Chronology in urban archaeology

– Bayesian modelling of radiocarbon dates from medieval Copenhagen as a high definition approach

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En modell för stadsarkeologi? Om Bayesiansk modellering av ^{14}C-dateringar från det medeltida Köpenhamn. Kronologi är en av arkeologins basala men absolut viktigaste redskap för att förstå och tolka händelser i det förflutna. På grund av det arkeologiska källmaterialets mer eller mindre fragmentariska natur kan förståelsen av en plats kronologi dock vara besvärlig. Som en del i arbetet med att analysera framväxten av det tidigmedeltida København, har möjligheterna att använda bayesiansk modellering av ^{14}C-dateringar utforskats. Genom bayesiansk modellering av material från två tidigmedeltida kyrkogårdar samt intilliggande bebyggelse har dateringen av de tidigaste aktiviteterna i København kunnat snävas in och förläggas till 1000-talets första hälft. Modellerna har indirekt bidragit till att skapa en ny kronologi för viktiga händelser i stadens tidiga historia. Skapandet av modellerna har dock varit ett komplext arbete med många potentiella felkällor. Studien visar, att bayesiansk modellering ökar möjligheterna att använda sig av ^{14}C-analyser i urban arkeologi, trots den utbredda problematiken med redeponerat material i städernas kulturlager. I artikeln redovisas arbetsprocessen som ligger bakom skapandet av modellerna för Köpenhamn, med särskild fokus på att presentera metodens potential men också dess begränsningar.

Introduction

This article discusses how the work with Bayesian modelling of radiocarbon dates from two sites from medieval Copenhagen contributed with new information of the chronology of structures and events stemming from the oldest period of the settlement.

The article's focus is on describing how the cultural historical context, which is the basis for the statistical modelling, can be used in combination with the radiocarbon dates, in order to optimize the information potential. The ambition is, with Copenhagen as a case study, to provide a concrete example of the process of the modelling. This comprises formulating of questions, selection of suitable material, setup of analysis, including source critical considerations, and interpretation of results. The article shall also be seen as an attempt to open the ”black box” of how ^{14}C-analyses are interpreted together with relative information provided by archaeological material. We wish to be open with the limitations and difficulties of using radiocarbon dates in urban environments, and therefore also the less successful results of our modelling work will be accounted for, as lessons learned for future analyses. A more technical presentation of the study is published in Radiocarbon, vol. 61:6, 2019 (Olsen et al. 2019).

The purpose of the modelling of radiocarbon ages was to gain a high definition chronology of some of the earliest archaeological findings from medieval Copenhagen, from the site of Rådhuspladsen and St. Clemens cemetery in today's central Copenhagen (Jensen & Dahlström 2009, Lyne & Dahlström 2015; see figure 1). The knowledge of Copenhagen's earliest history has for a long time been based on a rather fragmentary archaeological foundation and only very few written records from before 1200 CE. The predominant but vague theory of the age of Copenhagen has until recent years been that the first (seasonal) activities, dominated by fishing, took place sometime in the late 11th century, and that the settlement in the 12th century grew into something which can be described as a town (Fabricius 1999; El-Sharnouby & Høst-Madsen 2008; Dahlström et al. 2018). The role of Bishop Absalon, claimed to have been the founder of the town in the second half of the 12th century, has been difficult to get rid of in the eye of the public, even if many historians and archaeologists have pointed out that the town is likely to have been older than that (Dahlström et al. 2018). Excavations from the last ten years have now yielded a new source material, which enables a more coherent understanding of the kind of place Copenhagen was during its first period of existence (Dahlström et al. 2018). With the Bayesian modelling of radiocarbon dates, we wanted to see how we could enhance the dates received at these new excavations and try to create absolute dates and a relative chronology of events and development during the first 200 years of the town's existence. Bayesian models of radiocarbon ages are increasingly used in archaeology as a method in the interpretation of the usually broad age ranges (Bayliss & Bronk Ramsey 2004; Bayliss 2009, Bayliss 2015). This is done by adding information from relative dating, for instance from stratigraphical relations and finds typology. The principle is described by Alex Bayliss: “a chronology that relies on all the dating information available – ^{14}C- dates, stratigraphy, coins, typology etc. – is bound to be more reliable than one that relies only on one strand of information” (Bayliss 2009, p. 127). Through statistical simulations based on statistical probabilities combining the absolute and relative dating information, it is possible to narrow the age ranges considerably (Bronk Ramsey 2009).

The potential for using radiocarbon analysis in urban environments is often seen as quite limited. This has partly to do with the usually broad dating frames of up to 200 years, in which case the dating of finds give just as good dating information. The other reservation against radiocarbon dating of urban sites concerns redepositon and residuality of material in urban contexts. Primary deposits are very scarce, and how can we be certain that the material we date (seeds, charcoal, bone) really dates the archaeological deposit from where it was taken?

We will argue for how, and why – despite the valid reservations – it is possible to use radiocarbon dating in urban archaeology. Using Bayesian modelling removes the problem with broad age ranges. As we will show, under the right circumstances it is possible to come as close in dating as 20-year periods. The problem with redeposition is ubiquitous within (especially urban) archaeology, and as always, it needs to be carefully considered when choosing material for dating. We will account for how we – with mixed results – have selected material to avoid some of the pitfalls, and to minimize the risk of misguided dating information. As a closing point, the method of Bayesian modelling for urban material will be assessed and some of the most important criteria for success, as we see them, will be summarized. Already at this point it can be disclosed that a crucial criterion for success is close collaboration between the archaeological and scientific expertise.

Chronology in archaeology – from the present, to the past, and back again

Even if archaeologists are aware of the fact that we deal with fragments of the past, which they subjectively interpret, it is important to keep in mind the double temporality of archaeology, and its role in our understanding of the past. Archaeologists use material existing in the present – soil, sherds of ceramics, seeds, holes in the ground, stones, bones, et cetera – and build stories about the past, which are brought "back" to the present (Lucas 2004, p. 126–127). We, today, construct past events through the archaeological record (Larsson 2006, p. 66–73). The same is true of chronology. We create it in the present. We place events in the past in a certain order. Past chronology is not history; it is part of the present (Lucas 2012, p. 5). If we are not actively aware of this nature of the record we produce, there is a threat of overestimating and cementing the conclusions emanating from it.

We can also be critical towards *what* it is we chronologically order. We say that we order events and structures, but with chronologies based on radiocarbon dates, in reality we order depositions of isolated items of waste (most often) such as charcoal, seeds, bone, which at best come from activities at a known geographic location. How good are these small items as proxies for past events and structures? If we speak of relative chronology, we are in even more trouble. Most of the time we do not know how long has passed between two depositions, even if we can see from stratigraphy that one is older than the other is. In the best-case scenario, there are dateable finds, but if we speak of one year, ten years or 100 years between depositions is often uncertain.

As a way to untangle some of the difficulties with assessing which events we actually date, a tool to use is *biography*, or *life history*, of the features and contexts included in the chronology (Morris & Jervis 2011). Cultural deposits interpreted in their functional context and role in the events of which they are a part represent a more specific part of the life of a feature. It can be related to its construction, usage or deconstruction/disuse. If we use a pit as an example, it has at some point been dug, then used for a period of time, for a primary purpose and then perhaps reused for something else, and finally been backfilled. The period which passed in the life of the feature is something of crucial importance when we use material from it to date a chronological sequence, and from that create the temporality of past events. We must be fully aware of what part of the life history of the feature we use in the sequence.

With these considerations as a background, chronology is a necessary tool to entangle a course of events or trajectories – but also a post fact construction, which can trick us into seeing time and events as more "tidy" and linear than they actually were, and was perceived by the people who were a part of it. Sometimes it can be worth considering the contemporariness instead of chronology, when events are interpreted. Contemporariness is, however, a treacherous concept in archaeology. We can rarely decide on a true contemporariness, but most of the time work with likelihoods of events happening close to each other in time and possibly affecting each other.

In this analysis, much effort has been placed on the interpretation of the biography of the features, and on which part of the biography, that the context where the sample was taken from came. This was done as an attempt to come as close as possible to what it is, we actually date, and how that can inform us of the development of the site.

If we accept chronology as a simplified framework for the description, and possibly understanding, of the past, it is evidently a central tool for every archaeologist to examine the soil and the objects in the present and understand it as an order of events in the past. Discussing the limitations which the creation of a chronological sequence of archaeological material entails can instead be a tool which helps us see the complex relations between us, our source material and the past.

Bayesian statistics and archaeological dating

Bayesian modelling is based on an application of *Bayes theorem*, which is widely used for calculating probabilities across disciplines working with statistics. The application is called *Bayesian inference,* and is a formal description of how adding more data to a phenomenon changes our knowledge of it, to a certain probability. It is about creating statistical models calculating all available data to receive knowledge based on probabilities. Within archaeology, Bayesian modelling can be used for different types of probability calculations. When it is used to create dating models, different types of relative dating information can be added to the absolute radiocarbon dates – stratigraphy, dendrochronology and find dates. The concrete way that the relative dating information can enhance the absolute dating can be exemplified like this: if we have two radiocarbon dates showing similar, but broad dating frames, but we know from their stratigraphic relation that one is older than the other, that information can be added in the statistical program, calculating probabilities. If we have multiple observations of such type, of archaeological contexts or features with stratigraphical relations to each other, it will add many observations to the program. This results in the program calculating probabilities with much tighter age ranges than if the dates are looked at individually (and not modelled). However, it is important to note that Bayesian analysis is no magic tool which will evidently improve the age ranges of any data. Thus, any model is not any better than the data included in it. For example, if the probability age ranges are not overlapping then a Bayesian model will not be able to constrain the resulting age ranges. It is also important to stress that the model should be based on firm archaeological observations. If the archaeological information is vague, then model results may be misleading.

For urban archaeology, the usefulness of Bayesian modelling is considerable, since we work with quite short time periods and dating based on find assemblages seldom provide a tight enough age range to get closer to temporal change than 50–100 years. Dendrochronology can be used in some cases, but in those cases, the risk of reuse of wood is a challenge with respect to reliable ages. At the same time, the risk of redeposition and residuality inherent in all urban deposits make the use of radiocarbon dates doubtful. Even so, the potential gains are too good to miss, and here it is therefore tested how we can use them, with a very conscious, source-critical mind. In our analyses, *stratigraphical relations* is the only relative age information included the model. The models were tested and held up against finds of ceramics and combs. The tests disclosed weaknesses in the models, in those cases where the information from the different dating categories was not possible to combine. We will get back to the strategies we used dealing with this. The Bayesian models were constructed using the program OxCal 4.3 (Bronk Ramsey 2009). The technical setup is described in our article in Radiocarbon (Olsen, Dahlström & Poulsen 2019). The archaeological considerations for each model are described under each case in the following text.

What can a fine chronology do for early Copenhagen?

The need for a high-definition chronology for early medieval Copenhagen is based on the aim to detangle the order of events and structures in the early town. Knowing the absolute and relative chronology between these events and structures can contribute with important information on the actors and processes behind the formation and further development of the town. Another purpose with the fine-tuned chronology has been to learn more of the temporality and pace of settlement activities. This information may be used as a factor when how, and when, an urban way of life develops (Dahlström 2019). The archaeological remains from the site of Rådhuspladsen have been separated in up to seven settlement phases (depending on sub area), but the absolute chronology has been very tentative based on find dates and unmodelled calibrated radiocarbon ages.

The larger aim for fine tuning the activity phases identified at the site of Rådhuspladsen has been to create a new understanding for how the actors and processes involved in the early town have affected each other and, in this way, why the town developed as it did. An important part was also to learn more of the time frames within which the practices of daily life of the settlement evolved into an urban way of life.

Early Copenhagen

Until recently, a small area within the medieval fortification has been the focus when speaking about where the oldest town settlement was situated, and the core from which the later medieval town was thought to have grown from the 12th century and onwards. In the area stretchers of a broad ditch has been found, creating a "horseshoe"-shape, resulting in the proposition that this feature was the first fortification surrounding the town (Skaarup 1988; Fabricius 1999). Only small excavations have been carried out within this area, and they have only resulted in spread findings of early activity (Dahlström et al. 2018).

The last ten years of archaeological excavations have contributed considerably to our knowledge of the oldest settlement, resulting in the abandonment of earlier theories. It is foremost the area around present-day Rådhuspladsen (Town Hall Square; see figure 1) which has yielded new archaeological information regarding early Copenhagen. The area was located outside the later medieval fortification, but the recent excavations have showed that it, during the period 11th – 13th century, was a central part of the settlement (see figure 1).

In 2008, the northern part of the cemetery belonging to the St. Clemens church was excavated (KBM 3621), along with 1048 graves dated to the medieval period. Evidence of certain burial customs, arm positions of the buried individuals and findings of a pendant dated to the 11th century led to the interpretation that the cemetery (and the church) stemmed from the 11th century, instead of the 12th century as thought prior to the excavation (Jensen & Dahlström 2009). The proposed date was however quite tentative, and no radiocarbon analyses were conducted at the time of the excavation. In 2011–2012, the Metro Cityring excavation at Rådhuspladsen (KBM 3827) revealed an until then unknown part of the early settlement, with remains of dwellings and iron production, a road and, not least, parts of a cemetery. Dates from finds and radiocarbon analyses pointed to an age of the oldest activities to the 12th or even 11th century. In 2017–2018 more of the Rådhuspladsen cemetery was

Figure 1. Top left: Copenhagen, Denmark. Top, center: The late medieval extent of the town with the investigated areas marked. Main figure: an overview of the archaeological remains recovered at the excavation at Rådhuspladsen with areas included in the study marked. To the right is St. Clemens cemetery seen. After Olsen et al. 2019.

excavated, resulting in a total of 81 graves from the cemetery. Additionally, parts of a church foundation were encountered (Stafseth forthcoming). The indications made from these three excavations changed the picture of how we should imagine the formation of Copenhagen. However, the exact dates of activities were still lacking. In order to create a fuller picture of the processes and people behind the initiatives for the first settlement, and put them in a wider societal context, more precise dates were needed.

A key to the understanding of early Copenhagen lies in the two cemeteries, which seem to be among the oldest structures found so far. Central questions to seek answers to are: what is the chronological relation between them? How old are they? What can be learned from this regarding church patrons and why they decided to build churches in Copenhagen?

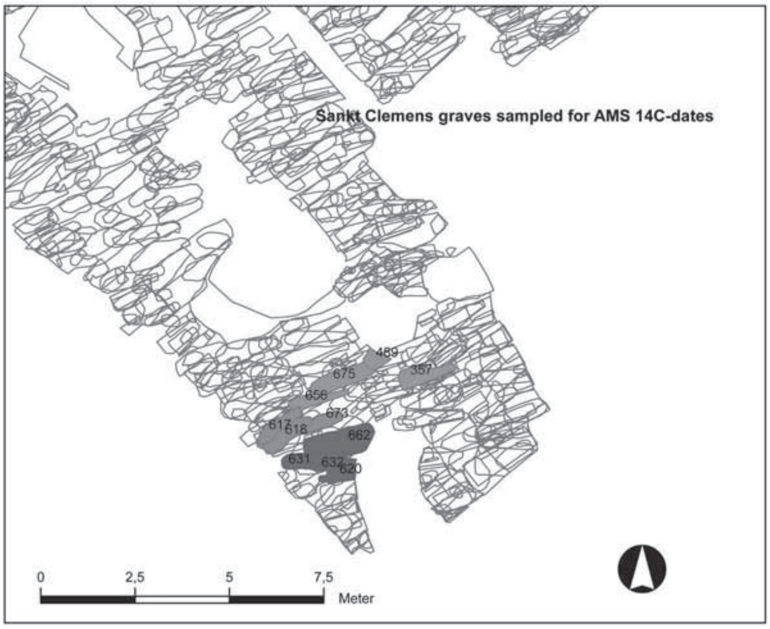
Further, the stratigraphically complex, but unfortunately fragmentary, remains of household and production activities suffered from the same lack of precise dating. How should they be understood in relation to the cemeteries? What can be said of the temporal development of the settlement?

With these questions as a foundation, we made a two-part strategy for creating a high-definition chronology of archaeological remains from the oldest Copenhagen. The first was to compare the ages of the two cemeteries by creating one statistical model for each cemetery. The second was to create individual models of different parts of the excavated material from Rådhuspladsen. The areas with best preserved stratigraphy and highest number of identified phases would serve as the basis for the interpretation of settlement development. The process of creating the models, and of interpreting them, will be presented below as two case studies, each contributing to the overall chronological understanding of the site.

Case 1: Two cemeteries

This case comprises the cemeteries of St. Clemens and Rådhuspladsen. If the two cemeteries were contemporaneous, it would have implications for the type of settlement Copenhagen was in its very first phase. If there were two churches at the same time, it implies a place of some complexity, attracting two church builders and most likely inhabited by people socially belonging to two different groups. Since the churches presumably were constructed before the establishment of the parish system, the groups attached to the different churches are presumed to have had a social or economic connection to different authorities (= church builders; Dahlström et al. 2018; Nyborg 2004).

From the church of St. Clemens, eleven graves were chosen for ^{14}C analysis (figure 2). The graves were grouped in three separate stratigraphical sequences (an error in selection



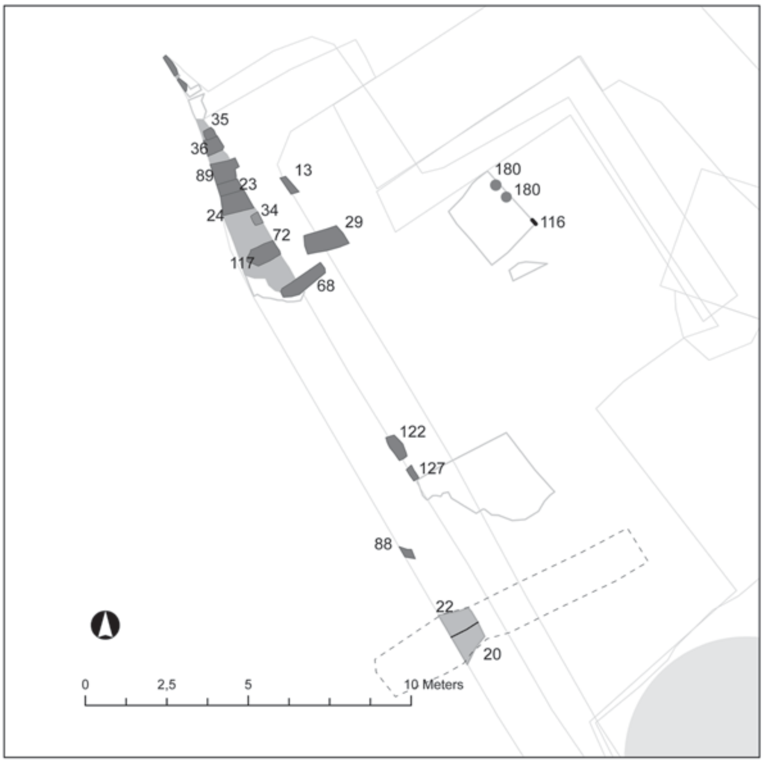


Figure 2a and b. The graves from St. Clemens (a; top) and Rådhuspladsen (b; bottom) sampled for radiocarbon dating.

caused one grave without stratigraphic relations to be dated). From the cemetery at Rådhuspladsen, a model of all nine in situ preserved graves was made (figure 3).

When dating human bone material, corrections for a possible marine reservoir effect always need to be part of the analysis, to avoid the ages coming out too old (Fischer et al. 2007; Olsen & Heinemeier 2009). The background for this, is that the radiocarbon concentration of marine and freshwater system is different from the contemporaneous atmosphere. Therefore, individuals with a preference for marine or freshwater diets will incorporate a ^{14}C signal which is typically lower (older) than individuals having a purely terrestrial diet. The percentage of marine diet can be estimated using stable isotope analysis (δ13C and δ15N, e.g. Fischer et al. 2007). The human bone from Copenhagen was calibrated with the mixed curve (IntCal13 and Marine13) method in OxCal 4.3 using the fraction marine diet to determine the mixture between different curves (Olsen et al. 2019; Bronk Ramsey, 2009; Reimer et al. 2013). It took two attempts to reach fine-tuned models for the cemeteries. In the first round, the information given to the model proved to be insufficient, in relation to sample size.

Aims of the cemetery models

The purpose with the St. Clemens model was to find out when the cemetery was taken into use. With the Rådhuspladsen model, the aim was both to find out when it commenced, and for how long it was used. The latter is of relevance, since the date of its disuse can be used in the discussion of why it was abandoned.

The comparisons between the dates could also reveal which church

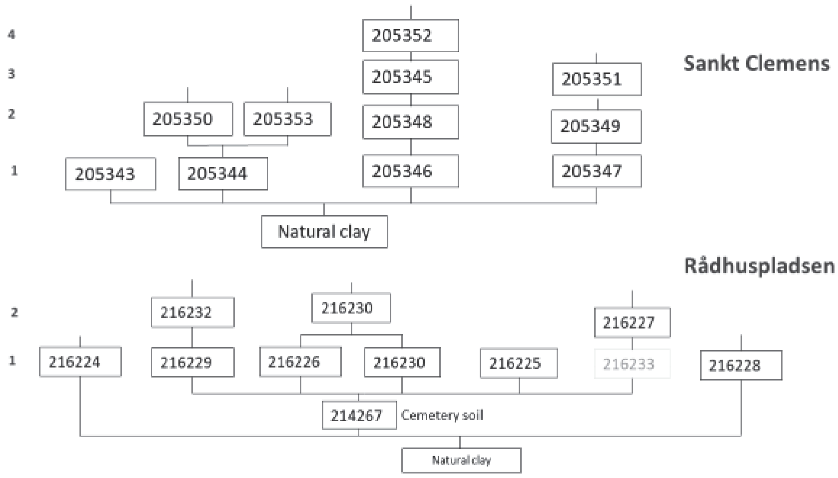


Figure 3. First attempt at modelling the cemeteries, showing the stratigraphic information included in the first model. (The lighter grey 21633 at Rådhuspladsen represents a grave with bone material low on collagen and could therefore not be AMS-dated.)

came first, if they were contemporaneous or if one followed the other. This would also shed light of power relations and degree of social complexity of the early town.

Initial analysis

Prior to Bayesian modelling, all graves at Rådhuspladsen were dated to the same, broad period: c. 1000 – 1180 CE (see figure 4; Kanstrup & Heinemeier 2012; Lyne & Dahlström 2015, p. 112). However, since they were found in two stratigraphic layers, they could not possibly be contemporaneous. The Bayesian modelling had potential to enhance the understanding of the absolute chronology of the graves.

Relative dating information and calibration information given to the cemetery models:

- The nine and the eleven graves respectively belong to the same usage phase (meaning that each cemetery had one, coherent usage)
- Graves with a direct stratigraphic relation to an older/a younger grave are younger/older than this
- Reference for marine reservoir effect was a Danish Neolithic material (Fisher et al. 2007)
- The fraction marine diet was estimated with a margin of error of 10%

In figure 4 the results of the first models are seen. The coloured/dark coloured curves represent the modelled dates, and the unfilled curves are the unmodelled dates. The differences are not that great. The age ranges are still c. 100 years, from 1020 to 1120 for Rådhuspladsen, and for St. Clemens the width of the age ranges differs, from c. 50 years to 180 years (according to calibrated possibilities, IntCal13.). The imprecise results were probably due to a very rough estimation of the fraction marine diet with an associated large error of ± 10%. In addition, there were few stratigraphical relations, or relative age information, to build into the model. However, the similar *probability distributions* from Rådhuspladsen could also point to a real, short usage period for the cemetery. For St. Clemens, the oldest graves date, after modelling, to the period 1020–1200 – a very unprecise result. The reason for the wide spread of dates, compared to Rådhuspladsen, were likely several. The burial rate for St. Clemens was likely different from Rådhuspladsen. Even if graves with direct stratigraphical relations to each other were selected, it is likely that more time passed between burials, compared to Rådhuspladsen. Also, the depositional history at St. Clemens was very complicated, possibly with other burials stratigraphically placed between those in the model (but without physical relations to both). To improve the results, there was a need for: 1 – More dates, to get more information to use as a basis for a less uncertain calibration. 2 – Improvement of the relative dating information.

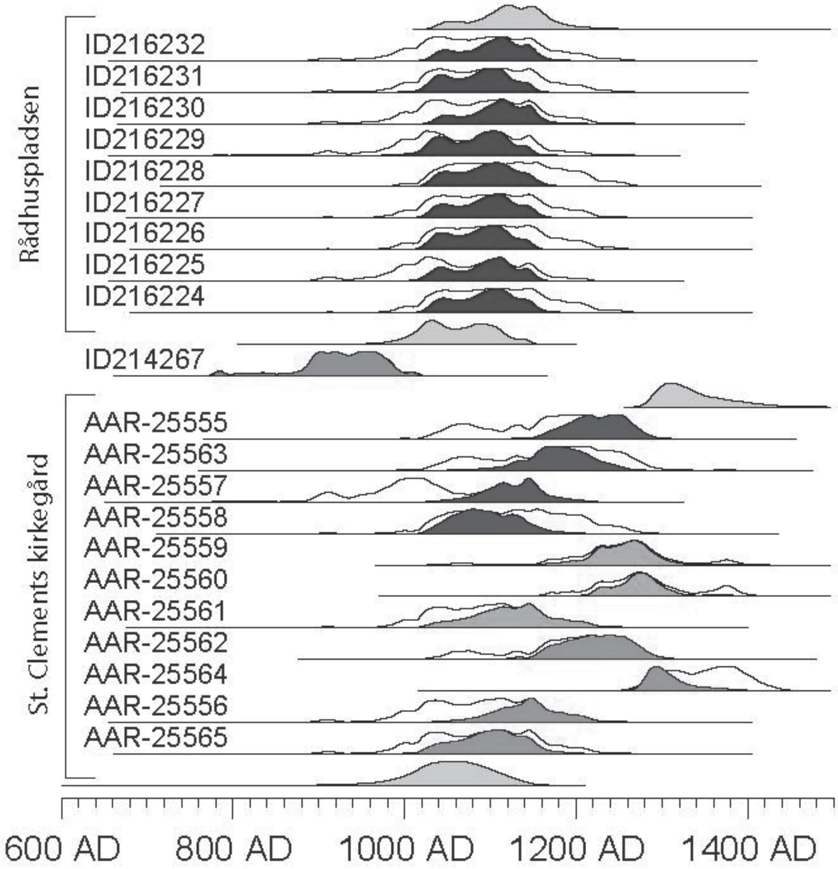


Figure 4.The results of the first modelling of the two cemeteries.

Second attempt: Extended model and analysis

We decided to add as much relative chronological information as possible to the model from Rådhuspladsen, since this material was easier to manage than the complex and extensive grave material from St. Clemens. By adding radiocarbon dates, including isotope analyses (for marine reservoir effect) of disarticulated human bones in grave fills and backfills of ditches, almost all stratigraphic information from Rådhuspladsen could be included. The new information included in the statistical model was based on the principle, that a bone found in in a grave fill must be considered older than the skeleton that was found in situ in the same grave. One such case, adding a new stratigraphic level to the model, was now added (grave 13, see figure 5). Also included were disarticulated bones in severely truncated graves without an in-situ skeleton. Lastly, human or animal bone found in ditches, seen

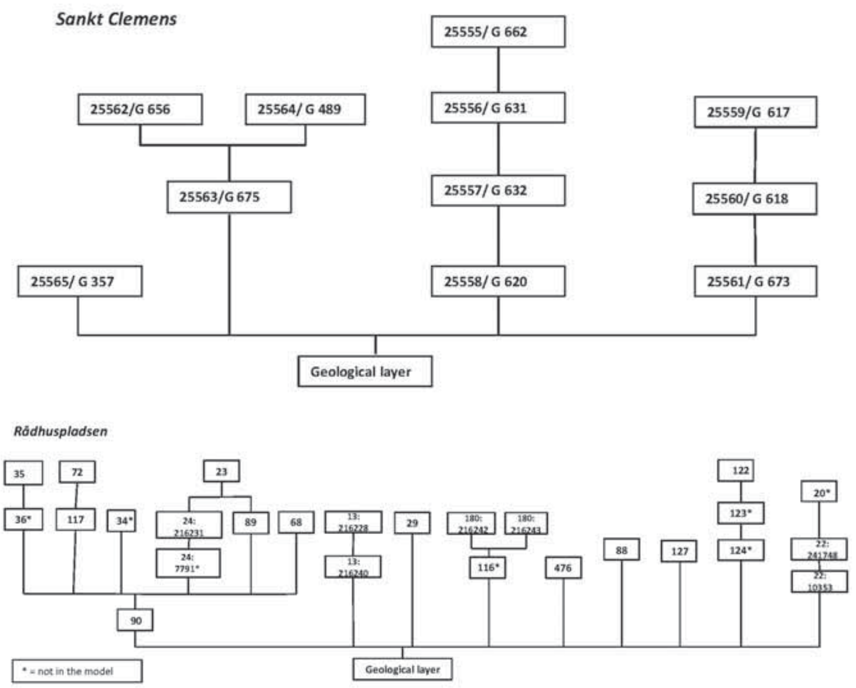


Figure 5. The extended stratigraphic information given to the new model. For St. Clemens there are no changes, but for Rådhuspladsen new stratigraphic information has been added plus more dates in total. The model has up to three levels. Every string of vertical relations is individual in the model. That is, since we do not know the chronological relation between different strings it is not presumed that the dates appearing horizontal to each other are contemporaneous. For different reasons (lack of sample or bad quality of sample), not all graves are included in the model. Those not included are marked with a star.

as connected to the cemetery were included, but without a stratigraphical relation between them.

The extended relative dating information and the larger total amount of dates, together with a more precise assessment of the marine reservoir effect (see below), resulted in a new calculation of statistic probabilities of the date for the cemetery (see figure 6).

Dating information in the extended Rådhuspladsen model:

- All graves and ditches have the same usage phase (meaning that the cemetery had one, coherent usage phase)
- Graves and ditches with a direct vertical stratigraphic relation to another are older/younger than this
- One grave with disarticulated bone in the fill – here the disarticulated bone is older than the in situ skeleton

The fraction marine diet was estimated using local terrestrial animals from the excavated animals on site resulting in a smaller percentage

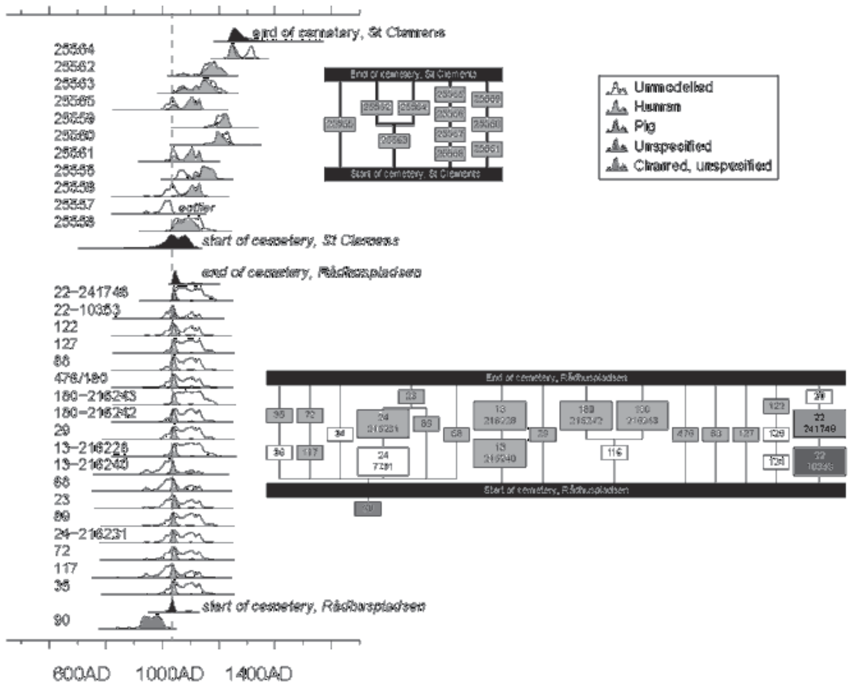


Figure 6. Results of the new models. Based on an increased amount of dates and new relative dating information, the Rådhuspladsen model resulted in a very tight age range. Also, the St. Clemens model improved due to the new marine calibration, allowing an assessment with less uncertainty (4% instead of 10%). After: Olsen, Dahlström et al. 2019.

error of c. ±4%. The new material from a Danish Iron Age population had an expected larger resemblance to the Rådhuspladsen material than the one used before, which was a Neolithic population (based on expected similarities in diet; Jørkov 2007).

The results of the improved models, including a better suited calibration of isotope values, show a very different picture than the first attempt above (figure 6). The age range for the Rådhuspladsen graves have narrowed down to statistically indicating an age to 1016–1036 (68.2%), while the St. Clemens graves date to 1005–1099 CE (68.2%; Olsen et al. 2019). The very early dates from Rådhuspladsen are affected by relative dating information for two relative date sequences, where dates where the younger date in each of the sequences (23 related to 89 and the in situ bone related to the grave fill bone in 13) are among the earliest. This also contributes to the very similar dates, with a steep calibration curve for the 11th century as an additional reason. The reason the St. Clemens dates change is the more precise reference for marine calibration (with an uncertainty of 4% instead of 10%).

There are many factors involved in the statistical model, each with its own uncertainty, which makes the dates more of an indicium than a certain absolute dating. They are, however, the best indicium we have at the moment, and the results of the Bayesian modelling should therefore be considered an important factor in the discussion of the dating of the two cemeteries. One advantage with radiocarbon dating of *in situ* bones from inhumations is that they are from primary contexts. The problem with redeposition discussed previously does not exist for this material. The exception is the disarticulated bones found in backfills of graves and other features. Of the bones found in the two fills in ditch 22 (figure 6), we do not know which are the oldest, despite the stratigraphical relation between the two fills.

The modelled dates in relation to other data

The very early dates indicated by the Bayesian models of the St. Clemens and Rådhuspladsen cemeteries were surprising. Compared to established theories of the dating of the town, it seemed like the dates were too early. We therefore made some minor changes to the model from Rådhuspladsen to test the robustness of the model. These included removing the date from the cemetery soil (90), made of charcoal without known wood species, and the stratigraphical relation between the two ditch samples (22). However, the model did not change in any decisive way.

We then viewed the archaeological information from the early sites with new eyes. Were the modelled dates compatible with other indications? The find's material from the oldest settlement is not very varied, but some elements typologically date to the 11th century: several bone combs, a ring of jet-stone and the pendant mentioned earlier (figure 7). Among the ceramics, one group of Baltic Ware has been pointed out as possibly belonging to an early phase within the usage period of the ware type (11th century). So, could those elements, which used to be seen as anomalies, instead be parts of a new pattern, indicating the oldest Copenhagen to be from the early 11th century?

As mentioned, during the new excavations at Rådhuspladsen undertaken in 2018, a stone foundation interpreted as the remains of a church was uncovered. Stone churches from the 11th century have been found in Lund and Helsingborg, but they are certainly not a common feature of this period. The presence of a stone church would not point in the same direction as the modelled ^{14}C-dates. However, the stone foundation at Rådhuspladsen was built on top of an older grave, indicating the presence of an even older church (Stafseth forthcoming) – perhaps a wooden church which should be seen in connection with the graves dated in our study? Clearly, there is more to find out about the oldest settlement, and the ongoing processing of the results

Figure 7ab. Bottom (a): The pendant from a grave at St. Clemens cemetery. Top (b): One of the combs dating to the 11th century. Photos: National Museum of Denmark.

from the new excavations at Rådhuspladsen – including new ^{14}C-dates – will most likely enhance the fragmented picture.

A new picture of early Copenhagen

The results from the Bayesian modelling of radiocarbon dates from the two cemeteries was a vital component in our interpretations of the early development of Copenhagen. The result was a development in three phases from the early 11^th^ century to c. 1200 CE, placing the onset of the cemeteries and, for Rådhuspladsen, the abandonment, in the center of events involved in the early initiatives forming the character of the settlement (figure 8). The interpretations change the societal context in which we shall see the early development of Copenhagen (Dahlström et al. 2018).

Case 2: The settlement

The second case considers the fragmentary, but partly stratigraphically complex, settlement remains which were found at Rådhuspladsen (KBM 3827; Lyne & Dahlström 2015), and which physically were situated in between the two cemeteries (see fig. 1). Together the remains of the cemeteries and the settlement cover a coherent area of c. 160 x 80 meters within the oldest settlement. The fragmentary character of the archaeological remains, due to the many later constructions in the area, complicates the process of dating the activities. The extensive use of the area through many centuries has resulted in the multiple phases of deposits and cuts preserved in "pockets" of small, coherent areas with preserved stratigraphy (figure 9). It is very difficult to reach an understanding of the contemporariness of these "pockets" of preserved cultural lay-

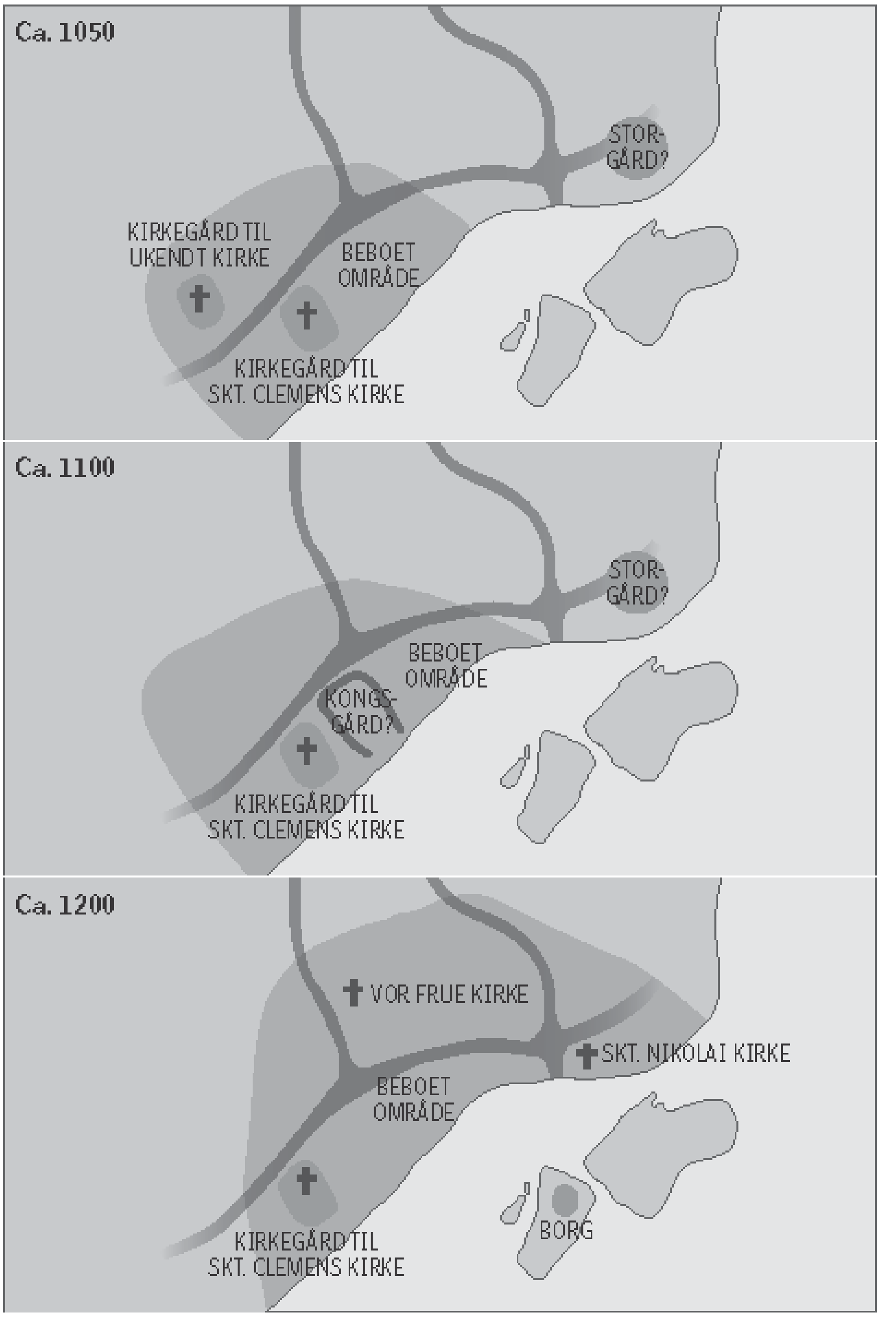


Figure 8. Three main phases of development of the settlement of Copenhagen until c. 1200 CE. After Dahlström, Poulsen & Olsen 2018.

Figure 9. Photo from 1944 showing the construction work of air raid shelters somewhere at Rådhuspladsen. They explain the fragmentary patterns seen in area 2. Photo: Unknown. Copenhagen City Archive.

ers in the greater area. The Bayesian modelling has the potential to both facilitate the dating of the individual stratigraphical sequences and assess their chronological relation to each other. It was decided to choose two sub-areas with the highest potential to represent the dating frames of the settlement and activities in the area. These areas (called 1 and 2B; see figure 1) had the most stratigraphic levels with vertical relations to each other. The main goal of the settlement models was simply to reach a fine absolute chronology, grasping the whole activity period. For area 1 a further goal was to reach absolute dating of the five settlement phases which had been identified with the help of stratigraphy. In area 2B seven stratigraphic levels of pits and wells were identified, but with the possibility that several of them belonged to the same main phase of activity.

At the excavation in 2011–2012 a large number of radiocarbon dates were made – however, without plans for statistical modelling. A total of 33 analyses were of medieval settlement remains. Of these, 20 could be used in the two models chosen in this study to represent the medieval settlement at Rådhuspladsen. These pre-existing 20 dates were complemented with seven new analyses, selected with the purpose to give the model at least one radiocarbon date for each archaeologically identified activity phase. The dates from 2011–2012 were made of seeds, charcoal or animal bones. For the new analyses, animal bones from sheep or goats were chosen for the samples. The choice was made considering that bones of the selected size would not be redeposited accidently, as could be the case with seeds or charcoal. Species were chosen to avoid the complication of marine reservoir effect, which could be an issue with using bones from cats, dogs or pigs.

The settlement models and the problem with waste

The features which the dated material comes from are pits, wells, road deposits and foundation deposits. The obvious problem with this material, unlike the human bone material, is the risk of redeposition and residuality (Bayliss 2009). In the bigger picture, there are several issues that need to be considered when assessing the results of radiocarbon dates from settlement material. Firstly, the sampled material's own age; but also, the risk of redeposition of material from activities considerably older than the activity we wish to date. The third issue involves the biography of the feature which the deposition belongs to – does the sample date the usage phase related to the building, or the demolition phase? These different conditions must always be assessed individually for each sample.

Model of Area 1

After the initial trial modelling of area 1, including all the available radiocarbon dates from the deposits in the stratigraphical sequence, some adjustments needed to be made. All dates came out very early, which was not compatible with the overall dates of the finds from the dated contexts. The reason for the early dates throughout the model were three very early radiocarbon dates in the youngest stratigraphical phase. The early radiocarbon dates, placed in some of the relatively speaking youngest remains, made the model date all remains too early. Was this reasonable? Looking closer at these samples, they were taken from two road layers, which could include older material mixed with newer. Also, two of the samples in question were taken from animal bones, which could have been reused from older roads, since they were suitable road fill material. Since these contexts were too problematic to sort out, they were taken out of the model. The model presented in figure 10 does not take these sample results into account.

The chronological information

Table 1. Relative dating information for Area 1.

	Dating info 1:					Dating info 2:	Dating info 3:
Act. Phase	**Strat. level**	**Uncal. BP**	**Context id**	**Contextual dating information**	**Dated material**	**Dating of pottery**	**Dating of combs**
5	**9**	832 +/-27	60	^{14}C dates usage phase, or end of usage phase	AB, sheep	1200–1300	
	8		113–22636	^{14}C date time before phase 5 – material obviously mixed (roads and surfaces)	Seed, elder	1200–	
	8	725 +/-45	113–100765		Seed, goosefoot		
	8		80–11028		AB, cattle	1200–	1000–1300
	8		80–21634		AB, pig		
4	**7**	950+/-45	70	^{14}C dates usage or end of phase 4 (pit)	Seed, barley	1150–1250	
	7	932 +/-26	63		AB, cattle	–1250	
3 b	**6**	935 +/-35	61	^{14}C dates end of phase 3 (pit)	AB, cattle	1000–1200	1000–1100
3 a	**5**	870+/-40	82	^{14}C date usage phase 3 or time before phase 3 (posthole and foundation-/levelling layers)	AB, cattle	1000–1200	
	5	915+/-40	271		Seed, barley		
	5	805 +/-40	315–241744		AB, cattle		
	5	870 +/-40	315–241743		AB, cattle		
	5	880 +/-35	446		AB, cattle		
2 b	**4**	950 +/-40	103	^{14}C dates end of phase 2	AB, pig	1000–1200	
2 a	**3**	915 +/-35	79	^{14}C dates usage or time before phase 2	AB, cattle		
1 b	**2**		19–7345	^{14}C date end of phase 1 (pits)	Unspec.	1000–1200	
	2		19–9799		AB, cattle		
	2	955 +/-45	104		Seed, barley	1000–1200	
1 a	**1**	940 +/-45	87	^{14}C date time before phase 1 (postholes)	Charcoal, hazel		
	1	955 +/-40	114		Cc, beech		

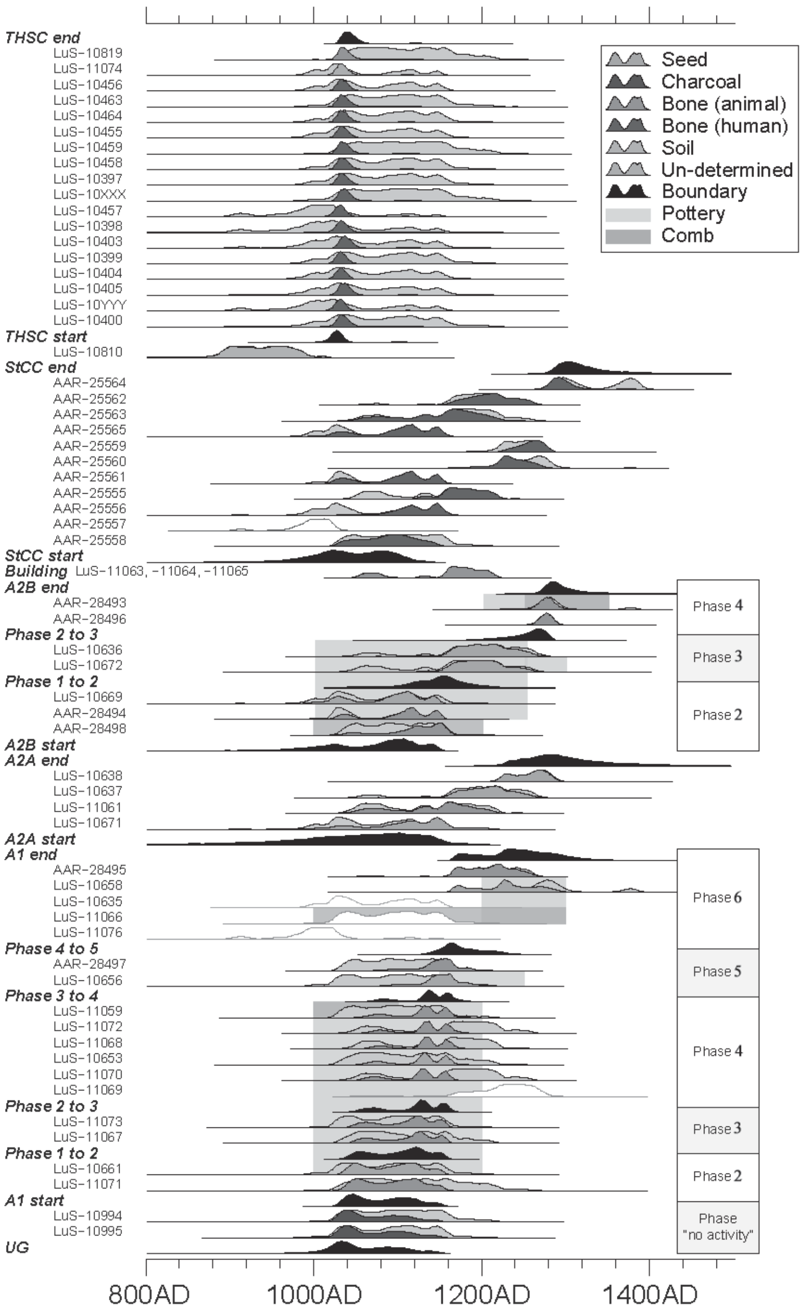


Figure 10. Calibrated probability density distributions of all samples together with the Bayesian modelled units (Copenhagen City Square cemetery, St Clements cemetery, Road, Area 1 and Area 2 A–B). Based on typology (combs and pottery) the expected archaeological ages are shown in boxes for area 1 and 2. The sample results taken out of the model are seen as unfiled graphs. After Olsen, Dahlström & Poulsen 2019.

put into the area 1 model was quite simple. It said, firstly that dates on the same stratigraphic level were contemporaneous, and secondly, that dates on one stratigraphic level were older than the one above and younger than the one below (see table 1). It is made of nine different stratigraphic levels and based on 14 radiocarbon analyses. The reason there are nine levels in the model, but only five activity phases, is that the model separates biographical stages of the features. In other words, the contextual relations of the sample are central in making as detailed a model as possible. The contextual information is described in the table. The model is based on absolute dating information from radiocarbon, and relative dating information from biographical stages and from dating of finds are added as a compliment. These are used to check if the dates fall within a reasonable timeframe, taking all dating information into consideration.

The exclusion of the problematic dates resulted in a wide age-range for the oldest dates, but a probability for a date in the first part of the probability distribution (dating curve; figure 10). It indicates that the oldest settlement was contemporaneous with the onset of the cemeteries, and that activities were coherent from that point. In addition, the youngest dates show a broad date curve, and the results for either of them do not really narrow the unmodelled dates. The greatest benefit was for the mid-phases. Activity phases 2, 3 and 4 can, according to the model, be placed respectively in the beginning, mid- and later part of the 12th century. These dates confirm that the 12th century was a period of settlement growth.

Area 2B

Area 2B provided even more difficulties than area 1. The stratigraphic information based on the documentation from the post-excavation work of KBM 3827 was used as relative dating information (Lyne & Dahlström 2015). Three radiocarbon dates already existed from the features included in the stratigraphical sequence, and an additional four were processed as part of this study. This means that the model of area 2B is built on seven dates, divided into three phases. Unfortunately, the eighth and oldest date, according to the stratigraphic sequence, was of inferior quality, and could not be used. The model consists of material from six pits and one well, which all have a direct stratigraphic relation to the feature above and below in the sequence (table 2). However, the stratigraphic relations between the features were very complex, and difficult to interpret. The interpreted order of the features was uncertain due to numerous truncations and recutting of older pits. The problems were also seen in the finds, where the dating of ceramics and combs did not match their place in the stratigraphic sequence.

The first attempt of modelling, based on these complex stratigraphical relations, resulted in a sequence without a chronologically logical order. Based on this result, in combination with the information from the finds, the interpretation of the stratigraphical order of pits was changed.

The model gave a slightly narrower dating frame than before modelling (see figure 10 above). It showed probabilities of dates within a margin of 70–80 years, but not with the same certainty as the Rådhuspladsen cemetery dates. All features in the model seem to date to the 12th and 13th century. This aligns well with what was expected and gives extra weight to the discussion of how to understand the development of the settlement. The activities in the centrally located parts of Rådhuspladsen, which 2B belongs to, do seem to start somewhat later than those in the west and east.

Assessment of the settlement models

The dates received from the Bayesian modelling of the settlement features add to our understanding of the chronology of the site in general. It seems likely that the settlement is as old as the cemetery, but in the first years of its existence the activities were on a quite low scale. Perhaps we can see a spatial distri-

Table 2. Relative dating information for Area 2b, after modification.

Dating info 1:						Dating info 2:	Dating info 3:
Phase	**Group id**	**Uncal BP**	**Sample id**	**Contextual dating information**	**Dated material**	**Dating of pottery**	**Dating of combs**
4	201	720 +/-34	28493 (AAR)	^{14}C possibly dates usage	AB, sheep	1200–1350	1250–1350
4	176	730 +/-25	28496 (AAR)	Third oldest backfill, ^{14}C date end of phase 4	AB, cattle	-	-
3	169	860 +/- 45	Lus 10672	^{14}C taken from oldest backfill, dates end of phase 3	Seed, barley	1200–1300	
3	174	840 +/- 45	Lus 10636	^{14}C possibly dates usage of pit	Seed, undet.	1000–1250	
2	194	931 +/- 25	28498 (AAR)	^{14}C possibly dates usage of pit (phase 2)	AB, sheep	1000–1250	1000–1200
2	193	980 +/- 45	Lus 10669	No strat rel.	Seed, sedge	1000–1250	
2	178/145	979 +/-27	28494 (AAR)	Second oldest backfill, ^{14}C dates end of phase 2	AB, cattle	1000–1250	-
1 oldest	*175*	*-*		*Third oldest backfill, ^{14}C date end of phase 1*	*Unvalid sample, not included*	-	-

bution of activities where the eastern and western parts were earlier occupied/used than the central area (area 2), but more analyses need to be conducted in the western part to be more certain. Most age ranges are narrowed with the help of Bayesian modelling, either in a suggestive way or more clearly indicated. The dates help in understanding the relations between activities across the site. A lesson learned in the process was, however, that areas with complex stratigraphy should be used with caution. It is worth considering working with less complex sequences with clearer stratigraphic relations or finding ways to include the complexity in the models by applying a point system (see Bayliss et al. 2016).

A model for urban archaeology?

The choice to remove radiocarbon dates which do not fit into the model, or adapt the model to what is reasonable, can be seen as problematic and needs some further explaining. What does it mean for the reliability of the method? Is the exclusion of sample results that do not fit us the same as creating our own truth?

The samples that were taken out (in area 1) were those which strongly contradicted one of the relative dating parameters – the finds. At the same time there was a reasonable explanation for the samples to be unfit to use – namely their context as potentially residual waste material. This means, though, that all sampled material can be potentially unfit, since more or less all of it is waste in one form. What does that say of the use of radiocarbon dating and Bayesian modelling of dates in urban contexts? Our view is that the method should be regarded as one of several parameters used for dating activities in urban environments. The radiocarbon dates need to be discussed in relation to other indicia, foremost the degree of residuality, biography of archaeological contexts and in relation to known find's typologies. Since the scientific dating information have been made dependent on archaeological information it needs to be treated on the same premises – that is, not as absolute dates per se, but as indications.

The challenges with combining the relative dating information with the absolute, scientific dating method had some unexpected positive effects. Conclusions about stratigraphy, which would otherwise be regarded as probable, and become a part of the interpretation of activities and chronology, were now scrutinized more systematically and in some cases resulted in a reevaluation of the chronology. Thus, the Bayesian modelling resulted in an extra quality control of the interpretation of stratigraphy.

Radiocarbon models in urban contexts

With the problems discussed in this article in mind, is it still recommendable to include Bayesian modelling of radiocarbon dates as a method to receive finer dating within urban archaeology? We say it is. With a strategic selection of radiocarbon samples for analysis, together with a critical assessment of the context and potential of the sample, Bayesian modelling is a valuable tool which enables discussions of activities and the course of events within tighter age ranges than otherwise would be offered. Under the right circumstances, it is possible to narrow the time frame of an activity to 20–30 years.

Important points to consider

To be successful in the creation of Bayesian models of radiocarbon dates, there are a few criteria we wish to highlight. Some should be seen as recommendations, while others are necessary.

- When samples are selected for radiocarbon dating, it is strongly recommended to sample contexts with stratigraphic relations to each other.
- If possible, select more than one sample from the same context, preferably taken of different materials.
- A conscious sample strategy is necessary – it is vital to be aware of what activity and which *biographical stage* of the feature which is dated.
- A close cooperation between archaeologist and radiocarbon specialist is vital. A certain degree of insight into the conditions and nature of each other's data and methods is necessary to select the material for the model, and to interpret its results.
- A critical view of the weaknesses and strengths of the material in question is necessary. The potential problems need to be included both in the creation of the model and when assessing it in relation to other data.

Lastly, going back to the discussion of the nature of chronology – the data and models we produce are very much simplifications. This is perhaps obvious but needs to be repeated. As archaeologists, working with relative data, the danger of seeing science as absolute, is a risk when assessing data from radiocarbon dates and Bayesian modelling. We need to remember that radiocarbon dates present *probabilities*, statistically modelled or unmodelled. The probabilities need to be held up against archaeological data for us to make as complete assessments as possible. If we manage to keep that balance, the method can certainly contribute to an enhanced understanding of our medieval towns.

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