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Towards Automating Crime Prevention through Environmental Design (CPTED) Analysis to Predict Burglary

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Abstract

The design of the built environment (such as housing developments, street networks) can increase the opportunity for crime and disorder to occur. For example, a housing development with poor surveillance can provide an opportunity for offenders to commit residential burglary and avoid detection. Crime Prevention through Environmental Design (CPTED) aims to reduce crime and disorder through the design and manipulation of the built environment. The police typically play an important role in the delivery and application of CPTED by assessing planning applications, identifying design features that may provide an opportunity for crime and offering remedial advice. In England and Wales, it is common practice for police specialists – Designing out Crime Officers (DOCOs) – to review architectural site plans during the planning process. However, owing to significant cuts to policing budgets, the number of DOCOs in post is reducing whilst the demand for new housing is on the increase. In this novel work, it is demonstrated that key knowledge about the opportunities for crime and disorder within the built environment can be elicited from a purposive sample of 28 experienced DOCOs, encoded in a domain model and utilised by Automated Planning techniques to automatically assess architectural site plans for future crime risk.

Introduction

The manipulation of the built environment to reduce the opportunity for crime, disorder and the fear of crime is referred to as crime prevention through environmental design (CPTED) (Crowe 2000). CPTED represents a multi-faceted approach to crime reduction and draws upon theories from environmental criminology, architecture and urban design. There is no shortage of evidence that the elements of CPTED are relevant to the incidence of crime (Armitage and Monchuk 2011). CPTED is underpinned by a number of principles (Poyner 1983; Cozens, Saville, and Hillier 2005; Armitage 2013; Montoya, Junger, and Ongena 2016; Armitage and Monchuk 2017). These include: 1) physical security; 2) surveillance; 3) movement control; 4) management and maintenance and 5) defensible space.

Physical security aims to ensure that robust security measures (i.e. door locks) are installed on individual properties to withstand attack from offenders (Tilley, Tseloni, and Farrell 2011; Grove, Tseloni, and Tilley 2012; Brooke 2013; Tseloni et al. 2017; Armitage 2018). Surveillance aims to ensure residents are able to observe the areas surrounding their home and neighbourhood to witness, challenge or report any suspicious behaviour/activity (Reynald 2009; Armitage 2018; Armitage and Monchuk 2017). Movement control aims to ensure that opportunities for access, egress and through movement (such as footpaths and alleyways) are minimized to prevent unauthorized access (Nee and Taylor 2000; Nee and Meenaghan 2006; Johnson and Bowers 2010; Armitage and Monchuk 2011; Birks and Davies 2017). Management and maintenance relate to the importance of ensuring that a development is free from graffiti, vandalism and litter. In doing so, it transmits signals to residents and visitors that the area is cared for (Cozens 2008). Defensible space refers to the clearly defined ownership of space in a neighbourhood and encourages and promotes residents to feel a sense of responsibility for the areas adjacent to their home (Newman 1973).

The application and delivery of CPTED depends for its realization on a number of different agencies, notably the police, urban designers, planning authorities and housing developers. In England and Wales, CPTED advice is delivered to planners by Designing out Crime Officers (DOCOs) who are employed within each of the 43 police forces. They review planning applications and assess the extent to which a development may pose opportunities for crime and disorder and suggest how they might be mitigated. In doing so, they review and deliberate over a number of different data sources, such as police recorded crime. This process of performing deliberation naturally aligns to Automated Planning (AP) and thus in this paper, the application to CPTED is presented and discussed. Researchers have demonstrated the application of AP in many domains where key decision knowledge is extracted from human experts and encoded in a domain model for automation purposes. For example, in manufacturing (Parkinson et al. 2014; 2017), security automation (Khan and Parkinson 2018), and enterprise risk management (Sohrabi et al. 2018). To the best of the author's knowledge, this is the first time researchers are focusing on automating CPTED processes.

Recent work demonstrates the potential to use Machine Learning to automatically score the built environment using computer vision (Naik et al. 2014). However, their approach is somewhat limited for crime prevention. Most significantly is that it is scoring the built environment once it has been constructed, therefore minimising any opportunity to rectify through influencing design and planning. Furthermore, their research is constrained to identifying factors that appear in the image and important crime contributing factors will be missed. For example, identifying a path with poor lighting going between properties, with poor surveillance, would be very challenging using street images alone.

This research is built upon a comprehensive study conducted within the field of criminology (Monchuk 2016). The study sought to examine how 28 DOCOs from 18 different police forces across England and Wales went about assessing the site plan for one residential development (Monchuk, Pease, and Armitage 2018). Although the primary purpose of the aforementioned study (performed by a criminologist) was to understand the application of CPTED and the decision making of DOCOs, it also revealed a common deliberation process that instigated this research. In the application of AP to CPTED, this common deliberation process is utilised to elicit a domain model consisting of key decision actions, which can subsequently be used to automate the assessment process of new residential developments.

The paper is structured as follows. First, the typical process through which the principles of CPTED were applied is discussed to enable the reader to understand the application domain and its alignment to Automated Planning. Second, the knowledge elicitation study whereby 28 DOCOs were consulted is outlined. This then leads to the development and presentation of the domain modelling. A case study is then used whereby the domain model is applied to a new and already reviewed residential site plan and the produced plan is evaluated by a CPTED expert to see if the findings are valid. Finally, a conclusion is provided discussing key achievements, limitations and a road map for future work.

The Application and Delivery of Crime Prevention Through Environmental Design

Planning applications are reviewed by DOCOs during the design and planning process. The earlier a DOCO engages in the design process, the more seamlessly the principles of CPTED can be embedded, thereby avoiding later objections by the police based upon crime concerns (Colquhoun 2004; Kitchen and Schneider 2007; Wootton et al. 2009; Monchuk 2011). Objections raised by the police late in the planning process can be frustrating for applicants and the greater the scale of recommended changes, the more expensive and time-consuming they become (Monchuk 2019).

Wootton et al (2009) and Monchuk (2016) identified that those undertaking the DOCO role have different professional backgrounds and levels of experience - some are serving police officers, whilst others are civilian staff. Concerns have been raised about the extent to which CPTED is applied by individual DOCOs (LHDG 2012) which can often lead to different interpretations being made. This has also be confirmed in academic research. Monchuk et al (2018) found that the application of CPTED was inconsistently applied with some individual DOCOs being more risk averse than others.

Nonetheless, the DOCO role is important. By identifying and mitigating future crime risk can reduce calls to police and the impact on victims. However, there has been a decrease in the number of DOCOs undertaking the CPTED role owing to significant reductions to policing budgets (Monchuk 2016). Furthermore, budgetary constraints coupled with an increasing demand for architectural site plans to be reviewed (as housing demand increases) means that the volume of plans has increased whilst the time available to spend reviewing and analysing them has reduced.

All DOCOs are required to complete a two week training course which includes modules such as the principles of CPTED, the role of DOCOs, interpretation of plans and drawings and planning law and procedures. This is the only dedicated training that DOCOs receive on how to assess plans and drawings, irrespective of their background.

Core Principles

As previously stated, the key principles of Crime Prevention through Environmental Design (CPTED) are:

1. Surveillance: ensuring that areas are well overlooked;
2. Physical security: ensuring that doors and windows have good quality locks that can withstand attack;
3. Movement control: ensuring that there are no unnecessary footpaths or access paths where offenders can hide or where it provides them with a justifiable reason to loiter. Where footpaths are included, they need to be wide, well lit and serve a legitimate purpose;
4. Defensible space: that areas are clearly marked as public, semi-public, semi-private, private and
5. Management and maintenance: that areas are well managed and maintained. (However, this is more applicable once the development is built and occupied).

Knowledge Elicitation

In order to acquire key deliberation expertise from DOCOs, a study was performed whereby 28 DOCOs from 18 police forces across England and Wales were asked to undertake an assessment on the site plan for a residential development (which had been built a decade earlier). The primary objective of that study was to determine if there is consensus in the locations chosen by DOCOs. Were there locations that all DOCOs deemed problematic? The extremes would be complete consensus as to whether a location is vulnerable or random selection such that one DOCO's judgement is unpredictable from another DOCO's selection.

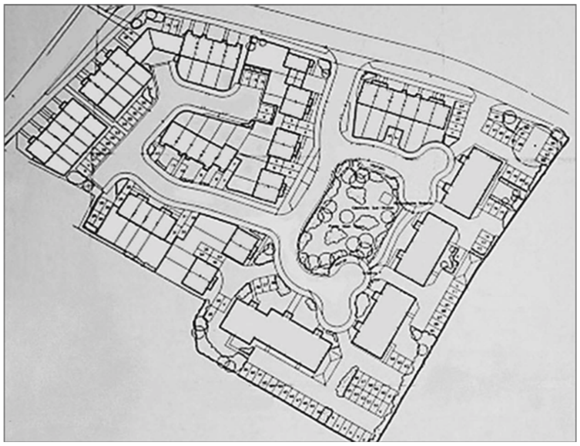

Figure 1: Site plan provided to each individual participant

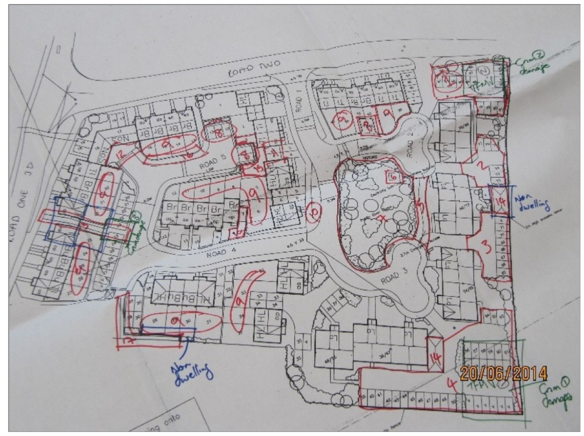

Figure 2: Example of annotated site plan

A stratified purposive sampling method was employed. Participants included 5 serving police officers; 10 retired police officers; 5 former built environment professionals and 8 civilian staff. Length in post ranged from 5 to 20 years. The rationale for selecting the most experienced DOCOs was that it was considered that the more proficient participants were more likely to have experienced successes and mistakes and learnt from problem-solving situations, allowing them to be more reflective in their responses (Paloniemi 2006).

The Process

The exercise was completed on a one-to-one basis. DOCOs were shown the site plan for the development (Figure 1) and provided with generic information relating to the development (number of dwellings and car parking spaces) as DOCOs are typically provided with this descriptive information when reviewing planning applications. DOCOs were asked to spend a couple of minutes reviewing and digesting the information provided and asked the two following generic questions:

- From looking at the site plan, what initially do you like about the plan from a crime prevention perspective and why?
- What do you not like about the plan and why?

DOCOs were asked to think aloud to help understand the following: how they assessed the plan (e.g. as per the principles of CPTED or by working through the plan in a certain direction), how they went about assessing future crime risk and the comments they would make to the planning officer/applicant regarding the proposed design and layout. DOCOs were encouraged to annotate the site plan to mark the locations that they perceived to be vulnerable to crime and disorder. For each annotation, participants were asked to provide a justification as to why they had identified that area as vulnerable and to detail what they would predict to occur at each location. After this general assessment, DOCOs were then asked to annotate the site plan to mark the locations that, in their professional opinion, were specifically at risk from burglary.

The data available for analysis comprise a site plan for each of the 28 DOCOs annotated with the locations at which they predict burglary occurred (Figure 2) and the addresses of the dwellings that experienced burglary between July 2006 and July 2010 which were recorded by the police. In addition, the researcher made audio recordings as the DOCOs made their assessment. DOCOs were encouraged to think aloud whilst performing their assessment so that key decision criteria could be established.

Findings

The number of locations identified as crime prone by the 28 DOCOs varied from 3 to 31. From processing the responses (annotated plans and audio recordings) provided by the 28 DOCOs, the criminologist (Monchuk 2016) was able to establish a key common set of decisions that DOCOs were making during their assessment. Figure 3 contains numbers corresponding to the following list to make it easy for the reader to correlate between these established decision criteria and the site plan:

1. This is a footpath connecting the development to a main road. The footpath is narrow raising concerns about the activities that may go on here and also whether it would be well overlooked by the two houses adjacent. It is worth noting that since the development has been built, the footpath has been closed due to reports of anti-social behaviour.
2. This area is a turning area/car parking area. It it not well overlooked as the rear of houses face into this space. This raises concerns about lack of surveillance, the opportunity for offenders to both gain access into the rear of each house and target vehicles parked in this location.
3. This is an access path that runs to the rear of a number of houses to help the homeowners gain access to the rear of their properties. For an offender, it provides an opportunity for them to gain access into the rear of these houses

Figure 3: Numbered site plan detailed areas of decision interest

without being seen. DOCOs suggested that this should be gated to prevent unauthorised access.

4. In this area, the rear of the houses abut a public highway. DOCOs questioned the height of the fence and recommended that it would need to be sufficiently high to reduce the opportunity for an offender to successfully climb over.

5-6. Within this area, there is car parking provision located adjacent to blocks of flats. Vehicles were identified as vulnerable (due to lack of surveillance) and concerns were raised that there was no defensible space and as such, DOCOs stated that it provided the opportunity for offenders to walk to the side and rear of the flats.

7-10. Within this area there are four blocks of flats. Residents are required to drive between the blocks to access the car parking to the rear. There is no access control (i.e. gates) to access the car parking. Thus, similar the areas 5-6 DOCOs felt that it provided the opportunity for offenders to walk to the side and rear of the flats.

Although researchers have identified the above deliberation points, it is worth noting that expert judgement was made as to whether or not to include a decision from a DOCO. There was significant variation in the number of identified crime locations (3-31, as discussed earlier). Furthermore, from analysing the audio recordings, it became apparent that the detail of deliberation undertaken varies significantly. This motivates the development of an automated technique to deliver the following benefits:

- Exhaustive exploration: As identified when studying the 28 DOCOs, there is variation in their background knowledge and experience, which in turn results in them performing a deliberation process of varying levels of detail (with some being more risk averse than others). Ensuring that an exhaustive exploration is undertaken can ensure a comprehensive assessment.
- Consistency: Although there is a wealth of documentation and literature available on CPTED and its implementation, due to different backgrounds, skills, experience and understanding of both national and local crime risk, DOCOs apply the principles in an inconsistent manner.

Domain Modelling

In this section, the CPTED process is modelled to enable the application of Automated Planning (AP). The Planning Domain Definition Language (PDDL) version 2.1 is used as a standardised mechanism to encode the domain, enabling the use of different planning algorithms and the use of the domain and problem instances by researchers within the AP community (Fox and Long 2003). There is no temporal component to the domain model; however, numerics are required to encode information regarding the national burglary level. The following section describes the encoding of the domain model and problem instances. Only key information is discussed in the interest of brevity and the author's refer readers to the Availability section for information on how the domain model and problem instances used in this paper can be acquired.

Objects, Predicates and Functions

Based on an understanding as to how DOCOs assess a development application, it can be established that they tend to break the site plan down into its principle objects for analysis. Key object types considered in this domain are are as follows: A `building` is used to represent residential properties. A `private_road` type is used to represent a road that is not a public highway and is for use by the immediate local buildings/residents only. The `public_road` type represents a road that can be used by the public. Both `carpark` and `turning_area` are used to represent areas where vehicles can park and areas of road large enough for vehicles to turn around, typically located at the dead-end of a private road. Finally, a `path` type is used to represent a public footpath, which could be a path joining a public and a private road with houses adjacent. An object type of `opportunity` is used to represent a crime opportunity (e.g. lack of surveillance) and `method` is used to represent the act of committing the crime (e.g. breaking a lock).

Predicates are used within the encoding to establish relationships amongst underlying object types. The predicate `(building_next_to_private_road ?building ?private_road)` is used to state that a building (`?building`) is adjoining a private road (`?private_road`). Predicates of a similar nature are used to model buildings adjacent to each other, public road, car parks, public footpaths etc. A `(defensible_space ?building)` predicate is used to encode that each building has some level of defensible space.

The final predicates are those essential to encoding crime opportunities. This includes the introduction of a `(crime_opportunity_building ?opportunity)` predicate which is used to state an opportunity for crime exists for buildings. Predicates of a similar nature for roads, footpaths, carparks, etc. are also used. Finally `(crime_method_building ?building ?method)` are used to encode that a crime method is possible for a specific building.

```
(:action building_path_loitering
    :parameters(?b - building ?p - path?
       ?r - private_road ?a - opportunity)
    :precondition
    (and
       (building_next_to_path ?b ?p)
       (private_road_next_to_path ?r ?p)
       (not(building_overlooking_path ?b ?p))
       (crime_opportunity_path ?a)
    )
    :effect
    (and
       (crime_method_path ?p ?a)
    )
)
```

Figure 4: A PDDL encoding of a decision action stating that a crime opportunity exists due to the site layout. This action specifically models a public footpath that provides the opportunity for loitering.

Numeric fluents (functions in PDDL) are introduced to encode a risk score of a crime method occurring based on a crime risk. For example, the likelihood of a building being burgled due to the presence of a crime risk, such as being located next to a footpath. The predicate used to encode this is `(crime_score ?method)`. The numeric input is acquired from national crime statistics and further information is provided later in the paper.

Operators

In the produced domain model, the following three types of operators are encoded: 1) those to indicate the presence of a crime opportunity, 2) the potential execution of a crime method and 3) a zero cost assessment. The following subsections describe these three action types.

Crime Opportunities These types of actions are used to encode the logical process of deciding if there is a potential crime opportunity within the site. This involves considering the logical constructs of the site, as well as their environment, to determine if a known crime opportunity exists. For example, the identification of a footpath between houses, connecting a private road to a public road presents the potential for an offender to have easy access and have a justifiable reason for loitering.

Figure 4 presents a PDDL action, which is used to state that a crime opportunity exists based upon the characteristics of the site. More specifically, that the building and private road is next to a footpath, yet there is poor surveillance. The PDDL action demonstrated in Figure 4 encodes this logical relationship as a series of preconditions and effects.

Crime Methods Actions are encoded to model the occurrence of a crime taking place, for example - burglary (Figure 5). The action has a precondition of a crime opportunity for a specific building that would increase the likelihood of a crime occurring. For example, the action displayed in Figure 4 results in the crime opportunity of a building having easy access. The presence of a crime opportunity, such as easy access is a necessary precondition for a crime method.

A crime method will have multiple opportunities that can increase its likelihood of occurring. The action in Figure 5 presents those arising from a footpath next to the building that is connected to private road, a building next to a public road, and also opportunities related specifically to an individual building.

Zero cost assessment Actions are used to assess an object within the site plan. Zero cost actions are necessary to state that each components have been analysed, which is a requirement of the goal state. Figure 6 illustrates an example zero cost assessment action. The action is termed zero cost as it does not have any numeric effect.

Initial and Goal State

The initial state specifies the logical construction of the built environment through the combination of objects and predicates. For example, `house22 - building` states that a house with a property number of 95 exists, and similarly, `path1 - path`, identifies that there is a path within in the built environment. Predicates are then used to state the relationships between the objects. For example, the predicate `(building_next_to_path house22 path1)` is used to state that a building `house22` is next to `path1`. This can be seen in Figure 3 (left hand side, illustrated by a "1") where house number 22 is next to a public path.

Crime opportunities are encoded as the relationship between `?opportunity` objects and the built environment. An example is the `(crime_opportunity_road easy_access)` predicate linking the `easy_access` opportunity with roads. Crime methods are expressed in a similar way, linking a crime `?method` with objects in the built environment. For example, `(crime_method_building burglary)` is expressing that `burglary` is a crime method associated with buildings. Finally, a crime score is encoded as a numeric fluent for each crime `?method`.

The goal state requires that every object within the built environment has been considered for crime opportunity and the possibility for them to be exploited by a crime method. This is achieved through using the `(looked_at_building ?building)` predicate.

Plan Metric

The following plan metric is introduced for optimising the quality of generated plans:

- `(:metric maximize (crime_score_acc))`

As the objective of this research is to automatically consider and identify crime that can occur due to the built environment, it is necessary to introduce a `maximize` metric to increase the accumulated crime score.

Plan Generation and Comparison

In this section, the produced domain model is used with a problem instance created to match that of the built environment used in the knowledge elicitation stage of this work

```
(:action building_burglary
    :parameters(?b - building ?p - path?
       ?r - private_road ?pr - road
       ?a - opportunity ?m - method)
    :precondition
    (and
       (or(and(building_next_to_path ?b ?p)
             (crime_method_path ?p ?a) (private_road_next_to_path ?r ?p))
          (or(and(building_next_to_road ?b ?pr) (crime_method_road ?pr ?a))
          (crime_method_building ?b ?a)))
       (crime_opportunity_building ?m)
       (not(looked_at_building ?b))
    )  :effect
    (and
       (looked_at_building ?b)
       (increase(crime_score_acc)(crime_score ?a ?m))
    )
)
```

Figure 5: A PDDL action detailing the crime method of burglary

```
(:action buil=ding_assessed
    :parameters(?b - building)
    :precondition
    (and
       (not(looked_at_building ?b))
    )
    :effect
    (and
       (looked_at_building ?b)
    )
)
```

Figure 6: The PDDL encoding of a zero cost assessment of a building

(Figure 1). The problem instance contains 95 houses, 5 private roads, 2 public roads, 2 paths, 8 crime opportunities and 5 crime methods. Crime statistics are used in the model to attribute a likelihood score of a crime method occurring. In this work, two different crime scores are considered, based on widely used offence groupings[1]. The metric values are provided as a percentage of households for a year ending July 2018. These scores are: burglary (2.2%) and vehicle-related theft (3.1%) - for example, `(=(crime_score home_burglary)2.2)`.

LPG-td (Gerevini, Saetti, and Serina 2003) is selected as a planning tool due to its exploitation in real-world planning applications, its good support of PDDL features, and its good performance. Experiments were run on a quad-core 3.0 Ghz CPU, with 4GB of available RAM. It has been given a 10 CPU-time minute cutoff for solving each problem, and optimise the quality according to the provided metric. The decision to allow a 10 minute time-frame was taken as, in an actual deployment of the planning-based proposed technique, planning for crime assessment may be required to be performed as an online process, i.e. the planning would be performed interactively as a planning officer is designing housing developments. In this scenario, waiting for longer than five minutes would be seen as negative for the user. LPG-td has been used in the "anytime" configuration; it keeps increasing the quality of plan, for a given problem instance, until the available CPU-time is over.

After 5 minutes of execution, 9 solutions have been identified. The highest score (cumulative crime metrics) is 105 whereas the first identified plan was only 16. This demonstrates that it is necessary to continue searching for a better solution rather than adopting the first identified. The best solution was identified after 374 seconds (6.2 minutes), thus motivating that searching beyond the 10 minutes cut-off time for a problem instance of this size is not necessary. The full solutions contains 123 actions.

Figure 7 illustrates a plan excerpt produced using the developed domain model and problem instance, illustrating its findings. Note that extracts have been taken from the plan to demonstrate its ability to mimic the decision making capabilities learned during the knowledge elicitation phase. The actions have been manually grouped into crime generating and crime methods pairs to aid this discussion.

The first two actions detail that `path1` exists next to `house23`, which results in a crime opportunity

[1]Statistics in this research are acquired from the UK's Office for National Statistics and are for the year ending June 2018: https://www.ons.gov.uk/peoplepopulationandcommunity/crimeandjustice/datasets/crimeinenglandandwalesappendixtables

Finding 1

```
0: (BUILDING_PATH HOUSE23 PATH1
PRIVATE_ROAD1 LOITERING) [1]
1: (BUILDING_BURGLARY HOUSE23
PRIVATE_ROAD5 PUBLIC_ROAD1 EASY_ACCESS
BURGLARY) [1]
```

Finding 2

```
0: (TURNING_PARK BUILDING18 TURNING2
POOR_SURVEILLANCE) [1]
1: (TURNING_PARK_BURGLARY TURNING2
POOR_SURVEILLANCE BURGLARY) [1]
```

Finding 5 and 6

```
0: (TURNING_PARK BUILDING49 CARPARK1
POOR_SURVEILLANCE) [1]
1: (TURNING_PARK_BURGLARY CARPARK1
POOR_SURVEILLANCE BURGLARY) [1]
0: (TURNING_PARK BUILDING40 CARPARK2
POOR_SURVEILLANCE) [1]
1: (TURNING_PARK_BURGLARY CARPARK2
POOR_SURVEILLANCE BURGLARY) [1]
```

Finding 3

```
0: (BUILDING_PATH HOUSE28 PATH2
PRIVATE_ROAD4 EASY_ACCESS) [1]
1: (BUILDING_BURGLARY HOUSE28 PATH2
PRIVATE_ROAD4 PUBLIC_ROAD1 EASY_ACCESS
BURGLARY) [1]
```

Finding 4

```
0: (BUILDING_PUBLIC_ROAD HOUSE94
PUBLIC_ROAD2 EASY_ACCESS) [1]
1: (BUILDING_BURGLARY HOUSE94 PATH1
PRIVATE_ROAD4 PUBLIC_ROAD2 EASY_ACCESS
BURGLARY) [1]
```

Finding 7, 8, 9, and 10

```
0: (LACK_OF_DEFENSIBLE_SPACE HOUSE87
EASY_ACCESS) [1]
1: (BUILDING_BURGLARY HOUSE87 PATH2
PRIVATE_ROAD4 PUBLIC_ROAD2 EASY_ACCESS
BURGLARY) [1]
```

Figure 7: Plan excerpt for knowledge elicitation site

`easy_access` whereby people are able to loiter. This leads to the occurrence of a crime method representing that `house23` could suffer from burglary due to `easy_access`. This relates to the first finding identified in 'Findings' Section.

The second finding was the potential for vehicle related crime in turning areas and car parks where natural surveillance is poor. As demonstrated in the next two actions in the excerpt, DOCOs have identified that the turning area `turning2` next to `house17` has poor `surveillance`. This subsequently resulted in DOCOs identifying that there is strong potential for the opportunity for crime to occur in this turning area. This relates to the the second finding from the knowledge elicitation stage. In addition, the next four actions, relating to the fifth and sixth findings, involves the identification of `surveillance` with `carpark1` and `carpark2`, resulting in the potential for vehicle crime.

The next two actions (Finding 3) demonstrate that the technique has identified that `path2` is providing `easy_access` to property `house28`, which results in the occurrence of the `building_burglary` action for the property. Finding 4 is demonstrated in the produced plan by the identification that building `house94` has a public road (`public_road2`), which results in there being `easy_access` to the property and results in the occurrence of `building_burglary`.

The final two actions are an example instance of Finding 5 whereby a lack of defensible space has resulted in the crime opportunity of `easy_access` to property `house87`, which subsequently results in the potential of burglary at the property in question.

After analysing the plan, it is evident that although nothing new is identified beyond what was identified in the collective DOCO results, the plan systematically considered every property and the output is equivalent to knowledge acquired from the accumulative assessment of 28 DOCOs. This is significant as it ensures that knowledge can be used by all DOCOs to deliver consistency, and potentially more significantly, provides an automated solution to help enable those with less expertise to perform expert like analysis. More specifically, as previously identified there was inconsistency in the number of issues identified by the DOCOs. This demonstrates the potential of the developed technique, whereby a DOCO is assisted in the assessment, which is based on learnt domain knowledge and national and local crime data. This will help to ensure that CPTED analysis is systematically performed throughout different geographic regions, regardless of DOCO expertise.

Case Study

In this section, a case study is performed using the developed domain model on a different housing development. This site has already gone through a review process by a DOCO and has subsequently been approved for development. In this analysis, the automated technique is specifically looking to identify any crime opportunities that exists that the DOCO may have missed in their initial assessment. The purpose of this case study is to investigate the generality of the technique and its capabilities when applied to a new site. Figure 8 illustrates the layout of the housing development to be considered. A PDDL problem instance is encoded to represent this problem instance. It contains 42 buildings, 4 public roads, 2 private roads, 3 paths, 5 car parks and turning areas. The same methodology is adopted here as in the previous section; a 10 minute CPU time-limit is set. The generated plan will be analysed by a DOCO with extensive expertise to determine what has been identified.

After 10 minutes of search time, 6 solutions have been identified. The solution with the greatest maximized metric was identified after 154 seconds (2.5 mins) and have an accumulated crime score of 96.

An excerpt of the produced solution is shown in Figure 9. Examples are shown to highlight the two key issues identified with the site plan. The following list summarises key findings identified using the technique, and a matching number is added on Figure 8 to locate the finding on the site map.

Figure 8: Case study site

Finding 1
```
0: (LACK_OF_DEFENSIBLE_SPACE HOUSE07
EASY_ACCESS) [1]
1: (BUILDING_BURGLARY HOUSE07 CYCLE_PATH
PRIVATE_ROAD4 PUBLIC_ROAD1 EASY_ACCESS
BURGLARY) [1]
```
Finding 2
```
0: (BUILDING_PATH HOUSE13 PATH1
PRIVATE_ROAD2 LOITERING) [1]
0: (BUILDING_BURGLARY HOUSE13
PRIVATE_ROAD2 PUBLIC_ROAD1 EASY_ACCESS
BURGLARY) [1]
1: (TURNING_PARK_BURGLARY CARPARK3
POOR_SURVEILLANCE BURGLARY) [1]
```
Finding 3
```
0: (BUILDING_PATH HOUSE34 PATH2
PRIVATE_ROAD2 LOITERING) [1]
1: (BUILDING_BURGLARY HOUSE34
PRIVATE_ROAD2 PUBLIC_ROAD1 EASY_ACCESS
BURGLARY) [1]
```

Figure 9: solution excerpt for case study site

1. There is easy access through the cycle path and a lack of defensible space around property 7 and 8. This allows easy access and provides an opportunity for burglary.
2. Access from the public road enables easy access to car parking spaces in front of properties 1, 13, 14, 15 and 16. This can result in both property and vehicle crime.
3. A path connecting a public and private road adjacent to multiple properties provides easy access an easy escape route, thus increasing the likelihood of burglary within the local vicinity. For example, house number 34 in the site.

It should be noted that only three potential areas of concern have been identified as this new development has already been reviewed by a DOCO and recommendations implemented to reduce opportunities for crime. The findings have been validated by DOCOs with extensive experience and it has been established that further modifications should have been made to the site plan to rectify the issues. This demonstrates the effectiveness of the approach and its ability to miss potential issues missed by human expert. Analysis of local crime data for this region further validates these findings where instances of burglary have occurred in each of the three regions, thus motivating the potential impact of using the automated technique during the design phase.

Availability

Domain models and problem instances used in this paper are available from the authors upon request.

Conclusion

In this work, the application of Automated Planning to Crime Prevention through Environmental Design (CPTED) is presented. The work demonstrates the potential to elicit expert knowledge from subject experts. The challenge obtaining high-quality knowledge was minimised through using common knowledge acquired from monitoring 28 DOCOs performing a manual assessment. This work focuses on the development of an action-based model, whereby actions represent key decision criteria of crime opportunities being present within the built environment, and also its exploitation by an offender (based upon police recorded crime figures).

The encoded domain model was then used on the same site shown to the 28 DOCOs to demonstrate the AP technique's capability and suitability at automatically constructing expert comparable CPTED assessments. The domain model is currently focused on burglary; however, there are many other crime types that will be encoded in future work. For example, vehicle crime and criminal damage. Future work will also include further technical developments to integrate the technique within the planning process, which will require the automatic construction of problem instances from site plans. The authors will also explore how such an approach can be utilised within the policing arena more widely and encompass a multi-dimensional approach.

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