Accuracy of a mobile app to identify suspect asbestos-containing material in Australian residential settings

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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.

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 (i.e. cement), have insulating properties, are flexible, and resistant to heat and chemical corrosion.[1, 2] 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 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.[3-9]

Australia is a case in point. Australia was the highest consumer of asbestos on a per capita basis during the mid-20th century,[10] and it is likely that almost all Australian households built prior to 1990 contain some form of asbestos.[11] 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.[5, 12] 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.[13] 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.

METHODS

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).

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.

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.[(13)] 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 1). 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.

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 (ASEA) and WorkSafe (Western Australia) as a competent person to conduct inspections for asbestos.[14] All inspections followed a template to ensure that the 14 key locations/categories included in ACM Check (Table 1) were also assessed by the consultant. The consultant was blinded to the answers collected using ACM Check.

Statistical Analysis

To determine the level of agreement between ACM Check and the environmental consultant’s assessments in regards 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).

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.[14]

Samples were analyzed at a National Association of Testing Authorities accredited laboratory. The method of asbestos identification was a qualitative identification of fiber 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 fibers detected,’ and ‘synthetic mineral fibers 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.

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 1). 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.

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. 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 fibers detected. There was substantial agreement between the consultant's opinion and the laboratory analysis (κ=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 Table 1). There was a fair strength of agreement between the app and laboratory analysis (κ=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.

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 2). 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 2) 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 (κ=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 2).

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 Table 2). 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 Table 2). 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 ($\kappa=0.718$, $p<0.001$). ACM Check had a sensitivity of 86% and specificity of 91.2% (Table 3). Agreement improved after excluding wall tile backing from the analysis (Table 3).

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 ($\kappa=0.918$), outbuilding walls ($\kappa=0.844$), and backing board to electrical meter box ($\kappa=0.826$) (Table 3). However, agreement between ACM Check and the onsite inspection was only fair for outbuilding roof ($\kappa=0.375$) and interior flooring ($\kappa=0.304$). 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 Table 2). 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 Table 2). 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 3).

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.[(15)] 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 fibers 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.

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.

CONCLUSIONS

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, the results from this study suggest that ACM Check can be modified for use in other countries by changing factors such as the years of asbestos use and types of ACM used. It can also be used as a data collection tool to identify the prevalence of *in situ* asbestos throughout the built environment.

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FIGURES

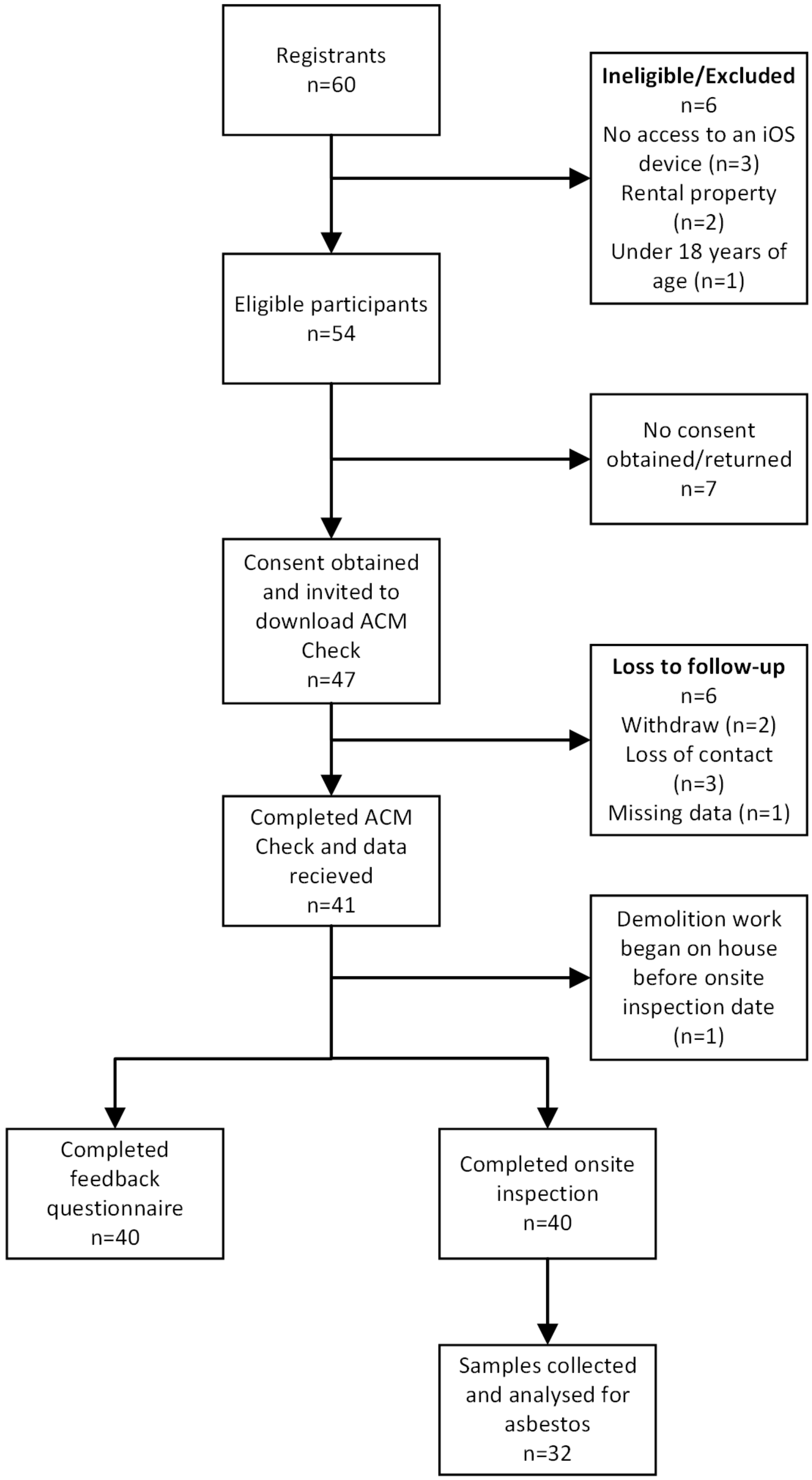

Figure 1. Flowchart showing participant recruitment and stages of data collection

TABLES

Table 1. 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

Table 2. Properties categorized 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%)	

Table 3. Agreement between ACM check and environmental consultant for categorization 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*