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Strategies for searching bricked up and concreted over objects

Establishing forensic search protocols within engineered structures

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ABSTRACT

The burial of objects (human remains, explosives, weapons) below or behind concrete, brick, plaster or tiling may be associated with serious crime and are difficult locations to search. These are quite common forensic search scenarios but little has been published on them to-date. Most documented discoveries are accidental or from suspect/witness testimony. The problem in locating such hidden objects means a random, or chance-based approach is not advisable. A preliminary strategy is presented here, based on previous studies, augmented by primary research where new technology or applications are required. This blend allows a rudimentary search workflow, from remote desktop study, to non-destructive investigation through to recommendations as to how the above may inform excavation. Published case studies on the search for human remains demonstrate the problems encountered when trying to find and recover sealed-in and sealed-over locations. Established methods include desktop study, photography, geophysics and search dogs: these are integrated with new technology (LiDAR and laser scanning; photographic rectification; close-quarter aerial imagery; ground-penetrating radar on walls and gamma-ray/neutron activation radiography) to propose this possible search strategy.

1. Introduction

1.1 General Background

Concrete, brick and other constructed layers are like hard natural surfaces (mineral crusts, rock) in that they are not diggable [1, 2] by either the perpetrator or investigator, making some aspects of established search methodology inapplicable [3]. Such a horizontal hard layer may cover an object in the floor of a building; occur over a pre-existing void (natural collapses like caves; human-made – drains, wells, basements), or an intentionally-dug outdoor (soil-based) burial. Brick, blocks and cement may also encase something in the vertical or inclined wall of a structure, again be it excavated for the purpose, or pre-existing (e.g. a chimney flue). Concrete, tiles and brick (for instance) differ from naturally-firm ground in that humans can create hard constructed surfaces, providing a specific challenge for the search specialist where only some of the guidelines for the search of soil, sediment [4] and open ground apply: part of the impetus behind writing this work. Common items that may be hidden in, below and behind such hard, made-structures include: human remains (dead or alive when hidden); other organic remains (liquor, animals, some drugs); valuable items (legally owned, but needing to be hidden) stolen goods or contraband, weapons, explosives. Most common are human bodies, often the result of murder/homicide and death from accidents [6] or natural causes.

1.2 Rationale for This Work

Although [5, 7, 8] indicate that such burial locations (summarised above) are uncommon, they are often high-profile, may need good planning by the perpetrator, and can be the result of premeditation, especially by serial killers (see review below). Conversely, Hawley et al. [6] state, “Common paving materials--concrete and asphalt--pose an unusual and complex barrier to disinterment and examination of human remains. Although not commonly encountered, these materials are seen with sufficient frequency to justify consideration of the procedures and equipment necessary for disinterment”. The type of perpetrator and nature of the burial/immurement make such hidden items difficult to detect, another rationale for writing this work. An object hidden behind bricks, in a brick wall, or below concrete slabs amongst other slabs, show far subtler lateral variations than in soil or vegetational disturbances for the search team to observe, but as every contact leaves a trace, so movement of materials will leave some impression. In beginning to devise a strategy for the search of such areas, the authors have inevitably compromised between a) reviewing the literature to extract the most fit for purpose methods and b) presenting examples of cases studied in order to combine published and unpublished work and develop a preliminary set of possible ways to investigate cases. The work is thus a mixture of background information, published cases and published methods (where available) and the author's own casework, especially where previous studies are unavailable.

Although brick and concrete are known from Egyptian times, the ease of moulding and drying mud has made bricks and clay tiles common building materials through history and pre-history. Bedouins (6500BC) knew how to make concrete, and this technology was used very extensively during Roman times, as the calcium-rich volcanic ash found near Naples in Italy provided a ready source copied elsewhere throughout their empire. British engineers in the 1800s revitalized the making of concrete and began the use of Portland Cement, when some of the earliest stories of burial and immurement start to emerge, although older historic clandestine activities using brick and concrete are possible. As with other developments in forensic science, early suggestions of hiding objects beneath floors and in walls occur in popular literature, such as Edgar Allen Poe's book 'The Cask of Amontillado' [9], in which a person is encased behind a wall alive (immurement). Many such stories have been used since, like novels such as Jackson's 2012 popular book, 'Impression of Bones' in which the central character, in restoring an old castle, discovers an historic murder victim bricked up in the fireplace. Popular books based on real crimes abound and these cases illustrate the need for some strategy in searching such problematic locations. These range from rumours to actual cases. The former include the possibility that the notorious U.S. Labour leader Jimmy Hoffa is encased somewhere in concrete following his 1975 disappearance. The proven include serial killers such as Fred West (and accomplice, his wife Rose) who buried teenage female victims in their English garden and below the concrete floor of their basement [10]. John Wayne Gacy [11] stands out as one of the best-known serial killers to bury victims below a concrete floor, as Sullivan and Maiken [11] state: "William Carroll was murdered and buried directly beneath Gacy's kitchen. Carroll may have been the first of four youths known to have been murdered between June 13 and August 6, 1976, and who were buried in a common grave located beneath Gacy's kitchen and laundry room …John Butkovitch, being found buried beneath the concrete floor of his garage precisely where Gacy had marked the youth's grave with a can of spray paint.” The spread of such popular literature, and shrewdness of some perpetrators, has caused immurement and below-floor burial to continue, with cases such as Marc Dutroux (Belgium, buried three persons beneath concrete in 1995-96); Saeed Qashash (Jordan, hid 11 victims of a mass-shooting behind a brick wall in 1999); Dr. Larry C. Ford (Irvine, Utah, had high grade explosives buried below concrete in his yard, 2000); Ward Weaver (Oregon City, 2004) killed his daughter’s friends and buried them beneath concrete; Michael Lock (Milwaukee, 2011), accused of having 3 bodies buried under concrete; Michael Fogt (Hillsboro, Ohio 2013), placed victim in a barrel and buried below concrete.

Such popular stories show the high-profile nature of such burials and hidden materials, reflected in a number of scientific publications concerning burial type and anthropology/archaeology. Congram’s work [12] in Costa Rica is a thorough account of the search strategy in woodland for a grave with concrete over the top. As such, this work is more akin to the classic open-ground search strategies devised by [3]. Congram [12] outlines the 10 sites identified and how the third was the grave. The concrete cap broke up on excavation, the biggest problem in recovery being the continual filling of the grave with rainwater. Dedouit et al. [7] found excavation of concrete to be their main issue, with the lifting of concrete slabs being ‘unwieldy’, their investigation concentrating on the excavation rather than search. Faller-Marquardt et al. [13] faced similar problems in excavating a polymer-bound cement. Such mixes are common in modern concrete and make breaking up of any cap to a grave or burial very difficult. Hawley et al. [6] go further, in outlining the seven cases they have dealt with, each using different cement/concrete mixes, some reinforced with metal rebars, others prefabricated and yet others laid as liquid. Again, their focus is on recovery not detection, although they do comment (p.105) on how the possible use of X-ray or gamma-ray imaging (methods discussed below) could have advanced their case, two methods described below. Madea et al [14] describe two cases of victims buried in cellars/basements, with concrete poured over the top. One was discovered following a confession the second after a witness observed the concrete being poured in from a ready-mixed truck.

Preuß et al [5] provide one of three of the most relevant background publications to this work. They state that “Common methods of dumping (n=?) are covering (31.4%), dumping (22.3%), burying (21%), leaving in lonely places (14.2%), concealing in boxes, fountains or caves (8.2%), dismemberment (7%) and combusting (2.9%) … exceptions … are dissolving in chemicals, feeding to animals, cannibalism and sealing with concrete and/or bricks. We (they) report on a series of six cases of dumping using setting in concrete and/or immuring with bricks." Their cases include the two included in Madea et al and a third that is similar (a cellar filled with concrete). Their Case 4 concerned a concrete-filled trough, flush to a wall, wherein the decomposition smell permeated an adjacent basement, leading to discovery. Case 5 was a body bricked up behind a basement staircase, found by cadaver dogs and their Case 6 concerned a burial in a garden (covered with concrete), discovered following inconsistencies in the suspect's story. The second most relevant work is that of Toms, [15] who recorded 5 deaths in 18 years in the Los Angeles police authority area where concrete had been used to cover the victims. One of their cases was an accidental discovery, the other four were from admissions and tip-offs. The investigators used metal detectors and x-ray imaging to define their excavations, but knew from the above information where the victim (if any) would likely be. The third work presented results of a simulated clandestine burial of a murder victim under domestic concrete patio slabs in an outdoor semi-urban environment [Fig. 1a and 16]. The pig cadaver was repeatedly geophysically surveyed over a 2 year monitoring period every three months, using 110 MHz, 225 MHz, 450 MHz and 900 MHz frequency antennae. An indistinct ½ hyperbolic reflection event was observed in the 110 MHz frequency 2D profiles throughout the study period over the animal cadaver, with it becoming progressively harder to detect (Fig. 1b). Clear ½ hyperbolic reflection events were imaged by 225 MHz and 450 MHz frequency 2D profiles up to 12 months after burial, after this period results were more indistinct. From 18 months post-burial to the end of the study a horizontal reflection event was observed over the animal cadaver (Fig. 1b). This was suggested to be caused by an air gap underneath the patio, caused by compaction of the grave soil, with a slight surface depression in the patio slabs also observed. This air gap was suggested to be an important target for forensic search teams if a suspected burial was more than 18 months old. This has also been observed in GPR 2D profiles over older shallowly grave vaults topped with horizontal stone slabs in UK graveyards and cemeteries [17]. A ½ hyperbolic reflection event was observed in the 900 MHz 2D profiles throughout the study but it would be difficult to differentiate this anomaly from the other non-target anomalies also present in the datasets (Fig. 1b). Potential forensic geoscience detection elements are summarized in Figure 1c schematic diagram.

In summary, whether human remains, explosives, drugs or other items behind a wall, in a covered cellar or beneath a stone, brick or concrete floor, the same problem faces those conducting a search: the location of any anomalies that could indicate the presence of the hidden item(s). Some of the above workers have used elements of what is combined and expanded on here as a logical search strategy. This follows similar strategies for countryside-based searches, with substantial modifications.

2. Pre-contact Search Strategy

The suggested workflow discussed here, follows elements of a regular search strategy [3] in a sequence from the completely non-invasive (desktop study), to largely non-destructive analyses [18] to non-invasive search where contact is made with the location (walk-over, photography, search dog(s) and geophysics) to minimally invasive (drilling, endoscope). The process of excavation and recovery of objects is not described, but some comments on excavation learnt from an iterative search strategy (that includes subsurface imaging of the target areas) are made. A misconception experienced by the authors is of those calling in scientists to assist in the search for hidden objects, is that intelligence, intuition, scientific devices will instantly produce results. The search coordinator is often disappointed with the caution a scientifically-based search specialist will show: the request is often due to some misconception of the reality behind such science. An excellent example is Billinger's [19] description of a case using ground-penetrating radar, where several false-positive anomalies were discovered, but no buried body. 'Can you come and use your x-ray machine to find an object in X place?' is a common question, when the answer is 'not until you tell me what the target is, what it is in, and what other complications may exist'. In other words, there is no magic bullet (as the review above shows) and these locations are really difficult to find things in, hence the need to gather all the available information first, from non-invasive, non-destructive to minimally invasive.

2.1. Desktop study

Unlike a countryside-based search where geology, soils, vegetation and changing land use are critical to a desktop study, for searches of areas where objects maybe below, behind or within concrete, cement, brick or similar, the search is pre-focused on these materials. This may be suspect location (home, work, known places visited), confession or witness reports. If the use of such hard media has been in soils or soft ground (as in [12]), so the search strategy of [3 and 12] may apply, as covert yet accessible, diggable ground is often needed, which geology and soil maps can help define. In urban environments, changes in landuse, (as recorded in planning applications for buildings and town plans from local/municipal authorities) can show what areas of concrete and buildings were planned as opposed to what is observed. Naturally, areas of building not included in municipal plans do not point immediately to suspicious activity other than disregard for the authorities and their planning process, or poor recording. More importantly, such records show when building or repair took place, which if consistent with other records, (see below) may be coincident with the time a person went missing or the activity of a suspect, excluding some areas/buildings from high priority searches and including others for further investigation by the means outlined below. Some buildings and surfaces pre-date planning records, but maybe suspect locations, in which case the history of the area and building can be critical. Such information may be kept in a public records office, or come from local information (stone masons, architects, builders, local history societies). Official records of legally-approved modification/repair to an historic building or area may once again exclude some locations, or make other places of increased significance. While non-official records/memories of local people may be subject to the vagaries of time, they are in effect witness testimony and can be valuable, if consistent with other information. An assessment of personal memories needs to be made, with caution for each case.

2.2. Walk-around survey

When (in the time allowed) as much pre-existing (desktop) information has been gathered, a look at the location and surrounding area prior to deciding how to proceed is advisable. This may have to be the month, day or hours before any further action is taken, for logistical reasons like travel to the site, imminent arrest of suspect(s), demolition of the feature or other compromise (weather, local hostility, media interest). Whatever period of time exists prior to deployment of further search assets, this is valuable for personal reflection, discussion and re-examination of the desktop information. A walk-around consideration may provide information on access to the site (who had this, where they came from, what possible eye-witnesses could see) as well as noting areas of different construction (changes in paved surfaces or walls), or indeed destruction (collapsed ground, piles of rubble). Spatially these can be recorded on a map by the specialist or police mapper, and/or by total station/GPS. Vertical features can be informally photographed if need be, although some element of judgment must be used – if one area is of obvious interest then it takes priority until excluded or included for further analysis. Should mappers, GPS not be available, or large numbers of potential targets are observed, some rationale as to how to record them must be used. Any materials likely to be compromised prior to image recording (see below) of the site could be preserved *in situ* (plastic bag covering, small tent) at this moment, or removed, but neither are recommended. Examples maybe loose materials that could be washed away, areas of human activity.

2.3. Imagery

Two common scenarios exist in the search for objects behind or below brick, stones and concrete: the vertical feature (e.g. a wall) and horizontal (a floor or path/road, or soil-based burial).

Vertical and near-vertical features that are to be searched poses the same challenges in recording in that they maybe located on a map, but not suitably recorded as they are orthogonal to a conventional map view. A walk-over survey of such areas may indicate suspect locations. These include areas or patches of different cement type, or moisture content, areas of fresh/different brick, block or stone surrounded by weathered surfaces, changes in mortar type and freshness. For walls or similar that are undergoing weathering (outdoors, damp basements), the observations of a specialist in stone weathering are invaluable, as such scientists can produce colour-coded maps of stone type and weathering [20] that are very helpful in defining a search. Such locations must be photographed in the standard way for crime scene photography. The problem with standard photography is that in the cases considered here, this is not just a record of what was found, but will be used to locate successive techniques. Oblique photographs should be rectified such that the viewer is orthogonal (at 90^0) to the majority of the surface being imaged. In the case illustrated in Figure 2, one of the builders employed to restore a 17th Century barn in Ireland later was suspected of involvement of a murder of a child. The areas he worked on were identified at the desktop stage and examined during walk-over survey. Two locations were noted, but were reconstructed by the suspect at 3-4m height while scaffolding was in place, making them immediately inaccessible for further study. Once police ladders were erected in order to examine the faces, these obscured the view and left the photographer too close to the wall to take an overall photo. Instead, the images were crudely geolocated with coloured stickers and manipulated using standard software [21]. Both sets of images are stored as standard forensic items (time, date stamped and sealed): the rectified images were used to locate the tracks of subsequent x-ray and geophysical surveying. Laser scanning (LiDAR) of large areas (metres) and object scanning of small (centimetres) is more specialist than photography, and although widely used by law enforcement (e.g. near-instant imaging of road traffic incidents), is not common in the search process. Such scans do not require rectification, can be used to create 3-D models of the structure, and record reflectance values from the stone, brick and mortar that can be compared to visual observations and condition surveys [22]. Laser scans are digital records that preserve more than a photograph in that they record the microtopography of surfaces (Fig. 3). The case of the 17th Century barn proved to be a false alarm – no human remains were discovered.

Horizontal (or gently sloping) surfaces (e.g. outdoor concrete/tarmac paving, patios, driveways, roads, parking lots, indoor concrete or tiled floors) are more suited (than vertical surfaces or structures) to recording on a regular crime scene map, measured by tape, laser sight (‘dumpy level’) and GPS. Such maps are not produced in real-time or even a few hours after the initial survey, which if needed to geo-locate further analyses, can delay the operation. A combination of on-site sketches and photographs, back-located onto the crime scene map are often used. Should scaffolding or an elevated platform (often known as a cherry picker) be available, this can be used for overhead photographs or LiDAR scans of rough surfaces. The Unmanned Aerial Vehicle (UAV), or small drone/quadcopter/hexicopter, carrying a camera on a gimble is gaining popularity amongst law enforcement agencies [23]. The UAV can be flown orthogonal to the surface in video mode for assessment and switched to camera-mode for real-time (on-site) imaging (Figure 3), ready to geo-locate further surveys as the device carries a GPS receiver. The UAV can take dual images for the creation of stereo-pairs and digital terrain models, and the camera changed for ultra-violet, infra-red (thermal) and other spectral imagers. The potential for thermal imaging from a UAV of surfaces with suspect burials below has yet to be fully realised.

3. Non-invasive (Contact) Search Strategy

3.1. *Pre-survey limited sampling*

Prior to any surveys that cause contact with the concrete, brick or stone surface to be investigated, some very limited sampling (a few grams) of suspect and surrounding control materials may be considered. Such samples may prove useful in later determination of relative age (from manufacturing process, absolute dating [radiocarbon, uranium-series, optical luminescence]) or possibly provenance of the materials, such as where a perpetrator obtained their construction materials. Should the search stages considered here lead to excavation, naturally many more samples of associated material will be made available for analysis. Standard recording and storage of such samples should occur, with pre- and post-sampling photography and image capture if possible.

3.2 Non-destructive Search Methods

The choice and sequence of investigative methods to be considered can be focused if the nature of the target (size, makeup), position (depth of burial) and surrounding medium (concrete, brick) are known. The better these parameters are defined, so the most fit-for-purpose methods can be used over a smaller area, saving time. The less is known, the more methods will be needed, possibly over a larger area, demonstrating the need for gathering as much time-saving desktop and background information as possible (above). Some case studies [5] mention the use of search dogs, wherein the above statement is true: if general suspicious activity is indicated, cadaver, explosives and drug detecting dogs may all need to be deployed: if the target is almost certainly known, only one type of dog(s) may initially be needed. Because this work is discussing search methods first, the specific location of a target is not known (otherwise the investigator could simply excavate). Therefore, the methods used for contact-based searching commonly begin with those that operate at the largest scale and can be used and evaluated in the least time, roughly from the macro- to the micro-scale. As the micro-scale (around the size of the object to be identified and recovered) of investigation is approached, so methods common in engineering and anthropological/archaeological studies become more relevant, and are only summarized here.

3.3 Geophysical Methods (macro to meso scale)

The most rapid, easiest, cheapest method that can assist a search of areas covered by a hard surface is a metal detector. Being commercially available, many variations exist, with manufacturers claiming their devices can differentiate coins from rings, treasure trove from metal waste. There is some truth in this, in that the frequency, modulation and area of coil detection can all be influenced by the target type. If the target is known to be (or contain) metal (ferrous or non-ferrous), then such a simple and rapid method is to be commended [15]. Three major problems exist with use of the metal detector. First, the most common targets are human bodies, drugs and explosives, all of which may not have metal associated, or be stripped of such. Second, many searches of hard surfaces occur in urban, suburban or agricultural locations, where other metal objects abound: in a rain forest in Costa Rica, Congram [12] discovered numerous metal objects, and on the uninhabited moors of northern England Donnelly [24] found numerous metal objects (including spectacles). Prefabricated concrete slabs may have metal rebar strengthening rods inside. Third, a deeply-buried, small metal object may not be detected by a standard device: the use of a military-grade minimum mine detector may solve this problem where no other artifacts are present that will cause interference or false-positive signals. Although really an aspect of engineering searches, the detection of small metal objects can be achieved using a cable or stud detector. These devices are widely available, can be rapidly deployed (Fig. 4) and allow the exclusion of areas with known (legal) utilities in. The surveyed areas where metal detectors have been used, as well as any metal discoveries, maybe located by differential GPS (sub-millimetre accuracy) and/or plotted on any imagery obtained in the first stages of the search: on vertical surfaces, surveyed areas maybe marked on directly with removable materials (waterproof labels) and cross-checked and marked on rectified photographs or LiDAR/object scans.

Ground penetrating radar (GPR) has been, and remains the most commonly-used true geophysical technique in the investigation of hard surfaces. The number of scholarly articles on the subject and commercial services dedicated to the surveying of concrete are too numerous to list here (e.g. see [25]), as are the general forensic applications, especially in the detection of soil- or sediment- buried human remains (although see [26] for summary). The use of GPR in investigating sub-concrete burials is more limited. [27] commented on the successes and failures of various forensic and archaeological cases, commenting that air-filled crypts or coffins present the best opportunity for GPR imaging. [28] compared different types of controlled graves in the Body Farm, Tennessee, some covered with concrete slabs: they met with good success. [29] discussed the use of GPR in law enforcement and conjunctive approaches for search using GPR where concrete coverings are included. [18] describes a classic case from Edmonton, Canada, in which a body was supposed to be interred beneath the concrete floor of a residential building. A GPR survey revealed some suitable anomalies, none of which turned out to be the target: as a search strategy such as described here was not carried out, we have no idea whether further background checks and other conjunctive analyses would have provided a greater level of assurance.

The above cases largely consider the search of horizontal surfaces that are appropriate for GPR surveying. Less often considered in the literature (hence highlighting the application here), is the use of GPR on inclined or vertical features like walls. Figure 6a shows a section of a tiled wall inside a house where terrorist-related explosive materials were thought to have been hidden. One suspect was a builder, so an expert in tiling was consulted, who identified three areas of unusually-stained or very coarse grout between the tiles (Fig. 6b). A high resolution GPR survey (Fig. 6c) was conducted and targets identified (Fig. 6d). The depth to these targets was modelled using the GPR, as well as their spatial distribution in the wall (Fig. 6e). Using the depth models to avoid destructive contact, explosives experts drilled into the wall and inserted endoscopes, confirming the location of suspicious objects (later recovered as percussion caps and a pipe-bomb).

3.4 Engineering, Anthropology/Archaeology Nondestructive Methods (meso- to micro-scale).

Radiography is one of the most commonly-cited methods in forensic literature [7, 15, 30-32], it being familiar to many of the engineers and anthropologists involved in the work. The most common method requires an x-ray source (inspector) on one side of the suspect feature and detector on the other. This makes x-ray imaging suitable for the search of walls and upstanding structures, where access can be obtained each side of a feature and across a small (centimetres to metres) area, although multiple images or large, specialist search machines can be used over tens of metres. X-ray imaging of inaccessible walls and horizontal surfaces (roads, floors, pavements) is thus impossible as no source can be placed behind the surveyed surface. X-ray sources are hazardous to human health and so restrictions are placed on where surveys may occur. An associated technique uses neutron activation as the radiological source (prompt gamma-ray neutron activation analysis or PGNAA), allowing assessment of the chemical makeup of the interior of a structure. PGNAA is highly hazardous, requiring the wearing of lead-lined clothing and is largely limited to the assessment of chemical and nuclear ordnance. Computerised Tomography (CAT) scanning of structures can be used [30,32], but frequently at a stage in the investigation beyond the search and location of objects, i.e. body or object recovery. Acoustic Imaging (sound and ultrasound waves) can be used at similar scales to x-ray imaging, and has the advantage of not needing a potentially hazardous source behind any surface to be investigated [33]. Imagery can be obtained over a larger area more rapidly than x-ray imaging, is typically good to centimetres and decimetres but requires careful interpretation. An alternative to the insertion of endoscopes is the use of search dogs: surprisingly only Madea [14] describe the use of a cadaver dog, and only in one of their cases. Hawley [6] suggest that in their cases, little volatile gas could escape, precluding the attention of insects and thus presumably dogs detection.

4. Invasive Investigation and Excavation

Following each stage of the pre-contact and non-invasive (contact) search, the relevant specialist(s) should consider discussing their findings with those who carried out the previous part of the work, as well as advising those who may follow. At no time is this more critical than when invasive methods are being discussed. From the focusing of a search from desktop, to an area, to a feature, to the actual anomaly, all the specialists from the investigator, historian/architect, search specialist, engineer/anthropologist or other expert may come together to consider how to proceed. This discussion may consider limited invasive methods such as drilling through the hard medium and visual inspection (as in the GPR case above), deployment of dogs and/or insertion of an endoscope. Some or all of these limited (but direct) methods may have convincing results, informing the search adviser whether they: abandon the search entirely; move away to another target; or deploy an excavation team. Abandoning the search is not the end of the process, as reports of what took place, ('exit strategy') what imagery was collected, samples taken and analyses undertaken will be required, and may prove useful if the area/target is the subject of a further search (usually the result of fresh evidence/new intelligence). The reasons for the result of the search should be discussed such that work flow strategies that are evolving (like this article), may be refined. The re-focusing of the search on a new target may not require all the procedures considered (above) in this work to be undertaken: the new area may have been subject to the desktop study, and if specialists or equipment are expensive or in short supply (usually both!), then they may have been used for simultaneous targets. At some stage however, the sequence in the search strategy will have to be started afresh. The deployment of an excavation team is also not the end of the work for the searchers: the results of what was found, the nature and depth of the target, the material of the enclosing/covering medium allow evaluation of how well the methods worked, allowing refinement of search strategies. How the excavation team cope with concrete, asphalt/tarmac, bricks is problematic [4, 6], but may be assisted by knowing from the search reports how thick, reinforced or dangerous (collapse) the hard surface is.

4.1. Investigation and excavation case study: a homicide case from Toronto, Canada

The following case demonstrates several of the work flow strategies described above for the search and recovery of human remains buried beneath a concrete basement floor in Toronto, Canada. Two victims were kidnapped (based on witness reports) and held captive for several days before one victim was released following the payment of a ransom. The second victim was never seen again and based on information from the released victim was believed to be dead. The desktop study involved information from the released victim to identify the location whereby the victims were held captive. Police intelligence determined that the crime was gang-related and a potential location was identified based on a dwelling in which several gang members previously resided. The residence had since been vacated and a walk-around survey identified several locations where a body could be buried (including the backyard and basement). A second search of the basement, following the removal of all storage items belonging to the landlord, identified an area of different construction where new concrete had recently been poured (Fig. 5).

This area became the prioritized search location until such time that it could be excluded or included for further analysis. The location was recorded by crime scene personnel before proceeding with a non-invasive search. Since the known target was human remains and there was no information to suggest that handcuffs had been used (the released victim reported being bound by rope), a metal detector was not used in this search. Instead, ground penetrating radar was chosen as the initial non-invasive search method due to its ease of use over a horizontal concrete surface and applicability to the situation (i.e. locating human remains [target] in concrete [surrounding medium]). Although the depth of burial was unknown, it was assumed to be relatively shallow and within the limits of the GPR, given the sub-surface depth of the basement floor and potential diggability of soil at this depth. The surrounding (old) concrete was approximately 100 mm thick and the newer concrete thought to be the same thickness. A 1000 MHz frequency antenna was capable of penetrating this depth to determine any anomalies below the concrete and was therefore chosen for the initial survey. Data was collected in grid format across the entire basement floor to identify any additional sub-surface disturbances. The collected data was interpreted using 3D depth slices which represent a birds-eye view of the sub-surface levels. Depth slices were collected at 25 mm increments. The depth slices between 0 and 100 mm showed minor variation in the suspect location due to differences in concrete properties with the surrounding medium. The depth slice between 150 and 175 mm (Fig. 6) demonstrated a distinct anomaly in the suspect location when compared to the surrounding soil medium. This anomaly was observed for multiple depth slices below 175 mm before radar wave penetration was lost at a depth of 450 mm.

Although not commonly reported, the use of cadaver dogs for locating human remains buried beneath concrete is a valuable search tool and minimally invasive. Following GPR determination of an anomaly below the concrete, three small holes (as in the explosives case, described above) were drilled in the suspect location to release any odour that was trapped beneath the concrete. Two cadaver dogs were sent into the basement independently and both alerted on one or more of the drilled holes. The use of cadaver dogs further confirmed the likelihood of buried human remains beneath the concrete. The potential crime scene was again recorded before excavation of the remains proceeded. Based on the instruction of a forensic anthropologist/ archaeologist, the victim was located at a depth of approximately 1.2 m or 4 feet (more than 1.5 m or 5 feet to the base of the grave).

This represented a particularly deep forensic burial but can be explained by the fact that the offenders were unlikely to be discovered as the burial was carried out in the house where they resided. It was also assumed that the offenders spent a considerable amount of time digging a deep grave with the intent that the remains would never be discovered. The grave was extremely water-logged and water was continually pumped out of the grave throughout the excavation. The water-logging resulted from the sub-surface depth (close to the groundwater table) and heavy clay properties of the soil beneath the basement floor. This was also thought to be the reason for the loss of GPR wave penetration at 450 mm depth. At the time of recovery, the victim had been buried for approximately 6 months. Due to the amount of water present in the grave, adipocere formation had occurred on parts of the victim, thus preserving soft tissue.

Although GPR did not necessarily detect the anomaly of the body at a depth of 4–5 feet (1200–1500 mm), the waterlogged conditions and soil disturbance immediately beneath the concrete was sufficient to locate a sub-surface anomaly using this non-invasive search technique. Use of an additional minimally invasive search technique, i.e. cadaver dogs, provided additional evidence that satisfied the police, leading to the removal of the concrete and excavation of the remains. The victim was identified as the missing, kidnapped individual.

5. Summary

The search strategy for objects placed covertly in walls, beneath floors/paths/roadways or in other brick, block, concrete or other structures require elements of strategies developed for other locations (for instance a desktop study), whilst also needing modification for the specific location, most especially the hard, possibly impermeable nature of the burial medium. This work takes a mix of methods from the outdoor search of countryside and the engineering or anthropology-based imaging of structures and surfaces. These established (and largely published) methods have fed into the very preliminary idea for a search strategy of horizontal and vertical concrete, cement, brick, stone, tiled and plaster surfaces. Where methods are new (LiDAR, UAV aerial photography, 3D GPR on walls) and no literature exists, to make as complete a strategy as possible, cases from the authors own work have been described. Together, the rudimentary strategy may be summarised in two main stages (below), both of which generally operate from a larger (macro, kilometres, tens of metres) to smaller (micro, generally the size of the hidden object) scales.

Stage 1. The search is initiated and a pre-contact macro to the micro (completely non-invasive or remote) stage begins. This may comprise: desktop study; intelligence concerning the makeup, size, depth of target; nature of surrounding/enclosing or covering medium; walk-over (more accurately, around) the location.

Stage 2. Contact with location (Non-invasive and non-destructive). This stage may include: walk-over; minimal (grams) sampling; photography; LiDAR scanning; search dog(s); geophysics; x-rays; gamma-rays; sonic/ultrasonic.

Both stages and successive internal stages benefit from discussion with other specialists, which should occur before minimally-invasive tests (drilling, further sampling) and excavation.

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Figures

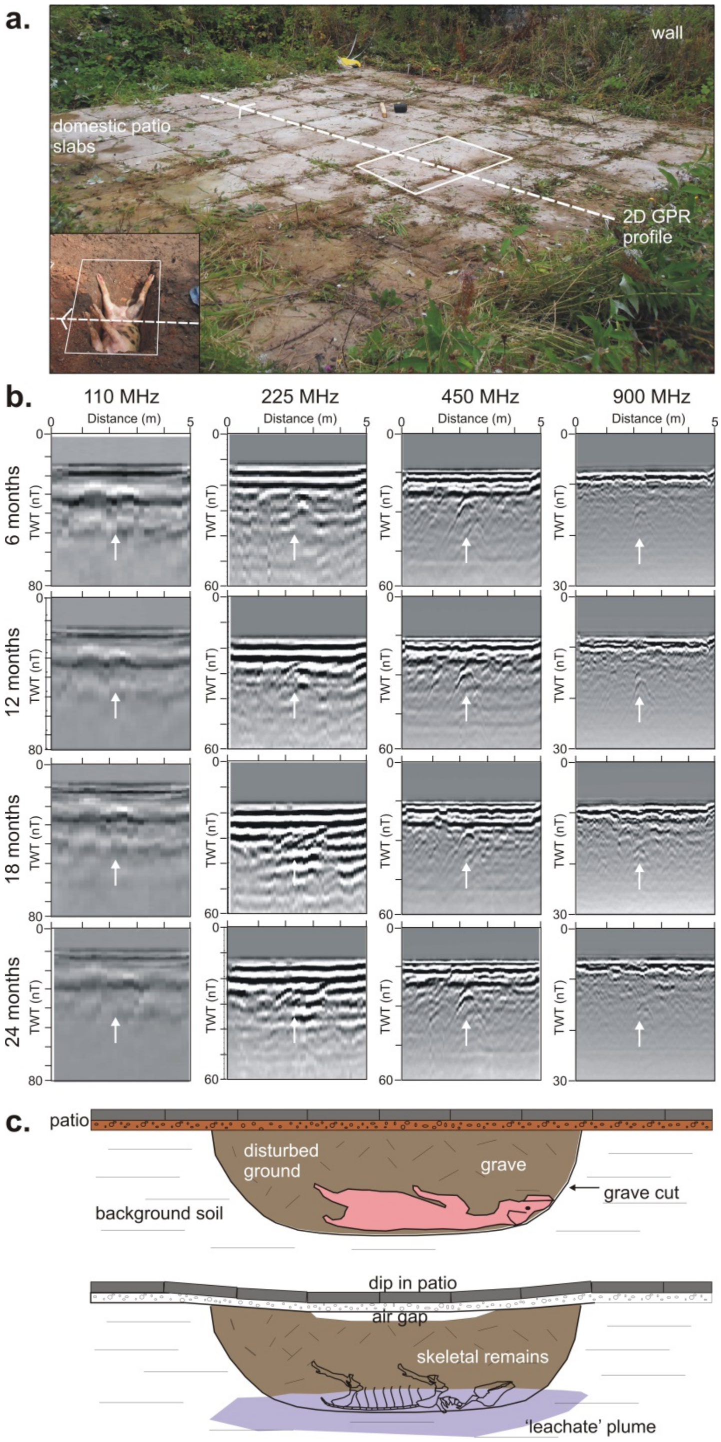

Fig. 1. a). Site photograph of simulated clandestine burial of murder victim under a domestic patio in a semi-urban environment with the pig cadaver 'victim' (inset). 1b). Multi-frequency GPR 2D profiles repeatedly acquired over the patio (see Fig. 2a for location) with post-burial dates and pig cadaver location arrowed respectively. 1c). Schematic 2D diagrams of (above) just buried and (below) two years after burial research project, detailing potential forensic detection elements. Modified from [16].

Fig. 2. a). Pre-rectification photograph of an area of a building being searched for terrorism-related items: area is 3-4m above ground. An expert in historic buildings identified the vertical cracks each side of the image as suspect: ruler is 10cm or 6 inches. 2b). Rectified image of the same photograph as Fig.2a., showing how distortion from taking the photograph at an angle is reduced, allowing accurate location of samples, search lines, anomalies and excavated items. 2c). Pre-rectification photograph of an area of a building being searched for terrorism-related items: area is 3-4m above ground. An expert in historic buildings identified the fresh mortar in the centre of the image as suspect: ruler is 10cm or 6 inches. 2d). Rectified image of the same photograph as Fig.2c., showing (as above) the removal of distortion.

Fig. 3. A camera-mounted hexacopter for orthogonal to vertical, oblique and orthogonal to ground imagery. A standard 16 megapixel digital camera is shown but any payload up to 1 kilogram can be deployed (see text for discussion).

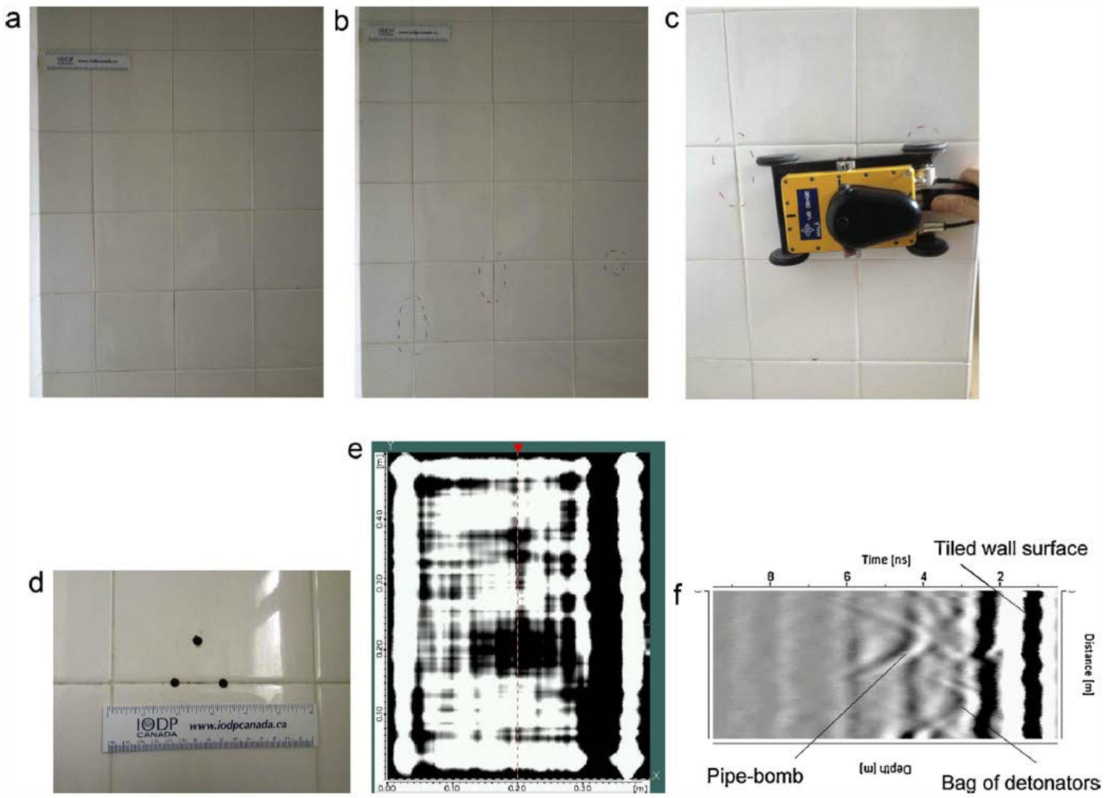

Fig. 4a). An area of tiled wall being searched in a house suspected of having hidden explosives. 6b). Areas of grout (between tile filler) that were observed as suspect by a specialist (discolouration, grain size variation). 6c). High-frequency GPR (1.6 GHz) being deployed along the grid, here over the anomalies. Note the four wheels, the upper right of which is an odometer wheel. 6d). drill-holes away from the anomalies, and to a depth less than any suspect device/object made by the investigators for endoscope insertion. 6e). A time-slice grid at 5cm depth, with the nature of the two anomalies (determined later) shown: the vertical dashed line is the position of the depth slice image shown in Fig. 6f. 6f). A depth slice image into the wall, with the anomalies marked. Total depth of image is 10cm.

Fig. 5. Suspect location identified in basement of residence in Toronto, Canada due to area of different construction.

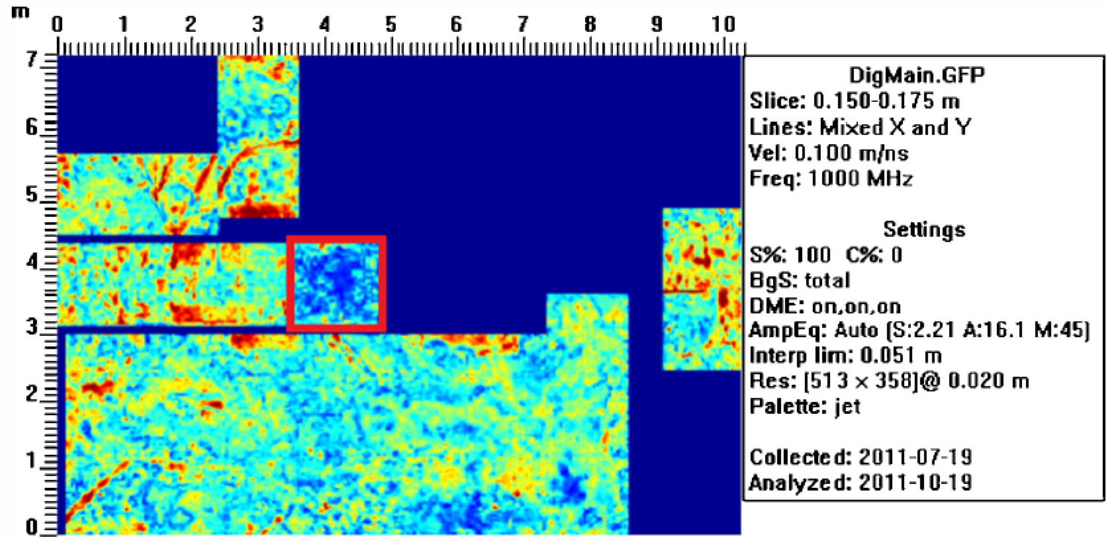

Fig. 6. 1000 MHz GPR depth slice at 150–175 mm beneath the concrete in the suspect location (highlighted by red box) depicting anomalous conditions to surrounding

medium. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of the article.)