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# Simulating Trial Trenches for Archaeological Prospection: Assessing the Variability in Intersection Rates

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ABSTRACT

In this study we draw attention to the inherent variability in the results of trial trenching, when taking into account the countless variations in orientation and positioning of trenches. Grids of trial trenches were simulated time and again on the excavation plans of 16 archaeological sites from Flanders, Belgium. Orientation and positioning of the grid layout was shifted randomly, whilst the area coverage varied from 2.5% to 80%. The intersection rates of the archaeological features allow to gain more insight in trends and variability that are inherent to the chosen design of trial trenches. It is assessed how robust a chosen grid layout performs on (multi-period) archaeological sites and how variable these results might be. The most effective layout appears to be a grid with short, parallel and discontinuous trenches or a standard grid, closely followed by 2 m wide continuous trenches. Implementing 4 m wide trenches reduces the effectiveness of the latter method substantially. When the area coverage of the trenches is below 10%, the results of the archaeological prospection become unreliable and can potentially lead to a substantial over-or underestimation of the actual feature density on the site. Copyright © 2016 John Wiley & Sons, Ltd.

*Key words:* Archaeological survey; trial trenching; simulations; archaeological heritage management; GIS toolbox; intersection rates

## Introduction

Trial trenching is the most widespread method in archaeological prospection in northwest Europe (Vander Linden and Webley, 2012). It is aimed at providing more insight in predicting and evaluating the presence, abundance, type, spatial distribution and preservation of archaeological features and artefacts (with ‘features’ being the immobile part of the archaeological heritage, and ‘artefacts’ the mobile part). Often it is the first – and sometimes even last – physical contact with an archaeological site or concentration of cultural finds. Therefore, this technique needs to be efficient, cost-effective and reliable (Tol *et al.*, 2004) and should allow to make an informed decision whether to proceed with an archaeological excavation, abandon further research or ensure *in situ* conservation of the archaeological record.

Trial trenching involves the layout of a systematic pattern of excavation trenches in a study area, thus investigating the presence of archaeological features and artefacts in a limited part of the terrain. A clear distinction should be made between trial trenching aimed at detecting the sheer presence of archaeological sites, and prospection targeted at the assessment and evaluation of archaeological features and artefacts (Verhagen and Borsboom, 2009; Webley *et al.*, 2012). The purpose of the latter is to acquire more insight in the density, the spatial arrangement and chronology of the intersected archaeological site(s), and the state of preservation of the related features and artefacts. In Flanders (northern Belgium), it is common practice to combine detection and assessment in one and the same prospection phase, using trial trenches covering 10% of the area and an optional 2.5% coverage by test

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pits/windows (De Clercq *et al.*, 2011, 2012; Wouters, 2012). This area coverage $C$ (expressed in percentages) is quite similar to daily practice in France (Blancquaert and Medlycott, 2006; Brun *et al.*, 2006). Slightly lower values are stipulated in the Netherlands (Borsboom *et al.*, 2012). Currently there is no standard for trial trenching in the UK, although there is a trend towards an area coverage of 5% in southern England (Fitzpatrick, 2012). In Germany, there is no standard either, but in a number of federal states an area coverage of over 20% is not uncommon (Stäuble *et al.*, 2011). These numbers show that the applied area coverage for trial trenching can differ significantly according to the goal of the prospection phase and local legislation.

For a stipulated area coverage, a wide array of grid layouts can be defined. The simplest configuration consists of continuous, parallel trenches (Figure 1a). In this layout, only two parameters need to be defined: the distance $D$ between the centre of the trenches, and their width $W$. The most common grid – at least in continental Europe – is a pattern of discontinuous, staggered parallel trenches. Next to the width $W$ of the individual trenches, now also their length $L$ needs to be defined. In addition, the spacing between the individual trenches needs to be determined by two parameters: the interval $I$ between trenches in the same transect, and the distance $D$ between the transects (Figures 1b and 1c). The same parameters ($W$, $L$, $D$ and $I$) apply when implementing staggered trenches that are rotated alternately by 90° (Figure 1d), which is referred to in the UK as the standard grid. For both the parallel and standard grids, a multitude of configurations can be designed for a desired area coverage, by modulating the four basic parameters. In Flanders, it is common practice to implement continuous trenches of 2 m wide with 15 m of spacing (De Clercq *et al.*, 2011). In France, continuous trenches and staggered parallel grids are most frequently used, both in a configuration that leads to a $C$ of 10%. The length $L$ of the trenches can vary between projects, but is often around 30 m. The so-called *Méthode à la Lorraine* is a configuration where $L$ = 10 m, $I$ = 10 m and $D$ = 20 m. The standard grid is almost exclusively used in the UK, where it is often laid out with 30 m × 2 m trenches with a $C$ of ca. 5% ($I = D \approx 35$ m).

In many regions a standard approach is imposed (e.g. in Flanders), sometimes with variants according to the landscape, soil texture or expected type of archaeological site (e.g. in the Netherlands). Although some authors have argued that a more flexible approach is advisable (De Clercq *et al.*, 2011; Fokkens,

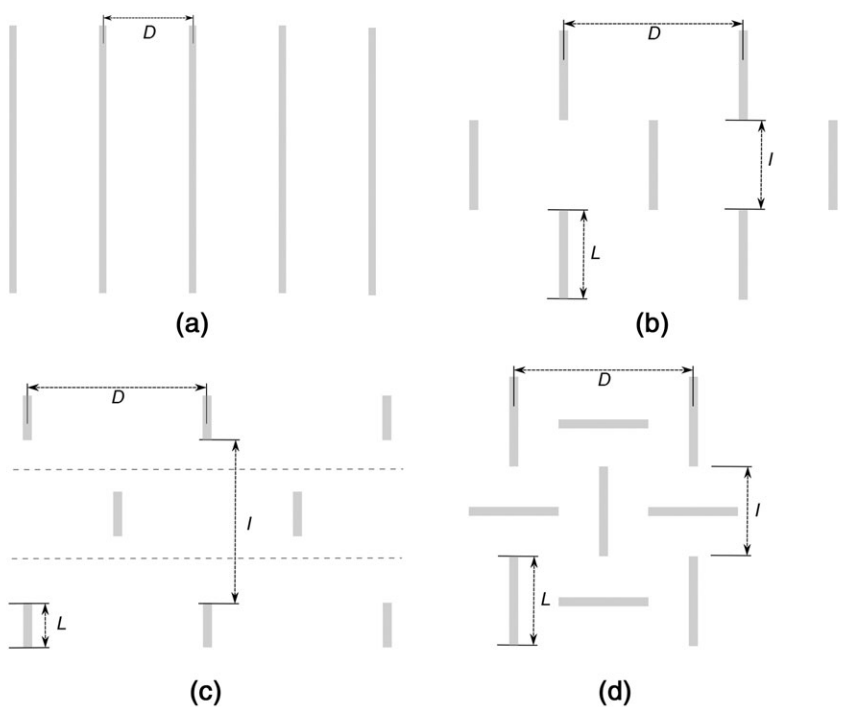


Figure 1. Grid layout for continuous trenches (a), discontinuous, staggered parallel trenches with $I = L$ (b) or $I > L$ (c) and a standard grid (d). The grids are defined by four basic parameters: the width $W$ of the trenches (not depicted), the distance $D$ between the centre of the trenches or trenchlines, the length $L$ of the trenches, the interval $I$ between individual trenches in a row.



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2007), in the context of commercial archaeology a standardized system is often preferred because it makes it easier to compare bids for doing survey.

The scientific evaluation of the effectiveness of the grid layouts of trial trenches has often relied on statistical approaches in which the chance of successfully recognizing an archaeological site is considered to be the product of the chance that the site is actually intersected by one of the trenches ($P_{\text{intersected}}$) and the chance that an archaeological feature or find will be detected ($P_{\text{detection}}$) (Krakker *et al.*, 1983; Verhagen, 2014). However, the only way to compute intersection probabilities for trial trenching is to simplify the extent of an archaeological site to a circle or an ellipse (e.g. Verhagen and Borsboom, 2009). Intersection probability then depends on the chosen grid layout and the assumed surface of the archaeological site. A different approach to evaluate the effectiveness of trial trenching was applied during large-scale construction projects in France (e.g. Planarch I and II in France: Blancquaert and Medlycott, 2006; Dubouloz, 2003) and England (Champion *et al.*, 1995; Hey and Lacey, 2001). Variable area coverages and grid layouts were applied on study sites, and the results were assessed after total excavation. In some studies this was also simulated in a geographical information system (GIS)-environment by overlaying different grids on excavation plans (Blancquaert and Medlycott, 2006; Hey and Lacey, 2001). Yet, the available studies have relied on a very limited number of repetitions of the same grid layout, with a specific positioning and orientation.

In this study we draw attention to the inherent variability in the results of trial trenching, when taking into account the countless variations in orientation and positioning of the trenches. With a high number of simulations, we aim to quantify the range of possible intersection rates that can be expected when implementing a specific grid layout. Furthermore, these simulations allow to evaluate the effectiveness of a chosen design in grid layout and area coverage. The framework for this study is the daily practice of archaeological prospection with trial trenches in Flanders and extensive excavations in this region. It is assessed how robust a chosen grid layout performs on (multi-period) study sites, how variable the results might be when a certain grid layout and area coverage are implemented, and how this is related to the feature density.

## Material and methods

### *Archaeological excavations*

For this study, 16 projects were selected on which an extensive archaeological excavation was performed (Table 1). The dataset is representative for current archaeological practice in Flanders and mostly consists of multi-period sites, with a wide chronological range from the Mesolithic up to World War II (chronology following Slechten, 2004). No sites are included in the dataset that contain artefact concentrations outside features. The surface of the analysed sites ranges from 0.0054 km$^2$ up to nearly 0.12 km$^2$, and they are located on sandy to loamy soils, and clayey alluvium (Dondeyne *et al.*, 2012).

Each project was a rescue excavation, and therefore a 'site' corresponds to an extensively excavated area

Table 1. Overview of the selected archaeological projects, and their characteristics.

| Number | Municipality: archaeological project | Label | Surface of the study site (km$^2$) | Number of features | Feature density (%) | Soil | Period(s) |
|---|---|---|---|---|---|---|---|
| 1 | Boom: KrekelenbergII | BO_KRE | 0.0118 | 535 | 0.7 | loamy sand | Iron Age; Roman |
| 2 | Beerse: Krommenhof | BE_KRO | 0.0195 | 1163 | 8.5 | sand | Neolithic; Bronze Age |
| 3 | Wichelen: Wijmeers2 | WI_WIJ | 0.0054 | 420 | 11.0 | clayey alluvium | Roman |
| 4 | Sint-Amandsberg: Hogeweg | SA_HOG | 0.0523 | 2968 | 8.5 | loamy sand | Bronze Age; Iron Age; WWII |
| 5 | Mortsel: Roderveldlaan | MO_ROD | 0.0048 | 143 | 5.1 | sandy loam | Bronze Age |
| 6 | Beerse: Beukenlaan | BE_BEU | 0.0214 | 1032 | 8.5 | sand | Middle Ages |
| 7 | Wijnegem: Blikstraat | WIJ_BL | 0.0229 | 963 | 7.4 | loamy sand | Bronze Age; Iron Age |
| 8 | Lier: Duwijck II | LI_DUW | 0.0669 | 1162 | 3.5 | sandy loam | Mesolithic; Iron Age |
| 9 | Olen: Industrielaan | OL_IND | 0.0822 | 2459 | 9.2 | sandy loam/ sand | Bronze Age; Iron Age; early modern; WWII |
| 10 | Hasselt: Ekkelgaarden | HA_EKK | 0,0088 | 364 | 17.8 | sandy loam | Iron Age; Roman |
| 11 | Tienen: Grijpenveld | TI_GRI | 0.1195 | 3882 | 14.2 | loam | Neolithic; Iron Age |
| 12 | Wevelgem: Ezelstraat | WE_EZE | 0.0143 | 283 | 9.1 | sandy loam | Roman; Middle Ages |
| 13 | Retie: Molenakkers | RE_MOL | 0.0297 | 602 | 0.9 | sand | Iron Age |
| 14 | Herentals: Draeybomen | HE_DBS | 0.0158 | 836 | 12.4 | loamy sand | Bronze and Iron Age; Roman; Middle Ages |
| 15 | Ieper: Kleine Poezelstraat | IE_KPS | 0.0148 | 51 | 4.4 | sandy loam | WWI |
| 16 | Poperinge: Sappenleen | PO_SAP | 0.0175 | 31 | 4.0 | sandy loam | WWI |



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whose perimeter is defined by the perimeter of a construction or development project, combined with the results of the preceding prospection phases.

The excavation plans were digitized as a shapefile (Environmental Systems Research Institute (ESRI), 1998), containing all the recorded cultural features as polygons (see Supporting Information for the excavation plan of each study site), and a separate shapefile delimiting the surface of the excavated area. Feature density on each study site was calculated as the ratio of the total area of the features recorded to the total surface of the excavated area. Two arbitrary threshold values for feature density divide the dataset into low-density (≤ 5%), medium-density (between 5 and 10%) and high-density (≥ 10%) sites. Consequently, some of the sites are classified as low-density sites (e.g. BO_KRE: 0.7%), whilst others (e.g. TI_GRI: 14.2%) are clearly high-density sites. The majority of the excavated areas in the dataset are considered to have a medium feature density (Table 1). Another distinction is made between excavated areas mainly consisting of small and compact features, such as postholes, and others with a substantial proportion of elongated and extensive features, such as war trenches or ditches. In order to quantify and visualize the diversity in shape and extent of the features, the isoperimetric quotient (IQ) was calculated for each feature ('shape index' according to de Smith *et al.*, 2015):

$$\mathrm{IQ} = \frac{4\pi A}{L^2}$$

where $L$ equals the length of a closed curve and $A$ the surface of the area it encloses. Elongated features are then represented by a low value, whilst circular features approximate a value of one. A histogram of the IQ-values for each of the analysed sites provides a helpful visual appreciation of the features' shape and extent on each location (Figure 2). Also, when plotting the average area of the features against the feature density on each of the analysed sites it becomes apparent that the dataset represents a wide range of sites in terms of feature density, shape and area (Figure 3). Two study sites, IE_KPS and PO_SAP, are not included in this graph as they contain very large features (average feature areas of over 12.5 $m^2$ and 22.5 $m^2$, respectively), with a low feature density of ca. 4%.

## *ArcGIS toolbox*

A toolbox was developed in ArcMap™ 10.1 (© 2010 ESRI) to simulate a multitude of configurations of trial trenches. The toolbox allows to vary the parameters for the configuration of three basic grid layouts for trial trenches: continuous trenching (CT), the parallel staggered grid (PG) and the standard grid (SG). For each of these layouts, the width of the trenches ($W$), length

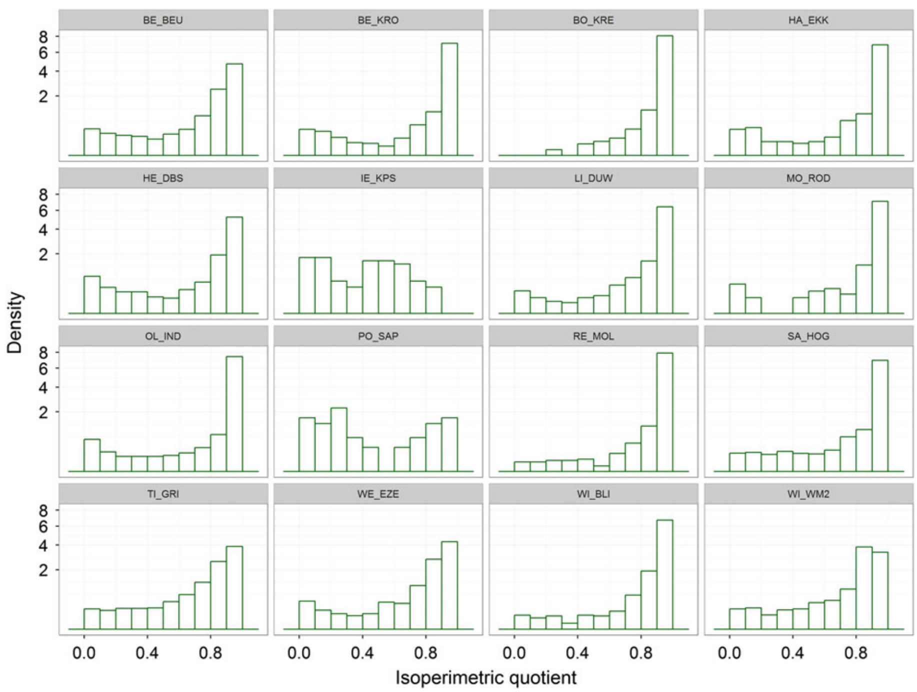


Figure 2. Histogram of the isoperimetric quotient of all features per study site. [Colour figure can be viewed at wileyonlinelibrary.com]



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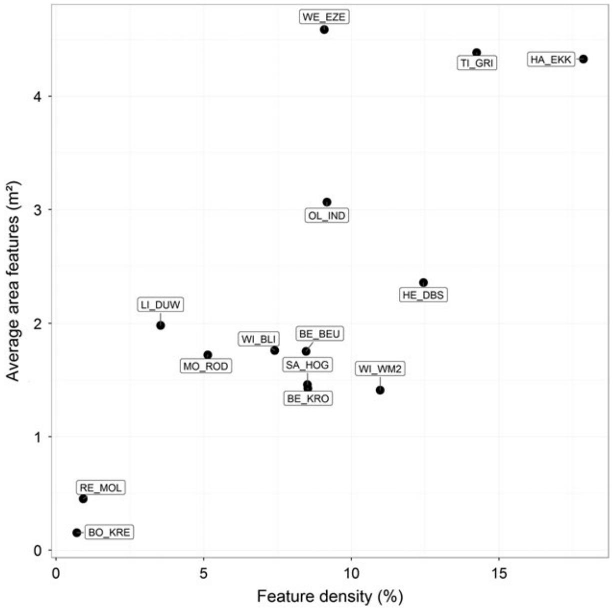


Figure 3. Feature density plotted against the average feature area, for each study site (IE_KPS and PO_SAP not included).

of the trenches ($L$) and distance between the transects ($D$) can be manipulated. The interval ($I$) between trenches in the same transect is an essential additional parameter for the parallel and standard grid.

In the simulation setup, the orientation of the trenches can be defined manually, or at random, as well as the position of the central point of the grid. This allows to apply a certain grid layout (with a chosen trench size) on countless possible positions on a shapefile of an archaeological excavation plan, by applying the same grid layout time and again. The exercise can be repeated with different $C$ values, different trench sizes, and different grid layouts.

After each run, three basic results are reported: (1) the number of features that is intersected by the trial trenches (F_INT) and its proportion to the total number of features of the analysed site (F_INT_P), (2) the total area of the features that is intersected (A_INT) and its proportion to the total area of the features (A_INT_P), (3) the number of times that features are intersected (N_INT) and its ratio to the total number of features on the site (N_INT_R). The latter can be higher than 100%, e.g. when elongated features are intersected multiple times by different trenches.

### *Simulated grid layouts and coverage*

The three grid layouts (continuous trenching, parallel staggered grid and standard grid) were simulated in varying configurations. For continuous trenching, the width $W$ of the trenches was set to 2 m (CT_W2) or 4 m (CT_W4). For both widths, the distance $D$ between the trenches was adapted in order to obtain an area coverage $C$ of 2.5%, 5%, 7.5%, 10%, 12.5%, 15%, 17.5%, 20%, 40%, 60% and 80% ($C = W/D$). When $C$ exceeds 20%, larger intervals were chosen because such configurations, although theoretically interesting, are never used in daily practice.

For the parallel staggered grids, three options were taken for the lengths $L$ of the individual trenches: short ($L$ = 10 m), medium-sized ($L$ = 25 m) and long ($L$ = 50 m) trenches. In addition, two configurations were selected: one in which the interval equalled the length of the trenches, $I = L$ (PG1), and a second in which the interval was set to twice their length, $I = 2 \times L$ (PG2). When applying the latter pattern, a smaller distance $D$ was required between the transects to achieve the same coverage $C$ in comparison to the pattern where $I = L$. For PG1 both 2 m (PG1_W2) and 4 m (PG1_W4) wide trenches were considered. Eventually, this resulted in nine different configurations for parallel staggered trenches, simulated with the same coverages as used for continuous trenching by adapting the distance $D$ between the transects ($C = (W \times L)/(D \times I)$). For PG2_W2, where $I = 2 \times L$, a coverage of $C \geq 40\%$ cannot be simulated as the trenches become self-intersecting (critical point: $D - W/2 < W$).

In standard grids, the trenches were alternatingly positioned perpendicularly to one another. Short, medium-sized and long trenches were considered in this case as well. The interval $I$ was set to be equal to or twice the length $L$ of the trenches. In this way, six different layouts were configured for the standard grid. Not all $C$ could be simulated as the trenches become self-intersecting when $D < L/2 + W/2$. For medium-sized ($L$ = 25 m) and long ($L$ = 50 m) trenches, this criterion is already met at a $C$ of 7.5% and 5%, respectively.

## Results

### *Replication*

Before simulating large batches of different grid layouts, test runs were performed in order to determine the desired number of repetitions for each configuration, which should be high enough to cover the random statistical variation and the whole spectrum of possible orientations and positions of each grid layout for the selected sites. One thousand simulations of continuous, 2 m wide trenches (CT_W2) for an area coverage of 12% were performed on two sites; BO_KRE (a site with



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low feature density) and HA_EKK (a high-density site), where both the orientation and position of the central point of the grid were set to vary at random. Of these simulations, a random subset of *n* simulations was taken (with *n* ranging from 25 to 975, taking steps of 25) and the average area of features intercepted (A_INT_P) was calculated. This procedure was repeated 1000 times for each step of 25. The larger the subsets became (increasing values of *n*), the less variability was observed in the average of A_INT_P for each subset. For the low-density site BO_KRE, the mean values of A_INT_P became stable after more than 500 simulations, in such a way that the 95.4% interval became less than 0.5% wide (Figure 4, dashed lines). For HA_EKK, this was already achieved with subsets of 150 runs (result not depicted). Subsequently, it was decided to run 500 simulations for each configuration for area coverages up to 20%. For higher values of *C*, only 300 (for *C* = 40%) or 200 (for *C* = 60% and 80%) simulations were performed, as these configurations provide more stable results.

## *Variability*

### Variability due to edge effects

When choosing a specific grid layout, it is common practice to adapt the distance *D* between the trenches in order to obtain the desired area coverage *C*. For a *C* of 10% with 2 m wide continuous trenches (CT_W2), *D* becomes 20 m, for a parallel staggered grid with *I* = 2 × *L* (PG2_W2) and trenches of 25 m by 2 m, the distance *D* becomes 10 m, etc. However, adhering strictly to the postulated grid layout might prevent some trenches from being laid out completely because they may (partly) fall outside the perimeter of the area that has to be prospected. Such edge effects can become substantial, especially when this perimeter is irregular and the ratio of girth versus surface becomes high. The variability caused by edge effects becomes clear when comparing the postulated area coverage *C* of a chosen grid layout with the area actually covered by the trenches in this grid (Figure 5). In 95% of the cases, the deviation from the targeted *C* is less than 0.5%, and this applies to most configurations. However, when 4 m wide trenches are implemented, the edge effects become more pronounced and this can lead to a higher deviation from the postulated *C*. When planning continuous trenching with 4 m wide trial trenches and a *C* of 10%, the actual area covered will generally vary between 9% and 11%.

### Variability due to random positioning of the trench grid

Overlaying the same grid layout time and again on an archaeological excavation plan with randomly varying orientation and positioning of the grid's central point, results in an array of values for the number and area of the features that are intersected by the trial trenches, expressed in absolute or relative numbers. The range of potential intersection values [as expressed by the 95% range and the standard deviation (s.d.) around the mean] is related to the chosen type of grid and to the study site's characteristics.

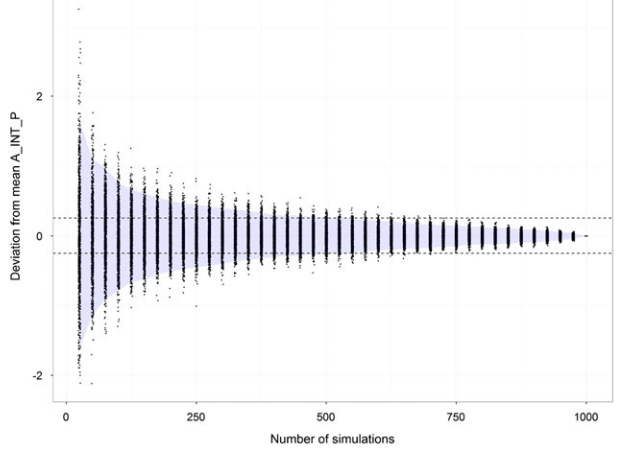


Figure 4. Evolution of the variability of the average value of A_INT_P for increasing number of simulations on study site BO_KRE. The blue area represents the 95% confidence intervals, the dashed parallel lines delineate a band of 0.5% deviation from the actual mean. [Colour figure can be viewed at wileyonlinelibrary.com]

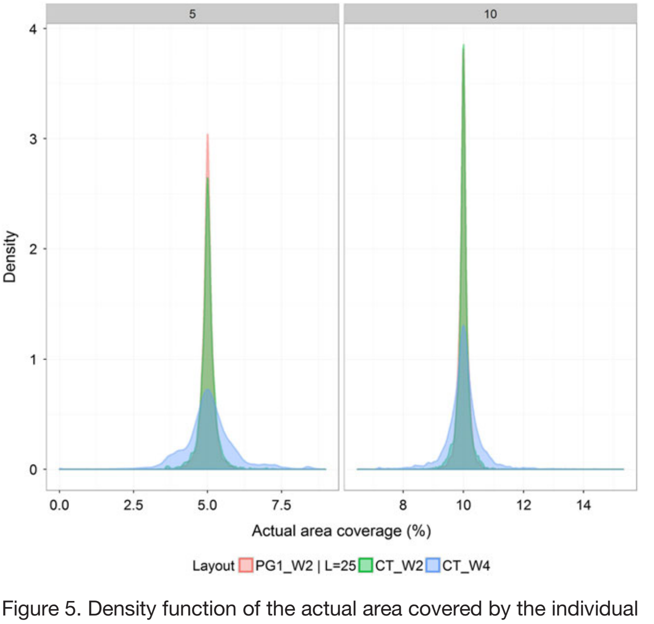


Figure 5. Density function of the actual area covered by the individual trenches for three layouts aimed at an area coverage *C* of 5% and 10%. [Colour figure can be viewed at wileyonlinelibrary.com]



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*Intersected feature area.* Considering the total area of the features intersected first, it should be clear that based on the total number of simulations the average area of the features that is intersected always corresponds to the area coverage of the trenches. So when $C$ equals 10%, on average 10% of the feature area is intersected. Figure 6 illustrates the range of potential outcomes for 500 simulations on two particular study sites, when applying a grid of continuous, 2 m wide trenches (CT_W2) with $C$ at 12.5% ($D$ = 16 m). In most cases the frequency distribution of the percentage of intersected feature area approaches a normal distribution, although this is not always the case, as can be seen for BO_KRE. The s.d. of the percentage of intersected feature area is in most cases around 1–1.5% (Table 2). However, for some sites, extremely high (e.g. BO_KRE, MO_ROD & RE_MOL) and low (e.g. TI_GRI & OL_IND) s.d. values were recorded. Accordingly, the difference between the minimum and maximum values observed for the intersected feature area varies widely per site (e.g. 25.8% for RE_MOL but only 3.2% for TI_GRI, Table 2). Considering all analysed sites together, with the same grid layout and area coverage, in some cases as little as 3.5% (MO_ROD), but on another site as much as 30.1% (RE_MOL) of the total area of features is intersected (Table 2). The 95% range of all observations per site is between 1.7% (TI_GRI) and 14.1% (BO_KRE) (Table 2). These figures clearly demonstrate that the outcome of the simulations may differ significantly in terms of variability. For BO_KRE, a low-density site, the results are quite unpredictable and the percentage of intersected feature area varies greatly according to the positioning of the trenches, with intersection

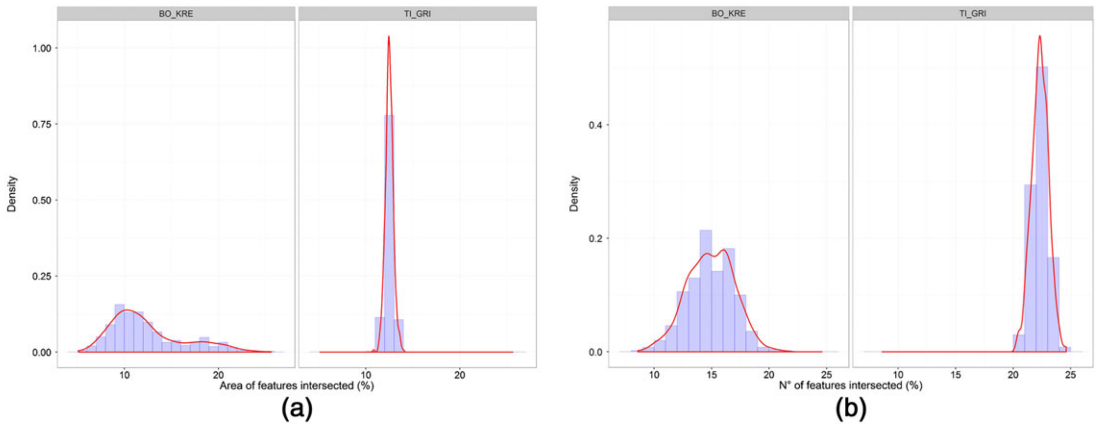


Figure 6. Density function of the area (a) and number (b) of features intersected (expressed as percentages of the total feature number/area), by repeated overlay of the same grid layout on the low-density site of BO_KRE and the high-density site of TI_GRI with an area coverage $C$ of 12.5%. [Colour figure can be viewed at wileyonlinelibrary.com]

Table 2. Overview of simulation results for the area and number of intersected features, with continuous trenches (2 m wide) for $C$ = 12.5%.

| Site | Intersected feature area (% of total): A_INT_P | | | | | Intersected number of features (% of total): F_INT_P | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Mean | s.d. | Minimum | Maximum | Width of 95% range | Mean | s.d. | Minimum | Maximum | Width of 95% range |
| BE_BEU | 12.5 | 1.1 | 8.2 | 17.5 | 4.2 | 19.7 | 1.7 | 14.9 | 27.3 | 7.0 |
| BE_KRO | 12.5 | 1.3 | 8.8 | 19.0 | 5.1 | 18.5 | 2.1 | 12.2 | 25.0 | 8.0 |
| BO_KRE | 12.3 | 3.9 | 5.1 | 25.6 | 14.1 | 14.9 | 2.0 | 8.6 | 21.1 | 7.9 |
| HA_EKK | 12.5 | 1.5 | 8.3 | 18.4 | 6.2 | 21.7 | 3.0 | 14.3 | 29.9 | 11.8 |
| HE_DBS | 12.5 | 1.1 | 8.8 | 17.1 | 4.8 | 22.8 | 2.2 | 16.3 | 28.6 | 8.7 |
| IE_KPS | 12.4 | 2.1 | 7.1 | 18.3 | 7.8 | 46.7 | 7.0 | 27.5 | 70.6 | 27.5 |
| LI_DUW | 12.5 | 1.2 | 9.1 | 16.3 | 4.7 | 18.5 | 1.5 | 14.5 | 23.3 | 5.9 |
| MO_ROD | 12.4 | 3.5 | 3.5 | 20.7 | 13.4 | 20.1 | 3.4 | 11.2 | 29.4 | 13.3 |
| OL_IND | 12.5 | 0.6 | 10.2 | 15.1 | 2.3 | 20.3 | 1.2 | 16.7 | 23.7 | 4.6 |
| PO_SAP | 12.4 | 2.0 | 7.2 | 19.6 | 8.3 | 52.5 | 8.0 | 29.0 | 74.2 | 29.0 |
| RE_MOL | 12.5 | 2.8 | 4.3 | 30.1 | 11.8 | 15.6 | 2.4 | 8.6 | 22.6 | 9.6 |
| SA_HOG | 12.4 | 1.0 | 9.2 | 15.8 | 4.2 | 17.7 | 1.2 | 14.8 | 21.2 | 4.4 |
| TI_GRI | 12.5 | 0.4 | 10.8 | 14.0 | 1.7 | 22.3 | 0.7 | 20.3 | 24.6 | 2.8 |
| WE_EZE | 12.6 | 1.8 | 7.1 | 20.0 | 7.5 | 22.4 | 2.5 | 15.9 | 30.7 | 9.4 |
| WI_BLI | 12.6 | 1.2 | 7.4 | 16.7 | 5.1 | 16.6 | 1.7 | 12.5 | 21.5 | 6.8 |
| WI_WM2 | 12.5 | 2.0 | 5.7 | 18.8 | 8.5 | 17.9 | 3.5 | 7.9 | 30.7 | 13.0 |



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values that range between 5.1% and 25.6% (Figure 6). On site TI_GRI, with a high density of features, this range is far more narrow: between 10.8% and 13.9% (Figure 6).

*Number of intersected features.* The range of results for the number of intersected features does not correlate with values of intersected feature area. On average the percentage of features intersected is substantially higher than the percentage of intersected feature area (Table 2 and Figure 6). For example, for the sites PO_SAP and IE_KPS with a low feature density but long and outstretched features (Figures 2 and 3), the results are extremely variable. The 95% range of possible outcomes for the number of intersected features of these sites is 29.0% and 27.5% wide, respectively. This demonstrates that on sites with long and outstretched features, the values for the number of intersected features must be interpreted with care when evaluating the efficiency of the grid layout.

*Feature density.* The density of archaeological features on a site also seems to influence the outcome and variability of the simulations. When repeating the same grid with different orientations and position, it seems that low-density sites tend to have a wider range of possible outcomes for intersected feature area compared to sites with medium to high feature density (Figure 7). With a feature density of more than 5%, the 95%-range of possible outcomes varies between 2.5 and 7.5% for continuous trenches. Similar trends are observed when implementing other grid layouts, such as staggered discontinuous trenches (Figure 7). But also for this configuration, the highest 95%-range in possible outcomes is observed for low-density sites.

*Feature density in trenches.* Often, a site's feature density is estimated by extrapolating the feature density observed in the trial trenches (T_dens) to the whole study site. The simulation results, however, show that this can potentially lead to a substantial overestimation or underestimation of the actual feature density on the excavated site. The potential difference between the genuine feature density on a study site and the feature density observed in the trenches is most pronounced with low values of *C*; a trend that is evident for all sites (Figure 8). Especially on sites with a high feature density, such as HA_EKK and HE_DBS, a potential deviation of the true feature density of up to 10% has been observed when only a low percentage (2.5–7.5%) was covered by trial trenches. On low-density sites (e.g. BO_KRE and RE_MOL), the deviation from the site's feature density leads to an overestimate or underestimate of actual feature density of less than 1% (Figure 8).

When regarding the total dataset, it was observed that for values of *C* of over 10%, the deviation of T_dens from the actual feature density became lower

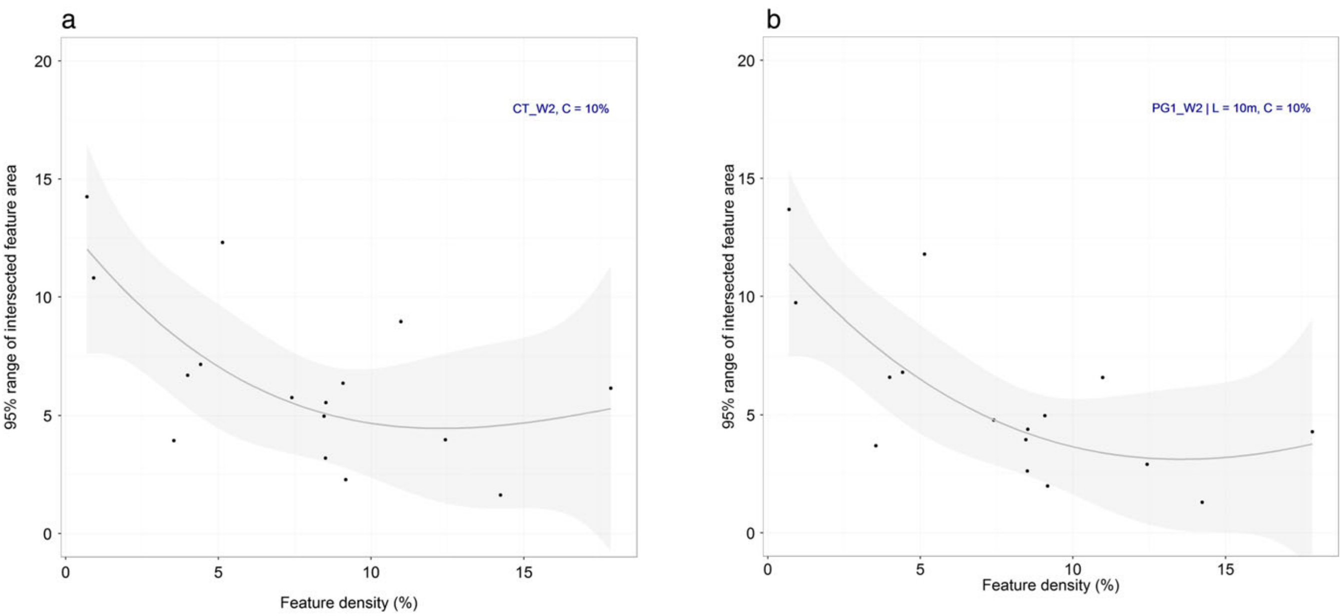


Figure 7. The 95% range of possible outcomes for the area of intersected features (A_INT_P) for two grid layouts: (a) continuous trenches of 2 m wide, (b) discontinuous parallel grid with short trenches. The general trend is visualized by a spline function with associated confidence intervals (grey band). [Colour figure can be viewed at wileyonlinelibrary.com]



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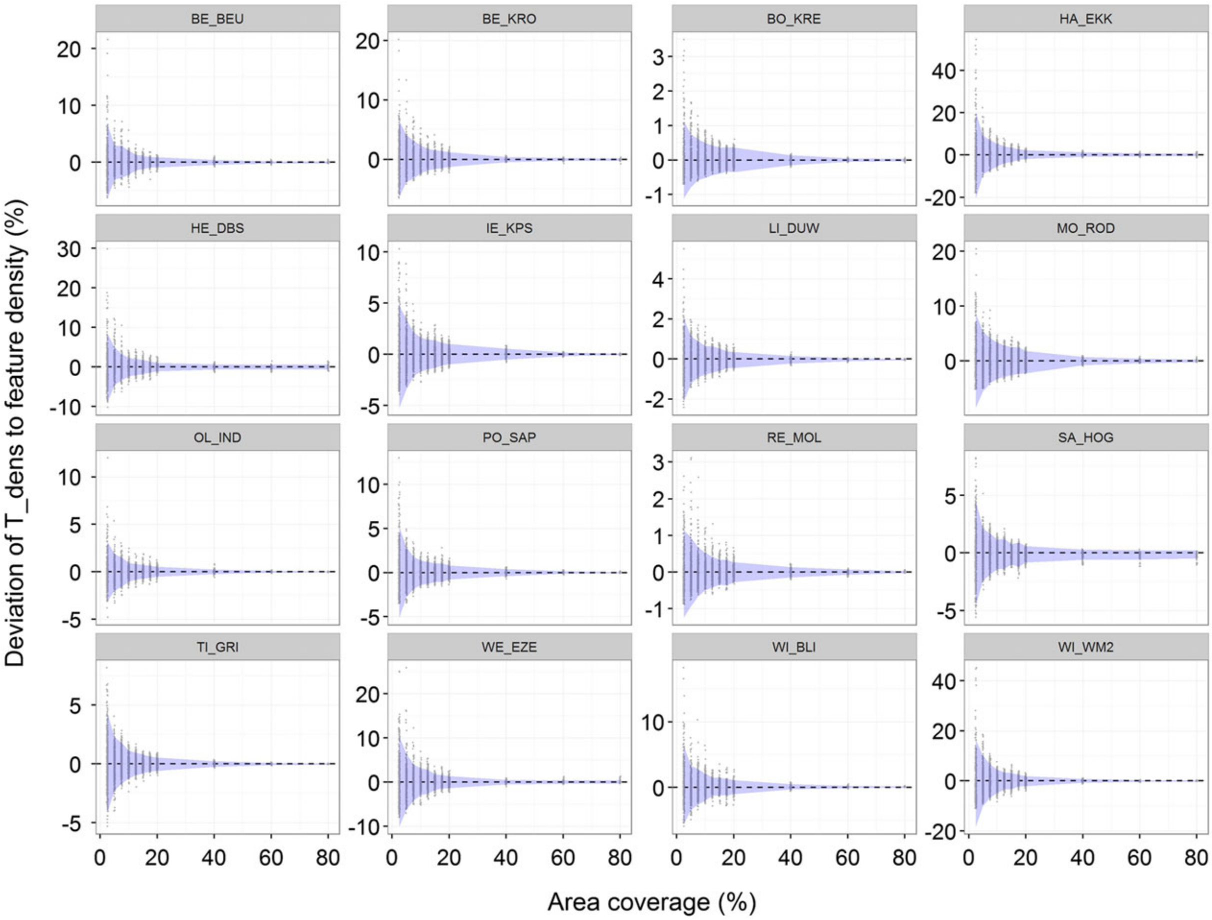


Figure 8. Observed feature density in continuous, 2 m wide trial trenches (T_dens), expressed as the deviation from the true feature density on each study site. The blue ribbon outlines the range for 95% of all simulations. [Colour figure can be viewed at wileyonlinelibrary.com]

than 2.5% (Figure 9). This means that in 95% of all simulations the feature density observed in the trenches deviates no more than 2.5% from the genuine feature density. For lower values of *C*, this potential deviation becomes substantially higher (7.1% for $C = 7.5$ and 9.8% for $C = 5$).

## *Coverage versus features intercepted*

For each configuration, the observed number and area of intersected features were visualized using box-and-whisker plots. This allows to evaluate trends observed when *C* increases from 2.5% up to 80%. As expected, the average feature area intersected follows a strict linear 1:1 relation with increasing *C* (Figure 10), meaning that when 10% is trenched, on average 10% of the area of the features will be intersected, no matter which configuration is chosen.

The number of features intersected follows a more curvilinear trend. With higher values of *C* (range

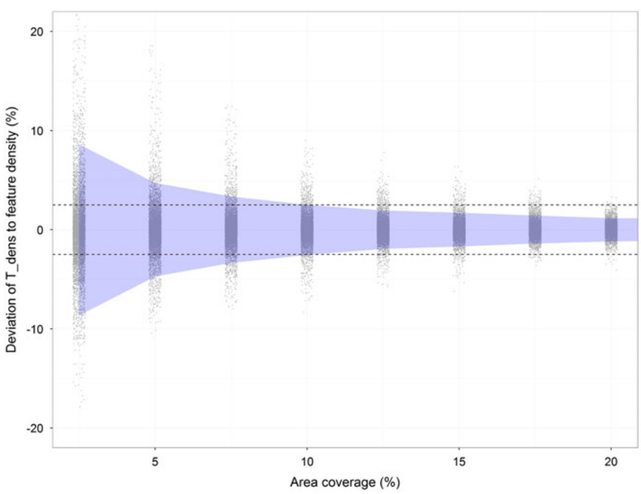


Figure 9. Observed feature density in continuous, 2 m wide trial trenches (T_dens), expressed as the deviation from the true feature density, for the entire dataset. The blue ribbon outlines the range for 95% of all simulations, while the dashed lines delineate a maximal deviation of 2.5% from the actual feature density. [Colour figure can be viewed at wileyonlinelibrary.com]



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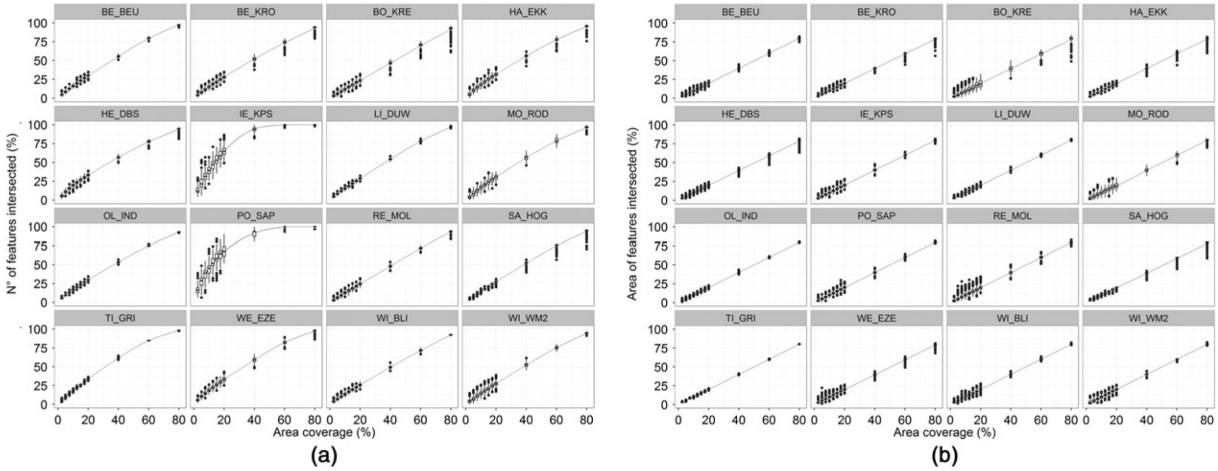


Figure 10. Number (a) and area (b) of features that are intersected by continuous trenches for increasing area coverage.

60–80%), the gain in the number of features intersected becomes less pronounced (Figure 10). However, in the range 2.5–20% the trend seems to be linear, with a slope that is higher than one. This means that for each 1% increase in $C$, the percentage of intersected features increases with more than 1%. The two sites with large and long trenches from WWI (IE_KPS, PO_SAP) display an anomalous pattern, where the slope in the 2.5–20% range of $C$ is even higher than three.

Figure 10 clearly shows that there is no optimum reached at any value of $C$, nor is there a point of inflection in the range 2.5–20% where an increase in $C$ results in a proportionally lower increase of information, be it in the number or area of features that are intersected.

## *Wide versus regular trenches*

In Flanders, archaeological prospection is usually performed using 2 m wide, continuous trenches. However, some archaeologists prefer wider trenches to increase the visibility of features in the field. A grid layout with 4 m wide continuous trenches implies that the distance between the trenches doubles when the same $C$ is targeted. The average number of intersected features is chosen as a measure for the effectiveness of the method. When comparing simulations of both widths (Figure 11) for the same $C$, it becomes clear that the 4 m wide trenches perform poorer in terms of the mean number of features that are intersected. The mean number of intersected features is significantly ($p < 0.001$) lower for the 4 m wide trenches (for $C = 10\%$: 13.4% compared to 15.8% for 2 m wide trenches). Also, the s.d. value is wider for the 4 m trenches (for $C = 10\%$: 3.4% versus 3.1%).

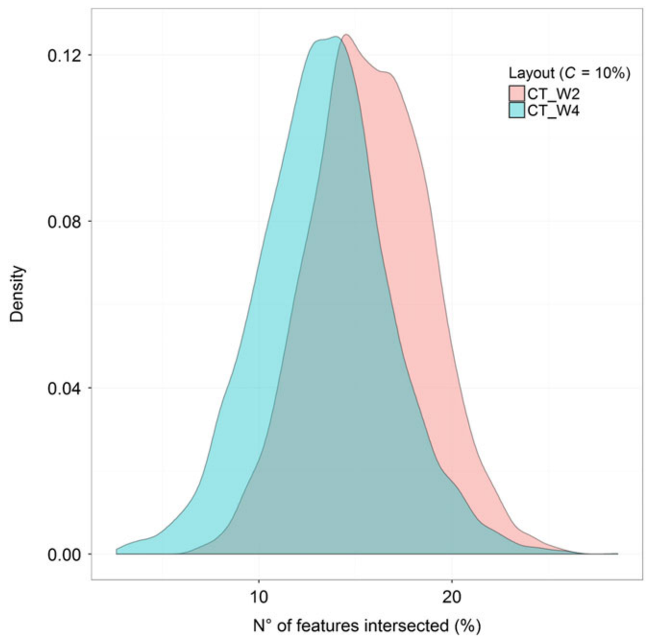


Figure 11. Density function of the number of intersected features by continuous trenches of 2 m and 4 m wide at 10% area coverage for the entire dataset. [Colour figure can be viewed at wileyonlinelibrary.com]

When inspecting the area of features intersected, the mean values are obviously equal for both methods (and related to $C$), but the difference in s.d. is even more pronounced: 1.9% for 2 m wide and 2.9% for 4 m wide trenches ($C = 10\%$).

This pattern is observed for each site in the dataset (Figure 12), where the maximum deviation of the average number of features intersected (at $C = 10\%$) for 2 m versus 4 m wide continuous trenches is 4.2% (TI_GRI). This means that the number of features one observes in the wider trenches can be highly variable and strongly



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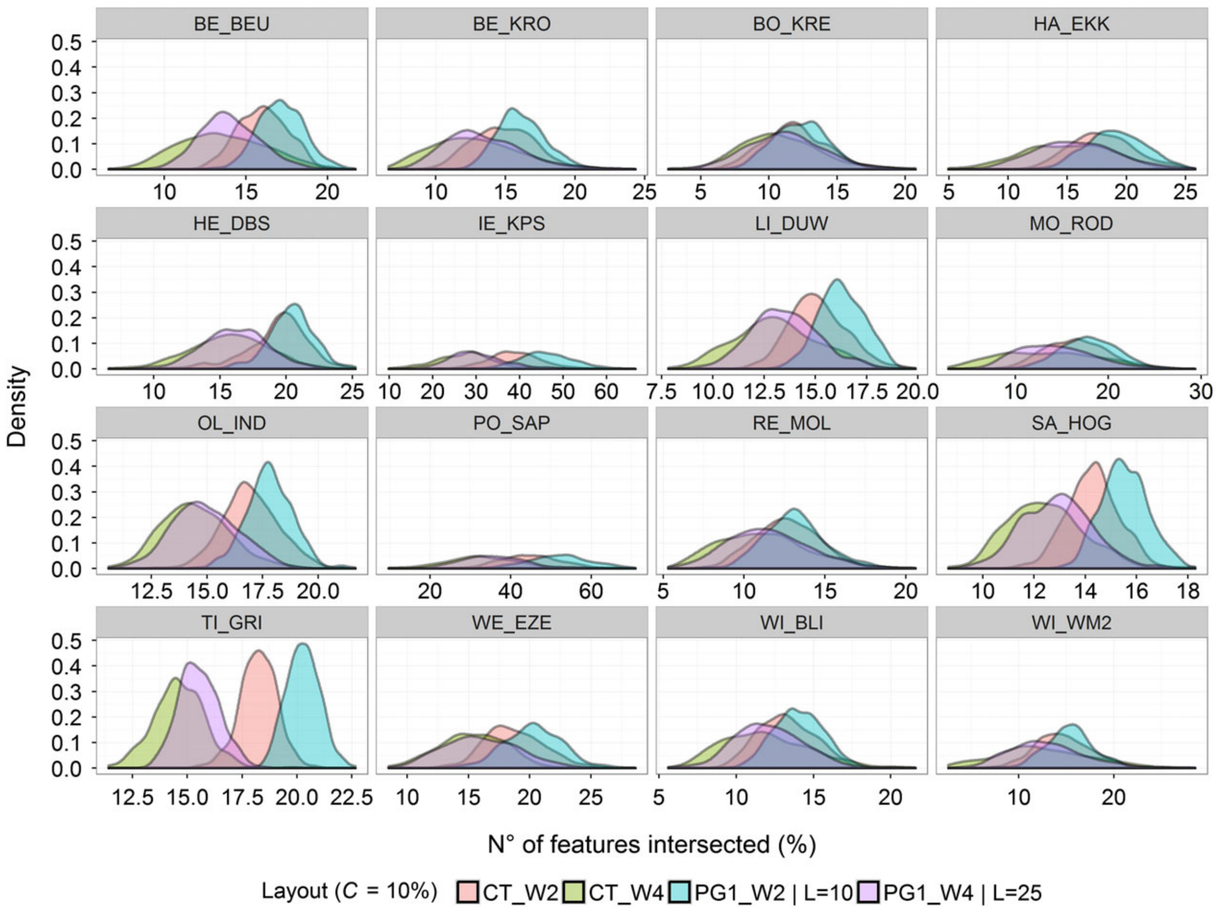


Figure 12. Comparison of the density plots of the number of features intersected applying continuous trenches of 2 m and 4 m wide, and two layouts of discontinuous parallel trenches, all with an area coverage *C* of 10%. [Colour figure can be viewed at wileyonlinelibrary.com]

dependent on the (random) choice of orientation and central point of the grid.

Although the mean area of intersected features does not differ between grid layouts, the s.d. is systematically larger for 4 m wide trenches compared to 2 m wide trenches. The largest difference in s.d. between both methods (for $C = 10\%$) is observed for site WI_WM2 (2.2% versus 4.4% = 2.2%). In terms of robustness, the grid with 4 m wide trenches is therefore considered less reliable, as it has a lower average number of features intersected and a higher risk of observing a feature density in the trenches that strongly deviates from the true feature density of the site. Obviously, perceiving an unrepresentative number of features in the trenches, could lead to a substantial underestimation or overestimation of the feature density within the excavated area.

When considering a parallel staggered grid, a similar trend is observed. The implementation of 4 m wide trenches results in lower detection rates for the number of features. And also, the variation (expressed by s.d. or 95% range) is larger compared to a grid with continuous, 2 m wide trenches (Figure 12).

## *Discontinuous parallel grids*

For parallel staggered trenches, there is a wide array of grids that can be conceived for the desired area coverage *C*. An important choice is the length *L* of the individual trenches. In this study trenches of 10 m, 25 m and 50 m long were simulated. Furthermore, the interval *I* between trenches in the same transect was kept equal to (PG1) or twice as long as (PG2) the length of the trenches. When comparing the average value of the number of intersected features for PG1 (both regular 2 m and wide 4 m trenches) and PG2 it is clear that the lowest average values are obtained with the three parallel grids (PG1) that have 4 m wide trenches, regardless of their *L* or area coverage *C* (Figure 13). In general, this type of grid intersects ca. 4–5% features less than grids with equally long, 2 m wide trenches



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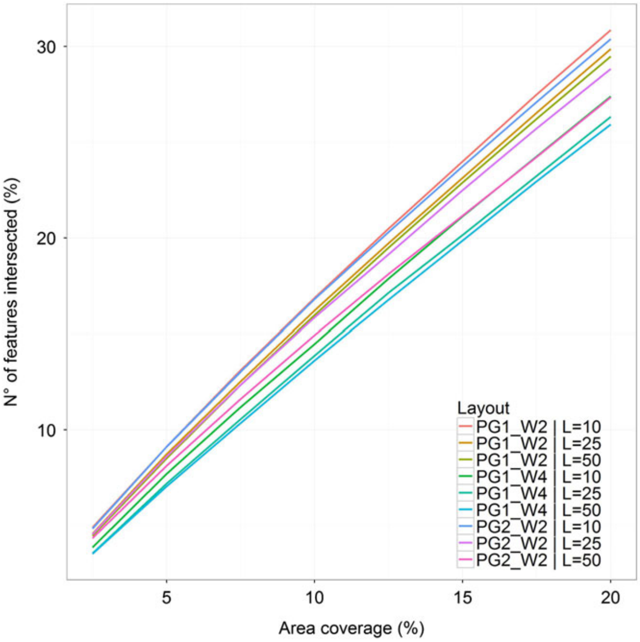


Figure 13. Performance of nine different layout grids of parallel staggered trenches ($L$ = 10 m, 25 m or 50 m) with increasing area coverage $C$. [Colour figure can be viewed at wileyonlinelibrary.com]

at an area coverage of 10%. These differences become even more pronounced for higher values of $C$.

The difference between parallel grids with $I = L$ and $I = 2 \times L$ is relatively small. The PG1 grid performs slightly better compared to PG2, but in general the absolute differences are less than 1% and are too small to be significant ($p < 0.001$) when $C$ is lower than 12.5%. For the configuration with 50 m long trenches, however, there is a significant difference between both layouts at all levels of $C$ higher than 2.5%.

The most obvious pattern is that the parallel grids with short trench lengths ($L$ = 10 m for PG1 and PG2) always perform better in terms of the number of features intersected than the same grid layout with longer trenches (Figure 13). The major drawback of this layout is that the number of trenches increases significantly from 10 per hectare for $L$ = 50 m up to 50 per hectare when $L$ is reduced to 10 m (for an area coverage of 10%). This requires more effort in planning and is more time-consuming in terms of operating time.

## *Continuous trenches versus staggered parallel grids*

Can it be recommended to implement a grid of parallel, staggered trenches in favour of continuous trenching, as the former perform slightly better in intersecting archaeological features (Figure 13)? To quantify this effect, a linear regression was performed on the simulation results for continuous trenches of 2 m and 4 m wide, and parallel grids with trenches of 10 m and 25 m long, with an area coverages $C$ between 2.5% and 20%. Within this range of increasing area coverage, the proportional number of features that are intersected (F_INT_P) follows a linear relation with $C$ as the predictor value [F_INT_P = $a + b(C)$] (Table 3). All four models differ significantly between each other ($p < 0.0001$).

From these models it is possible to deduce the equivalent of a layout at a certain $C$, in terms of the average number of F_INT_P, using one of the other grids. For continuous 2 m wide trenches at 10% area coverage, the same average number of intersected features (i.e. F_INT_P = 15.6%) will be achieved with staggered, 10 m long parallel trenches (PG1_W2 ∣ $L$ = 10 m) at an area coverage of 9.3% (Figure 14). For medium-sized

Table 3. Linear regression coefficients of four different models predicting the proportional number of features intersected for a particular grid layout.

| Layout | Term | Estimate | Standard error | $t$ Value | $p$ Value | $R^2$ |
|---|---|---|---|---|---|---|
| CT_W2 | intercept $a$ | 1.833 | 0.040 | 45.918 | <0.0001 | 0.81 |
| | slope $b$ | 1.375 | 0.003 | 463.732 | <0.0001 | — |
| CT_W4 | intercept $a$ | 0.920 | 0.042 | 21.858 | <0.0001 | 0.76 |
| | slope $b$ | 1.237 | 0.003 | 395.785 | <0.0001 | — |
| PG1_W2 | intercept $a$ | 2.218 | 0.041 | 53.557 | <0.0001 | 0.82 |
| ∣ L = 10 | slope $b$ | 1.445 | 0.003 | 469.564 | <0.0001 | — |
| PG1_W2 | intercept $a$ | 1.975 | 0.040 | 49.052 | <0.0001 | 0.82 |
| ∣ L = 25 | slope $b$ | 1.405 | 0.003 | 469.761 | <0.0001 | — |

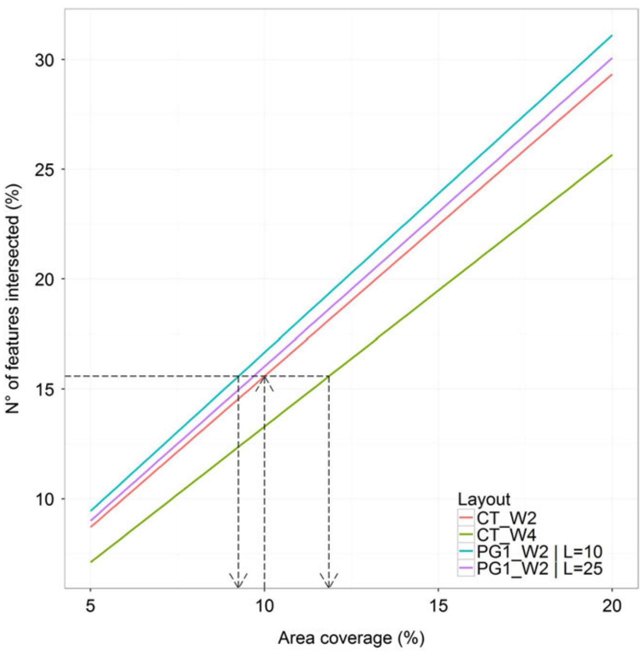


Figure 14. Linear regression of the number of features intersected by increasing area coverage of the trial trenches, for four grid layouts. [Colour figure can be viewed at wileyonlinelibrary.com]



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trenches ($L$ = 25 m) there is even less difference in $C$ compared to parallel trenching (Δ = 0.31%). This difference becomes slightly more pronounced at higher area coverages. When using continuous wide trenches ($W$ = 4 m), the same level of F_INT_P is reached at an area coverage of 11.6%. In terms of efficiency, continuous wide trenches require an increase of at least 1.6% in area coverage to reach the same intersection level as the smaller 2 m wide continuous trenches.

With these results in mind, it is clear that there is a relatively low profit – in terms of lower area coverage – in choosing parallel grids with small or medium-sized trenches over continuous trenching. It should be said however that the parallel trenches perform more robust in terms of inherent variability; i.e. the simulations display a lower s.d. in comparison to continuous trenching.

### *Feature density*

The efficiency of trial trenching to intersect archaeological features also depends on the density of features on an archaeological site (Figure 7). Obviously, on low-density sites the chances of finding archaeological features are much lower than on sites with a higher density of features. The question arises whether it is possible to optimize the grid layout according to the feature density expected, based upon previous archaeological research in the same area, soil characteristics or local topography. Therefore, the outcome of the simulations of different layouts was linked to the density of the archaeological features (= total area of features/surface of the analysed site) on the sites. Figure 15 displays the average number of features intercepted (F_INT_P), and s.d. as flags, for each site at 10% area coverage. The two sites with WWI trenches (PO_SAP and IE_KPS) have been omitted from the dataset because they can be considered as outliers, and would distort the general trend.

Again it becomes clear that no matter what type of site is prospected with trial trenches, the layout of the trenches has a significant influence on the number of features that are intersected. The implementation of wide trenches ($W$ = 4 m) is, regardless of the feature density encountered, the least efficient and least reliable method, especially on low-density sites, where this method intercepts on average a low percentage of the archaeological features. Also, the s.d. from the mean number of features intersected is very high, making this an unreliable method for prospection on low-density sites. The higher the feature density, the larger the difference in mean number of intersected features between methods. The standard grid and discontinuous parallel trenches, both with $L$ = 10 m, give

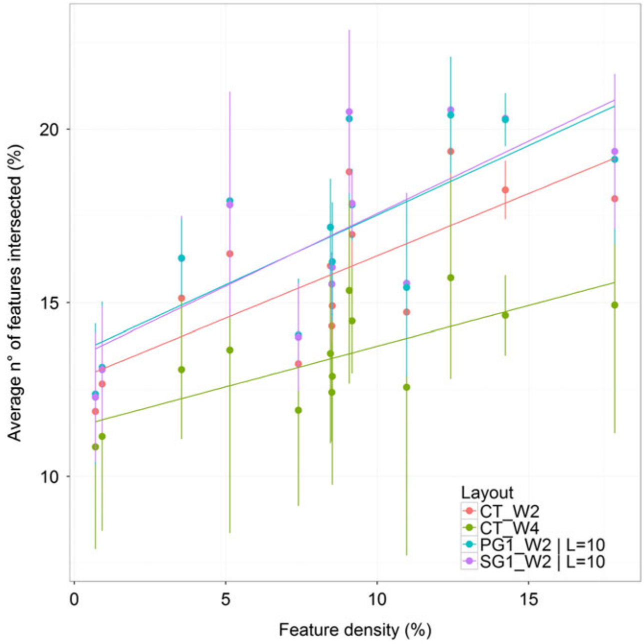


Figure 15. The number of features intersected by different grid layouts ($C$ = 10%) for study sites with increasing feature density. The general trend is highlighted by trend lines for each grid layout. [Colour figure can be viewed at wileyonlinelibrary.com]

the highest values for F_INT_P, closely followed by the prospection grid with continuous, 2 m wide trenches.

## Discussion

By repeating certain grids up to 500 times on excavation plans of 16 different study sites, more insight was gained in the trends and variability that are inherent to the chosen design of trial trenches and caused by random variation in orientation and positioning of the grid layout. Reducing the inherent variability of the method to a minimal level can only be achieved by making an informed decision about the grid layout to be implemented. The simulations demonstrate that the use of 4 m wide trenches is the least reliable method, especially in terms of the variability of possible outcomes. Both for continuous trenches and for the discontinuous staggered grid, the wide trenches intersect, on average, respectively 2.4% and 1.9% less features compared to 2 m wide continuous trenches (Figure 12). Also, the risk of intersecting a number of features that is not representative for the entire site is much higher for the wide trenches, as expressed by the higher s.d. of all simulations (Figure 12). Therefore grids that implement 4 m wide trenches should be considered to be a less robust prospection method.

The layouts that performs best in terms of intersection rates and robustness (low s.d.) are standard grids



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and parallel grids with short ($L$ = 10 m) and 2 m wide trenches. These layouts perform better than grids with the same layout but longer trenches, and then continuous trenches. This has already been demonstrated by Hey and Lacey (2001) and confirmed by statistical modelling (Champion *et al.*, 1995; Borsboom *et al.*, 2012; Verhagen and Borsboom, 2009).

For a standard grid, Verhagen and Borsboom (2009) already showed that this method is especially relevant for intersecting linear features, that can easily escape detection when oriented in the same direction as the trenches. However, when implemented on the wide range of analysed sites in this dataset, the difference in performance between a standard grid and a parallel staggered grid turned out to be particularly small in terms of the number of features intersected and the variability.

When looking at the performance of the different layouts to intersect a certain percentage of the features on a study site, the difference between a grid of continuous trenches (CT_W2) and a staggered parallel grid (PG1_W2 | $L$ = 10 m) is within 1% of the area coverage. In other words, compared to a grid with continuous trenches the same amount of features is intersected with a staggered grid of parallel trenches at an area coverage $C$ of minus ~1% (Figure 14). On large sites this 1% increase in $C$ could however lead to a substantial increase in the volume of topsoil that needs to be handled when digging the trial trenches. It must be said however that the results obtained from a parallel grid are more robust in terms of inherent variability. The difference becomes more pronounced when implementing 4 m wide trenches, which require an increase of $C$ of at least 1.6% to obtain the same intersection rates (Figure 14). From a practical point of view, both parallel and standard grids are more demanding in terms of planning, machine operating and manoeuvring (Hey and Lacey, 2001; Verhagen and Borsboom, 2009), and therefore potentially less cost-efficient (Dubouloz, 2003).

The assessment of intersection rates clearly focusses on one particular aspect of archaeological sites, i.e. the density of features. For a complete evaluation of the scientific and historical value of a site, it is also necessary to assess the quality of the preserved features and artefacts, to unravel the structures present, and to address the relation of the site to the surrounding landscape and environment. Density as such is inadequate for a full evaluation of an archaeological site's scientific potential (De Clercq *et al.*, 2012). The methods used here are therefore unable to address the risk of not recognizing and underestimating archaeological sites with low feature densities, but with a high scientific value. This problem can only be tackled by implementing a substantial number of additional test pits/windows and follow-trenches during the prospection campaign. These additional windows are not aimed at (artificially) increasing the feature density observed in the trenches, but serve to better understand certain features, structures and the spatial arrangement of the exposed archaeological record. Furthermore, these windows and follow-trenches significantly raise the chance to detect less frequent features such as wells, which often contain the most valid information on the landscape but, at the same time, are the most expensive to excavate and research.

Nonetheless, density remains a first and important variable that is used to decide on how to proceed and to make an estimate of the costs involved. Therefore, often, what is observed in the trial trenches is extrapolated to the whole study site. In this study it is shown that with low values of area coverage $C$, there is a higher risk of obtaining unrepresentative values for the intersected feature area. The density of features observed in the trenches (T_dens) is thus not always representative for the actual feature density on the entire site. Especially on high-density sites, the deviation from the actual feature density on a site to what is observed in trial trenches (T_dens) can be as high as 10% when less than 10% of the site is sampled. The risk of overestimating/underestimating feature density based on prospection results is substantially reduced when $C$ is higher than 10% (Figure 9). Under such conditions the difference between T_dens and the actual feature density for the whole study site becomes less than 2.5% (at a 95% confidence level).

It should be kept in mind that the results presented here are a purely analytical approach of archaeological prospection with trial trenches. The ArcGIS toolbox calculates the intersection of features, recorded as two-dimensional (2D)-polygons, but this does not strictly equal the detection and identification of archaeological features in the field. Furthermore, this analytical approach does not allow to evaluate the ability to assess the state of preservation of archaeological features and artefacts, which is the main goal of prospective trials aimed at detection and evaluation (De Clercq *et al.*, 2011, 2012; Hey and Lacey, 2001; Verhagen and Borsboom, 2009; Verhagen, 2014). Still, the more features that are intersected, in terms of total number or area, the higher the chance that archaeological features will be identified and evaluated. Obviously, what is not intersected, cannot be assessed.

It is clear that this study was not focussed on certain cultural periods nor on the recognizability and possible evaluation of archaeological structures characteristic for these periods. The study sites included in the



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dataset intersect archaeological sites from multiple periods and are considered to constitute a representative sample of archaeological sites that are evaluated on a regular basis in Flanders. The toolbox and the methodology presented here can be further used to focus on intersection probabilities for certain cultural periods, and the related specific features, artefacts and structures.

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