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Exploring visually the known and the ill-known about Kraków's centre urban evolution: an information visualisation perspective

Abstract

Studying and depicting the design and transformations of urban structures have been a concern ever since the 19th century, both from the point of view of historians, and from the point of view of urban planners. Where exactly is the impact of « digital humanities » on the way we today can renew our means of investigation? How can we usefully support the analyst's reasoning tasks, by visual means, in the context of historical research, and at the scale of a city? This chapter introduces on real-case experiments carried out on the city centre of Kraków, former capital of Poland. Through these experiments we illustrate the fundamental issue of *imperfect knowledge* in historical sciences, the need and constraints of handling ill-defined *temporal data*, and the necessity to, at least, complement “classic” virtual reconstruction efforts with visual solutions that better match the nature of the underlying data – doubts – and the nature of a city – an heterogeneous collection of structures that differ not only in terms of morphology and use, but also in terms of documentation quality.

We introduce an approach that bases on the idea that the gap between historical sciences one on hand, and information visualisation (InfoVis) on the other hand, *should* and *can now* be filled. Our record of experience shows the potential added-value of InfoVis-inspired abstract graphics in supporting reasoning tasks on the evolution of urban structures. Our contribution will illustrate on real cases in what the above mentioned methodological bridge can be a solution-provider in the context of urban analyses, and point out the actual scientific and technological locks we are facing.

Keywords

Information visualisation, Temporal data, Uncertainty, Inferences, Reasoning, Heterogeneous data sets

Introduction

Studying and depicting the design and transformations of urban structures have been a concern ever since the 19th century, both from the point of view of historians, and from the point of view of urban planners. Where exactly is the impact of “digital humanities”, or more precisely of digital technologies, on the way we today renew our means of investigation? How can we usefully support the analyst's reasoning tasks, by visual means, in the context of historical research, and at the scale of a city? What specific methodological bottlenecks does this context introduce? What can be done when there is simply not enough data to carry out a reconstruction, or when there is a need to formalise hypotheses that will back up a

reconstruction process? How can we support reasoning tasks when our concern is not on a spatial pattern but a temporal pattern?

A prominent difficulty when wanting to analyse the evolution of a “city” in the broad sense is naturally the fact that the information available is sometimes scarce, or questionable, when not simply absent. Hence this chapter raises a still-open research question: how can analysts formalise the ill-known, and introduce it from a pragmatic point of view into contemporary information systems?

But another difficulty is the heterogeneity of the objects under scrutiny. Consequently this chapter also underlines a key aspect of reasoning on a city, the step from analysing a single edifice to analysing an urban structure is not *quantitative*, it is primarily *methodological*. An urban structure is a system where interrelations, interdependencies, play a major role, may they be between edifices, between edifices and open spaces, or may they be between the urban fabric and a context – wars, floods, laws, aesthetics of a time, *etc.* In that sense, switching to the analysis of a whole urban structure may reveal interrelations, patterns of change, possible causal chains, and ultimately allow for information and knowledge discovery.

This chapter however is not a theoretical discussion on “reconstructing the past of cities”. It introduces real-case experiments carried out on the city centre of Kraków, former capital of Poland, and uses them as illustrations of some of the key scientific and technological locks we are facing when wanting to better understand, and better have others understand the way a city changed over time. Through these experiments we illustrate the fundamental issue of imperfect knowledge in historical sciences, the need and constraints of handling ill-defined temporal data, and the necessity to, at least, complement “classic” virtual reconstruction efforts with visual solutions that better match the nature of the underlying data – doubts – and the nature of a city – an heterogeneous collection of structures that differ not only in terms of morphology and use, but also in terms of documentation quality.

The city of Kraków developed significantly during the first six centuries of the second millennium, before entering a period of relative decline when the Swedish monarchs moved the capital of the kingdom to Warsaw. This relative decline constitutes an opportunity for us today, as the city experienced little significant change during the nineteenth and twentieth centuries compared to other cities of similar size. Moreover, years of preservation and investigative actions have resulted in the production of a large quantity of documents (descriptions, analyses, drawings, photographs, plans, *etc.*) which need to be collected, organised and visualised. Our research focuses on understanding, documenting, visualising the evolution of architectural and urban components (341 objects, 885 phases studied). Its inputs are primarily historical sources concerning directly these components, but also elements of context that can help spotting potential causal chains (legal issues, natural phenomena, fire propagation patterns, demography, wars and rulers, *etc.*).

We have been studying the evolution of Kraków’s historic centre, at various scales, for over fifteen years now. We have consequently quite soon switched from analysing an edifice to analysing an urban area. This switch clearly introduced a methodological break, not only in numbers (more elements) but also and above all in terms of heterogeneity (different objects of study, as well as different quantity and/or quality of data, or different levels of knowledge). A common sense assertion would be to consider that as time passed by we got to know more and more about the changes that occurred in the city. And indeed we did uncover a number of facts about individual edifices, the urban layout, uses and practices of urban spaces, the defensive system, *etc.* But, to be true, as it is often the case in historical research, as time went by we also unveiled more and more open questions, more and more ill-knowns or unknowns. The reality of historical research on a large, heterogeneous corpus – *i.e.* a whole city – is sometimes such

that the more one digs into the data, the more unknowns are revealed. To make it short, our experience underlines a sort-of counter-intuitive pattern: *the proportion of unknowns or ill-knows grows with the time spent on a comprehensive analysis of a city's evolution.*

But is that pattern really surprising? With time, we analyse more and more individual components of the city. But we also pull in more and more sources, more and more elements of context. Accordingly, we do not only add up the unknowns corresponding to each component, each piece of information, we also multiply doubts that arise over potential relations between components, components and context. A classic example of that trend is the fire propagation patterns in a city. If a source tells us a fire probably damaged an artefact *A*, there are chances it also had an impact on any *B* neighbour of *A*. And so not only is the information concerning *A* doubtful, but a whole chain of potential (and questionable) consequences is de facto created.

Furthermore, understanding a city's changes over time cannot be supported by only one or several "pictures" of its spatial layout at time t_1, t_2, \dots, t_n (synchronic analysis). It also implies understanding temporal patterns that characterise these changes: rhythms, order, cycles, *etc.*

Hence the necessity for us to complement "assertive" visual results such as 3D models, with other analysis platforms, better suited to the handling of massive data sets, doubtful information, and temporal data. On what methodological and/or technological basis can such platforms be designed and built? As will be shown, reasoning visually on large information spaces is at the heart of a sub-field of information sciences, namely *InfoVis* (Information Visualisation) and its sister field visual analytics. Our intent in this chapter is to try and show through real cases that historical research about the past of cities can benefit from complementing photorealistic representations with abstract graphics inspired by the *InfoVis* paradigms and practices.

In a brief first section we give an overview of some of the mainstream practices in terms of virtual reconstructions of cities. We then discuss four major scientific challenges such initiatives raise: dealing with the ill-known, representing temporal data, ensuring the reproducibility of experiments, enabling the analysis of collections as such.

Finally, we briefly position *InfoVis* with regards to its legacies and to the general context of information technologies, and detail some of our key experiments. As will be shown, these graphics are aimed at helping the analyst to re-read the data available, filter and re-organise it, and ultimately to explore visually the known and the ill-known about Kraków's centre urban evolution.

Virtual reconstructions: practices and open methodological issues

With the raise of digital technologies over the past twenty years, a number of new tools (in the broad sense) have been introduced in the process of historical research and in its communication: digitisation platforms, online databases, information systems, virtual reconstructions, augmented reality disposals, immersive 3D platforms, and others. Giving a general overview of all these "new" opportunities is beyond the scope of this chapter: what we shall do here is mention three significant trends, birthed in the early 1990s, so as to pinpoint underlying methodological issues that we consider common, and still open.

Back in 1993 Patricia Alkhoven published a research that remains in many ways a landmark: "The changing image of the city" (Alkhoven 1993). The author intermingles historical research on the evolution of the city of Heusden (Netherlands), with an architectural analysis of morphotypes, and with a significant 3D modelling effort that results in a series of "virtual reconstructions". The technology of the time is naturally today obsolete, but her research

already exemplified pitfalls, work processes, potential benefits of using 3D models in the course of such a research: heterogeneous and untrustworthy inputs, pieces of general knowledge called in to counterbalance missing data, case by case inferences, power of seduction of virtual environments, *etc.* Today, building “virtual reconstructions” at the scale of a city has become a popular research goal. However there are nuances in the way that activity is conducted.

The initial *virtual reconstruction paradigm* can be described as an effort to translate the expert’s understanding of a city’s layout and components at time *t* into a set of geometric shapes distributed in space. The underlying geometric canvas can be obtained by various means, from old maps to contemporary digitisation campaigns. Alkhoven’s 3D models partially base on a 1649 map by Joan Blaeu. The *Virtual Leodium* project (Pfeiffer et al. 2013) bases on a 3D survey of a physical model representing the city of Liège (Belgium) towards 1730. The *Virtual Kyoto* city model (Takase et al. 2008) integrates automatic generation of 3D city model using LIDAR data, 2D digital map and aerial photography. Significant research efforts are put today on trying to produce photo-realistic city models and publish them on the internet, with quite often more focus put on the technological suite than on the scientific added value.

But, as exemplified by Alkhoven’s, the objective is not necessarily to reach to a photo-realistic anamorphosis, in the virtual world. It can be testing different geometric combinations, or fostering an educated debate among scientists. Non-photorealism (NPR) appears here as a potential alternative approach (e.g. Döllner and Buchholz 2005).

Besides, beyond figuring a city’s outlook, 3D models can be used as interfaces – a sort-of 3D implementation of the GIS paradigm. An early attempt on the internet was carried out by (Heinonen Pulkkinen and Rakkolainen 2000) who developed what they call an *Information database for VRML Cities*, an interactive 3D model that can be queried interactively in order to retrieve information about services, shops, *etc.* We also applied this principle in early developments on the city of Kraków (Blaise and Dudek 2000), where the data we had gathered on each individual edifice or urban space was available using a 3D, non-photorealist model of the city. An interactive slider was used to browse through time, monitoring the content of the 3D model in real time. A number of graphic codifications were introduced in order to convey information about the nature of the documentation behind each component in the model, or about the nature of the hypothesis made in the reconstruction. The above mentioned *Virtual Leodium* project reinterprets this principle in a more contemporary technological suite: the objective behind the project is not only reconstructing the city, but also giving access to the historical evidence behind each edifice in the 3D model. Shortly said, to this day a clear evaluation of the performance (in terms of information retrieval) of such platforms still needs to be made.

With time passing by, and technologies reaching a higher level of accomplishment, virtual reconstructions tend to become primarily a media targeting general communication goals. We have been witnessing for the past decade a clear move from 3D modelling (used to produce images of past cities, and to test hypothetical reconstructions) to what could be called visual storytelling. Such initiatives, backed up by technological breakthroughs such as haptic interfaces, virtual and augmented reality (see for instance Dima, Hurcombe and Wright 2014) tend to borrow the visual language (when not the actual graphic engine or software suite) of computer games. They end up on with “visual products” that range from interactive 3D scenes to videos or serious games. The issue at stake for scientists is then to use other media in order to compile, memorise, and pass on the scientific basis behind such products. This is exemplified on our test field, the city of Kraków, by a research initiated on the occasion of 750th anniversary of the city’s foundation. A significant multidisciplinary research effort was conducted in order

to back up scientifically the production of a 3D model showing the city around 1650. Outputs include on one hand a series of very convincing communication products (videos, images, CD-Rom) and on the other hand scientific publications summing up the actual historical evidence on which hypotheses are built (Marek 2011, Firlet 2010, Rydzewski 2006, and others). Unfortunately, in many cases, such a comprehensive effort to pass on the making-of a 3D model is neglected.

In short, there is a potential pitfall for knowledge sharing in initiatives that focus not on the data and its interpretation process, but rather on fostering a sort-of artistic freedom, legitimate in the context of a communication-oriented activity, but endangering scientific legitimacy.

A major concern for actors involved in the creation of virtual 3D cities today is therefore the scientific and technological “sustainability” of the end products, and in parallel their growing dependence, including in terms of work processes, to tools and software suites. As an answer, a number of initiatives have flourished in order to try and apply “open science” approaches and solutions – typically, developing standards such as CityGML (Lorenzini 2009) or BIM (Building Information Modelling) approaches (Baik, Yaagoubi, and Boehm 2015).

Yet in this chapter we wish to focus on more fundamental challenges: underlying methodological issues. Four main aspects are discussed below, with no ambition for exhaustiveness: uncertainty, role of the time parameter, memorising inferences and reasoning on collections.

The uncertainty issue

Dealing with uncertainty in the process of reconstruction of a “lost city” is regularly quoted as a background issue in the scientific community. (Sylaiou and Patias 2004) put it this way: *“the main problem is that advanced graphic systems that are used for computer reconstructions may sometimes be too realistic. Things can be difficult, especially when they are based on partial evidence, but nevertheless suggest an impression of good knowledge of the past. [...] A very good 'image' can give the impression to the viewer that archaeologists know more than they actually know. Some products of computer reconstructions can be considered as scientifically accurate, because they seem to be accurate”*.

Back in 1999 (Strothotte, Masuch and Isenberg 1999) already picked up the issue and proposed to *“encode systematically more information about the model than just its geometry”* and then to *“produce non-photorealistic images which encode this additional information”*. In our first experiment on Kraków (1999) we backed up the idea by differentiating systematically the existing form the hypothetical through graphic encoding (textures and transparencies, Fig1, left). But what we have learnt over time is that there is nothing like a “general”, “overall” uncertainty: there are different factors of uncertainty: credibility of sources, precision, poor temporal density, contradictory data, and so on. Our claim is not that one should avoid representing objects that are ill-known, but that it is vital if a 3D reconstruction is to be reused scientifically, to keep track of all we know – including *what we do not know, what we partially know*, as well as *what we infer from analogies and generic knowledge* (Blaise and Dudek 2005). This means making a significant effort in formalising and passing on our doubts. The following list gives definitions of some of the notions that can be used in order to better differentiate uncertainty factors (partial list, includes the origin of the uncertainty).

| | |
|--|--|
| Reliability /credibility (<i>Origin: Sources</i>) | A judgment made by the human consumer of the information about the information source... An information source that produces data that conflict with other data, has produced unreliable data in the past, or is otherwise suspect for some reason leads to uncertainty. (Skeels et al 2010) |
| Imprecision (<i>Origin: Sources and interpretation</i>) | Inexactness of measurement (Thomson et al 2005). By extension, can apply to factual eye witness reports. |
| Incompleteness (<i>Origin: Sources</i>) | Information available to analysts is never complete. Even with excellent collection capabilities, observed evidence is likely to only be a small portion of the whole. (Thomson et al 2005) |
| Lineage (<i>Origin: Sources</i>) | Conduit through which info passed (number of steps). (Thomson et al 2005) |
| Approximation (<i>Origin: Sources and interpretation</i>) | Attempt to come close to measuring or describing a phenomenon when we cannot measure or describe it with perfect precision. (Skeels et al 2010) |
| Timing (<i>Origin: Sources</i>) | Temporal gaps between occurrence, info collection & use. (Thomson et al 2005) |
| Subjectivity (<i>Origin: Interpretation</i>) | Amount of private knowledge or heuristics utilized. (Zuk and Carpendale 2007) |
| Inconsistency (<i>Origin: Sources</i>) | Extent to which info components agree (5 say M; 2 say T). (Thomson et al 2005) |
| Accuracy (<i>Origin: Sources</i>) | Difference between observation and reality. (Thomson et al 2005) |

Table 1. Definition and origin of some notions that can be used in order to better differentiate uncertainty factors (partial list).

Historical research is clearly a relevant test field when wanting to investigate the uncertainty issue, yet the topic is scarcely at the heart of research works. By contrast it is already a hot

topic in information sciences as exemplified by (Zuk and Carpendale 2006), or (Gschwandtner et al 2014).

The time parameter issue

Reconstructing ‘lost cities’ is not only, and not even mainly, a matter of spatial distribution, of geometrical shapes: it is a matter of time. Handling the time parameter as such is, even in information sciences, an issue that remains scarcely addressed, although recent contributions like (Aigner et al 2011) help pushing it towards the top of the research agenda. In the context of historical sciences the issue is naturally crucial: we shall here mention two (and only two) bottlenecks we think actors involved in the analysis of ‘lost cities’ should be very conscious of: temporal consistency and the specificity of temporal data.

Ensuring the geometrical consistency of a 2D or 3D reconstruction is challenging because of the nature of the underlying data – repositioning of old maps is a typical example. But the same difficulty, although sometimes unsaid, exists when wanting to ensure the *temporal consistency* of a reconstruction. Quite often, the historical hints we handle do not permit to be sure of temporal co-occurrences of objects we represent in a single, synchronic view of a city (e.g. no direct evidence that two artefacts co-existed at time t). Even when we do have corroborated evidence that artefacts A and B coexisted at time t , we are often forced, due to lacking information, to represent A basing on information we have on A at time $t - \gamma$ and B basing on information we have on B at time $t + \delta$. There are some famous such anachronism in the cinema industry – a classic example is gladiators wearing watches.

A second bottleneck – and from our view even more prominent than the consistency issue – is understanding the nature of temporal data, and therefore providing analysts with means to perform reasoning tasks that are specific to the time parameter: spotting cycles, densities of changes, overlapping time slots, potential causal chains, managing uneven time granularities and branching time, uncovering significant trends such as speed of changes, or exceptions such as periods of intensive destructions, *etc.*. This implies primarily a conceptual modelling effort, building on notions that have stemmed from the information sciences community. This effort needs to be followed on from within historical sciences.

At this stage some precautions can be taken in order to minimise the impact uncertain or ill-defined temporal indications at various stages of the research process (conceptual modelling, data management, reconstruction itself):

- distinguish uncertainty concerning the geometrical aspects from this concerning the dating,
- record the real data, independently of the choices and hypotheses we need to make before a reconstruction (e.g. if evidence is available for 1658, and the reconstruction shows 1700, record 1658, and the inference made that it was “probably” unchanged in 1700),
- switch from a synchronic approach (*i.e.* corresponding to a *time point*) to a diachronic approach, where the focus is put on transformations (*time intervals*) rather than on states (Dudek and Blaise 2010),
- finally, when possible, inform the users visually about temporal inconsistencies in the 3D model itself (Blaise and Dudek 2003).

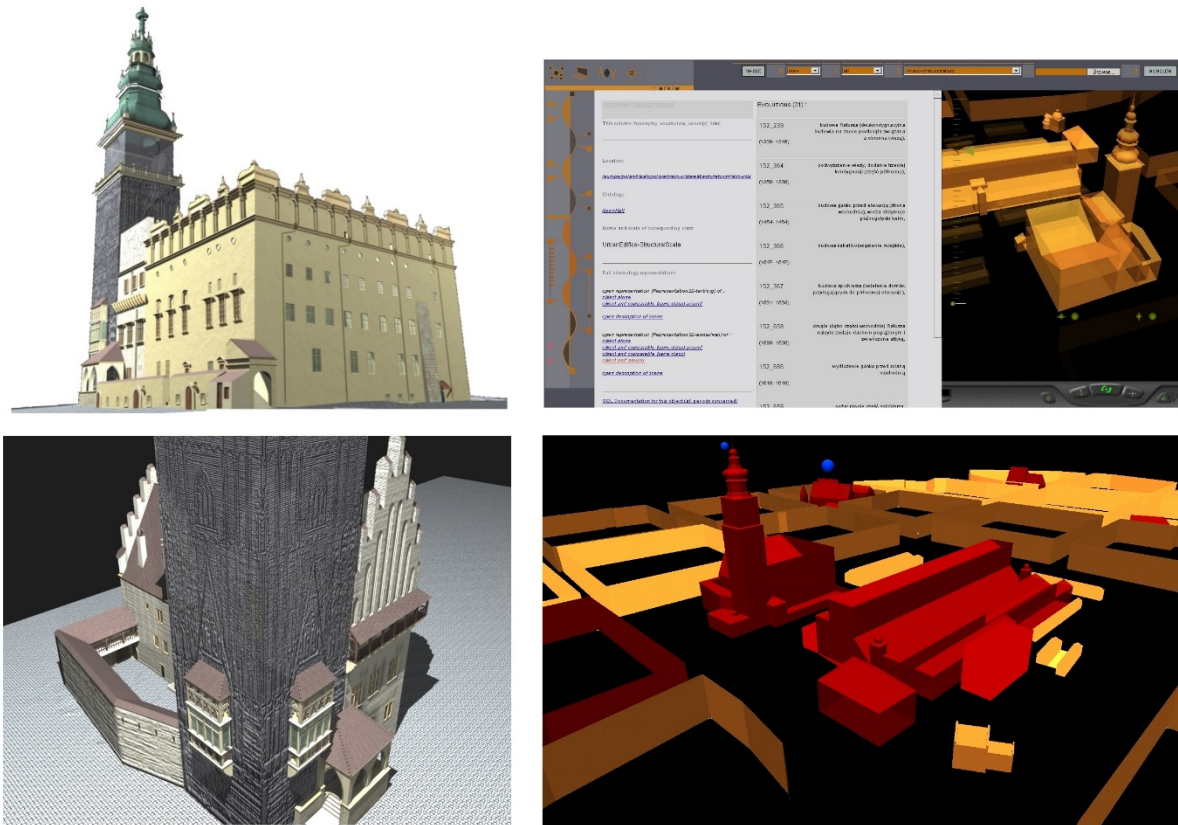


Fig 1. Left, virtual reconstructions of the town hall ensemble. Existing parts, (*i.e.* the belfry walls as they remain today) is differentiated visually from the hypothetical parts (represented in colour). Right, the VIA platform investigates the use of non-photorealistic 3D models as interface. Top, transparencies inform on confidence levels, a slider allows user-monitored browsing through time - each artefact can be queried (lifeline, bibliography, ...). Bottom, colour and emissivity are used to spot in a scene corresponding to a period t , shapes that correspond to an earlier or later phase of evolution.

[I. Dudek & J.Y. Blaise, UMR CNRS/MCC 3495 MAP]

Memorising choices: the “why” question:

Historical research starts with the cumbersome tasks of pulling together fragmental and heterogeneous evidence that will act as inputs in an analysis process. What is more processing these inputs requires numerous interpretation steps. Hence a huge potential information loss if the only result passed on to others is a 3D model, without indications about why the 3D model is what it is, about the inferences made by analysts during their study of the city (e.g. critical analysis and selection of sources, analogies used, generic knowledge called in, archaeological findings considered).

“Images” are easy to understand, and therefore simple to share with a wide public. 3D reconstructions of how that city could have looked like at this or that period, act as an interchange point where an interpretation process carried out by “the ones who know” (scholars, researchers, *etc.*) are made available for others in a form that is expected to be easily readable, and most often turns out to be assertive.

But what exactly does a 3D model contain in terms of knowledge? Recreating the spatial layout of a city in the past implies numerous interpretation steps, numerous inferences. Considering 3D reconstructions (*i.e.* 3D model) as the only result of this process would be like reducing a whole research process to its *conclusion*. Thereby if no precaution is taken it may conceal selections of inputs, assessments of data quality made during the analysis, inferences, and choices. 3D models most often leaves the actors with the responsibility of *memorising and passing on the research process* itself (Dudek et al 2015) - yet another methodological bottleneck. What is a 3D reconstruction, besides a one-shot visual production, if we do not give ourselves means to formalise, memorise and visualise more than *the result of a process*, if we neglect to mention *the way it was achieved*?

What is at stake here is not only transferring knowledge, or clarifying choices and inferences - it is a cornerstone of scientific practices: *reproducibility and intersubjective verification*.

From distributing individual components in space to reading a collection

Analysing a whole city does introduce a quantitative break when compared to a one-monument monograph: more edifices, or urban components at large, have to be taken into consideration. But the break is not only quantitative, it is also, and in our view primarily methodological. Shortly said, on one hand the information gathered while studying a whole city concerns heterogeneous urban components (an edifice, as well as an open urban space) and on the other hand includes non-localised data (e.g. a new law enforcing changes on this or that component), contextual information (e.g. a plague and its consequences on the population), reports of significant events (e.g. sieges, floods, *etc.*). Passing on the evidence, reasoning on it, requires an approach (and visual tools) that go beyond distributing individual components in space.

A number of such approaches, applied to the analysis of a city's territory and changes over time, have been convincingly introduced in the *InfoVis* community. (Slingsby et al 2009) for instance reuse a visual formalism called treemaps, introduced by (Johnson and Shneiderman 1991), for "showing spatial and temporal variation in house prices". And indeed their approach does allow a clear understanding of patterns of change in each district of a city, over time.

Focusing on the temporal aspect of the underlying data, the "*Commuting Scales*" experiment by (Beaude and Guillemot 2012) summarizes in an abstract way periodically recurring travel times inside a whole urban area. Yet another convincing example is A. Yabuuchi's "*Home to School diagram*" (Yabuuchi 2011), a visualisation, inspired by musical staves, that turns an urban route into a series of individual scenes. For each scene components in the surroundings (vegetation, buildings, vehicles, *etc.*) are visualised through specific icons and help portraying something rather intangible – an atmosphere.

These examples illustrate a fundamental observation: visualising and reasoning on a collection is not only allowing for the analysis of "lots" of individual items, it means depicting, and analysing, the collection as such.

Analysing a whole city differs from analysing a "list" of individual components in the sense that it implies the analysis of relations components may have with one another and with a wider context. Introducing *InfoVis* practices that focus on sensemaking in such large information spaces appears as a promising research path. However it has to be said that most examples found in that community use "well-defined" data sets. As mentioned before, reasoning on the *past of a city* means handling of large, heterogeneous data sets, hindered by uncertainties. Bridging *InfoVis*-birthed approaches and the reality of historical research therefore remains an open challenge at large.

Sensemaking in historical research: an information visualisation perspective

Information visualisation builds on a specific interpretation of the term *visualisation* that today encompasses a wide range of practices. This interpretation was worded by R. Spence (Spence 2014) as follows: “*visualisation is a cognitive activity*”. In other words, visualisation here clearly targets *understanding* - it is *not a result* but *a means* to perform reasoning tasks.

Information visualisation is defined in (Kienreich 2006) as “*the use of computer-supported, interactive visual representations of abstract data to amplify cognition*”. M. Friendly (Friendly 2006) considers the discipline as inheriting from the historical development of on one hand statistical graphics and data visualization, and on the other hand thematic cartography. Information visualisation is today an active research area, with however still rather scarce applications in historical research, although hot topics like time-oriented data, or handling “dirty data” can be seen as potential methodological bridges with the reality of historical research.

In this contribution we do not intend to discuss of information visualisation as such, but rather wish to illustrate through a chronology of experiences how visual tools inspired by that discipline can be profitable when facing the four major bottlenecks we have discussed above: uncertainty, time parameter, memorising choices, and reading collections as such. The experiences that are reported below share a number of common choices in terms of conceptual modelling as well as in terms of computer infrastructure:

- urban components (edifices, urban blocks, streets, squares, *etc.*) are modelled as one unique “being” with potentially several successive morphologies,
- the model includes typologies classifying on one hand *states* (a morphology and a time slot during which it is believed to have remained stable) and on the other hand *transformations* used to qualify what changes occurred and how long they took (Dudek and Blaise 2008),
- components are not considered as having disappeared until confirmed evidence can be found that states they have been fully dismantled (underground structures included),
- qualitative lexical scales are used to formalise various types of doubts arising about the lifeline of components, uncertain morphology, materials, functions, durations, *etc.*,
- all pieces of data are stored in an RDBMS and XML files,
- the infrastructure’s user interface is web-compliant (HTML produced on the fly),
- graphics (2D or 3D) are produced on the fly, as answers to user queries, in standard formats (mainly SVG – Scalable Vector Graphics).

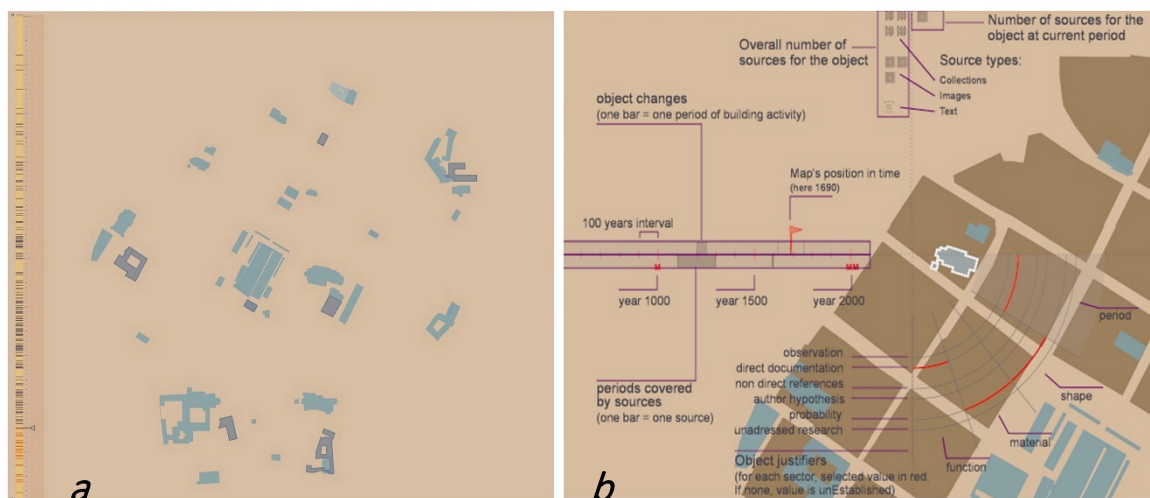
Localising and interfacing historical evidence

Uncertainty, as mentioned earlier, affects both (and differently) the spatial and the temporal determinacy of a component. Focused on the former, one of our earliest experiments was an Information System called *VIA*. The system establishes a direct link between historical sources and urban components, and produces 2D and 3D visual displays used as interfaces (Dudek and Blaise 2003). Each component can be queried in order to retrieve the information available on it, and vice versa any historical source can be queried in order to localise its “architectural content” in 2D or 3D. *VIA* gave us a first opportunity to dig into uncertainty factors (Fig 2, c). Each urban component is described by a set of “justifiers” – *i.e.* values representing our estimation of the reliability of sources concerning the morphology of the component, the

construction material, the function and the dating. Besides, a comparative chronology of transformations of a given component and of historical sources helps underlining potential anachronisms (*i.e.* temporal gaps between a change and its report in sources) or factual errors.

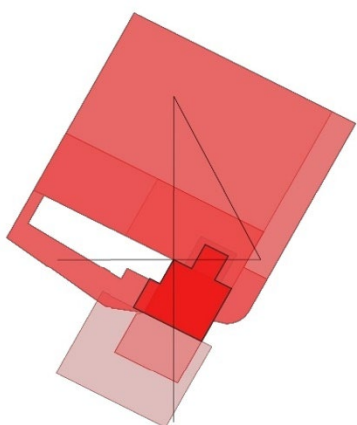
The temporal aspects were still underrepresented in the *VIA* first developments, although time sliders included in the visualisation did help browsing through time. But this solution only provides “temporal snapshots” on the data: only one period is visible at a time. Comparative chronology of changes and a map of densities of changes over time (Fig2, a) prefigure solutions we investigated since that early experiment in order to spot and analyse temporal patterns.

A later development of the *VIA* platform targets specifically visual sources that cannot be unambiguously localised using contemporary methods because of their artistic nature, because of lacking information on the captors, or because *de facto* they correspond to several points of view (e.g. historical panoramas). By contrast the *Locus Imaginis* project (Stefani et al 2013) illustrates an ambition to localise visual sources in the space of a 3D model, but focuses on *well-defined* visual sources. On what solution can the analyst base when facing old paintings, hand-drawn sketches, panoramas? The idea we have investigated in the *VIA* platform was to describe an approximate point of view using a combination of parameters: the viewer’s estimated position(s) (x,y,z), an estimated target point(s), a horizontal angular direction(s) of view, a geographical bearing(s), a vertical bearing(s), the image’s ratio and type (Fig 2, d). The approach allowed us to illustrate some noteworthy observations, typically when a painting turns out to correspond not to a real view but to a combination of several points of views carefully chosen by the painter to reach a satisfactory artistic result (Dudek and Blaise 2007).



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|-----------------|
| 1300-1316 (239) |
| 1350-1399 (364) |
| 1454-1454 (365) |
| 1547-1547 (364) |
| 1561-1563 (367) |
| 1580-1595 (658) |
| 1610-1610 (686) |
| 1632-1632 (659) |
| 1636-1636 (660) |
| 1678-1678 (368) |
| 1680-1680 (369) |
| 1681-1686 (370) |
| 1782-1782 (371) |
| 1783-1784 (372) |
| 1817-1820 (373) |
| 1864-1866 (661) |
| 1881-1882 (374) |
| 1889-1898 (375) |
| 1946-1946 (376) |
| 1961-1967 (662) |
| 1983-1987 (663) |

c



d

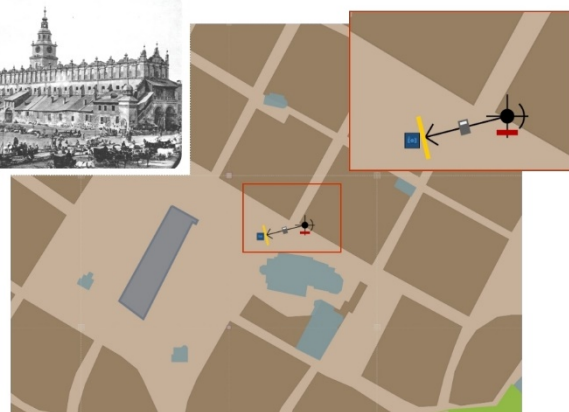


Fig 2. **a)** On the left a slider allows user-monitored browsing through time (here on a sub-selection of components, artefacts only). This slider is also used to show densities of changes over time: each little horizontal bar corresponds to a change in one of the components under scrutiny. Periods of high and low activity are revealed. **b)** Graphical codification of justifiers and comparative chronology of changes. **c)** Successive layouts of the town hall are superposed using transparencies, underlining the density of land use over time. **d)** Glyph used to position in space visual sources qualitatively.

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Understanding temporal patterns

Understanding how transformations of a city develop over time, and not only in space, is naturally a key aspect of historical research. The *InfoVis* community has been very active in the formalisation of time as such, with the introduction of models aimed at coping with notions like cycles, time granularity, density, determinacy (*etc.*) implemented on real cases. Temporal uncertainty has been addressed, for instance in the *PlanningLines* experiment (Aigner et al 2005) where time intervals are modelled with “floating” bounds in order to allow the assessment of risk of delays in the planning of chained activities. A similar mechanism was introduced in the *chronographs* project through which we introduced a methodological framework aiming at the description of life cycles in a diachronic approach (Dudek and Blaise 2010). Here focus is put on the way artefacts get transformed, with a grid of notions identifying life cycles as a sum of states and transitions. *Chronographs* act as *visual explanations* (a tribute to Tufte 1997) of the artefact’s life cycles, underlining temporal patterns of evolution within a site or across sites, but also underlining uncertainty of temporal bounds. They combine three elements: *diachrograms* and *variograms* that allow a global view on transformations, and *features variation visual assessments* that foster comparisons and the reading of consequences. The whole disposal is designed to combine vertical readings - “*what precisely happens at period p*” – and horizontal readings “*how does a feature change with time*”. In that sense, the disposal matches Bertin’s view of graphics as “*visual answer to a question*” (Bertin 2010).

Understanding *alternative* temporal patterns

The *chronographs* solution has proven quite efficient in performing reasoning tasks - it does help assessing causal relations and orders in time sequences, events and consequences in a robust manner. But *chronographs* have the pitfall of forcing the analyst to choose one and only one scenario of evolution for a given urban component - in other words it does not identify those key historical time slots for which the analyst has interpretation difficulties. In addition although doubts about the dating are duly visualised, no mean is given to say that the very existence/relevance of an event is questionable.

As an answer, we developed a new set of visualisations that capitalize on the user’s *a-priori* understanding of the timeline paradigm, but introduce visual interruptions marking key choices the analyst has to make before adopting an unambiguous scenario (Dudek and Blaise 2012). Three complementary graphics are produced, corresponding to different analysis needs:

- *multi-hypothesis chronology diagrams*, that deliver quick, synthetic view on where alternatives exist (in time) and on what options the analysts face;
- *graphs of potential interactions* (Fig 3), through which we introduce a classification of architectural consequences. These graphs position alternatives in time, help understanding their relative density when compared to well-established indications, and connect them to the corresponding clues;

- *visual measures of complexity*, a diagram that fosters comparisons of the relative complexity of artefacts evolution across the collection.

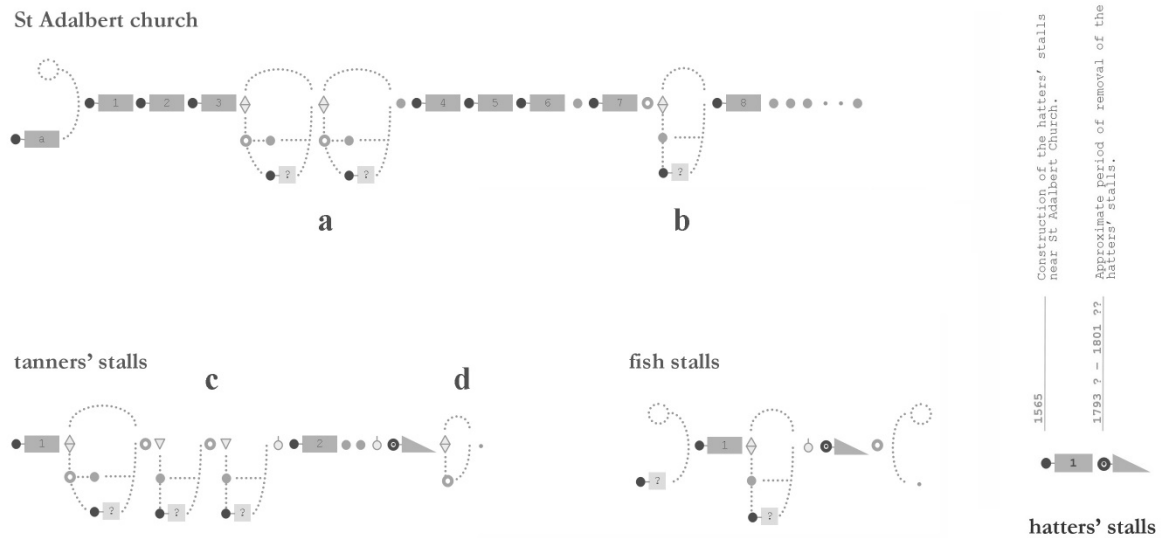


Fig 3. *Graphs of potential interactions* position changes in ordinal time, and allow for the visual assessment of alternative scenarios of evolution. Dark circles and rectangles correspond to known states. Triangles position events that result in temporal “forks”, *i.e.* moments when alternatives scenarios should be considered. Dotted lines above the triangles mean the event is NOT confirmed (**a**, **b**, **d**). Dotted lines below the triangles correspond to alternative potential consequences. The graphs are read as follows: **a**), **b**) and **d**) the event may not have occurred at all (triangle upwards, dotted line straight to next step) but if it did occur (triangle downwards) either it has had limited consequences (light grey circle) or it lead to a main change (black circle, rectangle with question mark). Outlined circles correspond to destructive changes. **c**) confirmed alternative: the event did occur for sure (triangle downwards) but either it has had limited consequences (light grey circle) or it lead to a main change (black circle, rectangle with question mark). Graphs are presented along with explanatory vertical texts, as in the rightmost example.

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These graphics help highlighting alternative explanations that can arise from the available data. However they have their pitfall too: they remain a solution putting “side by side” individual cases. Considering we studied in this experiment a collection of 27 artefacts, Tufte’s recommendation “*enforce comparisons within the eyespan*” was a challenge. We decided for a visualisation more or less inspired by the “small multiples” principle (concept attributed to Scheiner’s 1626 representation of changes in sunspots over time – see Friendly 2006). Life spans, the number of transformations, and the number of alternatives across the whole collection are visualised in a single graphics, helping the analysts to read the collection of artefacts as a whole.

Communicating about doubts

It is sometimes said that conveying doubts is irrelevant in the context of a communication effort. In an attempt at contradicting what we consider as a simplistic view, we have introduced an edutainment-oriented proof-of-concept prototype called *tangible chronology* (Blaise and

Dudek 2013). This prototype combines a master board, 3D physical models of the artefacts, with a coding of their position on the board and in ordinal time, and a tangible timeline for each artefact. Its specificity lies in tangible codifications used for various purposes, from positioning 3D physical models on the master board to reliability assessments. The initial concept was to offer users, including ill-seeing users, means to analyse the site's urban composition and evolution, for any time slot inside the 750 years covered. To do so users combine on the master board 3D physical models corresponding to each edifice's evolution at the period chosen. But what the experiment did underline at the end of the day is that consistency with the underlying historical evidence's specificity (temporal aspects, uncertainty) does not undermine scientific communication, it helps it.

Reasoning on space and time in a row

There are a number of reasons that can be pushed forward in order to explain why it is arduous to combine the reading of spatial and of temporal patterns in one unique visualisation. At the end of the day, whatever scale is concerned, visual solutions used to represent spatial features (in 2D or 3D) and temporal features are in most cases simply put side by side - typically a map or 3D model, complemented by a time chart like in (Rød 2003), (Stefani 2008) (Auer et al 2011) or (Tomaszewski 2012).

The *ConcentricTime* visualisation (Blaise and Dudek 2011) is by contrast an attempt at reading in a row the spatial distribution and the changes over time of a collection of artefacts. It capitalizes on basic, well-known, well understood representations (cartography, timelines) and introduces a specific, context+focus, graphic combination of spatial features and chronology. A map in the central part of the visualisation shows the layout of artefacts. Each artefact is connected with a radiating timeline along which its transformations are localised in time. Moments of change on the timeline, represented by coloured rectangles, can be interactively queried: the 2D contours corresponding to the user query are then projected in the central area. Because contours are drawn with a level of transparency, this mechanism enables user-monitored comparisons of contours such as neighbourhood analysis or transformation analysis (e.g. period of emergence of a given component).

The visualisation allows the reading of an individual artefact's lifeline, and fosters the reading of common behaviours inside the collection of artefacts (impacts of changes on one artefact on others, general patterns of change such as 19th century destructions, *etc.*)

ConcentricTime was designed in order to combine inside a unique information space, spatial features and chronology, with as constraints uncertainty assessment, interface capabilities, and simplicity. As a result, although limited by the fact that only one scenario is shown, and that the number of radiating timelines is finite, the concept does provide efficient support in carrying out reasoning tasks about architectural changes on a collection of artefacts, and appears as fairly generic (Fig 4).

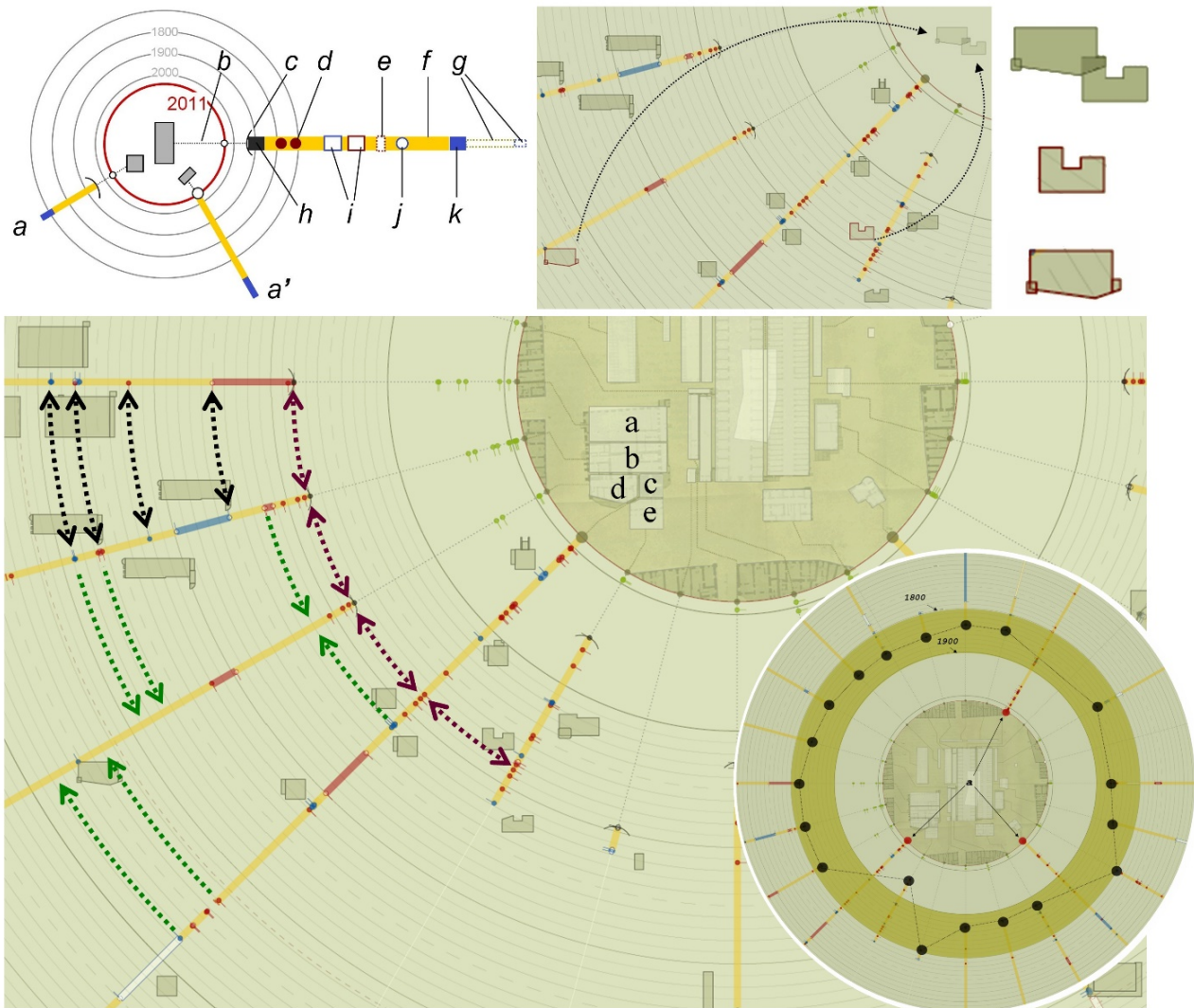


Fig 4. Principle of the *ConcentricTime* visualisation. Top left, artefacts are connected to radial timelines (**a**, **a'**) that distribute transformations in time. Colours differentiate event types: yellow (periods of stability, no known change, **f**), blue (morphological change, including construction, **k**), red (functional change, **d**), grey (destruction, **c**, meaning here that no visible trace is left above the ground). Shapes differentiate duration and certainty: long-lasting events (duration > year, rectangles – **i**, **e**, **k**), punctual events (duration < a year, circle - **d**, **j**), uncertain dating white filling and outline (**i**, **j**), hypothetical dating dashed outline (**e**, **g**). Top right, contours can be projected inside the central circle on user selection, enabling user-monitored comparisons (neighbourhood analysis for instance). Bottom, the visualisation can be used in “focus view” so as to allow a fine grain analysis of temporal patterns across a group of artefacts. Illustrated here is the town hall ensemble: a majority of temporal co-occurrences for artefacts **a** and **b** (Granary/Town Hall, black arrows), a majority of non co-occurrences for artefact **d** (prison) with neighbours **b** and **d** (town hall, belfry, green arrows), a phase impacting all the elements (purple arrow). Bottom right, the visualisation can be used in “context view” so as to spot patterns concerning the whole collection – here the massive destruction phase on the Market Square during the 19th century (only here artefacts, **a**, remain until now).

Making the best of an ill-defined data set

In a recent experiment (Blaise and Dudek 2014) we focused on very poorly documented edifices: wooden stalls that are known to have existed from textual sources, but for which no visual material is available. These commercial facilities share rather challenging particularities:

- They cannot be precisely localised (known only in archival sources by expressions such as “close to the town hall” or “located in the northern sector”). Moreover, they were wooden structures, demolished during the 19th century. There is accordingly no archaeological indication we can count on.
- No direct visual or textual archival material can be found that would help analysts say what were their construction and spatial layout. In fact, these facilities may even not have been “buildings” in the proper sense: they could in theory even have been rows of movable stalls, not physically connected to one another, but considered as a consistent group basing on their common function (goods/services sold).

If very little is known about these commercial facilities (in fact temporal aspects are better known than spatial aspects, which is not that common), we do have one document that gives useful indications: an 18th century inventory conducted by Kraków’s municipal authorities of the time. The challenge we were facing was then: *can we learn anything useful on the layout or organisation of these facilities basing in this only document?* As an answer, we re-interpreted two classic 18th century visual formalisms – *poleometric tables* and *candlestick charts* (Fig 5). Ultimately some noteworthy patterns were uncovered such as no relation of tax levels to surfaces, no catching-up process in the tax policy, regularities inside a consistent group of stalls with few contrasting components and so on.

This *re-vision* of classic visualisations did show the potential of InfoVis-inspired solutions when facing ill-defined data sets, and particularly how such an approach can facilitate workgroup discussions, unveil unexpected trends in data set previously considered as fully investigated, and in the long run uncover new research questions.

Collection reading visualisations

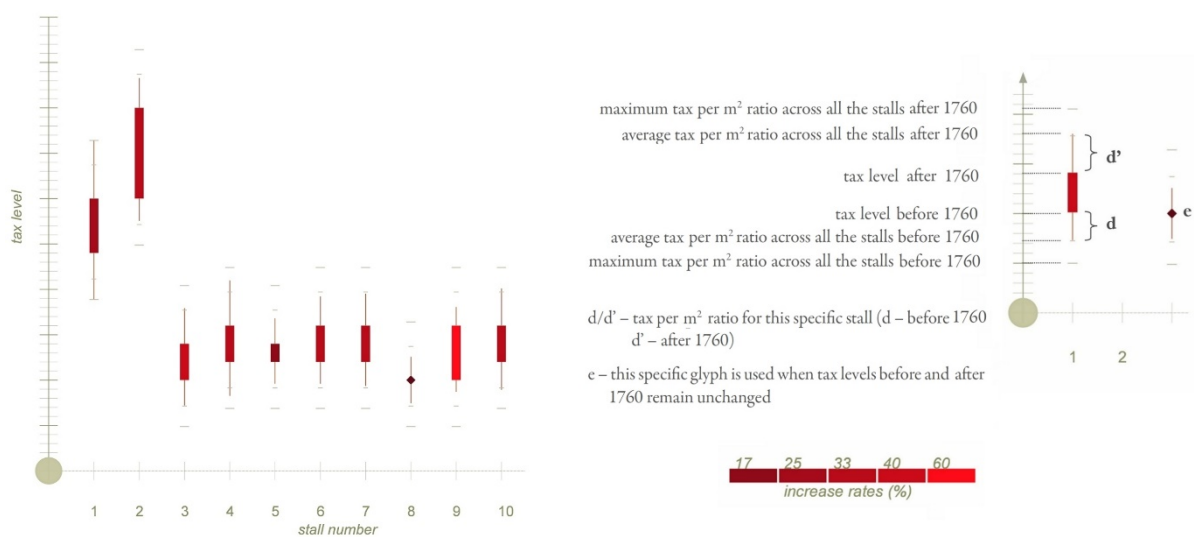
One of the key services expected from *InfoVis* solutions is to provide the analyst with tools that will help him cope with large information spaces, and uncover trends or exceptions that are simply not visible at first glance. This naturally goes for the spotting of “outliers” in a collection (may the ‘distance’ of the item from the rest of the collection be the result of faulty data, or a genuine difference) as well as for the spotting of general trends. From the practical point of view, this implies promoting visual solutions that implement a well-known mantra in the InfoVis community, worded by B. Schneiderman as follows: “*Overviews first, details on demand*”. It also implies, when needed, introducing grouping mechanisms that analysts consider as relevant for this or that reasoning purpose.

An example of this approach is the *evolution field* metaphor we introduced in order to analyse the spatial distribution of types of artefacts by “clusters”. The objective was to get a quick idea of whether groups that are consistent in space are also consistent in time, in patterns of evolution, in density of sources, *etc.* A multidimensional icon sums up various parameters: possible period of construction, overall lifetime, possible period of demolition/dismantling, confirmed or suspected events like fires, possible or definite transformations, archaeological remains of (or attributed to) the artefact. Icons are combined with regards to a given analysis need. The approach was applied for instance on Kraków’s market square ensemble in order to weigh the density and specificity of objects on both sides of the Cloth Hall. Wooden

commercial facilities on the west side outnumber by far those on the east side, some emerge earlier in time, their process of decay and demolition stand out as harder to date precisely – in fact activity as such appears as far greater on the west side (Fig 5).

Another example of the approach are *multidimensional transformation pie charts* organised in temporal clusters (Dudek and Blaise 2012). Here multidimensional icons of varying complexity are arranged visually either as classic time series or as small multiples (Fig 5). They help observing the data and its interpretation in a renewed way, typically highlighting source effects like the relation of the construction type to the nature, amount and assertiveness of the pieces of information available.

It is important to state that such visualisations show that there is room for comparisons and reasoning even when edifices for instance cannot be precisely localised in space - heterogeneity in terms of level of knowledge naturally remains a concern, but ceases to be a lock.

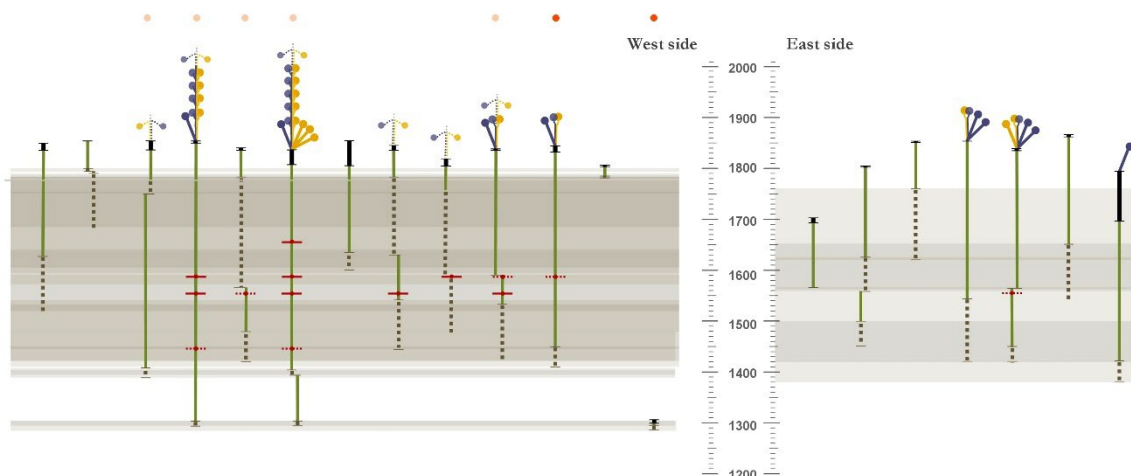
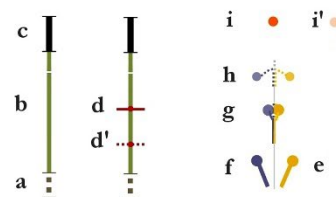


West side:

- 1) post-chart construction, 2) officers' house, 3) food supplies and general retail stalls, 4) gingerbread stalls, 5) stalls near the Town Hall, 6) salt stalls, 7) butter stalls, 8) bread benches and bakers' stalls 9) glass stalls, 10) pottery and lard stalls, 11) fish stalls, 12) Oszacki house, 13) cookshops

East side:

- 1) hatters' stalls, 2) 'Lithuanian' stalls, 3) stalls 'under Providence' and traders' stalls, 4) iron stalls (parts of this artefact could be built of stone and brick), 5) soap stalls, 6) stalls near the minor traders' hall, 7) glass stalls near St. Mary's Basilica cemetery



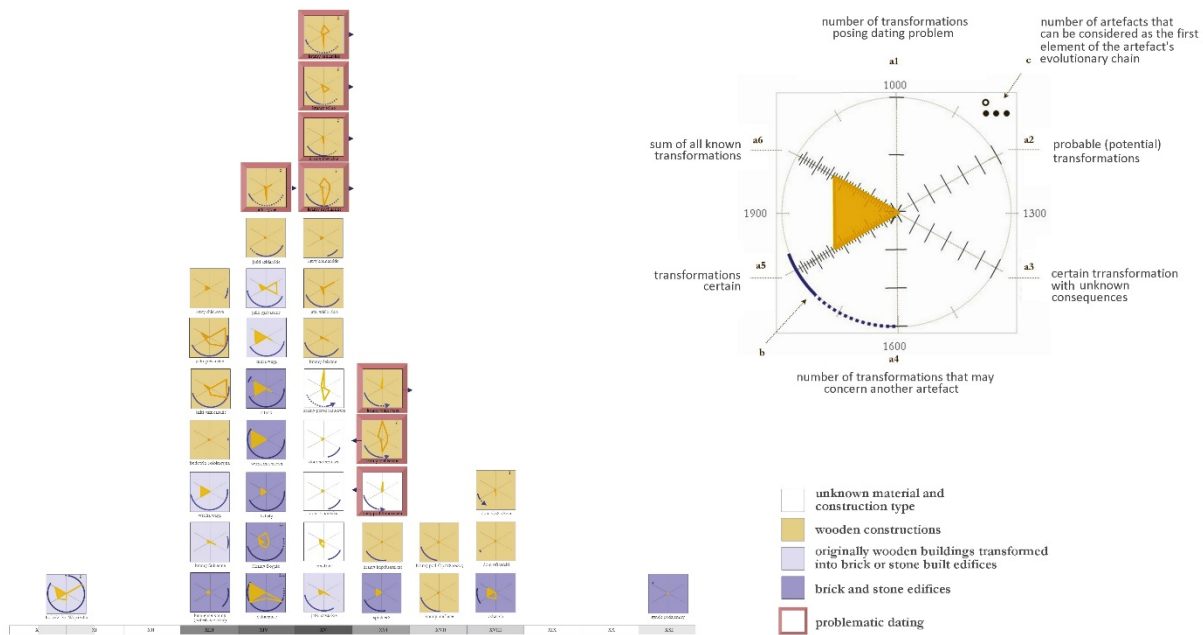


Fig 5. Abstract visualisations designed to facilitate the analysis of collections. Top, a re-vision of M .Homma’s *candlestick charts* is used to represent the relation of tax levels to surfaces in a group of comparable commercial stalls: “outliers” are easily spotted. Middle, the *evolution field* metaphor use to characterise the contrasting behaviours of artefacts located on the West and East sides of the market square. Bottom, multidimensional icons summarise characteristics of an artefact (here concerning transformations). They are then grouped into user-defined “temporal clusters” (represented by columns) - here a column corresponds to one century. Rhythms and general trends inside and across clusters can be spotted: the most important building activity on the market square in Kraków takes place during the 14th century, brick and stone buildings tend to be built earlier, wooden structures appear as harder to date and come in a second row, ...

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Context assessment and temporal co-occurrences in a collection

The last experience we mention aims at putting architectural transformations into a context, and at highlighting of temporal co-occurrences. Among uncertainty factors hindering the analyst’s reasoning process about the city and its transformations are potential results of events and facts that cannot be directly linked to this or that urban component (e.g. legislation, occupation by a foreign army, plagues, demographic variations, presence of important people, etc.).

If we are to support an analyst in his effort to understand and recount the evolution of a city, we definitely need to go beyond the depiction of consequences – *i.e.* spatial changes at time *t*, and correlate these changes with potential causes – or at least with a more general context. This is precisely the aim of the *historySkyline* visual metaphor. The visualisation pulls together in a time-oriented display the data we have on transformations of urban components (along with their uncertainty assessment and with the amount of sources used to document the changes) and a number of contextual indicators (rulers, military events, natural disasters, legal matters, global military context in the country, demography).

The design of the visualisation builds on the concept of *visual metaphor*, described by (Kienreich 2006). In practice it builds on the metaphor of an urban skyline, with the horizon line acting as a timeline (time goes from left to right). Shortly said, the building activity (changes) is represented as “blocks” or “facades”, and elements of contexts are superimposed on them.

At this stage the *historySkyline* visualisation is basically a proof-of-concept prototype, needing further development, but it appears as promising in identifying temporal co-occurrence patterns – expected or not (see Blaise and Dudek 2015).

Conclusions

Our record of experiences illustrates how we can today complement “conclusive” visual results such as 3D reconstructions with graphics aimed at supporting reasoning tasks on the data behind the analysis (e.g. at clarifying choices, considering alternatives, cross-examining the historical evidence, assessing contexts, interrelations, potential causal chains, *etc.*). Shortly said, it underlines the potential benefits of InfoVis-inspired abstract graphics as means to dig into ill-defined data sets, get aware of relations between the data, and investigate the time parameter. We have in particular discussed four major scientific challenges that the growing use of 3D models in the study of “lost cities” raise: dealing with the ill-known, reasoning on temporal data, ensuring the reproducibility of work processes, enabling the analysis of collections as such.

At the end of the day our research underlines methodological issues that intersect information sciences, and historical sciences. In that context, modelling and visualising doubts, or memorising research processes, remain issues to be further investigated. Understanding the time parameter as multidimensional (not only running from past to future, but needing to be described in terms of densities, rhythms, alternative paths, *etc.*) is indeed a challenge to come. Finally, the quantity and heterogeneity of data sets and of urban components concerned when analysing a whole city implies questioning the way we today handle collections.

Our record of experiences on Kraków shows that *exploring visually the known and the ill-known about a city’s evolution* can benefit from intersecting the above mentioned scientific fields, provided *the nature of the historical evidence* is considered as a research’s cornerstone.

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