative	4 (10%)	24 (60%)	

When examining individual materials, a total of 114 materials were categorized as positive for asbestos by the consultant, with 98 of these materials also categorized as positive by ACM Check (see Supplemental Materials Table 8). The majority of *in situ* asbestos was located outside the home (n=100; 87.7%). The most common ACM was corrugated asbestos cement sheet fencing, which was present at 33 (82.5%) homes. At 32 of those houses, the fence was categorized as positive for asbestos by both methods, while one house was categorized as positive by the consultant only (see

Supplemental Materials Table 8). The next most common ACM was the backing board to the electrical meter box, which was categorized as positive by both methods in 26 houses plus one other house categorized as positive by the consultant only. All cases of the house roofing and gutters were categorized as negative for the presence of asbestos by both methods.

Of 560 total observations, there were 505 (90.2%) observed agreements between ACM Check and the environmental consultant when categorizing a material as positive or negative for asbestos. Overall, there was substantial agreement between the two methods when combining all materials inspected across the 40 homes (κ=0.718, p<0.001). ACM Check had a sensitivity of 86% and specificity of 91.2% (Table 6). Agreement improved after excluding wall tile backing from the analysis (Table 6).

Table 6 Agreement between ACM Check and environmental consultant for categorisation of materials as containing asbestos

Category	Sensitivity	Specificity	Kappa(κ)	p-value
Overall				
All materials	86%	91.2%	.718	<0.001
All materials excluding wall tile backing	86%	95.6%	.810	<0.001
Outside				
Exterior wall cladding	80%	97.1%	.771	<0.001
Eaves	70%	90%	.474	.001
Roof	n/a	100%	n/a[A]	n/a
Gutters	n/a	100%	n/a[A]	n/a
Drainpipes	n/a	95%	n/a[A]	n/a
Backing board to electrical meter box	96.3%	84.6%	.826	<0.001
Fence	97%	100%	.918	<0.001
Outbuilding walls	100%	97.3%	.844	<0.001
Outbuilding roof	100%	92.3%	.375	.002
Inside				
Interior walls	75%	96.9%	.754	<0.001
Wall tile backing	n/a	47.5%	n/a[A]	n/a
Ceilings	80%	91.4%	.610	<0.001
Interior flooring	100%	89.7%	.304	.007
Heater flue	n/a	100%	n/a[A]	n/a

[A] *Cannot calculate kappa statistic due to ACM Check and/or inspection results being a constant*

Strength of agreement differed between the specific materials inspected with substantial levels of agreement between ACM Check and the consultant for several materials, in particular, fencing (κ=0.918), outbuilding walls (κ=0.844), and backing board to electrical meter box (κ=0.826; Table 6). However, agreement between ACM Check and the onsite inspection was only fair for outbuilding roof (κ=0.375) and interior flooring (κ=0.304). The low strength of agreement regarding interior flooring was due to ACM Check misclassifying four houses as positive for asbestos in the linoleum or vinyl sheet flooring (see Supplemental Materials Table 8). Although the app correctly indicated that linoleum or vinyl tile flooring was present, the consultant ruled out the possibility of asbestos in these cases due to the lack of either paper backing to the linoleum sheet flooring and/or adhesives holding the flooring to the base layer. With respect to outbuilding roof, the low kappa value was the result of three false positives by the app compared to the consultant (see Supplemental Materials Table 8). However, most (90%) of the outbuilding roofs were categorized as negative for asbestos by both methods (true negatives) and the specificity was high (92.3%; Table 6).

4.5. Discussion

ACM Check is the first app in Australia designed and developed to systematically guide users through a visual inspection of the home in order to identify suspect *in situ* ACM. A total of 40 houses were assessed using ACM Check and inspected by an environmental consultant for the presence or absence of *in situ* asbestos. Of these, 38 houses had a total of 98 materials present that were categorized as positive for asbestos by both methods with an additional 16 ACMs identified by the consultant only. The greater majority of *in situ* asbestos was located outside with corrugated asbestos cement sheet fencing being the most frequently detected ACM.

There were high levels of agreement between the two methods (as indicated by the kappa values) for a number of specific materials including exterior wall cladding, interior walls, fencing, and backing board to electrical meter boxes. In contrast, such categories as outbuilding roof and interior flooring only had fair levels of agreement between the two methods. Kappa is affected by prevalence, and two observers who appear to have high agreement may still emerge with low kappa values when the prevalence of the characteristic of interest is low (Feinstein & Cicchetti, 1990). As such, the low numbers of ACMs for these areas may have impacted the kappa value. Furthermore, a kappa value could not be calculated for five specific materials, including roofing, gutters, drainpipes, wall tile backing, and heater flue pipes, due to no occurrences of these materials being categorized as positive for asbestos by the consultant. Despite this, ACM Check reliably ruled out the presence of asbestos in these locations as evidenced by the high percentage of true negatives for the roofing, gutters, drainpipes, and heater flue pipes.

A larger sample size or targeted recruitment of participants living in known 'high-risk' locations throughout the Perth metropolitan region may have helped to increase the occurrences of these materials being present and detected by the two methods. Nevertheless, we believe that the ACMs that are of most relevance were captured in this sample and tested using ACM Check. For instance, the sample suggests that corrugated asbestos cement fencing, flat cement sheet eaves or soffit lining, and the backing board in old electrical meter boxes are still common in the Perth housing stock.

For apps such as ACM Check, an issue of particular public health importance/concern are the occurrences of "false negatives." Having a material categorized as "unlikely" ACM by the app when in fact it does contain asbestos can result in individuals putting themselves and others at risk of asbestos exposure. The risk arises if the user then disturbs the material through repair, refurbishment or removal without taking appropriate safety precautions because they assumed the material was asbestos-free. Furthermore, this can subsequently lead to the material being mislabelled and disposed of incorrectly by having the ACM placed in to normal waste collection. To combat these issues, it is important the app clearly states to the user that the ratings are probabilities, that the only way to confirm the presence or absence of asbestos is through sampling and laboratory analysis, and that if they are unsure then they should always suspect a material contains asbestos and implement the correct safety procedures. In fact, only 3% of assessments in our study were false negatives, and most of these were materials in the eaves of a building. We added multiple photos of example ACMs and provided further instructions in the app to help clarify what the user needs to inspect when screening for ACMs in this location.

In regards to the samples collected and analyzed in the laboratory, the strength of agreement between ACM Check and the laboratory analysis was fair when including all materials sampled. The main discrepancy between ACM Check and the laboratory result was for the samples of eaves/garage ceiling in which the app overestimated the likelihood that the eaves contained asbestos. The three false positive samples were taken from houses that were built between 1982 and 1987, which are the years that use of ACMs in residential buildings was being phased out. However, the true positive sample was collected from a house built in 1983. This highlights the challenges involved in visual identification of ACMs, particularly when trying to identify materials that were installed during the phase out period of the 1980s as opposed to the peak periods of asbestos use that occurred during the 1960s and 1970s.

Because the sampling was destructive in nature, requiring a fragment that was approximately the size of a thumbnail, it was impossible to take samples when materials were in clearly visible locations. There was also less risk of exposure to airborne asbestos fibres if the material was left undisturbed. The sampling was therefore opportunistic and did not provide the numbers needed for calculating a kappa value measuring the agreement between ACM Check and the laboratory analysis for specific materials or locations included in the app.

The low specificity of ACM Check (25%) when using laboratory identification of fibres as the standard is another limitation of this study. It is important that a tool screening for ACMs has high specificity as well as high sensitivity. The specificity may have been higher if the consultant also focussed on collecting samples from materials suspected to be negative for asbestos, which could have given a stronger assessment of ACM Check's validity in classifying materials as positive or negative for asbestos. However, ACM Check had relatively high specificities for the majority of material types when using the environmental consultant as the standard.

For this study, a single experienced environmental consultant was employed to conduct the onsite inspections with their results used as references for determining the sensitivity and specificity of the app. We acknowledge that there is variation even among trained and experienced consultants regarding their ability to identify different ACMs and qualitatively assess the risk of asbestos exposure. Employing multiple consultants would have allowed the results of the app to be more rigorously evaluated and allowed for stronger conclusions about the app's validity to be drawn. Additionally, this may have allowed us to evaluate the accuracy of the consultants and reduced uncertainty surrounding their opinions.

A further limitation of the study is that the sample population was self-selected. Therefore, participants may have already known whether or not their property had asbestos present and this prior knowledge may have biased their responses given in ACM Check.

A strength of this study was that the sample included a wide distribution of houses that were built in different decades, from the early 1900s through to the late 1980s. In addition, the sample reflected the peak period of asbestos use in Australia which began in the post-World War II period and lasted through to the 1970s. It was important to include houses built in different decades in order to capture and test ACM Check on a wide range of scenarios before it was released publicly. This is because the type and look of products containing asbestos changed over time. For example, a house with solid brick walls and metal roofing built in the mid-1980s presents a different set of issues than does a house built in the 1930s that had successive renovations conducted in the post-World War II peak periods such as in the 1950s and then again in the 1970s.

4.6. Conclusion

Despite asbestos being prohibited in many countries, inadvertent exposure can still occur when individuals repair, renovate or demolish older buildings containing *in situ* asbestos. Our study demonstrates that the mobile phone app, ACM Check, can provide promising results to help people detect the presence or absence of *in situ* asbestos in the most common sites in Australian homes. Our findings suggest that specifically designed mobile apps offer a suitable platform to help tradespeople, home renovators and householders identify *in situ* ACM in the residential environment. Moreover, ACM Check could be modified for use in other countries by changing factors such as the years of asbestos use and types of ACM used and then tested on a sample of local homes. It can also be used as a data collection tool to identify the prevalence of *in situ* asbestos throughout the built environment.

4.7. Supplemental Materials

Table 7 Samples categorised as positive or negative for asbestos by ACM Check and the laboratory analysis (N=27)

Category	**Laboratory analysis**	**ACM Check** **Positive, n (%)**	**Negative, n (%)**
Overall	Positive	19 (70.4%)	0
	Negative	6 (22.2%)	2 (7.4%)
Outside			
Exterior wall cladding	Positive	2 (100%)	0
	Negative	0	0
Eaves/garage ceiling	Positive	1 (25%)	0
	Negative	3 (75%)	0
Backing board to electrical meter box	Positive	1 (100%)	0
	Negative	0	0
Fencing	Positive	9 (81.8%)	0
	Negative	2 (18.2%)	0
Fence capping	Positive	4 (100%)	0
	Negative	0	0
Outbuilding wall	Positive	1 (33.3%)	0
	Negative	0	2 (66.7%)
Inside			
Interior walls	Positive	1 (100%)	0
	Negative	0	0
Linoleum or vinyl tile flooring	Positive	0	0
	Negative	1 (100%)	0

Table 8 Frequency of materials categorised as positive or negative for asbestos by ACM Check and the environmental consultant (N=40)

Category	Environmental Consultant	ACM Check Positive, n (%)	Negative, n (%)
Overall			
All materials	Positive	98 (17.5%)	16 (2.9%)
	Negative	39 (7.0%)	407 (72.7%)
All (excl. backing to wall tiles)	Positive	98 (18.8%)	16 (3.1%)
	Negative	18 (3.5%)	388 (74.6%)
Outside			
Exterior wall cladding	Positive	4 (10%)	1 (2.5%)
	Negative	1 (2.5%)	34 (85%)
Eaves	Positive	21 (52.5%)	9 (22.5%)
	Negative	1 (2.5%)	9 (22.5%)
Roofing	Positive	0	0
	Negative	0	40 (100%)
Gutters	Positive	0	0
	Negative	0	40 (100%)
Drainpipes	Positive	0	0
	Negative	2 (5%)	38 (95%)
Backing board to electrical meter box	Positive	26 (65%)	1 (2.5%)
	Negative	2 (5%)	11 (27.5%)
Fencing	Positive	32 (80%)	1 (2.5%)
	Negative	0	7 (17.5%)
Outbuilding walls	Positive	3 (7.5%)	0
	Negative	1 (2.5%)	36 (90%)
Outbuilding roof	Positive	1 (2.5%)	0
	Negative	3 (7.5%)	36 (90%)
Inside			
Interior walls	Positive	6 (15%)	2 (5%)
	Negative	1 (2.5%)	31 (77.5%)
Backing to wall tiles	Positive	0	0
	Negative	21 (52.5%)	19 (47.5%)
Ceiling	Positive	4 (10%)	1 (2.5%)
	Negative	3 (7.5%)	32 (80%)

Linoleum or vinyl tile flooring	Positive Negative	1 (2.5%) 4 (10%)	0 35 (87.5%)
Heater flue pipe	Positive Negative	0 0	1 (2.5%) 39 (97.5%)

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Chapter 5: Condition Assessment of *In Situ* Asbestos-Containing Materials Using a Mobile Phone App and by an Environmental Consultant: A Comparison of Methods

5.1. Introduction

A range of physical, chemical, and biological processes can result in the degradation or weathering of *in situ* ACMs. These processes can corrode and damage the surface of asbestos cement products which can result in asbestos fibres being released from the cement matrices that previously held the fibres in place. The free and/or loosely bound asbestos fibres can then be dispersed in rainwater and transported throughout the environment, e.g. in groundwater and soil, or dispersed into the ambient air by wind (ASCC, 2008a; Spurny, 1989).

The type and condition of an ACM determines the degree in which the material contributes to the ambient air concentrations of asbestos fibres. For instance, there is a negligible risk of exposure associated with *in situ* ACMs that are undisturbed and in good condition because the asbestos fibres are bound tightly into the matrix (enHealth, 2005). As a result, these ACMs will only contribute a very low amount of asbestos fibres to ambient air concentrations. In contrast to this, asbestos fibres can be dispersed into the air when the ACMs become damaged or are disturbed, which subsequently increases the risks of exposure to individuals in the vicinity (enHealth, 2005). Consequently, it is not enough to say that because an ACM is present in a residential setting that household occupants are exposed to asbestos fibres above "background levels."

Therefore, qualitative assessment of the condition of materials and their potential to release asbestos fibres is an important component of any exposure assessment of *in situ* ACM. In order to determine the potential of an ACM to release fibres, a visual inspection should include assessing such factors as the type of ACM, its condition and age, wear and weathering, exposed surface area, accessibility/location, and activity (enHealth, 2005). For this reason, an important component of the ACM Check questionnaire is a 'priority assessment' of 'possible' and 'likely' ACMs. The priority assessment has the user assess the material's current condition, which includes taking into account the wear and weathering of the material, and has the user assess the potential for disturbing the ACM, which takes into account the accessibility of the material and any activity of the occupants. ACM Check records these details to (1) generate a summary report for the user within the app; (2) assign an overall priority level to each 'possible' or 'likely' ACM, which informs the user on a general course of action; and, (3) collect data on the current condition of *in situ* ACM remaining in the housing stock. However, it was necessary to test the different elements of the priority assessment incorporated in ACM Check before the app was publicly launched. This chapter forms the second component of the validation study of ACM Check.

5.1.1. Objectives

The main objective of this component of the research project was to compare the *assessment* of the current condition and likelihood of disturbing identified *in situ* ACM using ACM Check to the results of an experienced environmental consultant's assessment (objective 2.2, Table 1).

5.2. Methods

5.2.1. General Study Design

As described in Chapter 4, a cross-sectional study was conducted between August 2016 and February 2017 that involved (1) participants downloading and completing ACM Check on their home and then (2) having an environmental consultant visit to conduct a residential asbestos inspection. A component of the ACM Check questionnaire was a 'priority assessment' of materials that were categorised as 'possible' or 'likely' ACM.

5.2.2. Assessment of *In Situ* ACMs using ACM Check

A detailed description of the priority assessment included in the ACM Check questionnaire is presented in Chapter 3. Briefly, each material/category inspected during the ACM Check questionnaire is automatically assigned a probability of containing asbestos, including 'not applicable,' 'unlikely,' 'possible,' or 'likely' ACM, which is based on the user's responses. A 'priority assessment' made up of three questions is then triggered for each material that is assigned a probability of 'possible' or 'likely' ACM.

The priority assessment asks two questions about the current condition of the suspect ACM. The qualitative question (*What is the current condition of [name of material]?*) has four possible outcomes including 'good,' 'fair,' 'poor,' and 'very poor' and is based on the degree in which the ACM demonstrates signs of weathering, deterioration, or physical damage, and on how friable it is. Descriptive text (see Table 9) accompanies each response option to help the user rate the ACM. The user is asked a further question where they rate the condition of the ACM on a scale of one (very poor) to ten (very good).

Table 9 Ratings and descriptive text for the qualitatively assessing the current condition

Rating	Descriptive Text
Good	Material is intact (undamaged). There is no or minimal visible water damage, physical damage, or deterioration; no signs of breakdown of any asbestos cement surface through weathering.
Fair	Material has minor damage or deterioration; a few scratches or surface marks; the material is mostly intact; for fencing, slight breakage through plant contact. Any friable (loose or easily crumbled) material is well contained.
Poor	There is moderate breakage, damage or deterioration of materials such as cracks, splits, scratches, panel buckling/distortion, or visible water damage. May have some loose asbestos fibres on the surface of the material. For fencing, there are visible, raised asbestos fibres or moss growth on surfaces due to weathering and age. If you were to touch, gently rub or apply light pressure to the material, the surface material may crumble. Enclosure of any friable material is incomplete or deteriorating.
Very poor	There is major breakage, damage, distortion or deterioration of materials such as multiple major cracks, splits and scratches. Materials such as floor tile extensively damaged and underlying mastic exposed. In the most damaged areas the surface material crumbles very easily upon contact. Any friable material is poorly contained.

The final question of the priority assessment asks the user to rate the likelihood of disturbance (*What is the likelihood of [name of material] being disturbed from access, use, repair, and/or renovation and maintenance activity?*) by selecting one of four possible outcomes including 'unlikely,' 'somewhat likely,' 'likely,' or 'highly likely.' This assessment refers to the likelihood that the *in situ* ACM is going to be damaged or disturbed, which reflects the chances of asbestos fibres being released from the material. Such disturbance can occur for multiple reasons including through use, access, repair, removal, or renovation and maintenance activities. Again, descriptive text (see Table 10) accompanies each response option to help the user rate the likelihood of disturbance.

Table 10 Ratings and descriptive text for assessing the likelihood of disturbance

Rating	Descriptive Text
Unlikely	Material is unlikely to be disturbed due to no or limited access (i.e. isolated or inaccessible location), no foreseeable need of maintenance or repair, and/or there are no immediate plans for renovation.
Somewhat likely	Material is somewhat likely to be disturbed due to either occasional access (more than once per year but less than monthly), potential need for minor repairs, and/or possible renovations involving the area containing the ACM in the future.
Likely	Material is likely to be disturbed due to either frequent or routine access (i.e. externals of residence and well trafficked areas), likely repairs in the future and/or likely/probable renovations of the area containing the ACM.
Highly likely	Material is highly likely to be disturbed from either frequent or very frequent access (i.e. internals of residence accessed through occupancy, such as kitchens or main bathrooms), planned repairs in the near future, and/or almost certain renovations of the area containing the ACM.

The user's rating of the qualitative current condition and likelihood of disturbance are automatically assigned numerical values and added together by ACM Check to provide a priority level for each ACM. This priority level has four categories: 'very low,' 'low,' 'moderate,' and 'high.' This priority level indicates the ACMs that are of most importance with respect to the potential risk of asbestos exposure and which ACMs require remediation at that property.

The key outcome variables collected through ACM Check and presented in this chapter include: (1) the current condition rating ('very poor,' 'poor,' 'fair,' or 'good'), (2) the likelihood of disturbance rating ('unlikely,' 'somewhat likely,' 'likely,' or 'highly likely') and, (3) the priority level ('very low,' 'low,' 'moderate,' or 'high') for each 'possible' or 'likely' ACM.

5.2.3. Assessment of *In Situ* ACMs by an Environmental Consultant

As described in Chapter 4, a residential inspection was performed at each property by an experienced environmental consultant in order to identify and then assess the condition of the *in situ* ACMs. The consultant also rated the likelihood of disturbance for materials that he judged to be 'possible' or 'likely' ACM. These two factors were rated following the same criteria and outcomes used in ACM Check. The consultant was blinded to the results of the priority assessments completed by participants using ACM Check.

5.2.4. Statistical Analysis

Only the 114 materials classified as 'possible' or 'likely' for asbestos by the consultant are included in this analysis. Of them, 98 were also classified as 'possible' or 'likely' by ACM Check (i.e., the true positive classifications made by ACM Check). To determine the level of agreement between ACM Check and the consultant in regards to the priority assessment of the 98 true positive ACMs, Cohen's kappa (κ) statistic was calculated for the qualitative current condition and the likelihood of disturbance ratings. A weighted kappa (κ_w) was also calculated due to the condition and disturbance ratings each having four levels and, therefore, the disagreement between raters could be more than one unit of measurement apart. A p-value of < 0.05 was considered statistically significant in all tests. All statistical analyses were completed in IBM SPSS Statistics for Windows, Version 24 (IBM Corp., Armonk, NY, USA).

5.3. Results

5.3.1. Summary of Houses Sampled and Identified ACMs

A total of 40 houses distributed across the Perth metropolitan area were inspected by the home owner using ACM Check and by the environmental consultant. There was a spread of houses built in different decades ranging from the 1890s through to the late 1980s (Figure 8). The median year of construction was 1966 (interquartile range, IQR 1942-1976).

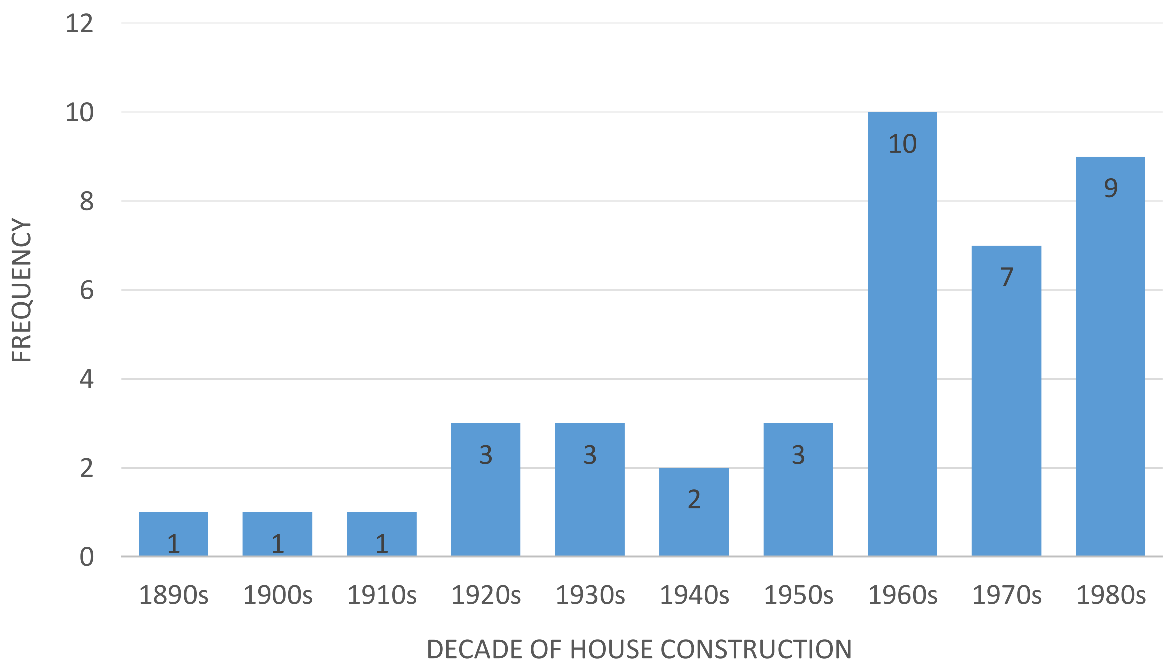

Figure 8 Decade of construction for the sampled houses (n=40)

As outlined in Chapter 4, 38 of the 40 homes had at least one type of material that was categorised as positive for asbestos by both the environmental consultant and ACM Check. The consultant categorised 114 out of a potential 560 materials as positive for containing asbestos whilst ACM Check correctly identified 98 (86%) of these. Materials categorised as positive by the consultant were largely located outside the home (n=100/114; 87.7%). Corrugated asbestos cement sheet fencing was the most frequently reported ACM (n=33/40; 82.5%) followed by flat asbestos cement sheeting used for eaves (n=30/40; 75%) and the backing board to the electrical meter box (n=27/40; 67.5%).

Although ACM Check tests for the presence of *in situ* ACMs in 14 different locations, the following analysis and discussion only includes the 10 locations in which there was at least one material considered to be positive for asbestos by the consultant. As such four categories were excluded: roofing, guttering, downpipes, and backing to wall tiles.

5.3.2. Current Condition Ratings of ACMs

Overall, the majority of true positive materials assessed using ACM Check were categorised as being in either 'fair' (n=40/98; 40.8%) or 'good' (n=37/98; 37.8%) condition. ACMs located outside were most frequently assessed as being in 'fair' condition (n=37/87; 42.5%) whilst the majority of ACMs located inside the homes were assessed as being in 'good' condition (n=8/11; 72.7%). Nearly one-fifth (n=19/98; 19.4%) of all ACMs were rated as being in 'poor' condition by users of ACM Check and these were all located outside the home. The majority of ACMs in 'poor' condition were fencing (n=12/19; 63.2%) and eaves (n=4/19; 21%). Only two ACMs were rated as being in 'very poor' condition, which included a fence and an outbuilding wall (Table 11).

In contrast to this, the environmental consultant rated 85.1% (n = 97/114) of ACMs as being in 'good' condition. Almost all inside materials were considered by the environmental consultant to be in 'good' condition (n=14/15; 93.3%) with only one being in 'fair' condition. There were only six (5.3%) ACMs rated as being in 'poor' condition by the environmental consultant and these were all located outside the home. More specifically, the ACMs in poor condition were exterior wall cladding (n=2), fencing (n=2), eaves and an outbuilding wall (n=1, respectively). The environmental consultant did not consider any ACMs to be in 'very poor' condition (Table 11).

Table 11 Current condition ratings for ACMs in each category as assessed by users of ACM Check and the environmental consultant

Category	ACM Check (n=98)					Environmental Consultant (n=114)				
	Good	**Fair**	**Poor**	**Very Poor**	**Total**	**Good**	**Fair**	**Poor**	**Very Poor**	**Total**
Outside										
Exterior wall cladding	2 (50%)	1 (25%)	1 (25%)	0	4	3 (60%)	0	2 (40%)	0	5
Eaves	7 (33.3%)	10 (47.6%)	4 (19%)	0	21	28 (93.3%)	1 (3.3%)	1 (3.3%)	0	30
Backing board to electrical meter box	17 (65.4%)	8 (30.8%)	1 (3.8%)	0	26	25 (92.6%)	2 (7.4%)	0	0	27
Fencing	2 (6.3%)	17 (53.1%)	12 (37.5%)	1 (3.1%)	32	25 (75.8%)	6 (18.2%)	2 (6.1%)	0	33
Outbuilding walls	1 (33.3%)	1 (33.3%)	0	1 (33.3%)	3	2 (66.7%)	0	1 (3.3%)	0	3
Outbuilding roof	0	0	1 (100%)	0	1	0	1 (100%)	0	0	1
All outside ACMs	29 (33.3%)	37 (42.5%)	19 (21.8%)	2 (2.3%)	87	83 (83.8%)	10 (10.1%)	6 (6.1%)	0	99
Inside										
Interior walls	5 (83.3%)	1 (16.7%)	0	0	6	7 (87.5%)	1 (12.5%)	0	0	8
Ceiling	3 (75%)	1 (25%)	0	0	4	5 (100%)	0	0	0	5
Interior flooring	0	1 (100%)	0	0	1	1 (100%)	0	0	0	1
Heater flue*	n/a	n/a	n/a	n/a	n/a	1 (100%)	0	0	0	1
All inside ACMs	8 (72.7%)	3 (27.3%)	0	0	11	14 (93.3%)	1 (6.7%)	0	0	15
Total	**37 (37.8%)**	**40 (40.8%)**	**19 (19.4%)**	**2 (2%)**	**98**	**97 (85.1%)**	**11 (9.6%)**	**6 (5.3%)**	**0**	**114**

No heater flues were identified and assessed by ACM Check

5.3.3. Agreement between Methods When Assessing Condition of ACMs

For the 98 true positive materials that had their current condition assessed by both methods, the overall strength of agreement between ACM Check and the consultant was $\kappa=0.026$ ($\kappa_w=0.072$). Users of ACM Check and the environmental consultant only agreed on 38.8% of current condition ratings, which included 34 materials rated as being in 'good' condition, 3 materials rated as being in 'fair' condition, and 1 rated as being in 'poor' condition. ACM Check users consistently rated ACMs as being in a poorer condition compared with how they were rated by the environmental consultant. For instance, users of ACM Check rated 19.4% (n=19/98) of materials as being in 'poor' condition whereas the environmental consultant only rated 5.1% (n=5/98) of materials as 'poor.' Similarly, ACMs were more frequently rated as being in 'fair' condition by users of ACM Check than by the environmental consultant (40.8% vs. 11.2%; Table 12).

Table 12 Agreement between methods for rating the qualitative current condition of true positive ACMs overall (n=98)

		ACM Check				
		Good	Fair	Poor	Very Poor	Total
Environmental Consultant	Good	34 (34.7%)	33 (33.7%)	14 (14.3%)	1 (1.0%)	82 (83.7%)
	Fair	3 (3.1%)	3 (3.1%)	4 (4.1%)	1 (1.0%)	11 (11.2%)
	Poor	0	4 (4.1%)	1 (1.0%)	0	5 (5.1%)
	Very Poor	0	0	0	0	0
	Total	37 (37.8%)	40 (40.8%)	19 (19.4%)	2 (2%)	98 (100%)

5.3.4. Likelihood of Disturbing the ACMs

Overall, users of ACM Check rated the majority of true positive ACMs as being 'unlikely' (42.9%) or 'somewhat likely' (39.8%) to be disturbed in the near future. Similarly, ACMs located outside were most frequently assessed as being 'unlikely' (n=38/87; 42.5%) to be disturbed whilst the ACMs located inside the homes were most frequently assessed as being 'somewhat likely' to be disturbed (n=5/11; 45.5%). Ten (10.2%) ACMs were considered by ACM Check users as 'likely' to be disturbed, and nearly all of these ACMs were located outside (n=9/10), with half being fences (n=5/10). Furthermore, there were seven ACMs judged as being 'highly likely' to be disturbed, and again, all but one of these materials were located outside. More specifically, the six ACMs that were 'highly likely' to be disturbed were fences (n=3/6; 50%), exterior wall cladding (n=2/6; 33.3%) and a backing board to an electrical meter box (n=1/6; 16.7%; Table 13).

The environmental consultant rated 110 of the 114 (96.5%) identified ACMs for the likelihood of the material being disturbed. The missing data for the four ACMs included two ratings for exterior wall cladding and fencing, respectively. Of the 110 ACMs that were assessed, nearly three-quarters were rated as 'unlikely' to be disturbed (n=81/110; 73.6%) with close to a quarter rated as 'somewhat likely' to be disturbed (n=27/110; 24.5%). A similar proportion of ACMs located outside and inside the home were 'unlikely' to be disturbed (73.7% vs. 73.3%, respectively). There were only two (1.8%) ACMs judged by the consultant as 'likely' to be disturbed including an outbuilding wall in poor condition and an inside ceiling that had a light fixing removed, which had damaged the panel and exposed asbestos fibres along the edges. The environmental consultant did not consider any identified ACMs as 'highly likely' to be disturbed in the near future (Table 13).

Table 13 Likelihood of disturbance ratings for ACMs as assessed by users of ACM Check and the environmental consultant

Category	ACM Check (n=98)					Environmental Consultant (n=110)				
	Unlikely	Somewhat Likely	Likely	Highly Likely	Total	Unlikely	Somewhat Likely	Likely	Highly Likely	Total
Outside										
Exterior wall cladding*	2 (50%)	0	0	2 (50%)	4	2 (66.7%)	1 (33.3%)	0	0	3
Eaves	8 (38.1%)	12 (57.1%)	1 (4.8%)	0	21	26 (86.7%)	4 (13.3%)	0	0	30
Backing board to electrical meter box	17 (65.4%)	6 (23.1%)	2 (7.7%)	1 (3.8%)	26	20 (74.1%)	7 (25.9%)	0	0	27
Fencing*	11 (34.4%)	13 (40.6%)	5 (15.6%)	3 (9.4%)	32	21 (67.7%)	10 (32.3%)	0	0	31
Outbuilding walls	0	2 (66.7%)	1 (33.3%)	0	3	1 (33.3%)	1 (33.3%)	1 (33.3%)	0	3
Outbuilding roof	0	1 (100%)	0	0	1	0	1 (100%)	0	0	1
All outside ACMs	38 (43.7%)	34 (39.1%)	9 (10.3%)	6 (6.9%)	87	70 (73.7%)	24 (25.3%)	1 (1.1%)	0	95
Inside										
Interior walls	3 (50%)	2 (33.3%)	0	1 (16.7%)	6	7 (87.5%)	1 (12.5%)	0	0	8
Ceiling	1 (25%)	3 (75%)	0	0	4	3 (60%)	1 (20%)	1 (20%)	0	5
Interior flooring	0	0	1 (100%)	0	1	0	1 (100%)	0	0	1
Heater flue	n/a	n/a	n/a	n/a	n/a	1 (100%)	0	0	0	1
All inside ACMs	4 (36.4%)	5 (45.5%)	1 (9.1%)	1 (9.1%)	11	11 (73.3%)	3 (20%)	1 (6.7%)	0	15
Total	**42 (42.9%)**	**39 (39.8%)**	**10 (10.2%)**	**7 (7.1%)**	**98**	**81 (73.6%)**	**27 (24.5%)**	**2 (1.8%)**	**0**	**110**

**Missing data for environmental consultant: exterior wall cladding n = 2, fencing n = 2*

5.3.5. Agreement between Methods When Assessing the Likelihood of Disturbance

Ninety-four identified ACMs had their likelihood of disturbance assessed by both the users of ACM Check and environmental consultant. As measured by the Cohen's kappa value, the overall strength of agreement between ACM Check and the consultant was $\kappa=0.029$ ($\kappa_w=0.008$). Moreover, no kappa values reached statistical significance for the individual categories of ACM. Users of ACM Check and the environmental consultant only agreed on 42.6% of likelihood of disturbance ratings. ACM Check users consistently rated ACMs as more likely to be disturbed compared to how they were rated by the environmental consultant (see Table 14).

Table 14 Agreement between methods for the likelihood of disturbance rating of true positive ACMs overall (n=94)

		ACM Check				
		Unlikely	Somewhat Likely	Likely	Highly Likely	Total
Environmental Consultant	Unlikely	28 (29.8%)	26 (27.7%)	7 (7.4%)	5 (5.3%)	66 (70.2%)
	Somewhat Likely	10 (10.6%)	12 (12.8%)	3 (3.2%)	1 (1.1%)	26 (27.7%)
	Likely	1 (1.1%)	1 (1.1%)	0	0	2 (2.1%)
	Highly Likely	0	0	0	0	0
	Total	39 (41.5%)	39 (41.5%)	10 (10.6%)	6 (6.4%)	94* (100%)

**Missing data, n=4*

5.3.6. Priority Levels of ACMs

The 'priority level' is derived from the current condition and likelihood of disturbance ratings using a risk matrix described in Chapter 3, and this is an automated process in ACM Check.

Over half (n=52/98; 53.1%) of all true positive materials assessed by ACM Check were categorised as 'very low' priority while a quarter (n=25/98; 25.5%) were categorised as 'moderate' priority. Only 3% of materials were categorised as 'high' priority by ACM Check. All high priority ACMs were located outside and included two cases of fencing and one case of exterior wall cladding (Table 15).

There was missing data for the environmental consultant's likelihood of disturbance ratings for four materials. Therefore, 110 of the 114 identified ACMs were assigned priority levels based on the environmental consultant's assessment. Ninety-one percent of identified ACMs were categorised as 'very low' priority based on the environmental consultant's assessment of current condition and likelihood of disturbance. No materials were categorised as ‘high’ priority and only two materials were categorised as ‘moderate’ priority (Table 15).

Table 15 Priority levels for identified ACMs based on ACM Check and the environmental consultant's assessment

Category	ACM Check (n=98)					Environmental Consultant (n=110)				
	Very Low	**Low**	**Moderate**	**High**	**Total**	**Very Low**	**Low**	**Moderate**	**High**	**Total**
Outside										
Exterior wall cladding*	2 (50%)	0	1 (25%)	1 (25%)	4	2 (66.7%)	1 (33.3%)	0	0	3
Eaves	10 (47.6%)	7 (33.3%)	4 (19%)	0	21	29 (96.7%)	1 (3.3%)	0	0	30
Backing board to electrical meter box	21 (80.8%)	2 (7.7%)	3(11.5%)	0	26	26 (96.3%)	1 (3.7%)	0	0	27
Fencing*	10 (31.2%)	7 (21.9%)	13 (40.6%)	2 (6.3%)	32	27 (87.1%)	3 (9.7%)	1 (3.2%)	0	31
Outbuilding walls	1 (33.3%)	1 (33.3%)	1 (33.3%)	0	3	2 (66.7%)	0	1 (33.3%)	0	3
Outbuilding roof	0	0	1 (100%)	0	1	0	1 (100%)	0	0	1
All outside ACMs	44 (50.6%)	17 (19.5%)	23 (26.4%)	3 (3.4%)	87	86 (90.5%)	7 (7.4%)	2 (2.1%)	0	95
Inside										
Interior walls	5 (83.3%)	0	1 (16.7%)	0	6	8 (100%)	0	0	0	8
Ceiling	3 (75%)	1 (25%)	0	0	4	4 (80%)	1 (20%)	0	0	5
Interior flooring	0	0	1 (100%)	0	1	1 (100%)	0	0	0	1
Heater flue	n/a	n/a	n/a	n/a	n/a	1 (100%)	0	0	0	1
All inside ACMs	8 (72.7%)	1 (9.1%)	2 (18.2%)	0	11	14 (93.3%)	1 (6.7%)	0	0	15
Total	**52 (53.1%)**	**18 (18.4%)**	**25 (25.5%)**	**3 (3.1%)**	**98**	**100 (90.9%)**	**8 (7.3%)**	**2 (1.8%)**	**0**	**110**

**Missing data for environmental consultant: exterior wall cladding n = 2, fencing n = 2*

Overall, there was little agreement between ACM Check and the environmental consultant for the priority levels as measured by the unweighted (κ=-0.045) and weighted ($κ_w$=-0.023) Cohen's kappa value. There was agreement between the methods for only 46.8% of priority levels, which included 44 materials of 'very low' priority. Priority levels of ACMs were consistently higher in the app compared to priority levels based on the environmental consultant's assessments. For example, 90.4% of ACMs were considered 'very low' priority based on the consultant's ratings whereas 52.1% of ACMs were 'very low' priority based on the ratings from ACM Check. Likewise, ACMs were more frequently rated as being 'moderate' priority based on ratings in ACM Check compared to the ratings of the environmental consultant (25.5% vs. 2.1%, respectively; Table 16).

Table 16 Agreement between methods for the priority levels of all true positive ACMs (n=94)

		ACM Check				
		Very Low	Low	Moderate	High	Total
Environmental Consultant	Very Low	44 (46.8%)	17 (18.1%)	21 (22.3%)	3 (3.2%)	85 (90.4%)
	Low	4 (4.2%)	0	3 (3.2%)	0	7 (7.4%)
	Moderate	1 (1.1%)	1 (1.1%)	0	0	2 (2.2%)
	High	0	0	0	0	0
	Total	49 (52.1%)	18 (19.2%)	24 (25.5%)	3 (3.2%)	94* (100%)

**Missing data, n=4*

5.4. Discussion

ACM Check correctly identified 98 of the 114 ACMs that were identified by the environmental consultant, and each of these materials had their current condition and likelihood of disturbance rated. Cohen's kappa statistic was calculated to determine the level of agreement between the two methods with respect to the ratings of the 98 ACMs. However, there was poor agreement between home owners using ACM Check and the environmental consultant's inspections. Users of ACM Check and the environmental consultant only agreed on 38.8% of current condition ratings and 42.6% of likelihood of disturbance ratings, with kappa values of κ=0.026 and κ=0.029, respectively. Therefore only 46.8% of priority levels were in agreement.

Users of ACM Check consistently rated the condition poorer and potential for disturbance higher than the ratings given by the environmental consultant. Compared with the environmental consultant, participants more frequently reported ACMs as being in 'poor' condition (5.1% vs. 19.4%, respectively). The pattern was repeated for the likelihood of disturbance ratings. For instance, participants reported ACMs as 'likely' and 'highly likely' to be disturbed (10.6% and 6.4% respectively), whereas the environmental consultant rated only 2.1% of ACMs as 'likely' and no materials as 'highly likely' to be disturbed.

Several reasons might explain the discrepancies between participants using ACM Check and the environmental consultant with respect to the condition and disturbance ratings. Firstly, the current condition and likelihood of disturbance questions are subjective in nature. They both require individuals to interpret the question and then to select what they think is the most appropriate answer based on their direct observations. Therefore, the rating can be influenced by the individual's previous experience, training, and level of knowledge, as well as their comprehension of the question. The environmental consultant had a wealth of experience, on-the-job training and knowledge that he could draw upon when assessing whether or not an ACM was in a condition that places occupants at risk of asbestos exposure and/or warrants action. Furthermore, due to the subjective nature of the assessment, there may have been inherent differences in what the consultant and the users of ACM Check considered a material in good, fair or poor condition.

In an attempt to counter the variation in users' experience with assessing asbestos, descriptive text accompanied each response option (as seen in Table 9 and Table 10). Nevertheless, the participants and the environmental consultant may have focussed on different elements of the overarching quality in question. Each rating (current condition and likelihood of disturbance rating) is made up of several different elements that can impact the selected response. For instance, the likelihood of disturbance rating is an 'overall' rating that requires the individual (user or consultant) to consider the accessibility (i.e. how easy a given ACM is to access), the frequency of access, and the plans to conduct repair, maintenance, renovation or removal activities on or near the ACM. Likewise, the current condition rating requires the individual to take into account the overall degree of damage or deterioration of an ACM and whether or not it is friable (i.e. easily crumbled). As such, each user may apportion different weightings to each of those elements when selecting their answer. This could be related to the level of experience.

Thirdly, the descriptive text may not have been helpful or explicit enough when it came to guiding the user on how to assess the ACM. Therefore, if a participant found it difficult to interpret the accompanying text then it is possible that some participants simply guessed. However, participants were given the opportunity to comment on the ACM Check questionnaire and provide feedback on how it could be improved (discussed in Chapter 6). No participants indicated that these two qualitative questions were difficult to interpret, although one participant commented with respect to the current condition question that "*It was also quite subjective in terms of what is in good order, but the detailed description was great*."

A further explanation regarding the likelihood of disturbance rating, participants may have been more aware of how and when they are likely to disturb ACMs located in and around their home. For instance, the users may already have plans to renovate a particular area of the house that contains *in situ* asbestos. This may possibly explain why some users rated the likelihood of disturbance higher compared to the environmental consultant who would have had limited or no knowledge of the home owner's intentions. However, in some instances the environmental consultant was able to discuss these intentions with the home owner and/or participant.

Finally, the users themselves are likely to be more concerned about asbestos compared to non-participants (non-users), which is inherent in their choice to participate in this study. The sample was self-selected, and therefore, the study could have appealed to people who may think that all asbestos is hazardous, regardless of condition. There is a high degree of community concern about asbestos with "scare stories" produced by media outlets about the hazards of asbestos being common in Australia, and specifically in Western Australia.

An important limitation of this study is that only one environmental consultant was used to perform the assessments with their results then compared to those obtained from ACM Check. As discussed in Chapter 4, there is variation even among experienced consultants regarding their ability to qualitatively assess the risk of exposure from ACMs. The consultant in this study may have been more conservative in their assessments of condition and disturbance compared to their colleagues and thus made users of ACM Check appear to overestimate the ratings. Therefore, it is unknown whether or not the findings relating to the priority assessment in ACM Check are generalisable beyond this consultant.

Nevertheless, the results presented in this chapter indicate that participants took a cautious approach to assessing the condition of *in situ* ACMs in and around their home, and importantly, that they were not underestimating the risks associated with asbestos. From a public health perspective, it is more desirable that users overestimate as opposed to underestimate the level of risk associated with *in situ* ACMs. By rating an ACM in a poorer condition than what an experienced assessor would, the user may be more cautious around the ACM and more inclined to incorporate preventative measures, such as have the ACM remediated (encapsulated) or even removed. Conversely, it would be more dangerous if we observed that users of ACM Check in the trial consistently underrated the current condition and likelihood of disturbing ACMs. However, it is important to consider that there are also risks associated with overestimating the condition, likelihood of disturbance, and priority level of ACMs in and around the home. Overrating the condition of an ACM could result in unnecessary expenditure, unnecessary removal of the product, and problems associated with waste disposal. Additionally, overestimating the potential for asbestos exposure from an ACM could result in unnecessary concern and anxiety about the health risks. In an attempt to mitigate users' unnecessary concern and anxiety, ACM Check provides additional information and links to relevant websites that discuss asbestos and ARD risks.

5.5. Conclusion

Qualitative assessment of the condition of ACMs and their potential to release asbestos fibres is an important component of any exposure assessment of *in situ* ACMs. Therefore, a simple priority assessment forms an important component of the ACM Check questionnaire. This chapter reported and compared the current condition, likelihood of disturbance, and priority levels obtained during the priority assessments of ACMs by participants using ACM Check and by the environmental consultant in Phase Two. Overall, the results indicate that participants took a cautious approach to the assessment of ACMs in and around their home. Moreover, participants often rated ACMs as being in worse condition and more likely to be disturbed compared to the environmental consultant's assessment. This is an acceptable outcome as it aligns with the precautionary principle.

Chapter 6: Formative Evaluation of the Functionality, Usability and Potential Impact of ACM Check

6.1. Introduction

Usability is a key factor in the adoption of software products, such as mobile apps. Usability has been defined by the International Organization for Standardization (ISO, 1998) as the "Extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use." This relates to three key factors including (1) the user, "Person who interacts with the product," (2) the goal, the "Intended outcome" and (3) the context of use, which includes "Users, tasks, equipment (hardware, software and materials), and the physical and social environments in which a product is used" (ISO, 1998). As such, the usability of ACM Check can be defined as the extent to which the app can be used by people living or working in residential settings, to identify and assess the condition of *in situ* ACMs in the residential environment with technical effectiveness, efficiency, and satisfaction.

There is a broad range of criteria that can be included when evaluating the usability and quality of mobile health apps. For instance, Stoyanov et al. (2015) include five broad categories of criteria for rating the quality of mobile health apps covering such domains as *functionality* (i.e., navigation, ease of use), *aesthetics* (i.e., graphic, layout), *engagement* (i.e., entertainment, fit to target group), *information quality* (i.e., credibility, visual information), and *subjective quality* (i.e., worth recommending, overall satisfaction rating).

Further to the app's functionality and usability, it is equally important to evaluate whether or not the use of the app has a positive impact on the users' behaviour post-completion. Although the data collected through ACM Check will be of value to the researchers, it is imperative that the user directly benefits from completing the app. Specifically, ACM Check needs to impact the users' awareness of residential sources of asbestos by helping to identify *in situ* ACMs and to provide links to further resources and information about asbestos in the home. In turn, it is intended that this increased awareness and knowledge leads to the user taking action towards preventing and/or minimising asbestos exposure in the residential setting. The long term goal of providing ACM Check is to raise awareness and prevent inadvertent exposure to residential sources of asbestos.

Therefore, two feedback and follow-up questionnaires formed an important component of the pilot testing and validation study (Phase Two). These questionnaires sought to obtain feedback on the usability, functionality, and potential impact of ACM Check so that appropriate changes could be made before it was launched to the public and used as the primary data collection tool in Phase Three of this research project.

6.1.1. Objectives

As discussed in Chapters 4 and 5, a validation study was conducted testing ACM Check on a sample of older homes in Perth, WA. This chapter discuss two objectives of the validation study:

1) To assess the usability and flow of the application (i.e., its functionality)
2) To investigate if completion of the application resulted in knowledge seeking or changes to participants' behaviour (i.e., its potential impact).

6.2. Methods

6.2.1. General Study Design

Two questionnaires were included as part of the pilot testing and validation study of ACM Check that was described in Chapters 4 and 5. The two questionnaires were administered online through Qualtrics with the links emailed directly to each participant. Aside from one reminder email being sent, no additional steps were taken to motivate participants to complete the questionnaires. The first questionnaire was a feedback questionnaire completed immediately after participants used the ACM Check app on their home. The second questionnaire was a follow-up questionnaire that was completed several months after the participants had used ACM Check and the onsite inspection by the environmental consultant was carried out. The feedback and follow-up questionnaires were approved by Curtin University's Human Research Ethics Committee. Ethics approval number RDHS-89-15 (Appendix C: Ethics Approval and Amendments).

6.2.2. Feedback Questionnaire

The feedback questionnaire was made up of 14 questions including 10 multiple-choice questions and four open-ended questions. The questions were split into three sections. Section one asked questions pertaining to the time, length and difficulty of answering the questionnaire in ACM Check that guided users through the inspection of their home and the usefulness of the summary report that was generated by the app once the inspection was completed. Section two collected feedback on the functionality and design of the app itself. This included asking the participants to rate their satisfaction with ACM Check's ease of use, look, feel, and navigation. Additionally, participants were given the opportunity to make further comment regarding the questionnaire, the results table, and the functionality of the app in the free text questions at the end of each respective section. The final section was an additional comments section made up of two open-ended questions including 'In your own words, what would you most like to improve in ACM Check?' and 'Please add any other comments, feedback or suggestions that you have regarding ACM Check'.

The response options for each multiple-choice question were a five-point Likert scale. Depending on the question these were: 'strongly disagree,' 'disagree,' 'neutral,' 'agree,' and 'strongly agree'; 'strongly dissatisfied,' 'dissatisfied,' 'neutral,' 'satisfied,' and 'highly satisfied'; or, 'very easy,' 'easy,' 'neutral,' 'difficult,' and 'very difficult.' For the complete questionnaire and response options, please refer to Appendix F2: Online Feedback Questionnaire.

6.2.3. Follow-Up Questionnaire

Once all participants had used ACM Check and all of the consultant's inspections were completed, an email was sent to participants containing a link to an online follow-up questionnaire. The survey investigated if the participants had taken any action to protect household occupants from any ACM following the completion of ACM Check. The questionnaire consisted of 17 items including two open-ended questions and 15 multiple-choice questions, of which 11 were yes-no questions. The questionnaire covered three domains including *knowledge seeking* (six items), *asbestos awareness* (two items), and *actions* (nine items). More specifically, participants were asked if they had looked for additional information on asbestos, accessed any of the links provided in the app, consulted an asbestos professional, discussed ACM Check and/or asbestos with family and friends, and if they had taken any steps in the management of any potential ACMs in or around their home. However, if a participant's home did not have any ACM present, then the nine items in the 'actions' domain were skipped. For the complete questionnaire and response options, please refer to Appendix F3: Online Follow-Up Questionnaire.

6.2.4. Statistical Analysis

Frequencies and percentages were calculated for the responses of both questionnaires using IBM SPSS Statistics for Windows, Version 24 (IBM Corp., Armonk, NY, USA).

6.3. Results

6.3.1. Feedback Questionnaire

Each of the 40 participants completed the online feedback questionnaire. However, questions relating to user satisfaction were not completed by one participant.

6.3.1.1. Feedback on the ACM Check Questionnaire and Results Table

The majority of participants were 'very satisfied' (62.5%) with the length (i.e. number of items) of the ACM Check questionnaire and 'very satisfied' (74.3%) with the time it took to complete it on their home. Furthermore, the majority of participants indicated the questions in ACM Check were 'very easy' (53.9%) or 'easy' (43.6%) to *understand* overall and 'easy' (55%) or 'very easy' (32.5%) to *answer* overall. Twenty-eight (71.8%) of the 39 respondents thought the results table generated by ACM Check at the completion of each inspection was 'very useful' (Table 17).

Table 17 Feedback on the ACM Check questionnaire and results table

Rating	Freq. (n)	Percent (%)
Length of ACM Check questionnaire		
Very satisfied	25	62.5%
Satisfied	14	35%
Neither satisfied or dissatisfied	1	2.5%
Dissatisfied	0	
Very dissatisfied	0	
Time to complete ACM Check*		
Very satisfied	29	74.3%
Satisfied	9	23.1%
Neither satisfied or dissatisfied	1	2.6%
Dissatisfied	0	
Very dissatisfied	0	
Overall difficulty *understanding* the questions*		
Very easy	21	53.9%
Easy	17	43.6%
Neither easy nor difficult	1	2.6%
Difficult	0	
Very difficult	0	
Overall difficulty *answering* the questions*		
Very easy	13	32.5%
Easy	22	55%
Neither easy nor difficult	3	7.5%
Difficult	1	5%
Very difficult	0	
Usefulness of the information presented in the app's results table*		
Extremely useful	7	18%
Very useful	28	71.8%
Moderately useful	3	7.7%
Slightly useful	1	2.6%
Not at all useful	0	

**Missing data, n=1*

Twenty four participants provided free text comments about the ACM Check questionnaire and/or the results table generated by the app at the end of each inspection. Overall, the comments were positive and ranged from a simple *"Well designed survey, very interesting outcomes*" through to "*I think this is a great app that will help home owners identify asbestos and decide the best course of action to reduce their risk of exposure.*" A recurring theme in the comments (n=5) was that the users found the images of the different materials "*extremely," "really" or "very"* helpful whilst another participant suggested that more photos of asbestos cement products should be included in the questionnaire.

All the questions were clear and concise. The order of the questions flowed well ie from outside to inside etc. The use of images when relevant is very helpful. Perhaps an 'email me my report' function could be handy.

I found this app very useful. Concise, well-planned questions with particularly helpful photo examples, both of which helped me run through the questionnaire quickly.

However, two participants had difficulties with the app generating the results table.

We did not receive a results table either at the end of the questionnaire or since - the package did not generate a results table.

Upon investigation, this was due to a technical error whereby if a user put in a particular pattern of responses then the app malfunctioned and a results table was not generated. This issue was resolved immediately so it did not impact the testing and user experience of subsequent participants.

Another participant noted that some of the questions were difficult to answer due to having recently moved into an older established house. Consequently, it was difficult to answer historical-based questions such as whether or not a material had been installed before or after 1990. However, during the development of ACM Check this was expected to be one of the limitations of using a questionnaire-based inspection.

Some of the items are difficult for me to answer, because I moved into an existing house where I do not exactly know when items have been last replaced.

6.3.1.2. Feedback on the Functionality and Design of ACM Check

The next series of questions related to the participants' evaluation of the functionality and design of the app as a whole and not exclusively about the questionnaire component. All 39 participants indicated that ACM Check was either ‘very easy’ (n=24; 61.5%) or ‘easy’ (n=15; 38.5%) to navigate. Similarly, all participants were either ‘very satisfied’ (n=23; 59%) or ‘satisfied’ (n=16; 41.03%) with the look and feel of ACM Check and ‘very satisfied’ (n=27; 69.2%) or ‘satisfied’ (n=12; 30.8%) with ACM Check’s ease of use.

Twenty-two (56.4%) of 39 participants responded that they were ‘very likely’ to recommend ACM Check to others. Furthermore, 13 (33.3%) were ‘likely’, 3 (7.7%) were ‘neither likely nor unlikely’, and 1 (2.6%) was ‘unlikely’ to recommend ACM Check to others. ACM Check was given a 5 star rating by 25 (64.1%) participants, 4 stars by 12 (30.8%), and 3 stars by 2 (5.1%) participants. Therefore, ACM Check had an average star rating of 4.59 out of 5 stars.

Participants were asked to comment on the app's functionality (look, feel, ease of use, and/or navigation). Most participants left positive comments regarding the app’s functionality including that ACM Check was “*Very user-friendly and easy to navigate,” “Simple and easy to use,” “Very self explanatory, visually appealing,”* and that it had a “*Nice clean interface.”* Again, several participants indicated the usefulness of the photos in answering the questions.

One participant thought that the ‘Back’ button should be made more visible on the screens showing the questionnaire so that it would be easier to navigate to previous screens and change your answers. Another participant commented on the design and appearance of the summary report generated in the app.

> *Consideration could…be given to making…the report generated…more aesthetically pleasing down the line. I felt the content of the report was excellent and useful but the design/look of the report itself appeared a little basic in comparison.*

Some participants made suggestions for how to improve the functionality of the app in this comment section and these are included in the following section (6.3.1.3).

6.3.1.3. Ideas to Improve ACM Check

Participants of the validation study were asked to make suggestions on how we could improve the app. While some participants indicated that no changes to ACM Check were necessary or took the opportunity to leave general comments, others made suggestions for how to improve the app.

> *You could provide a 'more detail' link for certain items if the user would like to learn more - this is more an education thing though. As with the 'walls' section, it may require clarification to include cupboards and other areas which may not be considered a wall.*

Notably, four participants suggested that more photos of different types of asbestos products would be useful.

> *The option to access more images or details about a question if you are unsure what feature is being asked about.*

Furthermore, two participants proposed the addition of a function in ACM Check that would allow users to take photos of suspected ACMs. These images could then be shared with the developer, a hygienist, or other users.

> *What about including a section where photos can be taken of suspected ACM and then sent through to the hygienist? This would make it similar to an auditing app.*

6.3.2. Follow-up Questionnaire

Of the 37 participants who completed the follow up questionnaire, 35 (94.6%) had at least one *in situ* ACM in or around their home whilst two (5.4%) had homes that were free of *in situ* ACM. Therefore, these two participants were not asked questions related to any actions taken.

Since completing ACM Check, three (8.3%) participants had looked for additional information on asbestos, which included seeking information on “asbestos exposure” (n=2), “asbestos removal” (n=2), “asbestos and its health effects” and “working with asbestos” (n=1, respectively). The main source of information for these enquiries were web sites (n=3), and academic journals (n=1). In addition, nearly half (43.2%) of the respondents accessed the links to asbestos-related websites or documents provided in the “Information: Organisations and Resources” section of ACM Check (Table 18).

Table 18 Responses to questions regarding knowledge seeking, asbestos awareness, and actions taken following the completion of ACM Check

Question	Yes, n (%)	No, n (%)
Knowledge seeking (n=37)		
Since completing ACM Check, have you looked for any additional information on asbestos?*	3 (8.3%)	33 (91.7%)
Did you access any of the links to asbestos-related websites or documents provided in ACM Check?	16 (43.2%)	21 (56.8%)
Asbestos awareness (n=37)		
Have you discussed the issue of asbestos-containing materials in the home with any friends or family since completing ACM Check?	33 (89.2%)	4 (10.8%)
Have you told any friends or family about ACM Check since you have used the app?	27 (73%)	10 (27%)
Actions taken (n=35)		
Have you had any asbestos-containing materials removed and/or replaced since completing ACM Check?	1 (2.9%)	34 (97.1%)
Have any damaged asbestos-containing materials in or around your house been repaired since completing ACM Check?	2 (5.7%)	33 (92.3%)
Have any renovations been conducted in areas of your house with potential asbestos-containing material since completing ACM Check?	0 (0%)	35 (100%)
Have you taken any other preventative measures or actions to protect household occupants from any asbestos-containing materials?	8 (22.9%)	27 (77.1%)

**Missing data, n=1*

With respect to raising awareness about asbestos and the app, 33 (89.2%) out of 37 respondents discussed the issue of ACM in the home with family and friends following the completion of ACM Check. Twenty-seven (73%) participants told friends and family members about the app (Table 18).

Very few participants had removed, repaired or renovated any ACMs in their home since using ACM Check (Table 18). For the 35 participants with potential ACM, eight (22.9%) indicated that they had taken other preventative measures or actions to protect household occupants from any ACMs (Table 18). When asked what preventative measures they took, the responses varied from "*Discuss the problem with kids, pointed out outside areas that contain asbestos and explained the need to treat asbestos-containing materials carefully (e.g., be careful not to scratch or kick asbestos-containing fences)*" through to "*Ensured all potential AC cladding and fencing is not disturbed.*" Three participants indicated that they were intending or preparing to encapsulate asbestos-cement products. This was by either painting the surface (n=2) or sealing the "*ragged*" edges (n=1) of the ACM.

6.4. Discussion

Two main objectives of Phase Two were addressed in this chapter: to assess the usability and flow of the app (i.e. its functionality); and to investigate if completion of the app resulted in knowledge seeking or changes to participants' behaviour (i.e. its potential impact). This was done with the intention of estimating the potential usefulness and impact of the app once it was launched in Australia.

The results from the feedback survey indicate that participants were satisfied with the functionality of ACM Check, specifically the look, feel, ease of use, navigation, length, and time it took to complete the app. Almost all participants reported no difficulties with understanding and answering the questions presented during the inspection, and the greater majority found the app very or extremely useful. Additionally, most of the participants were likely or very likely to recommend ACM Check.

The outcomes from the follow-up survey suggest that ACM Check may have a positive impact on users seeking further knowledge of asbestos, increasing asbestos awareness amongst family and friends, and taking action to reduce asbestos exposure. Close to all respondents indicated that they had discussed the issue of ACMs in the home with family or friends since completing ACM Check. A main goal of developing and releasing ACM Check was to raise awareness in the community of residential sources of asbestos. This formative evaluation suggests that this may be achieved not only by increasing the individual user's level of awareness, but by having the user bring the issue to the attention of family and friends.

Furthermore, it is intended that the user's increased awareness of asbestos as a result of completing ACM Check helps to prevent and/or reduce exposure to asbestos fibres that are released from *in situ* ACMs in residential settings. Close to a quarter of the respondents who had at least one ACM on their property took preventative measures or actions to protect household occupants since completing the app. However, only one respondent reported taking action towards removing or replacing an *in situ* ACM on their property whilst two repaired a damaged ACM. This is an area that needs to be evaluated following the release and implementation of ACM Check on a wider scale before any robust conclusions are made regarding the impact of ACM Check on reducing exposure and promoting safe management of ACMs.

The user feedback obtained during this phase of the study provides preliminary evidence that the objectives of Phase One of this research project were achieved. Objective 1.4 presented in Table 1, to direct users to further resources that assist in the safe management of asbestos, is supported by the results of the feedback and follow-up questionnaires.

Despite the positive feedback obtained from participants regarding the beta version of ACM Check, there were modifications and improvements that needed to be made. These are discussed in the following section.

6.4.1. Modifications to ACM Check Based on Participant Feedback

The participant's responses to the open-ended questions of the feedback questionnaire provided useful information for the improvement of ACM Check prior to it being publicly launched and used in Phase 3 of this research project. Four participants suggested that additional photos be included in the app showing a broader range of asbestos cement products. Therefore, 21 new images were included in the updated version of ACM Check that was released to the public, increasing the overall number of images by around 50% compared to the beta version. Moreover, six of the photos used in Phase 2 were replaced with multiple, new images that were higher resolution and better illustrated the characteristics of the ACMs in that particular location.

A second theme highlighted the importance of including clear and concise instructions when guiding users through a visual inspection of their home so that possible ACMs were not overlooked and subsequently treated as asbestos-free. Therefore, the app was modified to help clarify what materials and locations should be included in particular sections of the questionnaire. For example, we added instructions directing users to inspect and include cupboards, closets and splash backs in the internal walls section of ACM Check. Similarly, further instructions were included in the eaves/soffit linings section as well as the external walls section of ACM Check advising users of what materials should be included during that stage of the inspection.

A further modification was made based on the comment that we should "*Perhaps add a cancel button if you decide not to proceed, make a mistake or simply want to explore the app.*" This feature was included and can be seen in the top right-hand corner of the screenshot shown in Figure 9.

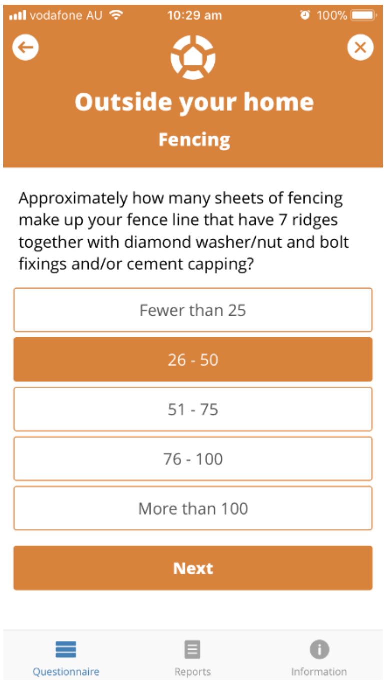

Figure 9 Screenshot from the fencing section of ACM Check

Finally, in the version of ACM Check used for the validation study, participants that had fencing categorised as 'possible' or 'likely' ACM had to answer a question about the exact number of panels of fencing present on the property, and then enter the number using a plus-minus counter function. However, based on feedback received, we changed this to a categorical question as can be seen in Figure 9.

6.4.2. Limitations of the Study

As previously discussed in Chapters 4 and 5, there were a number of limitations related to the pilot testing and validation study of Phase Two. Firstly the sample was self-selected. This could have influenced the results from the feedback and follow-up questionnaires in a number of ways. Primarily, participants may have been more inclined to provide amicable and positive feedback due to already having an interest in the study and asbestos. In an attempt to control this, no identifying information was collected in the feedback and follow-up questionnaires in order to maintain the participants' anonymity. This was done so that participants could provide honest answers, however, this may not have countered an already amicable and positive disposition to the app. Moreover, a self-selected group of participants may be better educated, more positively disposed to the app, and more inclined to seek further knowledge than the general population. This could account for the generally positive responses reported in this study, which may not reflect the opinions of the broader population. It is therefore recommended that further evaluation by a more representative population be undertaken. Secondly, the sample size for Phase Two was small. Although the sample size was sufficient to evaluate the functionality, design and technical aspects of the app, the sample size limits the generalisability of the app's potential impact to the broader population. Thirdly, the feedback questionnaire was not a validated instrument to assess usability. Therefore, if a similar study was to be repeated, then it is recommended that an additional, validated instrument for assessing the usability or quality of a mobile app be considered, such as the System Usability Scale (Bangor, Kortum, & Miller, 2008) or the User Version of the Mobile Application Rating Scale (Stoyanov, Hides, Kavanagh, & Wilson, 2016).

6.5. Conclusion

The formative evaluation of ACM Check involved the completion of feedback and follow-up questionnaires by the participants of Phase Two. Overall, the feedback suggests that the app is visually appealing and easy to use, navigate, and answer. These are all crucial factors that influence the user's experience and the subsequent uptake of an app once it is launched. Based on the follow-up, it is possible that ACM Check can raise people's awareness of residential sources of asbestos, and that completion of the app may lead to user's putting into place preventative measures or taking actions to protect household occupants from any ACMs. The feedback obtained during this stage led to a series of modifications being made to the iOS version of ACM Check before it was finalised and replicated on the Android operating system. Both versions were publicly launched and used as the data collection tool in the third and final phase of this research project.

Chapter 7: Using a Mobile Phone App to Identify and Assess Remaining Stocks of *In Situ* Asbestos in Australian Residential Settings

7.1. Introduction

Globally, Australia is the country that consumed the highest amount of asbestos on a per capita basis during the 1950s and 1960s (Lin et al., 2007; Takahashi et al., 1999). Australia mined asbestos as early as the 1880s and manufactured asbestos cement products from the 1920s until the late 1980s (enHealth, 2013; Leigh & Driscoll, 2003). The asbestos cement manufacturing industry accounted for 60% of all production (i.e., mining of raw asbestos) and 90% of all consumption (i.e., consumption equals production plus imports minus exports) of asbestos fibres in Australia (ASCC, 2008b; Leigh & Driscoll, 2003). By 1954, Australia was the fourth highest gross consumer of asbestos cement products globally, only behind the US, UK, and France (Leigh & Driscoll, 2003). Asbestos-containing materials (ACMs) were commonly used in Australian residential settings for such things as roofing, eaves, exterior and interior wall cladding, and fencing (Queensland Government, 2013). Up until the 1960s, 25% of new Australian homes were clad with asbestos-cement products (Leigh & Driscoll, 2003). It is currently estimated that one third of all Australian homes contain asbestos products and it is highly likely all homes built before the mid-1980s contain at least one ACM (enHealth, 2013).

In Australia, asbestos-cement materials were phased out of use in the 1980s, and a total ban on asbestos use of any type, including a prohibition on the importation, manufacturing, processing, sale, storage and re-use of asbestos and ACMs was implemented from 31 December 2003. Despite the prohibition, a large reservoir of asbestos remains *in situ* as a lasting legacy of Australia's past use. Individuals continue to be exposed to asbestos when these *in situ* ACMs are disturbed, such as through maintenance, renovations, and demolition of the building, or when the condition of the ACM deteriorates (Armstrong & Driscoll, 2016; ASCC, 2008a; Noonan, 2017; Riley & McNab, 2016; Sen, 2015). However, *in situ* ACMs are difficult to identify. Previous surveys have indicated that although the majority of Australian DIY home renovators and members of the general public believed that ACMs are common in Australian buildings, there was a considerable proportion who had no confidence in their ability to identify asbestos and did not know what types of materials contain asbestos (ASEA, 2014; EY Sweeney, 2016).

In addition, we do not know the amount of ACM remaining *in situ* in the residential environment or the current condition of these ACMs. There are little data pertaining to the distribution of ACMs into the built environment subsequent to import or manufacture (Donovan & Pickin, 2016). Despite knowing the total amount of asbestos consumed in Australia prior to it being banned, we have much less knowledge about where ACMs went and how much of the material remains in the residential environment. A primary recommendation arising from the *National Asbestos Profile for Australia* was that "there is an identified need for more research to gain a better understanding of the amount and location of ACMs in the residential sector" (ASEA, 2017b, p. 39). Furthermore, we have little knowledge of the extent of deterioration of remaining ACMs, which is needed to make appropriate decisions concerning either its prioritised removal or its containment.

For those reasons we developed (Govorko et al., 2017), tested (Govorko, Fritschi, & Reid, 2018), and released a specifically designed mobile phone app, ACM Check, which guides users through a visual inspection of the home in order to identify certain types of ACM remaining *in situ*. This app has two main purposes: (1) to increase the user's awareness and knowledge of potential ACMs present in the residential environment so that appropriate safety precautions can be used when dealing with the material; and (2) to collect data from consenting users regarding the type and condition of *in situ* ACM still found in Australian residential settings. The aim of this paper is to demonstrate how a mobile app can be used to estimate the prevalence and condition of ACMs remaining in the Australian residential environment.

7.2. Methods

7.2.1. Study Design

A cross-sectional study was conducted between June 2017 and May 2018 that involved individuals (1) downloading the mobile phone app, ACM Check, onto their mobile device from the App Store (Apple Inc) or Google Play (Google Inc), (2) consenting to share their questionnaire data and participate in the study, and (3) completing the app's questionnaire on an Australian residence. Data were only collected via ACM Check from consenting users. Individuals who downloaded the app and opted not to share their data still had full use of the app, but no information was collected from them. The study was approved by Curtin University's Human Research Ethics Committee (RDHS-89-15; Appendix C: Ethics Approval and Amendments).

7.2.2. Participant Recruitment

Curtin University distributed a media release on June 14, 2017, which began the recruitment campaign (see Appendix G: Curtin Media Release). The media release was circulated to a range of organisations in Australia related to asbestos, cancer prevention and awareness, occupational health and safety, and public and environmental health. Radio interviews, articles in local newspapers, posts on social media platforms (i.e., Twitter and Facebook), and advertisements on an online classifieds and community website were used to promote the app and the study. Additionally, approximately 500 recruitment flyers were delivered to homes located in the Perth metropolitan area. Non-WA participants were recruited through items posted on social media, webpages or distributed via subscription newsletters or emails.

The inclusion criteria for the study were that individuals were aged 18 years or older, had access to either an Android device or an iOS device (such as an iPhone, iPod Touch or iPad) with iOS version 8 or newer installed, and completed the app on an Australian residence. In order to participate, users had to click the toggle button to the "on" position on the first screen of ACM Check, which indicated that "I have read the information statement and consent to participate in the research."

7.2.3. Data Collection

All data collection occurred through the mobile phone app, ACM Check, between 14 June 2017 and 28 May 2018. A detailed description of the design and development of ACM Check has been published elsewhere (Govorko et al., 2017). In short, the app contains a questionnaire that guides users through a visual inspection of 14 key locations inside and outside of a residential building. The areas inspected for ACM include the exterior walls, eaves/soffit lining, roofing, gutters, downpipes, electrical meter box, fencing, outbuilding walls, outbuilding roofs, interior walls and splash backs, backing to wall tiles, ceilings, flooring, and heater flues. Questions ask about the age of the dwelling, renovation history, and key characteristics of the building materials used. ACM Check then uses the answers to automatically classify each material/category into one of four probabilities of containing asbestos ('not applicable,' 'unlikely,' 'possible,' or 'likely' ACM).

For each 'possible' or 'likely' ACM, the user is asked to rate the current condition ('very poor,' 'poor,' 'fair,' or 'good') and its potential for disturbance ('unlikely,' 'somewhat likely,' 'likely,' or 'highly likely'). Each response option is accompanied by descriptive text to assist the user in rating the material. The two ratings are automatically assigned numerical values and added together by ACM Check to give an overall priority level to each ACM ('very low,' 'low,' 'moderate,' or 'high' priority). The priority level indicates the ACMs that are of most significance regarding the potential risk of asbestos exposure at each property, and in turn, informs the user on a general course of action to minimise the risk.

At the completion of the inspection, the app automatically saves all questionnaire results to a secure external server in comma separated format (.csv). Furthermore, each user can complete the inspection on one or more houses.

7.2.4. Validity of ACM Check

Before the app was released to the public and implemented as a data collection tool, a cross-sectional study was conducted testing the app on a sample of 40 homes built before 1990 located in the metropolitan region of Perth, WA. The results are published elsewhere (Govorko et al., 2018). The participants completed the app on their home and the results were compared to the findings of onsite inspections conducted by an environmental consultant. Agreement between the two methods, determined using Cohen's kappa values, ranged from fair to substantial when categorising the different areas as positive or negative for asbestos. In particular, the tool overestimated the occurrence of asbestos in the category 'wall tile backing.' Therefore, all cases of wall tile backing were excluded from the analyses, or classified as negative in the current study. The highest probability of being an ACM rating that could be assigned to wall tile backing was 'possible.' The category was left in the app to keep users aware of the possibility of asbestos exposure when removing old wall tiles due to asbestos previously being used in mastics and adhesives.

7.2.5. Statistical Analysis

Data were combined into a single Microsoft Excel database and all statistical analyses were completed in IBM SPSS Statistics for Windows, Version 24 (IBM Corp., Armonk, NY, USA). There were originally four rating outcomes for the probability a material contained asbestos, either 'not applicable,' 'unlikely,' 'possible,' or 'likely' ACM. 'Possible' and 'likely' responses were coded as 'positive' for asbestos while 'not applicable' and 'unlikely' responses were coded as 'negative' for asbestos. Refer to Table 25 in Appendix I: Additional Results Tables for Phase Three for the frequencies of 'possible' and 'likely' ACM ratings before they were combined as 'positive.' The category 'wall tile backing' was excluded from the analyses due to ACM Check overestimating the occurrence of asbestos in this category during the pilot study.

In regard to the age of the dwelling, the user must select one of three age categories including 'Before 1985,' 'Between 1985 and 1990,' and 'After 1990.' If the user selects 'After 1990,' then the user completes an abbreviated questionnaire that only includes an assessment of the fencing and outbuilding roofs and walls (as these may be present from previous developments). All other materials are automatically labelled as 'not applicable' or 'unlikely' by the app and thus labelled as 'negative' for the analysis.

The houses were separated into WA and non-WA houses in order to examine if there were any differences in the prevalence and condition of *in situ* ACMs found in WA compared with other regions of Australia.

7.3. Results

7.3.1. User and Housing Characteristics

ACM Check was downloaded 1041 times between June 2017 and May 2018. The results for a total of 461 inspections were received of which 276 (59.9%) were for inspections completed in WA whilst the rest were completed in other Australian States and Territories (Figure 10). Most non-WA participants were from Victoria (n=69; 15%), New South Wales (n=45; 9.8%), and Queensland (n=38; 8.2%), the most populous Australian states. 'Community members' made up two-thirds (68.1%) of users in WA, but only 41.1% of users in other Australian states and territories (Table 19).

The majority of houses screened in WA were separate houses (86.6%), had 1-2 (42%) or 3-4 (37.7%) occupants, and close to two-thirds were built pre-1985 (64.9%). These characteristics were similar for inspections occurring in other Australian states and territories (Table 19).

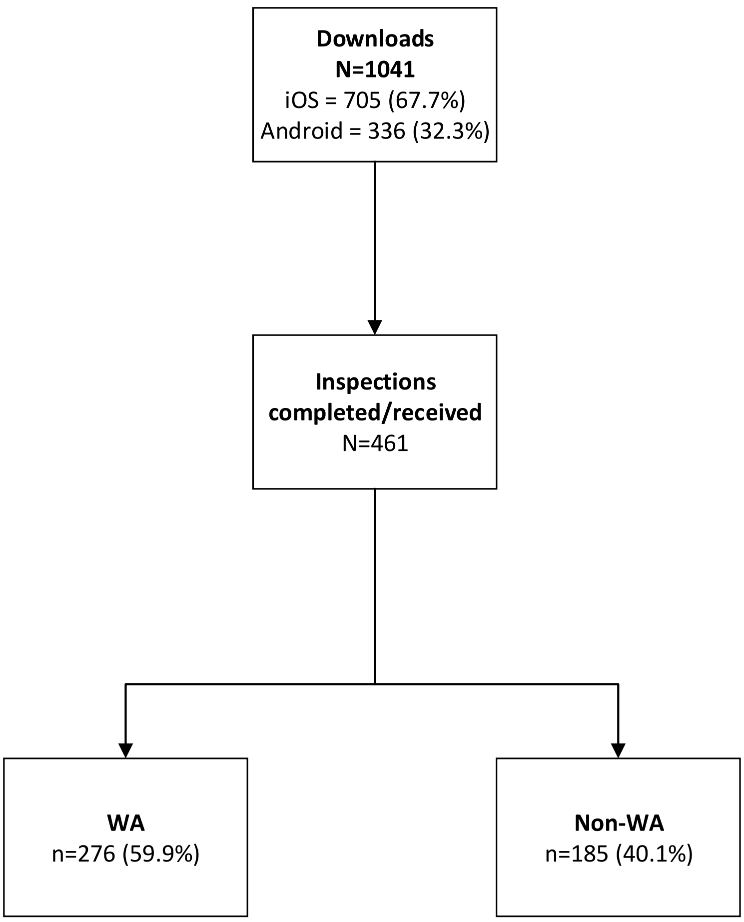

Figure 10 Flowchart of ACM Check downloads and datasets received

Table 19 Demographic information for users who completed ACM Check

Factor	WA (n=276)	Other (n=185)	Total (N=461)
User description			
Community member	188 (68.1%)	76 (41.1%)	264 (57.3%)
Environmental health officer	26 (9.4%)	46 (24.9%)	72 (15.6%)
Licensed asbestos removalist	12 (4.3%)	9 (4.9%)	21 (4.6%)
Tradesperson, labourer, handyperson	50 (18.1%)	54 (29.2%)	104 (22.6%)
Total users	276 (100%)	185 (100%)	461 (100%)
Period built			
Before 1985	179 (64.9%)	124 (67%)	303 (65.7%)
Between 1985 and 1990	45 (16.3%)	39 (21.1%)	84 (18.2%)
After 1990	52 (18.8%)	22 (11.9%)	74 (16.1%)
Type of dwelling			
Separate house	239 (86.6%)	157 (84.9%)	396 (85.9%)
Flat, unit or apartment	17 (6.2%)	12 (6.5%)	29 (6.3%)
Semi-detached, row, villa, terrace house or townhouse	20 (7.2%)	16 (8.6%)	36 (7.8%)
Number of occupants			
0*	21 (7.6%)	16 (8.6%)	37 (8%)
1-2	116 (42%)	78 (42.2%)	194 (42.1%)
3-4	104 (37.7%)	63 (34.1%)	167 (36.2%)
5+	35 (12.7%)	28 (15.1%)	63 (13.7%)

* *This includes houses that have no current occupants such as houses that are on the market*

7.3.2. Prevalence of Asbestos-Containing Materials

Of the 461 houses inspected by participants using ACM Check, 377 (81.7%) had at least one type of material that was categorised as positive for asbestos. A total of 362 (78.5%) homes had at least one material categorised as positive for asbestos located outside and 215 (46.6%) had at least one positive material located inside (Table 20). A total of 1,266 materials were categorised by ACM Check as positive for asbestos with the majority located outside the house (n=888; 70.1%). Moreover, the majority of these positive ACMs where initially categorised as 'likely' ACM (n=1061; 83.8%) by ACM Check (see Appendix I: Additional Results Tables for Phase Three).

Of the 276 WA houses, 224 (81.2%) had at least one suspected ACM located anywhere on the property with 52 (18.8%) houses being free of ACM. Two hundred and twenty (79.7%) houses had an ACM located outside and over one-third (39.5%) had an ACM located inside (Table 20). Across the 224 houses with suspected ACM, there was a total of 708 materials categorised as positive for asbestos with three-quarters of these located outside (n=533; 75.3%).

In WA, the most common ACMs were flat asbestos-cement sheeting used as the backing board to the electrical meter box and corrugated asbestos-cement sheet fencing, which were categorised as positive by ACM Check at over half of the properties (53.6% and 50.7%, respectively; Table 20). In addition, 64 (45.7%) of the 140 users with asbestos–cement fences indicated that some or all of the sections of fencing also had asbestos-cement capping. With regards to the amount of corrugated asbestos-cement sheet fencing present on the property, 63 (45%) users reported that they had less than 25 asbestos-cement sheets, while 42 (30%) users had 26-50, 22 (15.7%) users had 51-75, 9 (6.4%) had 76-100, and 4 (2.9%) users had 100 or more asbestos-cement sheets in place.

Furthermore, 107 (38.8%) houses had flat asbestos-cement sheeting used for the eaves, soffit lining, verandah ceilings and/or carport ceilings. The least common ACMs found in WA houses were asbestos-cement gutters (n=6; 2.2%) and corrugated asbestos-cement sheeting used for outbuilding roofs (n=17; 6.2%; Table 20).

For houses in other Australian states and territories, the most common forms of ACMs were flat asbestos-cement sheeting used for the eaves, soffit lining, verandah ceilings and/or carport ceilings (n=96; 51.9%); and flat asbestos-cement sheeting used for the backing board to electrical meter boxes (n=86; 46.5%). Similar to WA, the least common ACM in other Australian houses was asbestos-cement gutters (n=11; 5.9%; Table 20).

Table 20 Western Australian and other Australian state and territory houses with materials categorised as 'positive' for asbestos by ACM Check

Category	WA (n=276)	Other (n=185)	Total (N=461)
Outside			
Exterior wall cladding	49 (17.8%)	40 (21.6%)	89 (19.3%)
Eaves	107 (38.8%)	96 (51.9%)	203 (44%)
Roof	20 (7.2%)	26 (14.1%)	46 (10%)
Gutters	6 (2.2%)	11 (5.9%)	17 (3.7%)
Downpipes	23 (8.3%)	25 (13.5%)	48 (10.4%)
Backing board to electrical meter box	148 (53.6%)	86 (46.5%)	234 (50.8%)
Fencing	140 (50.7%)	17 (9.2%)	157 (34.1%)
Outbuilding walls	23 (8.3%)	29 (15.7%)	52 (11.3%)
Outbuilding roof	17 (6.2%)	25 (13.5%)	42 (9.1%)
Inside*			
Interior walls	45 (16.3%)	51 (27.6%)	96 (20.8%)
Ceiling	56 (20.3%)	58 (31.4%)	114 (24.7%)
Interior flooring	54 (19.6%)	67 (36.2%)	121 (26.2%)
Heater flue	20 (7.2%)	27 (14.6%)	47 (10.2%)
Overall			
Any outside ACM	220 (79.7%)	142 (76.8%)	362 (78.5%)
Any inside ACM*	109 (39.5%)	106 (57.3%)	215 (46.6%)
Any ACM*	224 (81.2%)	153 (82.7%)	377 (81.7%)

*****_Excluding 'wall tile backing'_

7.3.3. Priority Assessment of Suspected ACMs

7.3.3.1. Current Condition and Potential for Disturbance Ratings

Of the 708 ACMs in WA houses, the majority were rated as being in either 'good' (n=295; 41.7%) or 'fair' (n=294; 41.5%) condition. Over one in ten ACMs (n=101; 14.3%) were rated as being in 'poor' condition by WA users of ACM Check. The majority of ACMs in 'poor' condition were located outside (n=82/101; 81.2%) with fencing (n=31/101; 30.7%) and eaves (n=14/101; 13.9%) being the most frequently rated ACMs in 'poor' condition. Overall, only 18 (2.5% of ACMs) ACMs in WA houses were rated as being in 'very poor' condition. However, nearly a quarter of identified ACMs in other

Australian States and Territories were assessed as being in 'poor' (n=86/558; 15.4%) or 'very poor' (n=49/558; 8.8%) condition (see Appendix I: Additional Results Tables for Phase Three).

The majority of suspected ACMs in WA houses were rated as 'unlikely' (n=345/708; 48.7%) or 'somewhat likely' (n=244/708; 34.5%) to be disturbed in the near future. Nearly ten percent of suspected ACMs were rated as 'likely' to be disturbed (n=64/708). Fencing had the highest percent of ACMs 'likely' to be disturbed across the WA houses (6.5% of houses). A larger proportion of ACMs in other states were rated as 'likely' (n=81; 14.5%) or 'highly likely' (n=69; 12.4%) to be disturbed compared with ACMs in WA houses (9% and 7.8%, respectively). In contrast to WA, there were considerably fewer ACM fences that were rated as 'likely' or 'highly likely' to be disturbed (Appendix I: Additional Results Tables for Phase Three).

7.3.3.2. Priority Levels for WA Houses

Of the 276 WA houses, 20 (7.2%) had one or more materials categorised as 'high' priority for removal or remediation. More specifically, 18 (6.5%) houses had only one 'high' priority ACM, while one (0.4%) house had two and another (0.4%) had three 'high' priority ACMs present. Eighty-three (30.1%) houses had at least one ACM categorised as 'moderate' priority, which ranged from 53 (19.2%) houses with one 'moderate' priority ACM through to one (0.4%) house with a total of six 'moderate' priority ACMs. One-third of houses (n=96; 34.8%) had one or more 'low' priority ACMs and approximately two-thirds (n=174; 63%) had one or more 'very low' priority ACMs on the property.

When looking at only the positive materials (n=708) in WA houses that were assessed using ACM Check, over half (n=383; 54.1%) were categorised as 'very low' priority with approximately one-quarter (n=166; 23.4%) categorised as 'low' priority. Close to 20% (n=136; 19.2%) were categorised as 'moderate' priority while only 3.2% (n=23) of ACMs were categorised as 'high' priority by ACM Check. Fencing and interior flooring had the highest percentage of 'high' priority ACMs (Table 21).

Table 21 Priority levels of materials inspected in Western Australian houses (n=276)

Category	Priority Level				
	Very low	Low	Moderate	High	Total
Outside					
Exterior wall cladding	19 (38.8%)	14 (28.6%)	15 (30.7%)	1 (2%)	49
Eaves	59 (55.1%)	28 (26.2%)	18 (16.8%)	2 (1.9%)	107
Roof	9 (45%)	8 (40%)	2 (10%)	1 (5%)	20
Gutters	3 (50%)	1 (16.7%)	2 (33.3%)	0	6
Downpipes	16 (69.6%)	4 (17.4%)	3 (13%)	0	23
Backing board to electrical meter box	114 (77%)	16 (10.8%)	15 (10.1%)	3 (2%)	148
Fencing	66 (47.1%)	39 (27.9%)	29 (20.7%)	6 (4.3%)	140
Outbuilding walls	9 (39.1%)	5 (21.7%)	9 (39.1%)	0	23
Outbuilding roof	7 (41.2%)	4 (23.5%)	6 (35.3%)	0	17
Inside*					
Interior walls	23 (51.1%)	11 (24.4%)	11 (24.4%)	0	45
Ceiling	32 (57.1%)	14 (25%)	9 (16.1%)	1 (1.8%)	56
Interior flooring	20 (37%)	12 (22.2%)	15 (27.7%)	7 (13%)	54
Heater flue	6 (30%)	10 (50%)	2 (10%)	2 (10%)	20
Total*	**383 (54.1%)**	**166 (23.4%)**	**136 (19.2%)**	**23 (3.2%)**	**708 (100%)**

**Excluding 'wall tile backing'*

7.3.3.3. Priority Levels for Other Australian Houses

For the 185 houses screened in other Australian states and territories, 25 (13.5%) contained one or more 'high' priority ACMs. This included 13 (7%) houses with one 'high' priority ACM, six (3.2%) houses with two, three (1.6%) houses with three, two (1.1%) houses with four and one (0.5%) with five 'high' priority ACMs present. Similar to WA, 32.4% (n=60) of houses had at least one ACM present that was categorised as 'moderate' priority. This ranged from 30 (16.2%) houses with one 'moderate' priority ACM, 17 (9.2%) houses with two, through to one (0.5%) house with a total of eight 'moderate' priority ACMs present. Approximately 40% of houses (n=72; 39%) had one or more 'low' priority ACMs and close to two-thirds (n=118; 63.8%) had one or more 'very low' priority ACMs present in or around the residential building.

Regarding only the positive materials (n=558) in other Australian houses, close to 70% were categorised as either ‘very low’ (n=238; 42.7%) or ‘low’ (n=147; 26.3%) priority ACM. Over 20% of positive materials were categorised as ‘moderate’ priority (n=126; 22.6%) while 8.4% were categorised as ‘high’ priority (n=47; Table 22). Interior flooring and interior walls had the highest proportion of ‘high’ priority ACMs.

Table 22 Priority levels of materials inspected in other Australian state and territory houses (n=185)

Category	Priority Level				
	Very low	**Low**	**Moderate**	**High**	**Total ACMs**
Outside					
Exterior wall cladding	17 (42.5%)	9 (22.5%)	12 (30%)	2 (5%)	40
Eaves	53 (55.2%)	25 (26%)	13 (13.5%)	5 (5.2%)	96
Roof	9 (34.6%)	6 (23.1%)	6 (23.1%)	5 (19.2%)	26
Gutters	2 (18.2%)	3 (27.3%)	4 (36.4%)	2 (18.2%)	11
Downpipes	11 (44%)	6 (24%)	7 (28%)	1 (4%)	25
Backing board to electrical meter box	49 (57%)	18 (20.9%)	16 (18.6%)	3 (3.5%)	86
Fencing	5 (29.4%)	7 (41.2%)	4 (23.5%)	1 (5.9%)	17
Outbuilding walls	7 (24.1%)	11 (37.9%)	7 (24.1%)	4 (13.8%)	29
Outbuilding roof	8 (32%)	10 (40%)	4 (16%)	3 (12%)	25
Inside*					
Interior walls	21 (41.2%)	12 (23.5%)	12 (23.5%)	6 (11.8%)	51
Ceiling	29 (50%)	17 (29.3%)	10 (17.2%)	2 (3.4%)	58
Interior flooring	14 (20.9%)	18 (26.9%)	24 (35.8%)	11 (16.4%)	67
Heater flue	13 (48.1%)	5 (18.5%)	7 (25.9%)	2 (7.4%)	27
Total*	**238 (42.7%)**	**147 (26.3%)**	**126 (22.6%)**	**47 (8.4%)**	**558**

*****_Excluding ‘wall tile backing’_

7.4. Discussion

Since ACM Check was launched in June 2017, 461 people had used the app to systematically screen the inside and outside of a house for the presence of *in situ* ACM and had consented to share their data. Of these, 377 (81.7%) houses contained a total of 1,266 *in situ* materials that were categorised as positive for asbestos by the app. It is evident from the results that ACMs are still prevalent in the

Australian residential environment. The majority of *in situ* asbestos was located outside with flat asbestos-cement sheeting used as the backing board to electrical meter box, flat asbestos-cement sheeting used for eaves, and corrugated asbestos-cement sheet fencing being the most frequently detected ACMs.

One of the major differences between the type of ACMs in WA houses compared with houses in other Australian states and territories was the occurrence of corrugated asbestos-cement sheet fencing, which was much more prevalent around the houses assessed in WA than around houses in other states and territories (50.7% vs. 9.2%, respectively). In contrast, a greater percentage of houses in other Australian states and territories had an ACM located inside compared to WA houses (57.3% vs. 39.5%, respectively). Furthermore, a higher percentage of the identified ACMs were located inside the home in other Australian states and territories than in WA (36.4% vs. 24.7% of all ACMs were located inside, respectively). The lower occurrence of ACMs inside WA houses may be due to the fact that more houses built post-1990 (i.e., after the asbestos phase-out) were inspected in WA than in other Australian states and territories (18.8% vs. 11.9%, respectively; Table 19).

The results indicate that the majority of ACMs identified in the WA and other Australian state and territory houses screened were of 'very low' (n=621/1,266; 49.1%) or 'low' (n=313/1,266; 24.7%) priority for remediation or removal. However, there were 70 (5.5%) 'high' priority ACMs with the most frequent being interior flooring, interior walls and fencing. Furthermore, there was a higher percentage of houses containing at least one 'high' priority ACM in other Australian states and territories (13.5% of houses) compared with WA (7.2% of houses). The difference could possibly be explained by the higher proportion of inspections completed by users who were EHOs in other Australian states and territories compared to in WA (24.9% vs. 9.4%, respectively). EHOs may be attending or screening more 'at-risk' properties than the average community member due to the nature of their job. In addition, our pilot study showed that ACM Check users tended towards overestimating the priority of ACMs in and around their home (i.e., they frequently rated materials as being in poorer condition or having a higher potential for disturbance than did the environmental consultant). As such, it is unlikely that these results are underestimating the priority levels of the ACMs screened in this sample.

A limitation of the study is the sample size. A larger sample size would have provided greater information regarding the prevalence of *in situ* ACMs and their condition in the residential environment. Nonetheless, we believe that the sample still provides an indication of the most common ACMs remaining in Australian residential settings. For instance, the sample suggests that corrugated asbestos-cement sheet fencing, flat asbestos-cement sheet eaves, and the backing board to old electrical meter boxes are still prevalent in the Western Australian and wider Australian housing stock. A benefit of using this type of mobile app as a research tool is that data collection can be ongoing, and therefore a larger sample size can be obtained, provided the app is maintained and sufficiently promoted.

A second limitation of the study is that the sample population was self-selected. Therefore, individuals who already know where ACMs are located in their home may be unlikely to take the time to download and complete the app, resulting in either a lower response rate or an underestimation of the prevalence of ACM in our analysis. Conversely, these same individuals may be more likely to download and complete the app because they know that asbestos is present and want to contribute to the study. Thirdly, it is possible that the priority levels in this study are overestimated considering that the users of ACM Check tended to overrate ACMs in comparison to the environmental consultant's ratings in the pilot study (Chapter 5). Finally, an assumption when analysing the data is that all submitted results are from genuine inspections, and not simply the user testing the app.

7.5. Conclusion

Despite new ACMs being phased out of use in residential buildings during the 1980s, there remains a large reservoir of *in situ* asbestos in the Australian residential environment. However, the amount and condition of the ACMs remaining in the Australian housing stock is unknown. Our study shows that a specifically designed mobile phone app, ACM Check, can be used by a range of community members to collect data on the presence, current condition, and potential for disturbance of *in situ* asbestos in Australian residential settings. This is the first such mobile phone app and questionnaire to be trialled in this population. Based on data collected using ACM Check, the most prevalent *in situ* ACMs in the sample were used for the backing board to electrical meter boxes, eaves and soffit linings, and fencing. While the majority of ACMs were categorised as 'very low' or 'low' priority for removal or remediation, ten percent of all houses in the sample contained at least one 'high' priority ACM. Mobile apps offer a platform to help increase people's awareness of possible health hazards found in the residential environment, such as asbestos, while also being used to collect data for public and environmental health research.

Chapter 8: Discussion and Conclusions

This project saw the design, development, testing, modification, and implementation of a mobile phone app that aids in the identification and assessment of *in situ* ACMs in residential settings. This was the primary aim of the project. This was achieved through conducting a project made up of three key phases, each with a set of specific objectives (outlined in Chapter 1, Table 1; and shown below). This final chapter summarises the findings of the studies and their implications, strengths and limitations of the studies as a whole, and recommendations for how this project could be repeated or expanded in future studies.

Table 1 Specific aims and objectives of the research project

Aim 1: To develop a mobile phone app that can be used to identify and then assess the condition of *in situ* ACMs in residential settings. The app was created to do the following:	
1.1	To identify *in situ* ACMs inside and outside the home
1.2	To describe the condition of the ACMs
1.3	To collect data regarding the amount, type, and condition of ACMs in and around residential settings
1.4	To direct users to further resources that assist in the safe management of ACMs
Aim 2: To pilot test and validate the app on a sample of homes built pre-1990 in Perth, WA.	
2.1	To validate the accuracy of the app in identifying *in situ* ACMs located inside and outside of homes compared with onsite inspections conducted by an experienced environmental consultant.
2.2	To pilot test the condition assessment of ACMs using the app compared to the results of an experienced environmental consultant
2.3	To evaluate the usability and flow of the app (i.e., its functionality)
2.4	To investigate if completion of the app resulted in knowledge seeking or changes to participants' behaviour (i.e., its potential impact)
Aim 3: To demonstrate the ability of the app to estimate current patterns of domestic sources of asbestos in a community.	
3.1	To demonstrate that the app can be used to estimate the number of houses with potential/identified *in situ* asbestos, the sources of asbestos and the condition of the ACMs

8.1. Findings and Implications

8.1.1. Main Findings of the Studies and their Implications

Asbestos-related diseases are entirely preventable. The majority of Australians acknowledge that asbestos is hazardous, but they lack the knowledge and confidence to identify ACMs in residential settings. Therefore, the ACM Check app was designed and developed by a multidisciplinary team to target *in situ* asbestos in the residential environment. The app identifies potential ACMs, prioritises the materials for remediation or removal based on their condition and potential for disturbance, and produces a summary report for each screened house. Additionally, the app was designed to direct users to further resources that assist in the safe management of ACMs.

This research project demonstrates how a specifically designed mobile phone app can help both the user and the researcher learn about where ACMs are located in and around residential settings and their current condition. It was highlighted in section 2.8 of the literature review that we do not know: 1) the amount of *in situ* ACM remaining in the Australian residential environment; 2) the most common types of ACM and where they are located within Australian residential settings; and, 3) the current condition and level of deterioration of these ACMs. This was further underscored in the *National Asbestos Profile for Australia* where it was recommended that "there is an identified need for more research to gain a better understanding of the amount and location of ACMs in the residential sector" (ASEA, 2017b, p. 39).

The cross-sectional survey presented in Chapter 7 showed that a mobile phone app can be used to provide evidence of the prevalence and current condition of *in situ* ACMs located in residential settings throughout WA and other Australian states. The results highlight that asbestos is pervasive in the Western Australian residential environment despite the use of ACM in domestic settings being phased out during the 1980s. The data showed that the majority of *in situ* asbestos was located outside, and that the most frequently detected ACMs were: flat asbestos-cement sheeting used as the backing board to electrical meter box, flat asbestos-cement sheeting used for eaves, and corrugated asbestos-cement sheet fencing. In particular, the data highlighted that asbestos-cement sheet fencing was much more prevalent in the WA residential environment than in other Australian jurisdictions. As such, asbestos-cement fencing may need to be an area of focus for monitoring and remediation efforts by WA authorities.

The data collected using ACM Check during the cross-sectional survey contributes to our understanding of the current condition of ACMs remaining in the Australian residential environment. One in five ACMs across all Australian jurisdictions were rated by users of ACM Check as being in 'poor'

(14.8%) or 'very poor' (5.3%) condition. Furthermore, only 5.5% of all ACMs were considered to be of 'high' priority. The results of Phase Two (Chapter 5) indicated that participants took a cautious approach to assessing the condition and potential for disturbance of the *in situ* ACMs in and around their home, and they tended towards selecting more severe ratings compared with the environmental consultant. In light of this, it is unlikely that the findings in Phase Three (Chapter 7) are underestimates of the current condition. Therefore, it is likely that the majority of ACMs remaining in the Australian residential environment are in fair to good condition, with certain materials showing poorer levels of deterioration, such as interior flooring and outside fencing.

Identification of ACM is a significant step towards preventing asbestos exposure among community members as it increases their awareness of its presence in or around the house. This can subsequently lead to the appropriate handling or the proper elimination of the ACMs from the residential environment. As a result, ACM Check is a primary prevention tool targeting residential asbestos exposure and looks to contribute to the long term goal of the elimination of ARDs in Australia. In doing this, the aims and objectives of the app and project directly aligned with several strategies and goals outlined by the Australian Government's Asbestos Safety and Eradication Agency (2013) in their *National Strategic Plan for Asbestos Awareness and Management 2013-2018*. More specifically, the creation of ACM Check was a practical and implementable approach that contributed towards their overarching goal, "to prevent exposure to asbestos fibres, in order to eliminate asbestos-related disease in Australia" (ASEA, 2013, p. 1).

8.1.2. Novel Use of a Mobile Technology: New Solution for an Old Problem

The use of mobile technology for the purpose of identifying and collecting data on ACMs in residential settings is an emerging concept that takes advantage of the proliferation of smartphones and apps. Since the introduction of the smartphone in 2007, Australia has become one of the leading global adopters with close to nine in ten Australians owning a smartphone (Drumm et al., 2017). Apps have grown alongside the smartphone due to being versatile, accessible, and optimisable, which has seen their use penetrate into the field of public health research. Therefore, we harnessed this new mobile technology to address an old problem; to increase public awareness of *in situ* asbestos that remains in the Australian residential environment as a legacy of its use during the 20th century.

ACM Check is freely available from the App Store and Google Play for Australians who own an iOS or Android device. This means the app has the potential to reach a considerable portion of the Australian population because these are the two major operating systems globally and cover more than 75% of smartphone owners in Australia (Drumm et al., 2017). Thus, the app is easily accessible to Australians who may be likely to come into contact with or are concerned about asbestos in residential settings.

Individuals who may benefit from accessing ACM Check range from EHOs inspecting homes for asbestos hazards; tradespeople who work in older residential settings, such as carpenters and electricians; home buyers looking to purchase an older property; community members undertaking DIY renovations or maintenance; through to family members who are interested in the potential sources of asbestos in or around their home. Based on the sample of users who consented to participate in Phase Three (Chapter 7), the app was downloaded and completed by community members, EHOs, asbestos assessors, and tradespeople from around Australia, which demonstrates that the app has begun to reach the target audience. In addition to being easily accessible, the feedback in Phase Two (Chapter 6) suggests that the app is visually appealing and easy to use, navigate, and complete.

At the commencement of this project there were few free and accessible resources, and more specifically, no mobile phone apps directly addressing the issue of residential asbestos. The app developed during this project is the first specifically designed mobile phone app released in Australia – and to the best of our knowledge, internationally – that can help guide the user through a visual inspection of a residential property to screen for possible ACMs. At the same time it is also the first app that collects data on the presence and condition of asbestos in Australian homes for use by researchers and relevant government agencies.

The cross-sectional survey provides evidence supporting the use of mobile phone apps, such as ACM Check, as an easily accessible and adaptable data collection tool for environmental, public health, and/or epidemiologic research. Further, there is the potential for these tools and resources to be expanded, shared and modified for greater national or even international use. This research project offers a framework for how another jurisdiction or country could approach the design, development, user feedback, validation, and implementation of a digital tool targeting the identification of asbestos and the promotion of asbestos awareness. The project describes in detail our approach to the problem, the strengths and limitations of this approach, and recommendations on how it could be improved should a similar project be undertaken. In summary, the project provides evidence that such an app can be developed and successfully used to promote asbestos awareness in the community whilst also being of value to researchers and associated government and non-government organisations.

Box 3 Summary of the strengths and implications of the findings of the research project

Strengths of ACM Check

- **Multidisciplinary team** – developed in consultation with a range of experts
- **Tested** – tested on 40 WA homes; strong agreement with an experienced environmental consultant for a range of ACMs
- **Modified based on user feedback** – upgraded photos and clearer instructions
- **User-friendly** – feedback suggests it is easy to use, navigate, and complete as well as being visually appealing
- **Easily accessible** – freely available on the two largest mobile operating systems
- **First of its kind** – first app in Australia that guides users through a residential inspection to identify *in situ* ACM
- **Data collection tool** – collects data on *in situ* asbestos in residential settings from consenting users

Implications of the Findings

- **Primary prevention** – identification of ACM is a significant step towards preventing asbestos exposure among community members due to increased awareness
- **Addresses gaps in knowledge** – provides evidence of the prevalence and current condition of certain *in situ* ACMs located in residential settings throughout WA
- **Government priority** – aims and findings align with goals outlined in the *National Strategic Plan for Asbestos Awareness and Management 2013-2018* (ASEA, 2013)
- **Evidence** – provides evidence for the use of mobile technology in public health research
- **Framework** – provides a working model of how a similar app or project could be implemented in other jurisdictions and/or countries

8.2. Summary of Limitations

The specific limitations relating to each phase of the project were detailed in the respective chapters. The primary limitations of the project have been summarised below and relate to the sample selection, sample size, and methods used.

Sample selection. Participants in health research using mobile apps will generally be self-selected due to the nature of mobile app use; it requires the individual to go to the relevant app store or study webpage (and follow the links), download the app, and then take the time to complete it. As a result it is particularly difficult to have a randomly selected and representative sample. This was the case in both Phase Two (Validation Study) and Phase Three (Community Study) where the samples were self-selected. On the other hand, younger people (i.e., 18-35 year olds) have the highest rate of smartphone ownership in Australia at 95% (Drumm et al., 2017), and interest in DIY home renovation activity has risen among this younger cohort (EY Sweeney, 2016). As younger Australians are also less likely to be aware of asbestos and its dangers in the home compared to older Australians (EY Sweeney, 2016), this group may be more likely to download and use ACM Check.

The houses sampled during Phase Two were distributed throughout the Perth metropolitan area and built in different decades (i.e., from the early 1900s to the 1980s). Despite this, more targeted sampling from known or suspected high risk areas may have increased the occurrence of certain ACMs that were underrepresented in the study. For instance, no houses had asbestos-cement gutters or a corrugated asbestos-cement sheet roof (although there were instances of asbestos-cement roofing on outbuildings). This meant that the respective sections in the ACM Check questionnaire could not be compared to the environmental consultant's assessments. Secondly, the participants in Phase Two may have had prior knowledge of what ACMs were present in or around their home, which may have biased their responses when completing ACM Check. This could have influenced the strength of agreement between the app and the consultant in Phase Two.

Sample size. For both of these studies the sample size was small. For the validation study (discussed in Chapters 4–6), a larger sample size could have captured a wider range of scenarios in which to test the capabilities and accuracy of the app. It also would have provided a greater number of observations for comparison of the app to the consultant. However, the sample was adequate for identifying technical errors (i.e., 'debugging') and for obtaining feedback on user satisfaction, ease-of-use, navigation, and the look and feel of ACM Check. With regards to the community study, it is acknowledged that a larger sample size would have allowed us to draw stronger or more generalisable conclusions regarding the prevalence of *in situ* ACMs and their condition in Australian residential settings. Nevertheless, the app remains available to the public and will continue to provide data that can be analysed in the future.

Methods used. The initial plan was to use laboratory analysis of sampled materials as 'truth' in the validation of ACM Check due to it being the current gold standard for asbestos identification. However, it became apparent during the course of the study that this was difficult due to the destructive nature of the sampling. The sampling was, therefore, opportunistic and did not provide the numbers needed for calculating a kappa value measuring the agreement between ACM Check and the laboratory analysis for specific materials or locations included in the app. For that reason we used the results of onsite inspections conducted by a single experienced environmental consultant as references for determining the sensitivity and specificity of the app. It is acknowledged that variation exists even amongst trained and experienced consultants with respect to their ability to identify different ACMs and qualitatively assess the risk of asbestos exposure. Employing multiple consultants would have allowed the results of the app to be more rigorously evaluated and allowed for stronger conclusions about the app's validity to be drawn. Additionally, this may have allowed us to evaluate the accuracy of the consultants and reduced uncertainty surrounding their opinions.

Finally, using a mobile phone app as the main method to collect data on the presence and condition of ACMs is not without its challenges. ACM Check is a tool that attempts to capture the main sources and locations where ACMs are likely to be present in residential settings. It is acknowledged that the app is not 100% accurate due to the large and diverse uses of asbestos in the past. As such, ACM Check does not look to replace or eliminate the need for consultation with an asbestos professional. Furthermore, it is impossible to capture all scenarios and materials that could contain asbestos in the residential environment using ACM Check. Therefore, it is possible the findings of the community study either under- or over-estimate the prevalence of asbestos in the Australian residential environment.

8.3. Recommendations and Future Directions

There is a lasting legacy of *in situ* asbestos prevalent in the built environment. For industrialised countries that have prohibited the use of asbestos, asbestos exposure to *in situ* ACMs during repairs, renovations, and demolition of older asbestos-containing buildings is a predominant source of exposure. For developing countries that continue to mine, produce, and use asbestos, this is a source of exposure that will be an issue for a much longer period of time. Therefore, it is necessary to share the lessons learned and make recommendations based on the experiences and findings of this research project conducted in WA and Australia so that future projects can benefit.

8.3.1. Recommendations for Future Studies

It is recommended that certain modifications to the study design be considered if a validation study is to be repeated or conducted on future versions of ACM Check or another asbestos app. Firstly, there should be emphasis placed on the targeted sampling of at-risk locations known to have higher amounts of ACM by relevant authorities or professionals in the field. This is so that a wider range of exposure scenarios could be captured and the accuracy of the app could be tested on some of the less common ACMs. Furthermore, sampling of rural or regional areas may increase the generalisability of the app.

Secondly, the most accurate method to evaluate ACM Check's ability to identify ACMs and asbestos-free materials is through laboratory identification of asbestos fibres in collected samples. However, the destructive sampling of materials hinders this approach. Therefore, an alternative for the validation study may be to recruit participants who are going to be either demolishing or renovating an older home; the sampling and subsequent defacing of materials from these houses would be more acceptable than sampling from houses with intact materials that are not going to be removed in the near future. Additionally, this approach would allow for the sampling of both suspect ACMs and non-ACMs as well as provide a larger quantity of samples. This would subsequently allow for more accurate evaluation of the app's specificity and sensitivity in regards to classifying materials as being positive or negative for asbestos.

Thirdly, it is recommended that two (or more) experienced environmental consultants or asbestos assessors be used to inspect each house in the validation study. There can be variation in consultants' ability to identify different ACMs. Therefore, having at least two experts may increase the likelihood that all ACMs are identified and decrease the probability that ACMs went undetected. This would also allow for assessment of the inter-rater agreement between the experts as well as strengthen the findings when evaluating the validity of the app; if the app had strong agreement with *both* experts then it strengthens the conclusion that the app is accurate. Furthermore, having multiple consultants may strengthen the assessment of the validity of ACM Check's priority assessment (i.e., current condition and likelihood of disturbance ratings). This would require the consultants involved to use a standard template, such as the one presented in enHealth (2005), and to consult with the occupier regarding their intentions to renovate areas of the home being inspected. An alternative study design is to have multiple participants complete the app on the same set of homes. The added benefit of this approach would be the ability to assess inter-rater reliability and agreement between different users of the app. For instance, you could observe the variation (or agreement) between users regarding how they rate the current condition of the same ACMs.

From a research perspective, it is recommended that additional demographic information be collected during the community study, including factors such as length of residency at current address and occupancy status (home owner, renting, or state housing). In addition, data on the gender and specific age of the user could be collected in order to better assess the reach of the app. Another factor to be considered is the specific reason(s) for why the user is completing the app. For example, is it a user who is simply curious, an uninformed tenant, an electrician who is about to drill into an eave, or a prospective home buyer looking to see if a property has ACM present. This would allow for more rigorous assessment of how the app is being used in the community, whether or not the target audience is being reached, and if certain sub groups of the population need to be targeted in further promotion or recruitment efforts.

To further evaluate the impact of either ACM Check or a similar app, a possibility is to use push notifications during the community study. Push notifications are a way for app developers to send messages or information to app users through either pop-up messages, banners, badges or alerts; they can be sent to mobile devices with the app installed regardless of whether or not the app is open and being used at the time. During a community survey, these notifications could serve two purposes: 1) to notify the user of any updates to the app with respect to new modules, types of materials, images, or functions; and, 2) to notify and prompt the user to complete evaluation or feedback questionnaires. More specifically, notifications for an evaluation questionnaire could be programmed to occur a specific number of weeks post-inspection in order to have a consistent follow-up period as well as to increase response rates. Similar to the follow-up survey discussed in Chapter 6, it is recommended the survey assesses whether or not the user increased their knowledge, sought further information, or took action towards preventing exposure (maintaining, repairing or removing an ACM) after using the app. Another modification would be to ask users to self-report their perceived level of knowledge of asbestos, asbestos exposure, and ACMs pre- and post-inspection. This could be implemented either during the testing and validation phase or the community survey phase.

8.3.2. Recommendations for ACM Check 2.0 or Future Asbestos Apps

Mobile phone apps are rarely, if ever, a finished product. Therefore, there are a number of recommendations or possibilities for either the further development of ACM Check (i.e., ACM Check 2.0) or a future asbestos app.

Expanded questionnaire. ACM Check could be expanded so that it has the option for a more comprehensive questionnaire. The comprehensive questionnaire could have separate questions for the different elements of the current condition and potential for disturbance ratings, which are then used to create a composite rating. For example, the potential for disturbance could be broken down into a question on accessibility, one on frequency of access, one on weathering, and another question about plans for renovations, refurbishment, removal, and demolition. These could then be assigned specific numerical values that are used to calculate a potential for disturbance rating, which would be in the vein of a traditional asbestos survey (e.g., see Health and Safety Executive, 2002, p. 54; Oberta, 2005, p. 29).

In addition to this, the comprehensive version of the questionnaire could be designed so that the user enters data for each specific room within the house. For example, if the user is prompted in the early stages of the questionnaire (i.e., in Module One – General Housing and User Information) that the house is a '4x2' (i.e., contains four bedrooms and two bathrooms), then the app automatically presents a set of questions for 'Room 1,' then repeats the series of questions for 'Room 2,' and so on for the required number of rooms. The benefit of this would be more precise data on the amount and location of *in situ* ACM, however, it would increase the length and time to complete the questionnaire. As such, the comprehensive questionnaire with sections for specific rooms together with expanded condition and potential for disturbance ratings could be more applicable for commercial applications or for users who want an in-depth guided inspection.

Updated assessment of disturbance. Weather events, such as storms, can be another major source of disturbance in some settings. Integrating heavy rain or hail into the potential for disturbance rating should be considered, particularly for asbestos-cement roofs and exterior structures potentially exposed to these elements. Furthermore, asbestos-cement roofs in very poor condition could be considered high priority in all cases because heavy rain or hail will highly likely result in disturbance and release of fibres. For example, a South African study found asbestos fibres in the soil under asbestos-cement roofs, which was presumably due to run-off rain water (Phillips, Norman, & Renton, 2009). Although ACM Check included a question regarding where run-off rain water from asbestos-cement roofs is directed to via drainpipes and gutters (i.e., into a soak well, into the ground, or onto hard surfaces such as pavement), the answer was not incorporated into the priority assessment for asbestos-cement roofs on the house and/or any outbuildings. Doing so should be considered in subsequent iterations of the app.

Photo library. There is a need for useful photos to serve as points of reference for users, which was emphasised by user feedback discussed in Chapter 6. This is particularly important given the incredibly large and diverse range of asbestos products that were used and installed in the residential environment. Therefore, it is recommended that a future asbestos app looks into integrating a feature that allows for the capturing and sharing of photos of suspected or identified ACMs as well as ACMs in different conditions. There are a number of ways this could be implemented to improve the functionality, usefulness and data collection capabilities of the app. Firstly, a database or library of photos of ACMs could be included as an additional feature. A second possibility is allowing users to take their own photos during the course of their inspection and submit and upload these directly to the photo database. Moreover, such a feature could enable users to share photos of materials that aren't included in the questionnaire and provide suggestions for further development of the app.

Taking and sharing photos might also be incorporated into the app's priority assessment by giving users the option to take a photo of the section of a particular ACM that is in the poorest condition. This could provide researchers with supporting evidence for the user's qualitative assessment of condition (i.e., good, fair, poor, or very poor). A side benefit of this approach may be that researchers could compare how different users are rating the materials; whether certain users are over- or under-estimating the current condition of ACMs. Alternatively, it could be used as a function for monitoring purposes whereby users can track the deterioration of ACMs overtime.

Social connectivity. Making the app socially connected is a possibility that could be explored for further iterations of ACM Check or a separate asbestos app. This is a way to engage users in order to create an online community and can include in-app polls (i.e., answering a multiple-choice question and then viewing the aggregated responses), forums, or discussion boards. Social connectivity through conversation has been successfully implemented in other projects using mobile health applications, such as for breastfeeding support (White et al., 2016). Such an approach may be particularly beneficial for professionals who have difficult questions or encountered a challenging scenario in the field as it could provide them with a suitable platform to connect with other professionals.

International expansion. ACM Check offers a framework for releasing an app in other countries. The systematic approach to screening a house used in ACM Check (i.e., beginning outside the home and continuing to the inside) is appropriate for almost all dwellings regardless of country. The app could easily be modified and made relevant through the inclusion of country-specific factors, such as years that particular ACMs were installed in residential settings and the year asbestos use was prohibited (if applicable). For example, asbestos was banned from use in the UK in November 1999 (Health and Safety Executive, 2002), so the ACM questionnaire would be modified to use pre- and post-2000 as the cut-off dates if it was implemented in the UK. Additional materials relevant to the country could also be included; sections on sprayed coating, pipe insulation/lagging and asbestos insulation board could be incorporated for inspections of UK residential settings.

Mobile technology is constantly evolving and new innovations are continually being introduced to the market. Therefore, it is important that public and environmental health researchers collaborate closely with app developers so that the latest technology can be adopted, incorporated into mobile health apps, and used to benefit the community and collect the most relevant data. Likewise, it is important that public and environmental health researchers incorporate the latest evidence from the field regarding the prevalence of ACMs and asbestos exposure in the residential environment into new versions of the app.

8.4. Conclusion

This project resulted in the development, testing, and implementation of the first app in Australia that systematically guides users through a residential inspection to identify and assess the condition of *in situ* ACM. The identification of ACM is a significant step towards preventing asbestos exposure among community members as it increases their awareness of its presence in or around the house. The thesis demonstrates how a mobile app can be used as a data collection tool in order to estimate the prevalence and current condition of ACMs remaining in residential settings. Moreover, the thesis provides evidence for the use of mobile technology in public health research and provides a framework for how a similar app or project could be implemented in other countries looking to target asbestos exposure in the residential environment.

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Appendices

Appendix A: Co-Author Statements

Curtin University

7 June 2018

To Whom It May Concern

Please not the following three signed Co-Author Statements relating to papers published and papers planned for publication.

1) I, *Matthew Govorko,* contributed 70% to the publication entitled:

Govorko, M. H., Fritschi, L., White, J., & Reid, A. (2017). Identifying Asbestos-Containing Materials in Homes: Design and Development of the ACM Check Mobile Phone App. *JMIR Formative Research, 1*(1), e7. doi:10.2196/formative.8370

Matthew Govorko

I, as Co-Author, endorse that this level of contribution by the PhD Candidate indicated above is appropriate.

Associate Professor Alison Reid

Professor Lin Fritschi

Dr James White

2) I, *Matthew Govorko,* contributed 80% to the publication entitled:

Govorko, M. H., Fritschi, L., & Reid, A. (2018). Accuracy of a Mobile App to Identify Suspect Asbestos-Containing Material in Australian Residential Settings. *Journal of Occupational and Environmental Hygiene*, 1-21. doi:10.1080/15459624.2018.1475743

Matthew Govorko

I, as Co-Author, endorse that this level of contribution by the PhD Candidate indicated above is appropriate.

Associate Professor Alison Reid

Professor Lin Fritschi

3) I, *Matthew Govorko,* contributed 80% to the paper entitled:

Govorko, M. H., Fritschi, L., & Reid, A. (2018). Using a Mobile Phone App to Identify and Assess Remaining Stocks of In Situ Asbestos in Australian Residential Settings. Unpublished. (Planned for publication)

Matthew Govorko

I, as Co-Author, endorse that this level of contribution by the PhD Candidate indicated above is appropriate.

Associate Professor Alison Reid

Professor Lin Fritschi

Appendix B: Copyright Permissions

Govorko, M. H., Fritschi, L., White, J., & Reid, A. (2017). Identifying asbestos-containing materials in homes: Design and development of the ACM Check mobile phone app. *JMIR Formative Research, 1*(1), e7. doi:10.2196/formative.8370

Link to original publication: https://formative.jmir.org/2017/1/e7/

Govorko, M. H., Fritschi, L., & Reid, A. (2018). Accuracy of a mobile app to identify suspect asbestos-containing material in Australian residential settings. *Journal of Occupational and Environmental Hygiene*, 1-21. doi:10.1080/15459624.2018.1475743

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Taylor & Francis Group

Our Ref: P061318-02/UOEH

13/06/2018

Dear Matthew Govorko on Behalf of Curtin University,

Material requested: Matthew H. Govorko, Lin Fritschi & Alison Reid (2018)
Accuracy of a Mobile App to Identify Suspect Asbestos-Containing Material in Australian Residential Settings
***Journal of Occupational and Environmental Hygiene* (Online)**
DOI: 10.1080/15459624.2018.1475743

Thank you for your correspondence requesting permission to post the above mentioned **Authors Original Manuscript** in or on your institutions intranet or within the Institutional Repository of your institution.

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Appendix C: Ethics Approval and Amendments

MEMORANDUM

Curtin University

To:	A/Prof Alison Reid
	School of Public Health
CC:	Mr Matthew Govorko
From:	Dr Catherine Gangell, Manager Research Integrity
Subject	Ethics approval Approval number: RDHS-89-15
Date:	26-May-15

Office of Research and Development
Human Research Ethics Office

TELEPHONE 9266 2784
FACSIMILE 9266 3793
EMAIL hrec@curtin.edu.au

Thank you for your application submitted to the Human Research Ethics Office for the project: 5944

Developing a validated tool to identify asbestos-containing materials in domestic settings in the Western Australian community

Your application has been approved through the low risk ethics approvals process at Curtin University.

Please note the following conditions of approval:

1. Approval is granted for a period of four years from **26-May-15** to **26-May-19**
2. Research must be conducted as stated in the approved protocol.
3. Any amendments to the approved protocol must be approved by the Ethics Office.
4. An annual progress report must be submitted to the Ethics Office annually, on the anniversary of approval.
5. All adverse events must be reported to the Ethics Office.
6. A completion report must be submitted to the Ethics Office on completion of the project.
7. Data must be stored in accordance with WAUSDA and Curtin University policy.
8. The Ethics Office may conduct a randomly identified audit of a proportion of research projects approved by the HREC.

Should you have any queries about the consideration of your project please contact the Ethics Support Officer for your faculty, or the Ethics Office at hrec@curtin.edu.au or on 9266 2784. All human research ethics forms and guidelines are available on the ethics website.

Yours sincerely,

Dr Catherine Gangell
Manager, Research Integrity

Curtin University

Office of Research and Development

GPO Box U1987
Perth Western Australia 6845

Telephone +61 8 9266 7863
Facsimile +61 8 9266 3793
Web research.curtin.edu.au

16-Aug-2016

Name: Alison Reid
Department/School: Epidemiology and Biostatistics
Email: Alison.Reid@curtin.edu.au

Dear Alison Reid

RE: Amendment approval
Approval number: RDHS-89-15

Thank you for submitting an amendment request to the Human Research Ethics Office for the project **Developing a validated tool to identify asbestos-containing materials in domestic settings in the Western Australian community.**

Your amendment request has been reviewed and the review outcome is: **Approved**

The amendment approval number is RDHS-89-15-02 approved on 16-Aug-2016.

The following amendments were approved:

Updated and latest versions of the following documents: 1. Participant Information and Consent Form - Pilot Study; 2. Registration Form (administered through Qualtrics); 3. Feedback Questionnaire (administered through Qualtrics); 4. Follow-up Questionnaire (administered through Qualtrics); 5. The content and questionnaire of 'ACM Check' (the smartphone application), presented in Word Document format; and 6. Recruitment Flyer.

Employment status of Mr Peckitt, who will conduct the 50 residential inspections, has changed from an employee of the Department of Health to a consultant.

Any special conditions noted in the original approval letter still apply.

Standard conditions of approval

1. Research must be conducted according to the approved proposal
2. Report in a timely manner anything that might warrant review of ethical approval of the project including:
    - proposed changes to the approved proposal or conduct of the study
    - unanticipated problems that might affect continued ethical acceptability of the project
    - major deviations from the approved proposal and/or regulatory guidelines
    - serious adverse events
3. Amendments to the proposal must be approved by the Human Research Ethics Office before they are implemented (except where an amendment is undertaken to eliminate an immediate risk to participants)

4. An annual progress report must be submitted to the Human Research Ethics Office on or before the anniversary of approval and a completion report submitted on completion of the project
5. Personnel working on this project must be adequately qualified by education, training and experience for their role, or supervised
6. Personnel must disclose any actual or potential conflicts of interest, including any financial or other interest or affiliation, that bears on this project
7. Changes to personnel working on this project must be reported to the Human Research Ethics Office
8. Data and primary materials must be retained and stored in accordance with the Western Australian University Sector Disposal Authority (WAUSDA) and the Curtin University Research Data and Primary Materials policy
9. Where practicable, results of the research should be made available to the research participants in a timely and clear manner
10. Unless prohibited by contractual obligations, results of the research should be disseminated in a manner that will allow public scrutiny; the Human Research Ethics Office must be informed of any constraints on publication
11. Ethics approval is dependent upon ongoing compliance of the research with the Australian Code for the Responsible Conduct of Research, the National Statement on Ethical Conduct in Human Research, applicable legal requirements, and with Curtin University policies, procedures and governance requirements
12. The Human Research Ethics Office may conduct audits on a portion of approved projects.

Should you have any queries regarding consideration of your project, please contact the Ethics Support Officer for your faculty or the Ethics Office at hrec@curtin.edu.au or on 9266 2784.

Yours sincerely

Dr Catherine Gangell
Manager, Research Integrity

Curtin University

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05-May-2017

Name: Alison Reid
Department/School: Epidemiology and Biostatistics
Email: Alison.Reid@curtin.edu.au

Dear Alison Reid

RE: Amendment approval
Approval number: RDHS-89-15

Thank you for submitting an amendment request to the Human Research Ethics Office for the project **Developing a validated tool to identify asbestos-containing materials in domestic settings in the Western Australian community**.

Your amendment request has been reviewed and the review outcome is: **Approved**

The amendment approval number is RDHS-89-15-04 approved on 05-May-2017.

The following amendments were approved:

The following amendments need to be approved by Curtin HREC in order to conduct the third and final phase of this study:

1) Updated content and questionnaire included in the mobile application (ACM Check).

2) Inclusion of a feedback questionnaire for Phase 3 of the project, administered online through Qualtrics.

3) The creation of a webpage that includes an outline of the study and a downloadable Participant Information Statement.

Any special conditions noted in the original approval letter still apply.

Standard conditions of approval

1. Research must be conducted according to the approved proposal
2. Report in a timely manner anything that might warrant review of ethical approval of the project including:
    - proposed changes to the approved proposal or conduct of the study
    - unanticipated problems that might affect continued ethical acceptability of the project
    - major deviations from the approved proposal and/or regulatory guidelines
    - serious adverse events
3. Amendments to the proposal must be approved by the Human Research Ethics Office before they are implemented (except where an amendment is undertaken to eliminate an immediate risk to participants)

4. An annual progress report must be submitted to the Human Research Ethics Office on or before the anniversary of approval and a completion report submitted on completion of the project
5. Personnel working on this project must be adequately qualified by education, training and experience for their role, or supervised
6. Personnel must disclose any actual or potential conflicts of interest, including any financial or other interest or affiliation, that bears on this project
7. Changes to personnel working on this project must be reported to the Human Research Ethics Office
8. Data and primary materials must be retained and stored in accordance with the Western Australian University Sector Disposal Authority (WAUSDA) and the Curtin University Research Data and Primary Materials policy
9. Where practicable, results of the research should be made available to the research participants in a timely and clear manner
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11. Ethics approval is dependent upon ongoing compliance of the research with the Australian Code for the Responsible Conduct of Research, the National Statement on Ethical Conduct in Human Research, applicable legal requirements, and with Curtin University policies, procedures and governance requirements
12. The Human Research Ethics Office may conduct audits on a portion of approved projects.

Should you have any queries regarding consideration of your project, please contact the Ethics Support Officer for your faculty or the Ethics Office at hrec@curtin.edu.au or on 9266 2784.

Yours sincerely

Dr Catherine Gangell
Manager, Research Integrity

Appendix D: Published Papers

Original Paper

Identifying Asbestos-Containing Materials in Homes: Design and Development of the ACM Check Mobile Phone App

Matthew Hayden Govorko[1], MPH; Lin Fritschi[1], PhD; James White[2], PhD; Alison Reid[1], PhD

[1]School of Public Health, Curtin University, Perth, Australia
[2]Reach Health Promotion Innovations, Perth, Australia

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Abstract

Background: Asbestos-containing materials (ACMs) can still be found in many homes in Australia and other countries. ACMs present a health risk when they are damaged or disturbed, such as during do-it-yourself home renovations. However, community members lack knowledge and awareness about asbestos identification and its safe management in residential settings.

Objective: The objective of our study was to describe the process of developing a mobile phone app, ACM Check, that incorporates a questionnaire designed to identify and assess ACMs located in residential settings.

Methods: A multidisciplinary team was involved in the formative development and creation of the mobile phone app. The formative development process comprised 6 steps: defining the scope of the app; conducting a comprehensive desktop review by searching online literature databases, as well as a wider online search for gray literature; drafting and revising the content, questionnaire, conditional branching rules, and scoring algorithms; obtaining expert input; manually pretesting the questionnaire; and formulating a final content document to be provided to the software development company. We then constructed ACM Check on the iOS platform for use in a validation study, and then updated the app, replicated it on Android, and released it to the public.

Results: The ACM Check app identifies potential ACMs, prioritizes the materials based on their condition and likelihood of disturbance, and generates a summary report for each house assessed.

Conclusions: ACM Check is an initiative to raise community members' awareness of asbestos in the residential environment and also serves as a data collection tool for epidemiologic research. It can potentially be modified for implementation in other countries or used as the basis for the assessment of other occupational or environmental hazards.

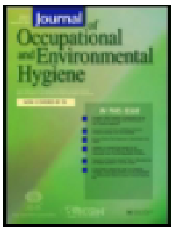
(JMIR Formativ Res 2017;1(1):e7) doi:10.2196/formative.8370

KEYWORDS

application development; asbestos; asbestos-containing materials; mobile phones; smartphone; residential environment; mobile applications; environment and public health

Introduction

Asbestos is the term given to a family of naturally occurring fibrous silicates that have been used in a wide variety of building materials, commonly referred to as asbestos-containing materials (ACMs) [1]. Australia was the highest per capita consumer of ACMs in the world during the mid-20th century [2]. Many of these ACMs were asbestos cement products, such as flat and corrugated asbestos cement sheeting, in which the asbestos fibers were bonded to a base material. These products were installed in residential settings between the mid-1940s and the late 1980s [3]. Until the 1960s, approximately 25% of all new Australian homes were clad with asbestos cement products [2], and it is likely that almost all houses built before 1990 contain some form of asbestos [3]. All forms of asbestos have been classified as carcinogenic [4], and a prohibition was declared



Taylor & Francis

Journal of Occupational and Environmental Hygiene

ISSN: 1545-9624 (Print) 1545-9632 (Online) Journal homepage: http://www.tandfonline.com/loi/uoeh20

Accuracy of a Mobile App to Identify Suspect Asbestos-Containing Material in Australian Residential Settings

Matthew H. Govorko, Lin Fritschi & Alison Reid

Appendix E: Summary Report Generated by ACM Check

ACM Report, 26 June 2017

Postcode: 6148	House built: Pre 1985			
Probability house contains asbestos based off house age: Likely				
Product type	**Probability of being an ACM**	**Current condition**	**Potential for disturbance**	**Overall rating**
Outside				
Exterior wall cladding	Unlikely			
Eaves / soffit lining	Likely	Good	Unlikely	Very low priority
Roofing	Unlikely			
Gutters	Unlikely			
Drainpipes / downpipes	Unlikely			
Backing board in electric meter box	Likely	Good	Somewhat likely	Very low priority
Fencing	Likely	Fair	Unlikely	Very low priority
Outbuilding roof	Unlikely			
Outbuilding walls	Unlikely			
Inside				
Interior walls	Unlikely			
Backing to wall tiles	Possible	Good	Unlikely	Very low priority
Ceiling	Unlikely			
Linoleum or vinyl tile flooring	Likely	Good	Unlikely	Very low priority
Heater flue pipe	N/A			

Recommendations	
• If you wish for the possible or likely ACM identified in this app to be confirmed as containing asbestos, we recommend that you have the suspect ACM sampled. • However, members of the public are advised not to undertake destructive sampling (i.e. sampling that involves cutting or breaking the material) and/or any sampling which involves friable ACMs, such as asbestos pipe lagging or asbestos fuses. To have these materials sampled please contact a qualified asbestos professional and have it tested at a laboratory accredited by NATA for asbestos analysis. • A list of certified labs can be found here or by calling 08 9486 2800. • To conduct passive sampling, i.e., collecting tape dust samples or picking up suspect ACM fragments, please refer to section 6.1 'Sampling and Analysis' found in the following document: Guidance Note: Identification of asbestos containing material. • Based on the overall rating of each possible or likely ACM (i.e. very Low priority, low priority, moderate priority, high priority), consult the following table for general recommendations.	
OVERALL RATING	**GENERAL RECOMMENDATIONS / ACTIONS**
Very low priority	**Monitor and no immediate action necessary.** Monitoring of potential ACM for any signs of visible deterioration or damage. ACM in good condition may benefit from preventive maintenance actions including painting, sealing or encapsulating.
Low priority	**Monitor and minor maintenance/repair.** Monitoring of the ACM should be conducted frequently. Maintenance and repair procedures should be considered as a short term measure for any minor damages (sealing cracks and surface scratches, painting the product if appropriate etc.) with plans for removal in the long term (pending on monitoring of the condition of the ACM).
Moderate priority	**Removal and replacement should be a priority. Major repair activity should be considered as a secondary and temporary action.** Maintenance and repair may be of insufficient benefit. It is recommended that you have the ACM removed and replaced. It is suggested that you contact your local government environmental health officer for advice and consider using the services of a licensed asbestos professional (depending on the work to be undertaken, this may be either a restricted or unrestricted asbestos removal license holder).
High priority	**Consult an asbestos professional for removal, disposal and replacement of the ACM.** Removal and replacement of the product as soon as possible is strongly recommended. It is highly recommended that you consult with an asbestos professional (e.g., local government environmental health officer, occupational hygienist, licensed asbestos removalist) for advice on how to deal with the ACM. For certain ACMs (i.e., friable ACMs) that are to be removed, it is strongly recommended that a professional with an Unrestricted Asbestos Removal License obtained from WorkSafe be used to remove and dispose of the material. View a list of Unrestricted Asbestos Removal License holders based in WA.

Appendix F: Pilot Testing and Validation Study Questionnaires

Appendix F1: Online Participant Registration Form

Registration for 'ACM Check' Pilot and Validation Study

Contact Information

Name

Residential Address

Suburb

State

Post Code

Email Address

Mobile Number

Inclusion/Exclusion Criteria

Are you eighteen (18) years of age or older?
- Yes
- No

Do you have access to an iPhone or iPod Touch with iOS 8 or later?
- Yes
- No

Are you the owner of the house that is to be inspected in the study?
- Yes
- No

Have you previously had this residence assessed for asbestos by an experienced professional?
- Yes
- No

Approximately what year was your house built?

Appendix F2: Online Feedback Questionnaire

"ACM Check" Feedback Questionnaire

Feedback - Questionnaire and Results

How satisfied are you with the length (i.e. number of items) of the questionnaire?

- Very satisfied
- Satisfied
- Neither satisfied nor dissatisfied
- Dissatisfied
- Very dissatisfied

How satisfied are you with the time it took to complete the questionnaire?

- Very satisfied
- Satisfied
- Neither satisfied nor dissatisfied
- Dissatisfied
- Very dissatisfied

How difficult were the questions to understand overall?

- Very easy
- Easy
- Neither easy nor difficult
- Difficult
- Very difficult

How difficult were the questions to answer overall?

- Very easy
- Easy
- Neither easy nor difficult
- Difficult
- Very difficult

How useful did you find the information presented in the results table?

- Extremely useful
- Very useful
- Moderately useful
- Slightly useful
- Not at all useful

Please add any comments that you may have relating to the questionnaire and/or the results table

Feedback - The App

How difficult was it to navigate 'ACM Check'?

- Very easy
- Easy
- Neither easy nor difficult
- Difficult
- Very difficult

How satisfied are you with the look and feel of 'ACM Check'?

- Very satisfied
- Satisfied
- Neither satisfied nor dissatisfied
- Dissatisfied
- Very dissatisfied

How satisfied are you with the app's ease of use?

- Very satisfied
- Satisfied
- Neither satisfied nor dissatisfied
- Dissatisfied
- Very dissatisfied

How likely are you to recommend 'ACM Check' to others?

- Very likely
- Likely
- Neither likely nor unlikely
- Unlikely
- Very unlikely

How would you rate 'ACM Check'?

- 5 stars
- 4 stars
- 3 stars
- 2 stars
- 1 star

Please add any comments that you may have relating to the app's functionality (look, feel, ease of use, and/or navigation)

Additional Comments

In your own words, what would you most like to improve in 'ACM Check'?

Please add any other comments, feedback or suggestions that you have regarding 'ACM Check'

Appendix F3: Online Follow-Up Questionnaire

'ACM Check' Follow-Up Questionnaire

Knowledge Seeking

Have you asked for another professional's opinion, advice or assessment of any potential or confirmed asbestos-containing materials in or around your house since completing *ACM Check*?

- Yes
- No

Who did you seek advice from? (May select multiple answers)

- Local Government Environmental Health Officer
- Asbestos Removalist
- Environmental Consultant
- Other, please specify

Since completing *ACM Check*, have you looked for any additional information on asbestos?

- Yes
- No

What asbestos-related issue did you seek information for? (May select multiple answers)

- Asbestos and its health effects
- Asbestos exposure
- Uses of asbestos
- Asbestos identification
- Asbestos in the home
- Asbestos removal
- Working with asbestos
- History of asbestos
- Other issue, please specify

What was the source of the information? (May select multiple answers)

- Web site
- Report
- Book
- Encyclopedia
- Newspaper
- Magazine
- Academic journal
- Other, please specify

Did you access any of the links to asbestos-related websites or documents provided in *ACM Check*?

- Yes
- No

Asbestos Awareness

Have you discussed the issue of asbestos-containing materials in the home with any friends or family since completing *ACM Check*?

- Yes
- No

Have you told any friends or family about *ACM Check* since you have used the app?

- Yes
- No

Actions

Did you have any possible or likely asbestos-containing material in or around your home based on *ACM Check*?

- Yes
- No

Have you had any asbestos-containing materials removed and/or replaced since completing *ACM Check*?

- Yes
- No

Was the removal and/or replacement of the asbestos-containing material done professionally or was it a Do-It-Yourself job?

- Professional job
- Do-It-Yourself job

Have any damaged asbestos-containing materials in or around your house been repaired since completing *ACM Check*?

- Yes
- No

Have any renovations been conducted in areas of your house with potential asbestos-containing material since completing *ACM Check*?

- Yes
- No

When conducting renovations, did you take extra precautions to limit disturbing the asbestos-containing material and prevent exposure to asbestos fibres because of what you learnt from *ACM Check*?

- Yes
- No

What precautions did you take?

Have you taken any other preventative measures or actions to protect household occupants from any asbestos-containing materials?

- Yes
- No

What preventative measures did you take?

Appendix G: Curtin Media Release

Media Release

50 YEARS OF INNOVATION | Curtin University

13 June 2017

New app maps the prevalence of asbestos in WA homes

Curtin University researchers are aiming to map the prevalence of asbestos in homes across Western Australia and help home renovators identify potentially deadly risks with a free new app, released today.

Aimed at combatting asbestos-related illnesses from do-it-yourself (DIY) renovators, ACM Check, which is available on Android and Apple devices, offers a step-by-step guide to assessing the level of risk that your home contains asbestos products.

The app has been developed by Curtin University PhD student Matthew Govorko, under the guidance of Associate Professor Alison Reid and Professor Lin Fritschi, from the School of Public Health at Curtin University.

"This app will help home renovators gauge the level of potential risk in their homes from asbestos-containing materials, and it will be the first time that we will be able to effectively map the prevalence of asbestos products in homes across the State," Associate Professor Reid said.

"Even though asbestos cement products were phased out in WA between 1981 and 1987, it is estimated one-third of all Australian homes contain asbestos. Australia has the second highest mesothelioma death rate in the world with about 600 cases of mesothelioma diagnosed across the country each year, so it is important we do all we can to ensure more people are not exposed to this deadly product."

Mr Govorko said the app had been designed as a screening tool to identify and assess the condition of potential asbestos-containing materials in and around the home, while also offering further information for home renovators from reputable sources.

"The app guides users through a series of questions, aided by photographs, to identify the potential level of risk in and around their homes before they start to renovate," he said.

"If a material is possibly or likely to contain asbestos, the user is asked to report the current condition of the material and specify if it is likely to be disturbed during home renovations. Once they have completed the questionnaire through the app, they are offered a series of recommendations about what action to take based on the level of risk identified for each product."

ACM Check can be downloaded for free from the Apple store and Google Play.

Ends…/

About Curtin University

Curtin University is Western Australia's largest university, with more than 58,000 students. Of these, over 15,000 are international students. The University's main campus is in Bentley near the Perth CBD. Curtin has five other campuses across WA, Malaysia and Singapore, with a new campus opening in Dubai in 2018. Curtin also has presence at a number of other global locations.

Curtin is celebrating '50 Years of Innovation' in 2017 – the combined history of the Western Australian Institute of Technology (WAIT), which opened its doors to students in 1967 and Curtin University, which opened in 1987.

Today, Curtin is estimated to be ranked 211th and in the top two per cent of universities worldwide, and 10th in Australia in the highly regarded Academic Ranking of World Universities 2016 (ARWU), and features highly in a number of other key world rankings.

The University has built a reputation around innovation and an entrepreneurial spirit, being at the forefront of many high-profile research projects in astronomy, biosciences, economics, mining and information technology. It is also recognised globally for its strong connections with industry, and for its commitment to preparing students for jobs of the future.

For further information visit curtin.edu.au.

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Appendix H: ACM Check Content for Phase Three

'ACM Check' Content

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Disclaimer

IMPORTANT NOTICE – DISCLAIMER

Every effort has been made to ensure that the information contained in this application is accurate, and that the results generated by the questionnaire contained in this application are reliable. Notwithstanding the foregoing, all such information and results are to be used as a guide only and should not be treated as a substitute for obtaining appropriate advice or making prudent enquiries. The application, and information generated by the application, is provided solely on the basis that users will be responsible for making their own assessment as to risks associated with the handling of materials which potentially contain asbestos. Users should independently verify all relevant information and results, together with any accompanying representations, statements and information, before handling any such materials.

Even if the information contained in or generated by this application is accurate at the time of first access by the user, it is possible that circumstances (including but not limited to changes in legislation) may subsequently impact upon the accuracy of any such information, and it remains the user's responsibility to determine the currency of the information.

The application contains links to third party resources. Curtin University accepts no responsibility for the accuracy of information sourced from linked sites. Reliance by the user of such third party information is solely at the user's own risk.

Information contained in or generated by this application does not constitute, and is not intended to be used as, legal advice or an interpretive document. Curtin University accepts no responsibility for a misinterpretation by the user as to the legal implications of information contained in or generated by the application, and independent legal advice should always be sought where appropriate.

Curtin University does not make any warranty or representation as to the accuracy, adequacy, reliability or completeness of the information contained in or generated by this application. To the extent permitted by law, this disclaimer excludes all warranties of any kind, whether express or implied, including without limitation any implied warranty of fitness for a particular purpose. Subject to the foregoing, the use of this application is at the user's sole risk and the user will be solely responsible for any loss, damage or third party liability incurred by the user or otherwise arising from the use or reliance by the user upon any information contained in or generated by the application. The user fully indemnifies Curtin University (including its staff, researchers and contractors) in respect of any liability including without limitation consequential loss, indirect loss and all and any loss or damage (including personal injury or death) sustained by the user or a third party arising out of reliance upon information derived by the user from the application.

Data from completed questionnaires will be collected and used by Curtin University for research purposes only. All data are non-identifiable and you will remain anonymous. You can opt out of sharing your questionnaire data. Further information about the study and a downloadable Participant Information Statement can be found here *(the URL to*

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the Curtin University Webpage outlining the study will be inserted when it has been created)

(On/Off switch) I have read the information statement and consent to participate in the research.

Information Tab

What are asbestos-containing materials (ACMs)?

- In Australia, asbestos was used widely in building materials between the 1940s and the 1980s due to its durability, affordability, flexibility and fire resistance properties. (For a detailed outline of the history of asbestos in Australia please visit the Australian Asbestos Network http://www.australianasbestosnetwork.org.au/asbestos-history/)
- Asbestos containing materials (ACMs) can fall into two broad categories – non-friable (bonded) or friable (loose form of asbestos). Non-friable ACMs are made primarily of a bonding agent, such as cement, with the asbestos fibres being bound firmly to the base material. Friable ACM are products where asbestos fibres are loosely bound or attached to another material such as textile, insulation or lagging. These products contain loose fibres which can be readily released into the air when disturbed or deteriorated and therefore pose a higher risk.
- Since the 31st of December 2003 there has been a total ban on asbestos use of any type, including a prohibition on the importation, manufacturing, processing, sale, storage and re-use of asbestos and ACM. Most ACM were however, phased out of manufacture prior to the national ban during the mid to late 1980s.

What are the risks?

- ACMs only pose a health risk when there is potential for asbestos fibres to be released and subsequently inhaled i.e. they are friable. Non-friable ACMs in the home that are in good condition and remain undisturbed pose minimal risk to health because the fibres are still bound tightly into the product. However, when they are extensively damaged or degraded (from weathering) there is an increased risk because the asbestos fibres are more readily released into the air, particularly if disturbed. Asbestos fibres are mainly released into the air when people work with or remove ACM, such as during renovation and maintenance activity, without taking proper precautions.

Organisations and Resources

Organisations

Asbestos Diseases Society of Australia Inc.
Tel (08) 9344 4077
Email: website@asbestosdiseases.org.au
http://www.asbestosdiseases.org.au/

Asbestos Safety and Eradication Agency
Tel 1300 363 079
Email: enquiries@asbestossafety.gov.au
https://asbestossafety.gov.au/

Cancer Council Western Australia
Tel 13 11 20
https://www.cancerwa.asn.au/

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For the 'kNOw asbestos in your home' eLearning module, please go to
http://elearning.cancer.org.au/courses/know-asbestos-in-your-home.html

Department of Health (Western Australia)
(Environmental Health Directorate)
Tel (08)9388 4999
Email: ehinfo@health.wa.gov.au
http://www.public.health.wa.gov.au/2/871/1/environmental_health_directorate.pm

National Association of Testing Authorities
Tel (08) 9486 2800
http://www.nata.com.au/nata/

WorkSafe WA (division of the Department of Commerce)
Tel 1300 307 877
https://www.commerce.wa.gov.au/worksafe

Resources

Department of Health (WA). Asbestos regulators and information sources.
http://www.public.health.wa.gov.au/cproot/3999/2/Asbestos%20regulators%20and%20information%20sources.pdf

Department of Health (WA). Guidance Note: Identification of asbestos containing material.
http://www.public.health.wa.gov.au/cproot/6302/2/Guidance%20Note%20-%20Identification%20of%20asbestos%20containing%20material.pdf

Department of Health (WA). Guidance Note on asbestos cement fences.
http://www.public.health.wa.gov.au/cproot/6329/2/Guidance%20Note%20on%20Asbestos%20Cement%20Fences%20Feb%2016.pdf

Department of Health (WA). Guidance Note on asbestos cement roof.
http://www.public.health.wa.gov.au/cproot/6336/2/Guidance%20Note%20on%20Asbestos%20Cement%20Roofs%202016%20(2).pdf

Department of Health (WA). Asbestos. http://healthywa.wa.gov.au/Articles/A_E/Asbestos

Department of Health (WA). Asbestos cement products in your home.
http://healthywa.wa.gov.au/Articles/A_E/Asbestos-cement-products-in-your-home

Department of Health (WA). Asbestos – carpet underlay.
http://healthywa.wa.gov.au/Articles/A_E/Asbestos-carpet-underlay

enHealth. Management of asbestos in the non-occupational environment.
http://www.health.vic.gov.au/archive/archive2014/nphp/enhealth/council/pubs/pdf/asbestos.pdf

enHealth. Asbestos: A guide for householders and the general public.
http://www.health.gov.au/internet/main/publishing.nsf/content/ohp-enhealth-asbestos-may2012.htm

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U.K. Health and Safety Executive. Asbestos: The survey guide HSG264 (2nd ed.).
http://www.hse.gov.uk/pUbns/priced/hsg264.pdf

Queensland Government. Asbestos: A guide for minor renovations.
http://www.deir.qld.gov.au/asbestos/resources/pdfs/asbestos-home-renovators-trades-guide.pdf

Disclaimer

Users can re-read the disclaimer by clicking on this option.

Allow anonymous data collection

There is an "on-off" toggle that allows users to easily switch between sharing their data from completed questionnaires anonymously with Curtin University and choosing not to share their data. If users switch the toggle to "off", there are no disadvantages to the user and they still have full access to all of ACM Check's functions and information. The user can switch between having data collection on and off as many times as they wish.

Contact Us

Clicking on 'Contact Us' allows the user to email matthew.govorko@curtin.edu.au

Complete our feedback survey

Clicking on 'Complete our feedback survey' opens a web browser and takes the user to our usability and feedback questionnaire on Qualtrics. The questionnaire has been submitted for approval by Curtin's HREC. The link is: https://curtin.au1.qualtrics.com/jfe/form/SV_8229j0IWk0abQyN

ACM Check Questionnaire

Module 1: Demographics (User and general housing information)

Qu 1.1: Please select what state you are in

- ◻ WA
- ◻ ACT
- ◻ NSW
- ◻ VIC
- ◻ TAS
- ◻ SA
- ◻ NT
- ◻ QLD

If a state other than WA is selected the following message appears: **'This app was developed and validated in WA conditions and therefore, caution should be used if using the app outside of WA. If you choose to proceed, any predictions/recommendations should be considered cautiously'.**

Qu 1.2: Please select the description that best describes why you are using this App

- ◻ I am a community member who is interested in finding out more about asbestos in my own or someone else's household
- ◻ I am an Environmental Health Officer who needs to assess and deal with asbestos in the community
- ◻ I am a licensed asbestos removalist
- ◻ I am a tradesperson, labourer, handyman who works in residential settings.
  - Qu 1.2.1: Can you please choose your main job role from the list below?
    - ◻ Bricklayer
    - ◻ Builder
    - ◻ Carpenter
    - ◻ Carpet layer/timber floor installer
    - ◻ Ceiling fixer
    - ◻ Electrician
    - ◻ Fencing Contractor
    - ◻ Maintenance/handyman
    - ◻ Painter and decorator
    - ◻ Plasterer
    - ◻ Plumber
    - ◻ Renovator
    - ◻ Roof restoration
    - ◻ Tiler – wall and floor
    - ◻ Other

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Qu 1.3: When do you estimate this house was built? Please select one.

- □ Before 1985
- □ Between 1985 and 1990
- □ After 1990

Qu 1.4: Post code: _ _ _ _

Qu 1.5: Please select the type of dwelling

- □ Separate house
- □ Flat, unit or apartment
- □ Semi-detached, row, villa, terrace house or townhouse

Qu 1.6: How many of the following people live here?

- □ Children and young adolescents (<18): (select from 1 – 10)
- □ Adults (18-64): (select from 1 – 10)
- □ Older adults (65<): (select from 1 – 10)

Module 2: Potential locations of ACM outside your home

Instructions: Please go outside and to the front of the house in order to begin.

Exterior wall cladding

Qu 2.1: What are the main construction materials of the external walls, including any gable ends if applicable? (Select all that apply)

- ▫ Timber
- ▫ Brick
- ▫ Render
- ▫ Stone
- ▫ Metal cladding
- ▫ Imitation brick cladding
- ▫ Cement sheet or "Fibro"
- ▫ Don't know

The side of a 1960s house clad with flat asbestos cement sheeting known as Fibrolite or "Fibro".

Flat asbestos cement sheeting used for external wall cladding above the brick.

Imitation brick cladding on a late-1940s house

Qu 2.1.1: Are any external walls made up of individual panels that have joining strips or mouldings? (Similar to the picture below)

- ☐ Yes
- ☐ No

Flat asbestos cement sheeting used as external wall cladding on a 1950s home. Note the thick joiner strips.

Eaves/Soffit lining

Qu 2.2: Does this house have lined eaves? (The edge of the roof that overhangs the face of the wall is referred to as the eave whilst the lining under the eave is termed the soffit or soffit lining.) Include any sections of lining/ceiling underneath external verandahs, patios, carports and garages.

- ☐ Yes
- ☐ No

Eaves lining the side of a house

Verandah or patio lining

Carport or garage ceiling

Qu 2.2.1: What material are the eaves made from? (Select all that apply)

- ☐ Wood panels
- ☐ Fibre cement panels
- ☐ Other
- ☐ Don't know

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Eaves constructed from fibre cement panels on a 1960s house

Qu 2.2.2: If fibre cement panels are there visible joiners/joining strips? (Similar to what is pictured below)

- ▫ Yes
- ▫ No
- ▫ Don't know

Eaves that contain asbestos on two 1960s house. Note the wide battens or joiner strips made of asbestos cement (top) or wood (bottom)

Qu 2.2.3: Have any of the eave panels been in place since before 1990? (i.e. they were installed prior to 1990 and have not been replaced since)

- ▫ Yes, these panels were installed pre-1990
- ▫ No, all panels were replaced after 1990
- ▫ Don't know

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Roofing and gutters

Please do not climb up onto your roof to inspect. Find a suitable viewing area that gives you the best view of the roof.

Qu 2.3: What material is the roof constructed from?

- ☐ Corrugated concrete or fibre cement sheeting (similar to the roofing in the pictures below)
- ☐ Tile (clay/concrete)
- ☐ Metal (corrugated) i.e. Colorbond® roof

Corrugated asbestos cement roofing

Qu 2.3.1: Where do the gutters and/or drainpipes flow to?

- ☐ On to a hard surface (concrete slab or paved driveway etc.)
- ☐ Into a soak well
- ☐ Into the ground etc.

Qu 2.3.2: What material are the gutters made from?

- ☐ Fibro cement
- ☐ Metal - galvanised steel (colorbond)
- ☐ Other

Downpipes (drainpipes)

Now go around the property and look at all the downpipes.

Qu 2.4: What material(s) are the downpipes/drainpipes constructed from? (Select all that apply)

- ☐ "Fibro" cement
- ☐ Plastic (PVC)
- ☐ Metal (galvanised steel or Colourbond®)
- ☐ Don't know

Qu 2.4.1: Has the "Fibro" cement drainpipe/downpipe been in place since before 1990?

- ☐ Yes
- ☐ No
- ☐ Don't know

Backing boards in electrical meter boxes
Please move to the electrical meter box and open it up.

Qu 2.5: Does the electrical backing board have a smooth finish that is dark brown or black in colour?

- ☐ Yes
- ☐ No
- ☐ Don't know

Qu 2.5.1: Has this electrical meter box been in place since before 1990?

- ☐ Yes
- ☐ No
- ☐ Don't know

Backing board to electrical meter boxes may contain asbestos, similar to the zelemite board shown here.

Fencing
Please inspect the fence line surrounding this property.

Qu 2.6: Is there any fencing on this property that is cement sheeting (aka "Fibro")? Similar to the pictures below.

- ☐ Yes
- ☐ No, the entire fence line is made from other materials such as Colourbond®, brick, limestone, timber lap etc.
- ☐ Don't know

Qu 2.6.1: Has any section of this fence been in place since before 1990?

- ☐ Yes, either the whole fence line or parts of the fence line have been here since before 1990
- ☐ No, the whole fence line was replaced or installed after 1990
- ☐ Don't know

Qu 2.6.2: How many corrugations (i.e. ridges) are there per panel? See below for examples.

Hardifence (left) is asbestos free and has 5 ridges per panel.

Super Six (right) contains asbestos and has 7 ridges per panel.

- All of the panels have five corrugations
- Some or all of the panels have seven corrugations.

Qu 2.6.3: Do the fence sheets have diamond washer/nut and bolt fixings similar to the one pictured?

- Yes
- No

A diamond washer and nut and bolt fixing

Qu 2.6.4: Do any sections of the fence line have capping? And if so, what material is the capping?

- ☐ Some or all of the sections have "fibro" cement capping (similar to the first picture below)
- ☐ All of the sections have metal capping (similar to the second photo below)
- ☐ None of the sections have capping

Super Six fencing with asbestos cement capping

Hardifence with metal capping

Qu 2.6.5: Approximately how many sheets of fencing make up your fence line that have 7 ridges together with diamond washer/nut and bolt fixings and/or cement capping?

- Less than 25
- 26 – 50
- 51 – 75
- 76 – 100
- More than 100

Qu 2.6.6: Is the fence (and capping if applicable) painted or sealed?

- ☐ Yes
- ☐ No
- ☐ Don't know

Outbuildings – Sheds and garages

Qu 2.7: Is there an outdoor shed, structure or separate car port on this property?

- ☐ Yes
- ☐ No

Qu 2.7.1: Has it been here since before 1990?

- ☐ Yes
- ☐ No
- ☐ Don't know

Qu 2.7.2: Are any sections of wall and/or roof of the outdoor shed, structure or car port made from corrugated or flat cement sheeting?

- ☐ Yes, roof and walls
- ☐ Yes, walls only
- ☐ Yes, roof only
- ☐ No, they are both constructed from another material (i.e. galvanised steel sheeting, corrugated iron, timber, brick etc.)

Shadowline used for external wall cladding on an outbuilding. Note the flat corrugated profile.

Corrugated cement sheeting used for roofing and Shadowline used for external wall cladding on an outbuilding

Qu 2.7.3: Are the walls made up of individual panels that have visible joiner strips?

- ☐ Yes
- ☐ No

The outside module of this questionnaire is now complete. Please make your way to the inside of the house in order to begin the next module.

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Module 3: Potential locations of ACM inside your home

Interior walls

Qu 3.1: Are any inside walls/wall panels (including cupboards, closets, and splash backs) made from a material other than brick, concrete or wood? (i.e. are any walls plasterboard or "fibro" cement)?

- □ Yes
  - *If yes then* Please select in what areas? (Select all that apply)
    - □ Bathroom
    - □ Toilet
    - □ Laundry
    - □ Kitchen
    - □ Veranda/sleep out
    - □ Other
- □ No
- □ Don't know

Qu 3.1.1: Have these walls been in place since before 1990?

- □ Yes
- □ No
- □ Don't know

Qu 3.1.2: Are there any walls made up of individual panels that have visible joiner strips or are they 'flush' walls without joiners?

- □ Yes, walls have visible joiners
- □ No, walls are flush without joiners

Qu 3.1.3: Do any of the wall surfaces have a marbelled or Terazzo finish?

- □ Yes
- □ No
- □ Don't know

Qu 3.1.4: Are there any wall tiles in the laundry, toilet or bathroom that have been in place since before 1990?

- ☐ Yes, all or a section of wall tiles have been in place since before 1990
- ☐ No, there are no wall tiles or they have all been replaced since 1990
- ☐ Don't know

Ceilings

Qu 3.2: Are any sections of the ceiling made up of individual panels that have visible (wooden or other) joiner strips? (Similar to the ceiling pictured below)

- ☐ Yes, ceiling has visible joiners
- ☐ No, ceiling is smooth

Ceiling made from asbestos cement sheeting. Note the thick battens or joining strips.

Interior flooring

Qu 3.3: Is there vinyl sheet linoleum or vinyl tile flooring anywhere in the house?

- ☐ Yes
- ☐ No

The backing to linoleum and vinyl sheet flooring commonly contained asbestos which can be exposed when the flooring is damaged or degraded, as seen here. Asbestos may also be within the vinyl tiles.

Qu 3.3.2: Was this linoleum or vinyl tile flooring installed before 1990?

- ☐ Yes
- ☐ No
- ☐ Don't know

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Qu 3.3.3: Are there any rooms with the original carpet that was installed pre-1970?

- ☐ Yes
- ☐ No
- ☐ Don't know

Hessian bags were sometimes used as carpet underlay in homes built before the 1970s. The hessian bags were originally used in the transport of raw asbestos fibres and then recycled as carpet underlay. Unfortunately, they were still contaminated with asbestos.

Heater flue pipe in living areas

Qu 3.4: In any of the living areas, is there an old heater (wood, gas or otherwise) that has a flue (chimney) coming out of it and going into the roof?

- ☐ Yes
- ☐ No

Qu 3.4.1: Was this installed prior to 1990?

- ☐ Yes
- ☐ No
- ☐ Don't know

Qu 3.4.2: What material is this flue pipe constructed from?

- ☐ Fibre Cement
- ☐ Metal
- ☐ Brick Chimney
- ☐ Other
- ☐ Don't know

Priority Assessment

Qu A: What is the current condition of *insert name of material*?

- ☐ Good: Material is intact (undamaged). There is no or minimal visible water damage, physical damage, or deterioration; no signs of breakdown of any asbestos cement surface through weathering.
- ☐ **Fair:** Material has minor damage or deterioration; a few scratches or surface marks; the material is mostly intact; for fencing, slight breakage through plant contact. Any friable (loose or easily crumbled) material is well contained.
- ☐ Poor: There is moderate breakage, damage or deterioration of materials such as cracks, splits, scratches, panel buckling/distortion, or visible water damage. May have some loose asbestos fibres on the surface of the material. For fencing, there are visible, raised asbestos fibres or moss growth on surfaces due to weathering and age. If you were to touch, gently rub or apply light pressure to the material, the surface material may crumble. Enclosure of any friable material is incomplete or deteriorating.
- ☐ Very Poor: There is major breakage, damage, distortion or deterioration of materials such as multiple major cracks, splits and scratches. Materials such as floor tile extensively damaged and underlying mastic exposed. In the most damaged areas the surface material crumbles very easily upon contact. Any friable material is poorly contained.

Qu B: Please rank the overall condition of *insert name of material* on a scale of 1 to 10?

1 2 3 4 5 6 7 8 9 10

Very Poor Very Good

Qu C: What is the likelihood of *insert name of material* being disturbed from access, use, repair, and/or renovation and maintenance activity?

- ☐ **Unlikely:** Material is unlikely to be disturbed due to no or limited access (i.e. isolated or inaccessible location), no foreseeable need of maintenance or repair, and/or there are no immediate plans for renovation.
- ☐ **Somewhat likely:** Material is somewhat likely to be disturbed due to either occasional access (more than once per year but less than monthly), potential need for minor repairs, and/or possible renovations involving the area containing the ACM in the future.
- ☐ **Likely:** Material is likely to be disturbed due to either frequent or routine access (i.e. externals of residence and well trafficked areas), likely repairs in the future and/or likely/probable renovations of the area containing the ACM.
- ☐ **Highly likely:** Material is highly likely to be disturbed from either frequent or very frequent access (i.e. internals of residence accessed through occupancy, such as kitchens or main bathrooms), planned repairs in the near future, and/or almost certain renovations of the area containing the ACM.

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Reports Tab: Results and general recommendations

The participant will receive instant feedback from the application with a summary of the results from the questionnaire accompanied by general recommendations being made available to the user within the app. This report is generated as a pdf file and can be exported (emailed or saved to the mobile device). The 'Reports' tab on the home page allows users to access reports from previously completed questionnaires. See the following page for an example report that was generated on the 2nd of August 2016 and exported from ACM Check.

ACM Report, 2 August 2016

Postcode: 6147	House built: 1985 - 1990			
Probability house contains asbestos based off house age: Possible				
Product type	**Probability of being an ACM**	**Current condition**	**Potential for disturbance**	**Overall rating**
Outside				
Exterior wall cladding	Unlikely			
Eaves / soffit lining	Likely	Good	Unlikely	Very low priority
Roofing	Unlikely			
Gutters	Unlikely			
Drainpipes / downpipes	Unlikely			
Backing board in electric meter box	Likely	Good	Unlikely	Very low priority
Fencing	Likely	Fair	Somewhat likely	Low priority
Outbuilding roof	Unlikely			
Outbuilding walls	Unlikely			
Inside				
Interior walls	Unlikely			
Backing to wall tiles	Possible	Good	Unlikely	Very low priority
Ceiling	Unlikely			
Linoleum or vinyl tile flooring	N/A			
Heater flue pipe	N/A			

Recommendations
• If you wish for the possible or likely ACM identified in this app to be confirmed as containing asbestos, we recommend that you have the suspect ACM sampled. • However, members of the public are advised not to undertake destructive sampling (i.e. sampling that involves cutting or breaking the material) and/or any sampling which involves friable ACMs, such as asbestos pipe lagging or asbestos fuses. To have these materials sampled please contact a qualified asbestos professional and have it tested at a laboratory accredited by NATA for asbestos analysis. • A list of certified labs can be found here or by calling 08 9486 2800. • To conduct passive sampling, i.e., collecting tape dust samples or picking up suspect ACM fragments, please refer to section 6.1 'Sampling and Analysis' found in the following document: Guidance Note: Identification of asbestos containing material. • Based on the overall rating of each possible or likely ACM (i.e. very Low priority, low priority, moderate priority, high priority), consult the following table for general recommendations.

OVERALL RATING	GENERAL RECOMMENDATIONS / ACTIONS
Very low priority	**Monitor and no immediate action necessary.** Monitoring of potential ACM for any signs of visible deterioration or damage. ACM in good condition may benefit from preventive maintenance actions including painting, sealing or encapsulating.
Low priority	**Monitor and minor maintenance/repair.** Monitoring of the ACM should be conducted frequently. Maintenance and repair procedures should be considered as a short term measure for any minor damages (sealing cracks and surface scratches, painting the product if appropriate etc.) with plans for removal in the long term (pending on monitoring of the condition of the ACM).
Moderate priority	**Removal and replacement should be a priority. Major repair activity should be considered as a secondary and temporary action.** Maintenance and repair may be of insufficient benefit. It is recommended that you have the ACM removed and replaced. It is suggested that you contact your local government environmental health officer for advice and consider using the services of a licensed asbestos professional (depending on the work to be undertaken, this may be either a restricted or unrestricted asbestos removal license holder).
High priority	**Consult an asbestos professional for removal, disposal and replacement of the ACM.** Removal and replacement of the product as soon as possible is strongly recommended. It is highly recommended that you consult with an asbestos professional (e.g., local government environmental health officer, occupational hygienist, licensed asbestos removalist) for advice on how to deal with the ACM. For certain ACMs (i.e., friable ACMs) that are to be removed, it is strongly recommended that a professional with an Unrestricted Asbestos Removal License obtained from WorkSafe be used to remove and dispose of the material. View a list of Unrestricted Asbestos Removal License holders based in WA.

Appendix I: Additional Results Tables for Phase Three

Table 23 Number of inspections conducted using ACM Check in each Australian state and territory

State or Territory	Freq. (n)	Percent (%)
Western Australia	276	59.9%
Australian Capital Territory	6	1.3%
New South Wales	45	9.8%
Northern Territory	2	0.4%
Queensland	38	8.2%
South Australia	10	2.2%
Tasmania	15	3.3%
Victoria	69	15%
Total	461	100%

Table 24 Summary of priority assessment of positive materials in Western Australian and other Australian houses

Factor	WA (n=708)	Other (n=558)	Total (N=1266)
Current condition			
Good	295 (41.7%)	208 (37.3%)	503 (39.7%)
Fair	294 (41.5%)	215 (38.5%)	509 (40.2%)
Poor	101 (14.3%)	86 (15.4%)	187 (14.8%)
Very poor	18 (2.5%)	49 (8.8%)	67 (5.3%)
Potential for disturbance			
Unlikely	345 (48.7%)	221 (39.6%)	566 (44.7%)
Somewhat likely	244 (34.5%)	187 (33.5%)	431 (34 %)
Likely	64 (9%)	81 (14.5%)	145 (11.5%)
Highly likely	55 (7.8%)	69 (12.4%)	124 (9.8%)
Priority level			
Very low	383 (54.1%)	238 (42.7%)	621 (49.1%)
Low	166 (23.4%)	147 (26.3%)	313 (24.7%)
Moderate	136 (19.2%)	126 (22.6%)	262 (20.7%)
High	23 (3.2%)	47 (8.4%)	70 (5.5%)
Total positive materials	708 (100%)	558 (100%)	1266 (100%)

**Excluding 'wall tile backing'*

Table 25 Western Australian and other Australian state and territory houses with materials categorised as 'possible' and 'likely' for asbestos by ACM Check

Category	WA (n=276)			Other (n=185)			Total (N=461)		
	Negative	Possible	Likely	Negative	Possible	Likely	Negative	Possible	Likely
Outside									
Exterior wall cladding	227 (82.2%)	0	49 (17.8%)	145 (78.4%)	0	40 (21.6%)	372 (80.7%)	0	89 (19.3%)
Eaves	169 (61.2%)	24 (8.7%)	83 (30.1%)	89 (48.1%)	15 (8.1%)	81 (43.8%)	258 (55.9%)	39 (8.5%)	164 (35.6%)
Roof	256 (92.8%)	0	20 (7.2%)	159 (85.9%)	0	26 (14.1%)	415 (90%	0	46 (10%)
Gutters	270 (97.8%)	0	6 (2.2%)	174 (94.1%)	0	11 (5.9%)	444 (96.3%)	0	17 (3.7%)
Downpipes	253 (91.7%)	8 (2.9%)	15 (5.4%)	160 (86.5%)	10 (5.4%)	15 (8.1%)	413 (89.6%)	18 (3.9%)	30 (6.5%)
Backing board to electrical meter box	128 (46.4%)	27 (9.8%)	121 (43.8%)	99 (53.5%)	15 (8.1%)	71 (38.4%)	227 (49.2%)	42 (15.1%)	192 (41.6%)
Fencing	136 (49.3%)	26 (9.4%)	114 (41.3%)	168 (90.8%)	7 (3.8%)	10 (5.4%)	304 (65.9%)	33 (7.2%)	124 (26.9%)
Outbuilding walls	253 (91.7%)	12 (4.3%)	11 (4%)	156 (84.3%)	6 (3.2%)	23 (12.4%)	409 (88.7%)	18 (3.9%)	34 (7.4%)
Outbuilding roof	259 (93.8%)	0	17 (6.2%)	160 (86.5%)	0	25 (13.5%)	419 (90.9%)	0	42 (9.1%)
Inside*									
Interior walls	231 (83.7%)	0	45 (16.3%)	134 (72.4%)	0	51 (27.6%)	365 (79.2%)	0	96 (20.8%)
Ceiling	220 (79.7%)	0	56 (20.3%)	127 (68.6%)	0	58 (31.4%)	347 (75.3%)	0	114 (24.7%)
Interior flooring	222 (80.4%)	18 (6.5%)	36 (13%)	118 (63.8%)	10 (5.4%)	57 (30.8%)	340 (73.8%)	28 (6.1%)	93 (20.2%)
Heater flue	256 (92.8%)	16 (5.8%)	4 (1.4%)	158 (85.4%)	11 (5.9%)	16 (8.6%)	414 (89.8%)	27 (5.9%)	20 (4.3%)

Excluding 'wall tile backing'

Table 26 Current condition ratings of materials inspected in Western Australian and other Australian state and territory houses

Category	WA only (n=276)					Other (n=185)				
	No asbestos	Good	Fair	Poor	Very poor	No asbestos	Good	Fair	Poor	Very poor
Outside										
Exterior wall cladding	227 (82.2%)	17 (6.2%)	23 (8.3%)	8 (2.9%)	1 (0.4%)	145 (78.4%)	13 (7%)	15 (8.1%)	10 (5.4%)	2 (1.1%)
Eaves	169 (61.2%)	41 (14.9%)	51 (18.5%)	14 (5.1%)	1 (0.4%)	89 (48.1%)	41 (22.2%)	40 (21.6%)	9 (4.9%)	6 (3.2%)
Roof	256 (92.8%)	4 (1.4%)	12 (4.3%)	3 (1.1%)	1 (0.4%)	159 (85.9%)	6 (3.2%)	10 (5.4%)	5 (2.7%)	5 (2.7%)
Gutters	270 (97.8%)	2 (0.7%)	2 (0.7%)	2 (0.7%)	0	174 (94.1%)	2 (1.1%)	4 (2.2%)	3 (1.6%)	2 (1.1%)
Drainpipes/ Downpipes	253 (91.7%)	10 (3.6%)	9 (3.3%)	4 (1.4%)	0	160 (86.5%)	9 (4.9%)	7 (3.8%)	6 (3.2%)	3 (1.6%)
Backing board to electrical meter box	128 (46.4%)	100 (36.2%)	37 (13.4%)	10 (3.6%)	1 (0.4%)	99 (53.5%)	44 (23.8%)	30 (16.2%)	7 (3.8%)	5 (2.7%)
Fencing	136 (49.3%)	30 (10.9%)	74 (26.8%)	31 (11.2%)	5 (1.8%)	168 (90.8%)	4 (2.2%)	7 (3.8%)	5 (2.7%)	1 (0.5%)
Outbuilding walls	253 (91.7%)	7 (2.5%)	10 (3.6%)	6 (2.2%)	0	156 (84.3%)	6 (3.2%)	14 (7.6%)	5 (2.7%)	4 (2.2%)
Outbuilding roof	259 (93.8%)	6 (2.2%)	6 (2.2%)	4 (1.4%)	1 (0.4%)	160 (86.5%)	7 (3.8%)	10 (5.4%)	7 (3.8%)	1 (0.5%)
Inside*										
Interior walls	231 (83.7%)	26 (9.4%)	17 (6.2%)	2 (0.7%)	0	134 (72.4%)	22 (11.9%)	19 (10.3%)	6 (3.2%)	4 (2.2%)
Ceiling	220 (79.7%)	31 (11.2%)	18 (6.5%)	6 (2.2%)	1 (0.4%)	127 (68.6%)	26 (14.1%)	23 (12.4%)	6 (3.2%)	3 (1.6%)
Interior flooring	222 (80.4%)	18 (6.5%)	21 (7.6%)	11 (4%)	4 (1.4%)	118 (63.8%)	16 (8.6%)	28 (15.1%)	13 (7%)	10 (5.4%)
Heater flue	256 (92.8%)	3 (1.1%)	14 (5.1%)	0	3 (1.1%)	158 (85.4%)	12 (6.5%)	8 (4.3%)	4 (2.2%)	3 (1.6%)
Total (all materials)*	**2880 (80.3%)**	**295 (8.2%)**	**294 (8.2%)**	**101 (2.8%)**	**18 (0.5%)**	**1847 (76.8%)**	**208 (8.6%)**	**215 (8.9%)**	**86 (3.6%)**	**49 (2%)**

*****_Excluding 'wall tile backing'_

Table 27 Potential for disturbance ratings of materials inspected in Western Australian and other Australian state and territory houses

Category	WA only (n=276)					Other (n=185)				
	No asbestos	Unlikely	Somewhat likely	Likely	Highly likely	No asbestos	Unlikely	Somewhat likely	Likely	Highly likely
Outside										
Exterior wall cladding	227 (82.2%)	20 (7.2%)	14 (5.1%)	11 (4%)	4 (1.4%)	145 (78.4%)	17 (9.2%)	14 (7.6%)	4 (2.2%)	5 (2.7%)
Eaves	169 (61.2%)	57 (20.7%)	35 (12.7%)	10 (3.6%)	5 (1.8%)	89 (48.1%)	49 (26.5%)	28 (15.1%)	13 (7%)	6 (3.2%)
Roof	256 (92.8%)	10 (3.6%)	9 (3.3%)	0	1 (0.4%)	159 (85.9%)	7 (3.8%)	9 (4.9%)	6 (3.2%)	4 (2.2%)
Gutters	270 (97.8%)	2 (0.7%)	3 (1.1%)	1 (0.4%)	0	174 (94.1%)	2 (1.1%)	5 (2.7%)	2 (1.1%)	2 (1.1%)
Drainpipes/ Downpipes	253 (91.7%)	16 (5.8%)	6 (2.2%)	1 (0.4%)	0	160 (86.5%)	13 (7%)	7 (3.8%)	5 (2.7%)	0
Backing board to electrical meter box	128 (46.4%)	90 (32.6%)	41 (14.9%)	12 (4.3%)	5 (1.8%)	99 (53.5%)	47 (25.4%)	25 (13.5%)	5 (2.7%)	9 (4.9%)
Fencing	136 (49.3%)	67(24.3%)	49 (17.8%)	18 (6.5%)	6 (2.2%)	168 (90.8%)	6 (3.2%)	9 (4.9%)	1 (0.5%)	1 (0.5%)
Outbuilding walls	253 (91.7%)	9 (3.3%)	8 (2.9%)	3 (1.1%)	3 (1.1%)	156 (84.3%)	8 (4.3%)	11 (5.9%)	5 (2.7%)	5 (2.7%)
Outbuilding roof	259 (93.8%)	7 (2.5%)	8 (2.9%)	0	2 (0.7%)	160 (86.5%)	9 (4.9%)	10 (5.4%)	3 (1.6%)	3 (1.6%)
Inside*										
Interior walls	231 (83.7%)	14 (5.1%)	21 (7.6%)	2 (0.7%)	8 (2.9%)	134 (72.4%)	15 (8.1%)	17 (9.2%)	10 (5.4%)	9 (4.9%)
Ceiling	220 (79.7%)	30 (10.9%)	18 (6.5%)	3 (1.1%)	5 (1.8%)	127 (68.6%)	25 (13.5%)	20 (10.8%)	8 (4.3%)	5 (2.7%)
Interior flooring	222 (80.4%)	17 (6.2%)	21 (7.6%)	3 (1.1%)	13 (4.7%)	118 (63.8%)	8 (4.3%)	27 (14.6%)	17 (9.2%)	15 (8.1%)
Heater flue	256 (92.8%)	6 (2.2%)	11 (4%)	0	3 (1.1%)	158 (85.4%)	15 (8.1%)	5 (2.7%)	2 (1.1%)	5 (2.7%)
Total (all materials)*	**2880 (80.3%)**	**345 (9.6%)**	**244 (6.8%)**	**64 (1.8%)**	**55 (1.5%)**	**1847 (76.8%)**	**221 (9.2%)**	**187 (7.8%)**	**81 (3.4%)**	**69 (2.9%)**

*****_Excluding 'wall tile backing'_