Application of crime theory in urban ecology, evolution and planning: factors influencing the disappearance of field equipment

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Abstract

1. Research in urban ecology and evolution relies on the use of deployable scientific equipment. If left unattended in the field, it may be prone to vandalism and theft, especially in the urban space. We empirically applied crime theory, specifically the Routine Activity Theory (RAT), to predict disappearance rates of scientific equipment in an on-going urban ecology research project.

2. First, we tested a routinely applied method of equipment protection - labelling - and tested whether equipment disappearance varied with label information content and message tone. Second, we tested whether equipment attributes (price, mass, volume, colour and type of installation) and environmental variables (human presence, tree cover, distance to paths and distance to roads) covaried with the disappearance of two types of field equipment, and whether patterns of disappearance changed over time spent in the urban space (novelty effect).

3. The disappearance of 474 nestboxes and 141 frassboxes was followed over four years and two field seasons, respectively. By using a crime theory framework, we successfully predicted that nestboxes were less likely to disappear than frassboxes. In contrast to an earlier study, we did not find any association between label type and disappearance rates. Instead, we identified environmental variables that covaried with equipment disappearance: for both types of scientific equipment, there was an interaction between human presence and tree cover. Thus, in highly-frequented places, people were more likely to remove scientific equipment if they were less seen (e.g. in areas with high tree cover). Moreover, we detected an interaction between distance to roads and paths for frassboxes but not nestboxes, revealing that equipment properties may interact with environmental setting. Importantly, frassbox disappearance decreased over time in both study seasons, confirming the important role of novelty for scientific equipment disappearance rates.

4. We encourage other researchers, site-managers and stakeholders working in cities and other frequently visited areas to apply the RAT framework, as it is an easily applicable and inexpensive way to gain insight into patterns of equipment disappearance in the public space, thereby strengthening the potential for informed project planning and as a result, safer, and more effective studies.

Key words:

crime prevention, crime theory, equipment protection, field equipment, labelling, socio-eco-evo, urban ecology, urbanisation

INTRODUCTION

Urban areas currently occupy about 3% of the Earth's land and are home to more than half of the human population; both numbers are expected to increase over time (Seto et al., 2012, United Nations et al., 2019). In line with this growth, urban ecology and evolution emerged in the past decades as blooming fields of research worldwide (Rivkin et al., 2019, James & Douglas, 2014, Szulkin et al., 2020). Knowledge gained from these studies can ultimately allow us to build more sustainable cities, and guarantee a more harmonious coexistence of humans and other biological life in the urban space (Douglas et al., 2010). As such, both the scientific community and land managers working in the urban space need carefully planned data collection protocols to work efficiently.

Field studies are the cornerstone staple for the collection of biological data. To achieve reliable and repeatable results, scientists must apply efficient data collecting protocols that rely on the use of field equipment, and the same holds true for site managers and land-planners. Deployable equipment is used to gain information on biological processes across a wide-range of habitat types: from green areas – including natural reserves and national parks – to urbanised neighbourhoods (e.g. Munshi-South & Kharchenko, 2010, Sprau et al., 2017, Corsini et al., 2022). Such equipment may vary in terms of costs, quality and scope (Perkin et al., 2014, Zárybnická et al., 2016), but for the purpose of urban data collection, it is often left outdoors. Human response may vary widely – from indifference and inoffensive curiosity to worse case scenarios, equipment theft and / or vandalism. The latter risk is likely to be amplified in urban areas due to increased densities of humans (Corsini et al., 2019; see Table S1 in Supporting Information). The loss of equipment is usually irreparably translated into data loss or, more generally, failure in achieving research aims or site management-objectives (Meek et al., 2018). It can also threaten the target species of the study: for example, the removal of nestboxes with eggs or nestlings inside (personal obs.) will inevitably lead to the death of these individuals.

Preventing the disappearance of field equipment

Steps taken to minimise the loss of scientific equipment in the field are regularly considered and may include: securing items with chains, locks or boxes (Fiehler et al., 2007, Meek et al., 2012), hiding and camouflaging (Jackson & Hutchison, 1985), placing the items in hard-to-reach places, avoiding the set up in highly-frequented areas, (Rovero & Marshall, 2009, Gil-Sánchez et al., 2011) or shortening deployment periods (Meek et al., 2018). Some of these practices can significantly undermine the quality of obtained results: for example, Meek et al. demonstrated that placing camera traps at three meters height to avoid their potential theft may significantly reduce the detection rates of mammals (Meek et al., 2016). Attaching labels with pictograms and messages to inform city dwellers about the study is another avenue to minimise equipment loss (Clarin et al., 2014). Clarin et al. (2014) have shown the effectiveness of phrasing and verbal tone used on the scientific equipment labels to prevent vandalism and theft events: 60 identical equipment dummies – consecutively distributed for a week in four urban parks in Munich, Germany – were assigned with one out of three types of labels differing in tone (*neutral, personal or threatening*). The authors found conclusive evidence that the *personal* label, which was written in a kind tone and accompanied by a picture of a juvenile squirrel, revealed to be the most effective in reducing the overall number of vandalism and theft events in the unattended equipment. Although methods applied by Clarin et al. (2014) paved the way for investigating a new and pertinent approach to reducing the disappearance of scientific equipment – focused on the verbal aspect of labelling – the study was not set in the context of a real-life study (thus bringing greater liberty in modulating treatment effects, such as label tone), nor did it investigate other important drivers of disappearance, which include:

- **environmental variables** – the characteristic of the immediate environment next to the scientific item of interest – such as human presence, distance to paths or roads, tree cover (Fig. 1) – or, more generally, – the wider spectrum of habitat types pertaining to the spatially heterogeneous urban mosaic.
- **equipment attributes** – the intrinsic properties of an item, such as approximate value, mass, volume, colour or type of installation (Fig. 1 & Box 1).
- **temporal aspects of equipment disappearance**, and specifically – the effect of passers-by habituation with the items (further referred to as *novelty*) on disappearance probability (Dinnin, 2009)

According to the quite distinct field of crime theory (Cohen & Felson, 1979, Felson & Clarke, 1998), (Felson & Clarke, 1998)all drivers outlined above can play a crucial role in the probability of object disappearance when driven by theft. Therefore, in this study, the following research questions were addressed:

1. **Extrinsic factors.** Do environmental variables affect the dynamics of deployable field equipment disappearance in urban areas?
2. **Intrinsic factors.** Are some types of deployable field equipment more prone to disappearance?

3. **Novelty.** Does novelty, (measured as the period the equipment spent in a certain area), play a role in the item's disappearance over time?

Based on crime theory (and specifically Routine Activity Theory (acronym RAT)) and VIVA theory embedded within RAT; see Fig. 1 and full details in Methods; Miró, 2014), we predicted that external factors may considerably affect the dynamics of deployable scientific equipment disappearance by providing more or less suitable settings for its removal (Fig. 1). Likewise, some intrinsic properties of the equipment may simplify and encourage or, conversely, impede and discourage its removal (Fig. 1, Box 1). As part of these intrinsic factors, verbal cues in labelling (such as language and tone in labelling) may play a role in the disappearance of scientific equipment, as readily investigated by Clarin et al. (2014). Lastly, we also predicted a decrease in scientific equipment disappearance over time, which can be potentially explained by visitors' habituation to the equipment presence itself in the studied areas, leading to further reduction in removal rates (Dinnin, 2009).

Labelling and Routine Activity Theory Implementation

Based on Clarin's et al. (2014) work, we conducted a follow-up study in the city of Warsaw, Poland, a capital city of c 1.76 million inhabitants in Central Eastern Europe (Statistics Poland, n.d.). We implemented the method of equipment labelling while setting up study sites for a long-term research project on the ecology and evolution of two urban birds: the great tit (*Parus major*) and the blue tit (*Cyanistes caeruleus*) (Szulkin et al., 2020, Corsini et al., 2021, Corsini et al., 2022). We monitored the disappearance of two types of equipment deployed in the field (Fig. 3, Box 1): specifically, nestboxes, where hole-nesting passerines rear their young, and frassboxes, i.e. collectors of caterpillars' faeces – an important field-method commonly used to quantify the total biomass of natural-food resources available to tits in the environment whilst feeding young (Perrins, 1991).

Crime theory set out in the RAT-VIVA framework allowed us to formulate concise and testable predictions about the role of distinct external variables characterising the urban space on the dynamics of scientific equipment disappearance (Fig. 1). Moreover, we also implemented VIVA to compare the attributes of both types of equipment in order to predict which of these were more prone to disappear (Box 1). To the best of our knowledge, it is the first time that the Routine Activity Theory was empirically tested in the context of urban ecology and evolution research.

MATERIALS AND METHODS

In this study, we refer to all cases of equipment removal by passers-by with the neutral word *disappearance,* which includes both theft or removal for other purposes.

To infer patterns of disappearance of scientific equipment in the urban space, we detail below (1) the RAT-VIVA framework derived from crime theory (Cohen & Felson, 1979, Felson & Clarke, 1998), (2) study sites and equipment, (3) drivers of equipment disappearance, and (4) statistical methods.

1. Crime theory-based RAT-VIVA framework and resulting predictions for the selective disappearance of scientific equipment

To better understand the dynamics of equipment disappearance, we took an interdisciplinary approach and applied theory from criminal studies to our research. Tools developed in this field often focus on the issue of infringement of private property and, as such, provide a useful framework for this study. Cohen and Felson (1979) formulated the Routine Activity Theory (RAT): one of the most influential theoretical constructs in the field of criminology (Fig. 1). Put succinctly, instead of focusing on the figure of the criminal and the psychological, biological or social factors that motivate the criminal act, RAT studies crime as an *event* (Miró, 2014). The theory highlights crime's relation to space and time, and emphasizes its ecological nature and the implications thereof. Cohen and Felson (1979) specified three essential elements needed for a criminal event to occur and to explain it: (1) a potential offender with the capacity to commit a crime; (2) a suitable target or victim; (3) the absence of guardians capable of protecting targets and victims (Fig. 1).

An important aspect of the Routine Activity Theory in terms of identifying the causes of scientific equipment disappearance relates to the *suitable target* concept ((2); Fig. 1). The probability of an item becoming a target is influenced by four attributes: Value, Inertia, Visibility, and Access (acronym VIVA; Fig. 1; Box 1) – described from the point of view of the offender (Cohen & Felson, 1979, Felson & Clarke, 1998, Miró, 2014). All of these four attributes are predicted to translate into object disappearance:

- **Value**, real or symbolic, from the perspective of the offender;
- **Inertia**, referring to size, weight, and shape, or to other physical aspects of the good;
- **Visibility** of target to the offender;
- **Access**, referring to object positioning in space.

Figure 1. Graphical representation of the RAT-VIVA framework, including predictions on the effect of external factors on the scientific equipment disappearance. The definition of a guardian (3) is not limited to a person, it is a concept: „the physical or symbolic presence of an individual (or group of individuals) that acts either intentionally or unintentionally to deter a potential criminal event" (Hollis et al., 2011). Therefore we treat labels as potential guardians (analogous to the use of "watching eyes" imagery in studies inferring theft reduction and other socially negative behaviours (Dear et al., 2019)).

Routine Activity Theory (RAT)		
(1) potential offender	**(2) suitable target**	**(3) absence of guardians**
Applicable factors in the study:		
human presence	elaborated in terms of VIVA (below)	labels
Predictions:		
likelihood of item disappearance increases with increasing number of people around the object	likelihood of item disappearance increases with its *suitability* determined by VIVA	likelihood of item disappearance is influenced by label tone

Value, Inertia, Visibility, Access (VIVA) **(Within equipment type)**			
(2.1) Value	**(2.2) Inertia**	**(2.3) Visibility**	**(2.4) Access**
Applicable factors in the study:			
novelty	constant within equipment type	tree cover	closest path closest road
Predictions regarding the likelihood of theft:			
value of an item decreases over time (Dinnin, 2009)	N/A	visibility increases with lower tree cover	access increases with decreasing distance to paths and roads

Box 1. (A) VIVA comparison of nestbox and frassbox attributes determining their disappearance susceptibility. (B) Translation from qualitative to quantitative predictors of disappearance of scientific equipment. The monetary value of a nestbox and of a frassbox can be approximated by eye, as the latter is made from a single sheet of paper (see Methods and Fig. 3)

Descriptive comparison of nestboxes and frassboxes in terms of VIVA

(A)	**Value**	**Inertia**	**Visibility**	**Access**
Applicable factors	*Price*	*Mass and volume*	*Colour*	*Installation type*
Nestbox	*c.* 26,00 €	Mass = 3,6 kg Volume = c. 8000 cm^3	Brown, blending with trees	Hung 214-325 cm above the ground
Frassbox	*c.* 0,03 €	Mass = 0,015 kg Volume = 930 cm^3	Paper-white, highly contrasting with its surrounding	Fixed to the ground with a nail
Predictions	An item with higher price is more valuable	A lighter and smaller item is easier to carry	An eye-catching item is more visible	An object that is easier to reach is more accessible

Predictions formulated under the VIVA framework can be further translated into quantitative predictions of nestbox and frassbox susceptibility to disappearance in the urban space:

(B)	**Value**	**Inertia**	**Visibility**	**Access**	**Total of *suitable target* points**	**Predictions under the RAT-VIVA framework**
Nestbox	1	0	0	0	**1**	A frassbox is a more suitable target for disappearance than a nestbox
Frassbox	0	1	1	1	**3**	

2. Field Data

2.1 Study sites

We used field data collected as part of a long-term project addressing the impact of urbanisation on the biology of two wild passerines in Warsaw, Poland (Fig. 2). Poland is a democratic, post-communist country in Central Eastern Europe and its capital city, Warsaw, hosts *c*. 1,76 million people, making it the largest city of the country (Statistics Poland, 2018) and the 11th largest city in the European Union (*Eurostat / Regions and Cities Illustrated (RCI)*, 2017). The project started in 2016 and currently consists of eight study sites that include: (A) a suburban village c. 20 km from Warsaw, (B) a national park, (C) an urban forest, two (D and F) residential areas , (E) an urban woodland, (G) an urban park and (H) a university campus (Figure 2). Wherever possible, nestboxes are set out in a 50 m grid (for more information on the study sites please see Table S1, S2 & Text S1; these are also detailed in Corsini et al., 2019, Corsini et al., 2022, Szulkin et al., 2020).

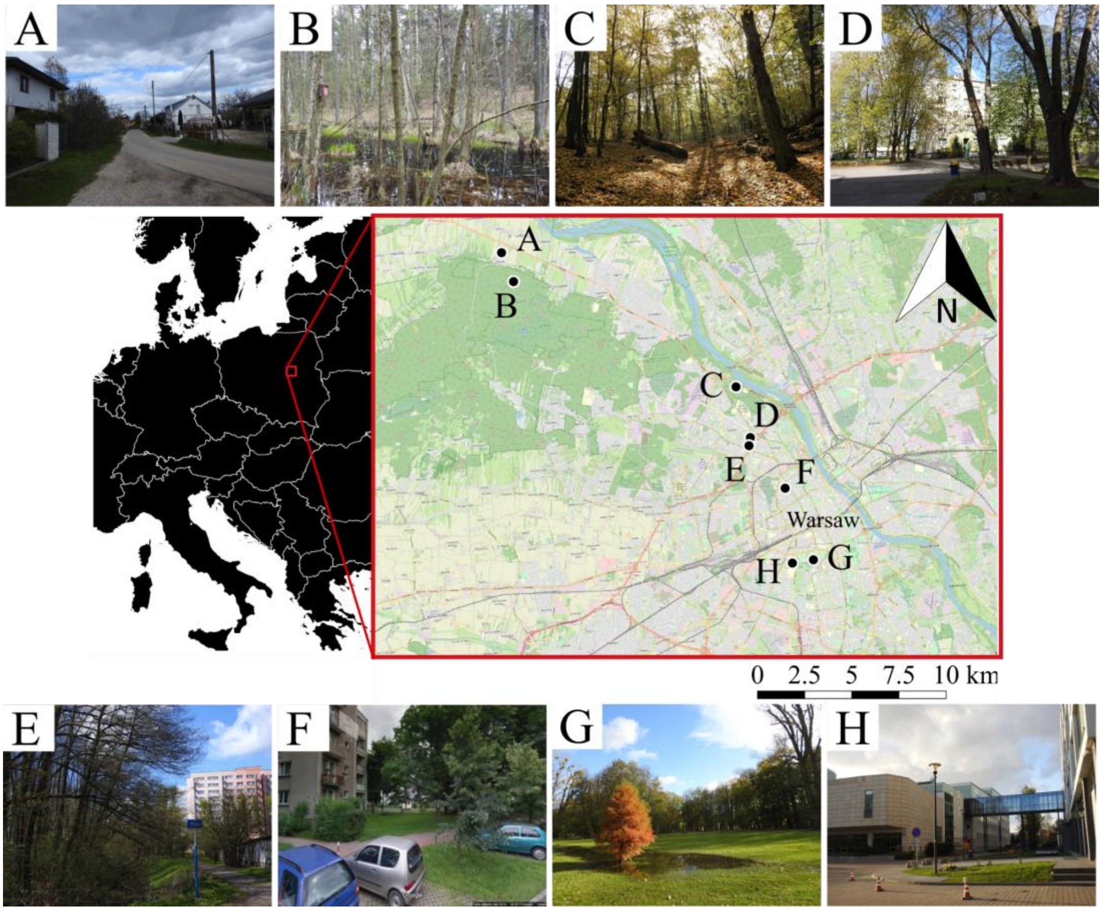

Figure 2. Map of study sites located in the Warsaw gradient of urbanisation, Poland. These include: a suburban village (A), a national park (B), an urban forest (C), two residential areas (D and F), an urban woodland (E), an urban park (G) and a university campus (H).

2.2 Scientific equipment in the field

In this study, we compared the disappearance of two types of scientific equipment: nestboxes, used as breeding cavities in the project, and frassboxes - used in a two-year study to quantify caterpillar abundance in a gradient of urbanisation, assessed by collecting frass (e.g., caterpillar faeces; Fischbacher et al., 1998) from frassboxes across the urban matrix (Stadnicki et al., in prep).

Schwegler woodcrete nestboxes (Schorndorf, Germany; type 1B; Fig. 3 A & Fig. S1) are brown with pinkish doors, measure W 17 x H 26 x D 18 cm and weigh *c.* 3,6 kg. They are hung on metal grips, which are fixed to trees, and distributed in all study sites in a 50-m distance grid whenever possible. Nestbox disappearance data covered four years of study (2016-2019).

Frassboxes (Fig. 3 B & S1) were made with thick A4 white paper (at least 200g/m2), folded into containers of caterpillar frass by bending the walls and stapling them together (Sudyka et al., 2022). They measured *c.* W 24 x H 2,5 x D 15,5 cm, weighed *c.* 15,5 g., and were set in groups of three items (based on nearby nestbox occupancy), fixed to the ground with a long metal nail under the most common tree species of a given location. The frassboxes were used in all but one study site (site B, National park) where frass assessment was not possible due to permit restrictions. Frassboxes were placed at the exact same locations in both years of the study. Frassbox disappearance data covers two consecutive breeding seasons (from May to mid-June in 2018 and 2019).

Figure 3. Field equipment assessed for disappearance consisted of nestboxes (A) and frassboxes (B). For pictures with scale see Fig. S1 in Supporting Materials.

3. Equipment disappearance and its drivers

For the empirical analysis of RAT-VIVA framework-based predictions (Fig. 1, Box 1), we used equipment disappearance data and analysed it in the context of equipment labelling, environmental variables contributing to fine-scale urban heterogeneity, equipment attributes and the time the equipment spent in the field.

3.1 Equipment disappearance

Nestboxes were regularly checked each year (2016 - 2019) during cleaning in October, in early spring and during the entire avian breeding season (March - July). Frassboxes were placed in the field around the 1st of May (2018, 2019) and checked every four days until mid- June (12 checks in 2018 and 11 checks in 2019). Each disappearance of either type of scientific equipment (nestbox or frassbox) was recorded and the missing item was replaced. At each replacement, new items always had a different type of labelling tone (see below).

3.2 Labels

To assess the impact of labelling tone (phrasing), we applied the experimental design of Clarin et al. (2014), who tested the effects of contrasting labelling tone on the vandalism and theft of scientific equipment dummies left unattended in a 4 urban parks in Munich, for a total of 23 days. Here, the original approach was applied to an on-going research study set in a gradient of urbanisation in an Central Eastern European capital city (Warsaw). Both nestboxes and frassboxes were labelled with one of three types of labels (8 x 5 cm, metal for nestboxes and paper for frassboxes; Fig. 4). The message on each type of label was reported as follows (text translated from Polish):

1) *Informative:* ***We are studying the effect of cities on the life of birds. Please do not disturb! Thank you. Centre of New Technologies University of Warsaw***
2) *Neutral*: no message
3) *Harsh*: ***Please, do not disturb! Centre of New Technologies University of Warsaw***

An equal number of each type of label (1, 2, 3) was assigned to all nestboxes and frassboxes, which were further evenly spread across space in the study sites.

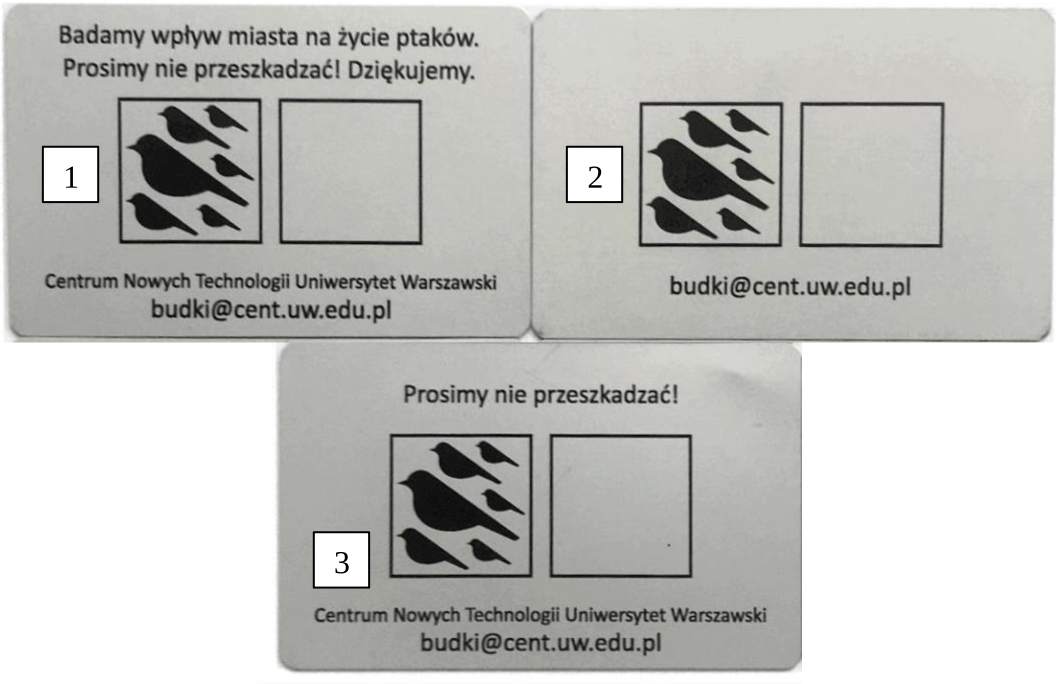

Figure 4. Labels placed at the bottom of 474 nestboxes across 8 study sites: 1 (*Informative*), 2 (*Neutral*), 3 (*Harsh*). Similar labels, printed on paper, were fixed to 121 frassboxes (Fig. 3).

3.3 Environmental axes of urbanisation

We characterised urban heterogeneity by measuring human presence, tree cover and distance to closest paths and roads at fine-scale resolution, specifically at the nesbox and at the frassbox level.

Human presence. At each study site, fieldworkers counted for 30 s all humans and dogs within a 15 m radius from each nestbox. Counts were repeated 20 times for every nestbox location (for more details, see Corsini et al., 2019). To extrapolate human presence data at each frassbox location, we used the open-source software QGIS (v.3.10.4) to calculate the Inverse Distance Interpolation (IDW) on the human presence data quantified at each nestbox location. Specifically, the IDW was derived from the geoprocessing toolbox: nestbox locations were fitted as vector layers, while the human presence index was fitted as the interpolation attribute (z). Each IDW was calculated by selecting manually the extent on canvas for each study site separately.

Tree cover. The percentage of tree cover was measured at the nestbox and frassbox level following (Szulkin et al., 2020). After downloading a raster layer from Copernicus Land Monitoring Services, the data was processed in QGIS. Averaged value of the tree cover (in %) was calculated in a 100 m radius from the nestbox using the *Zonal Statistic*s function.

Distances to paths and roads. The spatial location of nestboxes was recorded using a GPS Garmin Map 64s and all the coordinates were downloaded using the open-source Software *DNRGPS Minnesota*. Distances to the closest road and closest path were measured in meters between the middle of the road/path and the equipment (i.e., frassbox or nestbox) location using the Measure line tool in *QGIS* (Szulkin et al., 2020).

3.4 Novelty

To measure the effect of *novelty* – passers-by habituation to specific items over time (Dinnin, 2009) – on disappearance probability of equipment, we used disappearance data collected over the years (see Methods (3.1)). Frassboxes were left in the field for two months in both 2018 and 2019, and their checks occurred at regular intervals – every four days from 1st of May to mid-June. *Frassbox novelty* in the environment was thus measured as the number of days an item spent in the field before disappearance occurred (starting from the set-up date until the end of frass collection each year). Each check was treated separately (consequently, the sample size of frassbox disappearance events was the outcome of the number of frassbox locations * the number of frassbox checks performed; random effects were fitted to control for repeated sampling of the sample frassbox location (see below)). We were unable to perform an analogous *novelty* analysis on nestboxes as the study sites were set in different years (see Methods (2.1)) and the checks were performed infrequently over the year and during the field season (see Methods (3.1)).

4. Statistical analysis

Statistical analyses were computed in R (v. 3.6.2). Plots and diagrams were built and visualized using *ggplot2* (v.3.3.5) (Wickham, 2011) and the open-source software *Inkscape (Inkscape project, 2003)*. Detailed R-packages used for each analysis are detailed below. Nestbox and frassbox disappearance was always analysed separately.

4.1 Effect of labels on scientific equipment disappearance

We used Chi-squared tests to infer whether differences in scientific equipment disappearance are driven by label type. To test the effect of labelling on disappearance of both types of equipment, each item's label was treated separately (*i.e.*, both original and replacement labels). The items were replaced only if they were found missing or damaged (see *3.1 Equipment disappearance* for details on equipment checks). A new label, containing a different type of message than the phrasing that disappeared (see Fig. 4) was provided at each replacement. Because frassboxes were deployed in both 2018 and in 2019 for the duration of the breeding season (note that nestboxes remained throughout the entire duration of the study), we summed the number of disappearances and the total number of available frassboxes within each label type from the first and the second year of the study.

4.2 Environmental drivers of scientific equipment disappearance across the urban mosaic

Nestbox disappearance was monitored across 4 years (2016-2019). As multiple disappearances of the same nestbox were rare (N = 4), we fitted a binomial response variable as 0 - never disappeared - or 1 - disappeared at least once (contrarily to the label analysis where all disappearance events were analysed). Because the response variable was zero-inflated (i.e., observed zeros in the dataset exceeded predicted zeros), we used the R-package *glmmTMB* (v.1.0.2.1) (Brooks et al., 2017), specifying the binomial family and the *ziformula* as 1, which applied a single-zero inflation parameter to each observation. Due to the high correlation ($r_{Pearson} > 0.6$, $p < 0.001$, N=474) between the environmental variables *Distance to road*, *Distance to path,* and *Tree cover* in the nestbox dataset (see Fig. S2 and Table S3), we fitted three distinct models, which differed in including one of these variables in substitution of the other, but contained an analogous model structure in terms of the other predictors: specifically, *Human presence* (fitted as continuous explanatory variable) and *Site* (fitted as random effect to control for visitor behavioural differences (and approach towards scientific equipment) in the different sites, [e.g. national park *vs* urban park] (Zegras, 2004, Teixeira, 2021), N = 8 levels).

Frassbox disappearance was analysed using *Generalised Linear Mixed Effects Model*s (GLMMs), where the total number of disappeared frassboxes was fitted as a Poisson-distributed response variable (*glmer* function in *lme4*, v.1.1-21) (Bates et al., 2007). Because of the strong correlation between *Distance to the road* and *Tree cover* ($r_{Pearson} = -0.7$, $p < 0.001$, N = 141, see Fig. S2 and Table S3), analyses were performed in two distinct models, which included one or the other environmental variable (as described earlier). The other predictors included in both models were *Human presence, Distance to paths* (both as continuous), and *Year* (as a two-level factor). Frassbox ID, nested within *Site* (N=7 levels), were fitted as random effects to avoid pseudo replication in both models. Multicollinearity was checked using the R-package *performance* (v.0.8.0) (Lüdecke et al., 2021) and always resulted in vif < 2. All model fits and assumptions were verified using the *DHARMa* package (v.0.4.4) (see Fig. S3, Hartig, 2020). Continuous predictors in all models described above were scaled and mean-centred for estimation clarity. All interactions between predictors were tested and retained in the final models only if significant.

4.3 Novelty and scientific equipment disappearance

To test whether *novelty* was associated with disappearance probability, we fitted a Generalised Linear Mixed Effect Model (GLMM) where the binomial-variable (disappeared or not disappeared, coded as 1 or 0, respectively) was set as response, and *Novelty* (starting with 1 from the day of equipment setup at the start of each breeding season; see Table 3 & Table S4a-b) was included as continuous predictor. Frassboxes were distributed on the ground across the study sites starting when the majority of great tit and blue tit nestlings were in the nest (from 1st of May until mid-June in 2018 and in 2019). *Year* was included as a two-level factor (2018 or 2019) and *FrassboxID* was fitted as a random effect, as the same frassbox was regularly checked (every four days) at multiple times each year (N of checks = 12 and 11 in 2018 and 2019, respectively). Multicollinearity issues, as well as model fit and assumptions, were checked as described in Methods 4.2. The *Novelty* analysis was not performed for nestboxes due to a different experimental setup (see Methods 3.4).

RESULTS

A total of 474 nestboxes and 141 frassboxes were followed over the duration of the study. 45,36% of nestboxes were followed for four years, 40,93% for three years and 13,71 % for two years. All frassboxes (100%) were followed for two field seasons (see Table S1 and S2).

Different types of equipment disappear at different rates

Over the duration of the study, 6.33% (N=30) of nestboxes disappeared at least once. In contrast, frassbox disappearance was *c.* eight times larger, as almost half (49,65%, N=70) of all available frassboxes disappeared at least once.

No effect of labelling on scientific equipment disappearance

Label type did not influence disappearance of either type of equipment. For nestboxes, we had 15 disappearances of *informative* labelled items (out of 171 available items with this type of label), nine disappearances of *neutral* items (out of 163) and 10 disappearances of *harsh* items (out of 170) – χ^2 =1.4774, d.f. = 2, p-value = 0.478. For frassboxes, we observed 91 disappearances of *informative* items (out of 217), 84 disappearances of *neutral* items (out of 224) and 95 disappearances of *harsh* items (out of 212) – χ^2 =1.8021, d.f. = 2, p-value = 0.600.

Covariation between environmental variables and scientific equipment disappearance

Nestbox disappearance

When applying the RAT-VIVA framework to scientific equipment disappearance patterns (Fig. 1), nestbox disappearance was associated with the interaction between human presence and tree cover. In other words, nestbox disappearance increased with higher human presence in areas with higher tree cover, and decreased with higher human presence in areas with low tree cover (Fig. 5, Table 1). Nestbox disappearance was not associated with nestbox distance to roads or distance to paths (see Table S5).

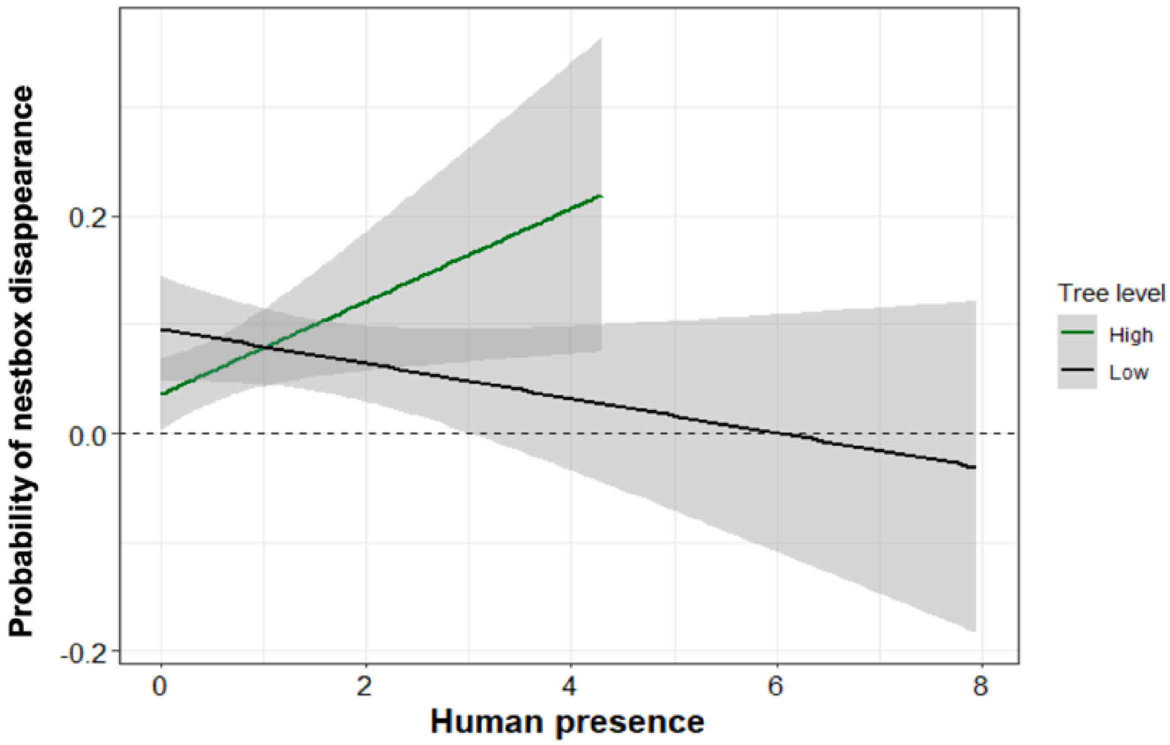

Figure 5. Linear regression (with 95% confidence intervals) reporting the probability of nestbox disappearance in areas with high human presence and high tree cover. To visualise the interaction, we used the *lm* function in *ggplot2;* tree cover was categorised based on the median value of the full dataset as low (N = 237, values between 0 and 26.4, mean ±se, 7.46 ±0.45); black line and high (N = 237, values above 26.4, mean ±se, 63.2 ±1.01; green line).

Table 1. Zero-inflated models with binomial distribution testing the association between nestbox disappearance and environmental variables.

Environmental drivers of nestbox disappearances				
***Family**:* zero-inflated with binomial (logit) distribution, N $_{nestboxes}$ = 474				
Model structure: **Disappeared nestbox (0/1)** ~ Human presence $_{sc}$ * Tree cover $_{sc}$.				
Variable	**Estimate**	**se**	**z-value**	**p-value**
Intercept	2.261	1.825	1.239	0.215
Human presence * Tree cover	**4.138**	**2.076**	**1.993**	**0.046***
Human presence	3.634	2.390	1.521	0.128
Tree cover	1.448	1.491	0.971	0.331

Table 1. Zero-inflated GLMMs models with binomial distribution testing the association between probabilities of nestbox disappearance (fitted as never disappeared, 0, or disappeared at least once, as 1, in four years). Models were analysed using the R-package *glmmTMB*. Continuous predictors were mean-centred and scaled (sc). Significance levels are indicated **in bold**: ***p <0.05, **p<0.01, ***p<0.001**.

Frassbox disappearance

As in the case of nestboxes, frassbox disappearance was also positively associated with the interaction between human presence and tree cover (Fig. 5). Overall, frassbox disappearance increased with human presence, and particularly so in areas with high tree cover (Fig. 6). At the same time, frassbox disappearance was also associated with the interaction between distance to roads and distance to paths. Specifically, the disappearance rate increased closer to roads, if those were located further away from paths (Table 2).

Table 2. Generalised Linear Mixed Effects Models (GLMMs) with Poisson distribution testing environmental drivers of frassbox disappearance across the urban mosaic.

Environmental drivers of frassbox disappearances				
Family: Poisson (log), *Random*: Frassbox ID nested within Site, $N_{frassboxes}$ = 282, N_{sites} = 7				
Model structure: Frassbox disappearances $_{(Total)}$ ~ Human presence$_{sc}$ * Tree cover$_{sc}$ + Distance to paths$_{sc}$ + Year.				
Variable	**Estimate**	**se**	**z-value**	**p-value**
Intercept	-0.935	0.349	-2.680	0.007**
Human presence * Tree cover	**0.503**	**0.216**	**2.321**	**0.020***
Human presence	**0.948**	**0.252**	**3.758**	**<0.001*****
Tree cover	**-0.610**	**0.245**	**-2.487**	**0.012***
Distance to paths	0.061	0.181	0.336	0.736
Year (2019)	-0.215	0.122	-1.759	0.078
***Model structure** (glmer):* Frassbox disappearances $_{(Total)}$ ~ Distance to roads$_{sc}$ * Distance to paths$_{sc}$ + Human presence$_{sc}$ + Year.				
Variable	**Estimate**	**se**	**z-value**	**p-value**
Intercept	-0.841	0.509	-1.652	0.098
Distance to paths * Distance to roads	**-0.956**	**0.385**	**-2.482**	**0.013***
Human presence	**0.406**	**0.183**	**2.212**	**0.027***
Distance to roads	-0.089	0.277	-0.323	0.746
Distance to paths	-0.282	0.220	-1.279	0.201
Year (2019)	-0.214	0.122	-1.758	0.078

Table 2. Generalised Linear Mixed Effects Models testing the effects of environmental variables on cumulated frassboxes disappearances. Continuous predictors were mean-centred and scaled (*sc*). Model details are reported in Section 4.2. Significance levels are indicated **in bold**: ***p <0.05, **p<0.01, ***p<0.001**.

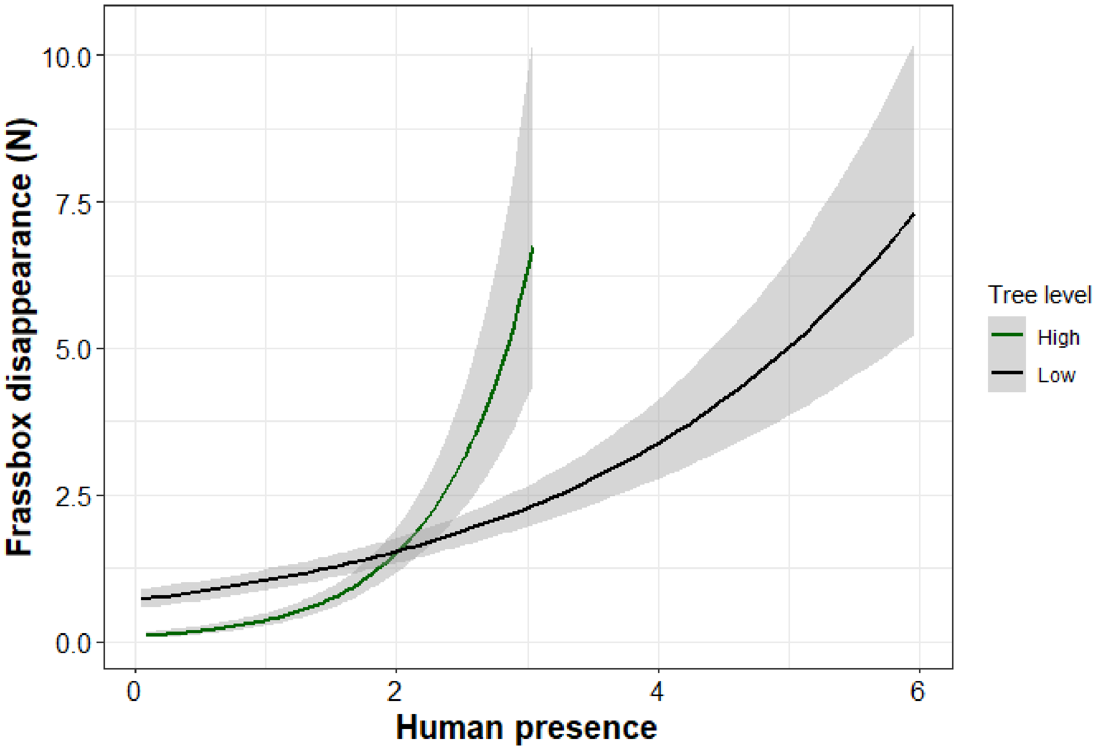

Figure 6. 95% confidence intervals reporting frassbox disappearance in areas with high human presence and high tree cover. To visualise the interaction, we used the *lm* function in *ggplot2; Tree cover* was categorised based on the median value of the full dataset as low (N = 142, values between 0 and 27.42, mean ±se, 8.65 ±0.73) and high (N =140, values above 27.42, mean ±se, 51.68 ±0.9).

Novelty as a predictor of scientific equipment disappearance

Frassbox disappearance was highly sensitive to the novelty effect, as the majority of frassboxes disappeared in the initial stage of the study (at the start of the breeding season), when items were deployed in the field; the frequency of these disappearances subsequently and gradually decreased. Most items ($N_{2018} = 21$, $N_{2019} = 24$) disappeared in the first, four days long period of frass collection in the season (Table 3, Fig. 7).

Table 3. GLMMs testing the association between novelty and frassbox disappearance.

Effect of novelty on frassbox disappearance (2018 & 2019)				
Family*:* Binomial, Random = Frassbox ID (N = 141).				
Model structure *(glmer):* Disappeared $_{Frassbox}$ (0/1) ~ Novelty$_{sc}$ + Year.				
Variable	**Estimate**	**se**	**z-value**	**p-value**
Intercept	-3.749	0.275	-13.650	<0.001***
Novelty	**-0.487**	**0.081**	**-6.014**	**<0.001*** **
Year (2019)	-0.262	0.157	1.676	0.094

Table 3. Generalised Linear Mixed Effects Model testing the association between novelty and frassbox disappearance. **Novelty was calculated as the entire period - in days – the collectors were left in the field (1=1st of May, each year, as 2018 or 2019).** Continuous predictors were mean-centred and scaled (*sc*). Model details are reported in Methods (Section 4.3). Significance levels are indicated **in bold**: ***p <0.05, **p<0.01, ***p<0.001**.

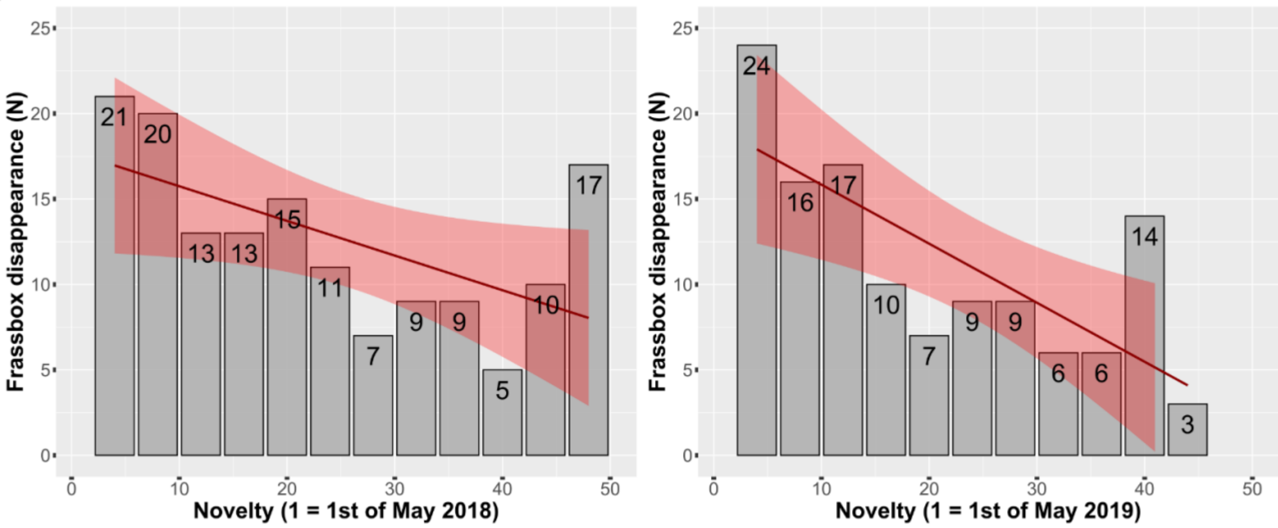

Figure 7. Frassbox disappearance was highest when frassboxes were novel in the environment. Barplots indicate the cumulated number of disappeared frassboxes per check in the field (over a total of 141 deployed frassboxes). The trend line was generated using a Linear regression (*stat_smooth* function in *ggplot2*). Similar trends were found if the models were run separately for both years (208 & 2019; see Table S4a-b).

DISCUSSION

In this paper, we empirically applied event-focused theory developed in the context of criminal studies – the Routine Activity Theory (RAT; Cohen & Felson, 1979, Felson & Clarke, 1998) – to urban evolutionary ecology research. By doing so, we were able to successfully predict and statistically verify which external variables and equipment attributes are associated with field equipment disappearance.

The *potential offender* element of RAT (Fig. 1 (1); modelled by human presence), interacted with *visibility* (Fig. 1 (2.3); represented here by tree cover) to influence the disappearance of both nestboxes and frassboxes. Thus, in highly-frequented places, people were more likely to remove the scientific equipment if they felt less seen – for example in cases where trees could act as a cover. Indeed, urban greenery is reported to have a significant influence on rates of a variety of crimes: a recent study reporting property crimes over multiple cities from South Africa are fully in alignment with our findings, confirming that higher tree cover was associated with increased property crime (Venter et al., 2022).

The *absence of guardians* element of RAT (Fig. 1 (3)) was modulated by label tone. Contrary to Clarin et al. (2014), we did not find a significant difference in the disappearance of either type of equipment based on label types (see *Results*). A possible explanation is that the labels used in this study needed to be applied to a real-life scenario of efficiency and informativeness, worded specifically for the sake of the long-term study it was designed for. Consequently, the messages were more explicit (for example, they did not include images of a juvenile squirrel, or of an overly threatening warning sign), and were not as radically different from each other as in the hypothetical scenario assessed by Clarin et al. (2014). Therefore, the overall effect of labels on equipment disappearance in our study system may be weaker. Importantly, relative to Clarin et al. (2014), this study was run on two different types of equipment, considerably larger sample sizes (474 nestboxes and 141 frassboxes vs 60 equipment dummies), and greater – and more diversified in terms of land use – number of study sites (eight sites set in a gradient of urbanisation vs four urban parks), as well as a longer study period (two to four years [nestboxes] and c. 90 days [frassboxes] vs. 24 days in Clarin et al. (2014)). Consequently – following recommendations in Clarin et al. (2014) regarding the need of replication in other regions of the world – our findings suggest that labelling may not be a sufficient method to protect the equipment if applied to a realistic, long-term project across different cultural and spatial contexts.

Based on the four VIVA attributes (*value*, *inertia*, *visibility* and *access*), we predicted that nestboxes are a type of scientific equipment that is less susceptible to disappear than frassboxes (Box 1(B)). This prediction was confirmed, and reflected in the percentage of disappearances recorded as binary events (nestbox disappearance rate of 6,33% vs frassbox disappearance rate of 49,65%). As expected by the framework features, a small, light, eye-catching and easily accessible item such as the frassbox is significantly more prone to negative interactions with people than the unhandy, harder to spot and to reach nestbox; even with a considerable difference in value – visually a woodcrete nestbox is more valuable, than a paper frassbox, which is also reflected in items' price (Box 1).

Importantly, the VIVA framework allowed us to determine which attributes are influencing the disappearance of items within the same type of equipment (Fig. 1).

- *Value*, determined by *novelty*, influenced the disappearance of frassboxes (Fig. 7). As anticipated (Fig. 1), most disappearances occurred in the early period of equipment setup, after which the numbers gradually decreased. This strongly suggests that city dwellers lost their original interest in interfering and removing the equipment once it was familiar (Dinnin, 2009). Note that this might not be the case with considerably more valuable equipment, such as camera traps, where the financial cost of the equipment itself can interact with the temporal dimension of novelty (Meek et al., 2018)
- *Inertia* is consistent within equipment type (as the volume and weight of all items [e.g. nestboxes or frassboxes] is the same), thus it could not influence the disappearance dynamics at this level.
- *Visibility* – discussed above (see above).
- Finally, *access* – measured by item's distance to the closest path or road – was found to be associated with the disappearance of frassboxes, but not nestboxes. These findings suggest that researchers, site-managers and stakeholders should consider securing easily reachable field equipment, especially in accessible areas (see Introduction for examples of equipment securing methods). At the same time fixing the equipment beyond the reach of passers-by may also decrease a chance of equipment disappearance (as in case of nestboxes).

Our results thus confirm that the disappearance of field equipment, as tested in the context of a real-life research project run in the urban field, is the result of an interaction between external variables (Fig. 1) – such as *potential offender* (human presence), *relative value* (novelty), *visibility* (tree cover), *access* (distance to paths

* distance to roads) – and equipment attributes (Box 1) – that is an item's *assumed value* (here approximated by price), *inertia* (volume and weight), *visibility* (colour), *access* (type of installation).

Conclusions

The results reported here confirm that in urban areas, certain study site settings may facilitate or impede equipment disappearance. Similarly, some types of deployable scientific equipment may be predisposed for negative interactions with people. Moreover, the interactions between the two – the study site setting and equipment characteristics – also affect equipment disappearance. This observation further enhances the importance of accounting for sociological aspects while conducting eco-evo research in areas occupied by humans, such as cities (Des Roches et al., 2021).

Those findings illustrate the universal validity of the Routine Activity Theory (RAT), and the VIVA framework embedded within this theory for urban ecology and evolution research. Examining the equipment and the study locations under the RAT-VIVA framework is an easily applicable and inexpensive way to better understand patterns of equipment disappearance, thereby strengthening the potential for informed project planning and as a result – safer, and more effective studies not only in the urban space but also other frequently visited areas.

It is important to remember that this study was conducted in a European capital city (specifically – a democratic post-communist Central Eastern European capital city), and as such provides valuable insight into processes (equipment theft) that may carry both local features (shaped by specific socio-cultural norms), as well as universal ones pertaining to human psychology. Thus, our results fully align with a study on property crime committed in urban areas from the Global South (Venter et al., 2022). Importantly - the RAT-VIVA framework presented here is fully amenable to modifications of original predictions based on cultural and geographical variation, and as such can be applied to any location of interest. We encourage other researchers to conduct similar studies during their research, particularly by adding a greater understanding of the dynamic of scientific equipment disappearance in the urban space when tested in cities of variable size and in different social contexts.

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Data accessibility statement:

This manuscript is currently being submitted to an academic journal for the first time. Full datasets will be uploaded upon final acceptance in a peer-reviewed journal.