Analyzing Alternative Scenarios of Evolution in Heritage Architecture: Modelling and Visualization Challenges

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ABSTRACT: *Our objective is to support reasoning tasks in heritage architecture with graphics enabling analysts to visualise and share their understanding of how, from a given set of information, alternative scenarios or evolution can be inferred. The paper comments on the nature of the cognitive processes in historical sciences, on factors that need to be weighed when interpreting sets of information, and on the characteristics of the parameter time when depicting architectural changes. Visual solutions are illustrated and evaluated on real cases in Kraków, Poland. They help to spot where alternative explanations should be considered in order to avoid unjustified assumptions and certitudes on the evolution of artefacts. The contribution expects to demonstrate that reasoning on uncertainties in historical sciences can be fruitfully backed up by concepts and practices from the infovis community.*

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1. Introduction

Analysts who investigate the evolution of architectural artefacts – may it be for research, teaching or protection purposes need to carry out reasoning tasks in the context of what Gershon identified as "*imperfect knowledge*" [13]. Our intent is to show that a shared understanding of spatial dynamics, in heritage architecture, can be usefully supported by analytical graphics – provided these graphics do take into consideration the nature of the data handled, and the nature of the analyst's cognitive process.

Generally speaking, investigations into the chronology of artefacts imply an interpretation and a cross-examination of heterogeneous, questionable sets of information from which are derived consistent clues and ultimately a scenario of evolution. Naturally a number of solutions do exist to present results of such analyses (may they be time-oriented - timelines, time series, etc.; or space- oriented - GIS platforms, 3D simulations) like [15, 21] for instance. In a previous contribution [9], we showed that beyond depicting a researcher's conclusions in terms of chronology or of physical changes, visual solutions can also underline processes of change, and support non-verbal thinking. But in these contributions a preferred scenario of change is chosen, and then made as understandable as possible. Casual and/or teleological reasoning is present, but limited by the scenario chosen. Delattre [8] usefully warns analysts about possible consequences of neglecting to assess choices made, and focusing on interpreted material:

"Through our ignorance [of alternative explanations] slogans are inserted in our understanding that, by dint of being repeated, brings to the fore certainties that our knowledge alone would not justify".

In this research our objective is to try and support visually the early phases of analysis, before a "*most likely*" univocal scenario is chosen, before a subjective, "*preferred* " scenario is spotted and exploited. This implies giving ourselves means to consider, represent, and make visible what E. R. Tufte called alternative explanations [28]. As will be shown in section 3, these alternative explanations exist due to the various interpretations an analyst needs to do of a given set of information. And when the time has come to visualize and share an understanding of how a given artefact has evolved over time, analysts usually rely on the nature of ethnic languages to mention where and why doubts remain, using expression like "*a refurbishing may have taken place as a consequence of a fire that supposedly damaged a neighbouring artefact* ". When the analyst is studying one and only one artefact, and when he is alone in studying it, hesitations are duly passed on to the reader, and it could just as well remain as it is. But when wanting to compare levels of knowledge across artefacts, across historical periods, when trying to understand and cross-examine different interpretations of a given set of information by different analysts, how can we weigh and visualize, in a more or less objective manner, doubts and choices?

Should we interpret expressions like "*may have occurred* " and "*it is possible that* " as meaning the same thing (not mentioning, naturally, translation problems)? As an answer, we do not intend to over-interpret divergent interpretations (see Figure 1, left). Instead, we try to understand the nature of the analyst's cognitive process, in order to propose a set of visual tools which expressly indicate doubts and alternative scenarios. These tools are designed to allow an objective comparison of the scenarios researchers may have preferred, and of their relative levels of complexity. In other words, we shall try to answer to a simple question: can we substitute to verbal figures such as "*it is likely that*" by a framework for the visualisation of alternative scenarios?

We expect to better identify and weigh the uncertainty when handling historical clues, and to uncover patterns of uncertainty within the collection – an application of J.Albert's "1 + 1 = 3 *or more*" principle [28]. The approach is tested on the evolution of artefacts located on the market square in Kraków, Poland (see Figure 1, right). This market square, Rynek GBówny, is a 200 * 200m urban space dedicated to trade and administration of the town since its foundation in 1257. Artefacts we analyse are quite well documented thanks to comprehensive historical investigations ever since the XIXth century. But they have been built, modified, and for most of them destroyed, over a rather long period – leaving a number of questions unanswered.

In this paper we first analyse factors that need to be weighed by analysts when facing historical evidence in architecture. We introduce the modelling choices made in order to structure outputs of the information interpretation step (notions of states and transitions, classification of changes occurring during the transition phase, differentiation between confirmed and unconfirmed alternatives, etc.). We then present a set of visual tools designed to support reasoning tasks as well as knowledge sharing in the early phases of architectural analysis. Finally, we briefly report on the implementation and evaluation, in section 5, and sum up our findings in section 6.

2. Research context

Understanding and providing models to handle the dynamics of change, has been and remains a hot research topic in geography or geospatial sciences. Applications range for instance from the analysis of human movements [28] to the visualisation of physical phenomena [18]. Among models for spatial analysis that [23] usefully compiles, Hagerstrand's time-geography offers a potentially fruitful conceptual framework, clearly described and exemplified in [7]. Time-geography puts space and time on equal terms, and introduces in spatial analyses individual behaviours – which are points we also need to make.

However these various approaches focus on the modelling of dynamics that have little to do with the very nature of data sets handled in historic sciences (uncertainties, incompleteness, etc.). They neither imply an interpretation of the underlying data sets, nor call for an assessment of reliability of sources. Furthermore, even when dealing with urban changes (see for instance [14]) most approaches use a systematic spatial clustering that cannot be transferred (without losses in semantics) to ill-defined architectural spaces. The issue we are facing closely resembles what [14] identifies as the drawback of "*descriptive models* [..] *based on static situation*" : a weak understanding of processes and of causal relations. Little has specifically been done, in the field of the architectural heritage, in order to describe and represent visually the time-chain between successive moments in the evolution of artefacts. Seen from closer, our research raises two families of question:

• understanding the analyst's cognitive process, i.e. steps and inputs from raw data to a scenario of evolution,

• supporting this process with relevant graphics, i.e. graphics that "*amplify cognition*" [17] on the successive choices the analyst faces when trying to spot and describe artefact changes.

Reasoning into a historical phenomenon, and here into artefact changes, has been described as hypo-deductive by [21] or

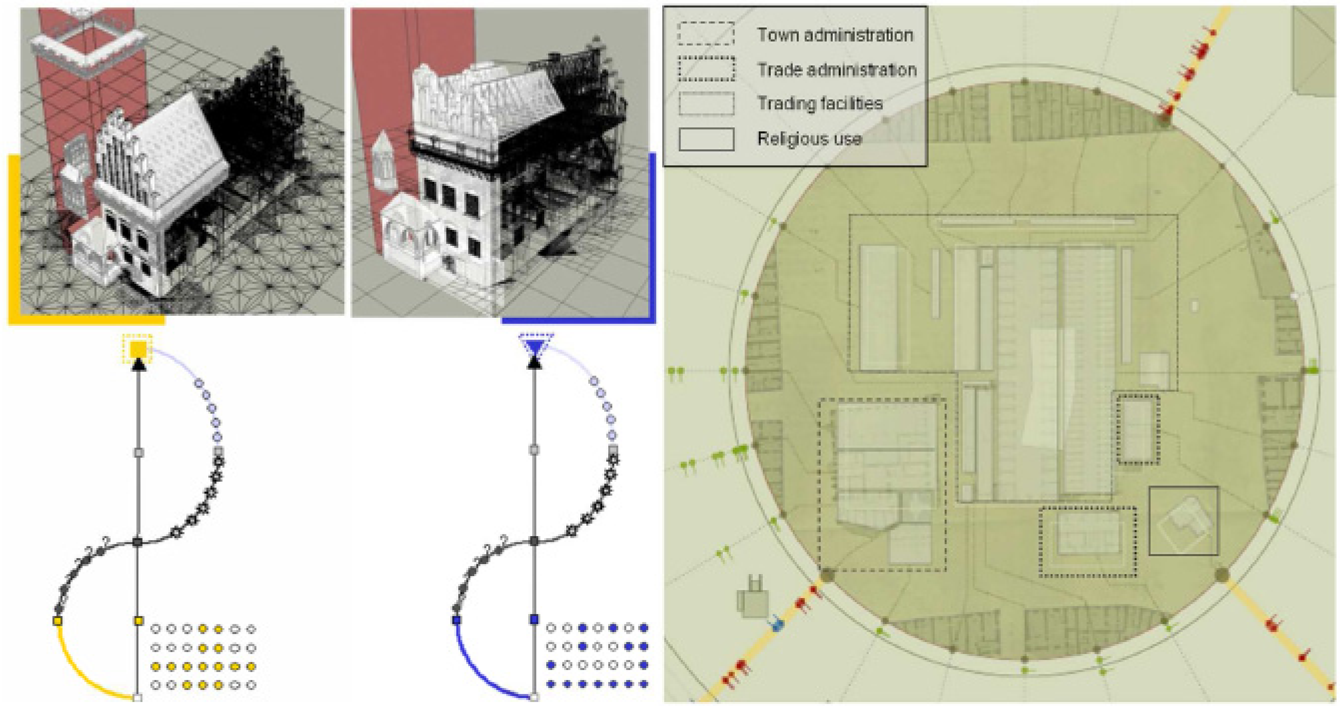

Figure 1. Left – a symbolic illustration of how a reconstruction is built- (subjective) choice of an information sub-set, casual or teleological argumentation, choice of a unique scenario, eventually a possible spatial layout. Shown here are two layouts corresponding to alternative selections inside the information sets on Kraków's old town hall. (From left to right : reconstructions by F. Christ (1950) and A. Essenwein (1869). Coloured dots represent (symbolically) alternative selections in the artefact's information space; stars along the curve represent decision-making steps. Right - Krakow's main square with simplified outlines superimposed on a XVIIth century map and identification of social uses of artefacts.

reductive and non-inductive by [6]. Figure 2 sums up and exemplifies these visions on our application field.

The point to stress here is that the input an analyst handles– questionable pieces of information - needs to be interpreted. Each interpretation, willingly or even unwillingly, depends of an a priori knowledge, or paraphrasing [19], of how "*knowledge interferes with reasoning*". This interpretation phase is the moment when alternative choices are offered – and where we expect to provide analytical graphics. Naturally, interpreting pieces of information is not specific to architectural analysis, or more generally to historical sciences. [27] proposes a significant contribution on what uncertainty.

is, and how to deal with it in the context of intelligence analysis. Authors analyse efforts made in developing classifications and representations for different types of uncertainties in geographic information science on one hand, in the field. What is interesting to point out is that although authors do mention that "a*nalysts who have consistent, comprehensive, representations for multiple uncertainties* […] *make better decisions*", they propose a typology but seemingly no visualisation – a sign that graphics are not that trivial to design... In line with Bertin [5], we consider that graphics are not an end but a means to understand doubt.

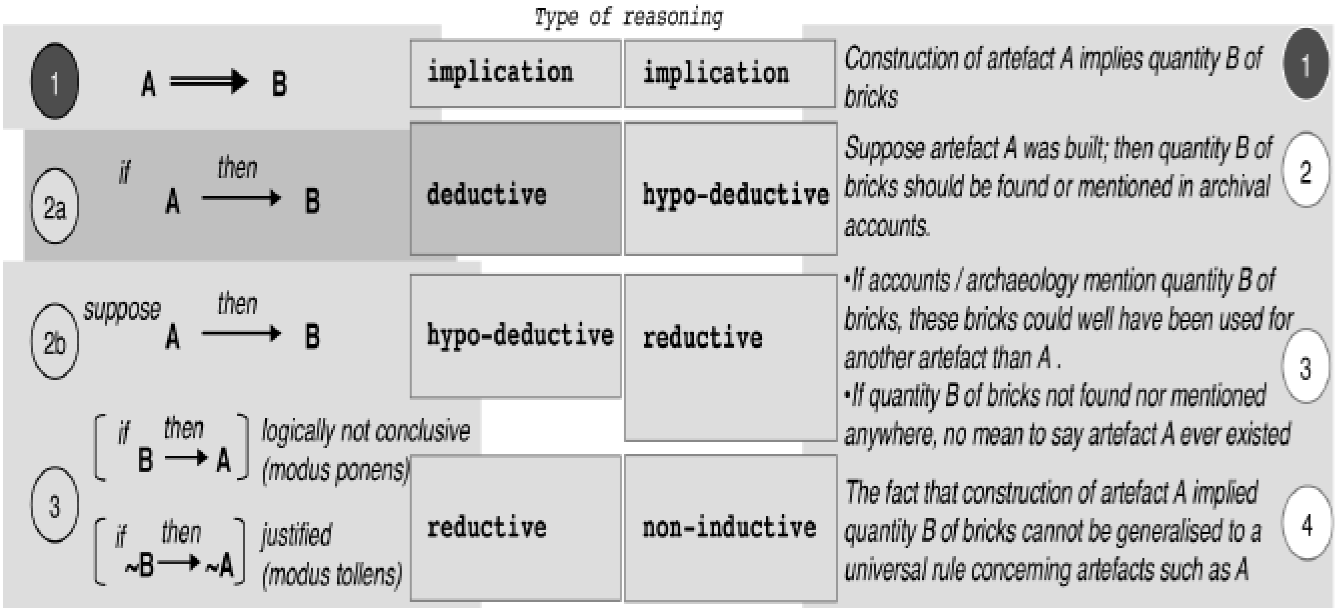

Figure 2. Reasoning tasks in historical sciences, based on [6]; and exemplification of his view on classic cases found in architectural heritage analysis

Michael Friendly's "*Brief history of data visualization*" [12] shows that a wide number of solutions have been investigated on how to represent spatial dynamics. Contemporary research works often privilege representations relying on (and limited by) the GIS paradigm. J.K Rød [20] compares visualisation and communication, stating that the former reveals unknowns, whereas the latter presents knowns. His point of view clearly matches our approach better: providing visual tools aimed at uncovering alternative explanations. We therefore consider heritage architecture analysts need to further investigate approaches developed in the infovis community – either in terms of method, with reference examples in [12, 28] Friendly, or of inspiring applications like [29, 22, 24, 3].

In previous contributions [9], [10], [11] we introduced the *chronographs* and *concentric time* visualisations as part of a knowledge modelling effort that was dedicated at classifying, typing, visualising occurrences and states as they succeed to one another all along an artefact's lifeline. The focus was put on differentiating changes in ordered time (pictures of how they actually impact the artefact) assuming there was no "*branchng futures*", to quote J.F Allen [4]. By contrast, in this paper we primarily focus on how to deal with branching pasts – or multivocal pasts – and introduce time-related concepts such as sequences for instance. In addition, whereas in our previous experiments the only outcome expected was the story of an individual artefact through visual means (this includes a comparison of individuals of course), we shall here introduce specific collection reading mechanisms (portraying trends and relations to sources).

It has to be made clear right away that this contribution will leave aside some of the issues one may expect to be addressed in the context of infovis and/or visual analytics contributions (namely the computational layer, and in many ways the interaction layer). There is little to expect from automation and interaction in a research context where a sensible and operational analysis and classification of the information – here raw archival material and the writing of history - has not been achieved. Accordingly this paper should be understood as an effort to try and shift from basically stating that we face imperfect knowledge, to solutions that would fully fall within the domains of infovis and/or visual analytics as they are defined in [26] or [24].

3. Modelling choices

3.1 Understanding the nature of the information

In most publications in and around archaeology and history of architecture pieces of information are at some point or another portrayed as being uncertain, imprecise, unevenly distributed in space and time, etc. Doubt, in a broad sense, is inherent to the information handled. Alternative choices can be made in order to perform reasoning tasks on architectural changes because of the various interpretations a researcher can do of the sets of information available. In historical sciences, researchers make use of three types of inputs: general pieces of knowledge (theory, geo-historical knowledge of the artefact under scrutiny and of the area around, analogies, etc.), historical sources (textual or graphic) and finally archaeological investigations. Each of these inputs needs to be considered in a different manner, notably in terms of credibility, accuracy and relevance.

Our position is that although doubts exist in any research where historical inputs are dominant, the nature of the doubts, and the way they can be dealt with, and visualized, strongly depend on the nature of the information, and on the goals of its interpretation (a view confirmed in [27]). So when talking specifically about historical artefacts analysis, we propose to weigh pieces of information with regards to what we consider as six main factors:

1. Likelihood: This factor corresponds to what the analyst can say of the sources backing up a fact, prior to their interpretation: are they consistent? Contradictory? Numerous? Are fragments missing? Pieces of information are used to identify events, facts that supposedly occurred at time t. But is the information enough to consider the fact really established? Phrasing like "*event may have occurred*" is common in historical reports, and the researcher has to take some decision on how to handle it.

2. Spatial span: pieces of information can affect the artefact under scrutiny, but also some of its sub-parts, neighbouring artefacts, the whole area around. If some information is duly established for artefact A, to which extent should it be taken into consideration when analysing its neighbour artefact B? This of course depends on the nature of the information: a fire on A is likely to have consequences on B, but a change of owner may probably not have any. This factor includes the various uses of analogical reasoning.

3. Interpretation and credibility: pieces of information can be transmitted by direct witnesses of an event or fact – but they are often indirect, processed several times. We here face a whole gradation from trustworthy contemporary observers to hearsays. This factor encompasses several sub-categories naturally – broadly speaking it introduces scientific choices made by the analyst in the reasoning loop[1]. As mentioned in [25], this type of uncertainty spans various steps or levels in the reasoning loop.

4. Precision: Time slots are classic examples of how pieces of information vary in terms of precision. Historical records may well use phrasings like "a*t the end of the twelfth century, during the spring period* " leaving researchers rather confused at implementation time. Yet a statement like "*during the spring period "* may be considered as fairly precise if the witness knew how to differentiate winter from spring, and spring from summer (although the resulting time interval is rather wide)[2]. By *precision* we refer to the act of acquiring information: the actual sub-categories may strongly vary depending on the nature of the information.

5. Transferability: Among the pieces of information analysts deal with are a number of bills, lists of items, inventories, tax reports, etc. These documents do not give direct indications on the shape and size of the artefact. For instance, a carpenter's invoice can indicate some change has occurred – but what change? In other words the role of the interpretation is sometimes to transfer the information from one point of view to another one; in our example from accounting to architectural analysis.

6. Duration: It is almost self-evident to try and differentiate punctual events from processes (and also rather easy to spot a fire, a flood, a bombing as punctual events). However it is in a number of cases less obvious to say which is which: is a siege a punctual event or a process?[3] Furthermore, researchers welcome pieces of information that can directly feed the analysis of anthropogenic changes. Unfortunately numerous indications relate to long-term processes that are not anthropogenic: if a record tells us an artefact is "*in poor condition*", it indicates that a long-term process is going on, and little can be inferred on when the process started.

[1]*The term credibility is defined in [30] as "heuristic accuracy and bias of analyst".*

[2]*It is important to mention that lacks of precision can also occur in spatial data – in our case study an artefact called "Smatruz" (an open market hosting temporary traders) is rather well documented in terms of social use and of chronology, but at this stage impossible to locate.*

[3]*This factor - duration - should not be mixed up with the time points vs time intervals characteristic proposed in [3] events may here correspond to a temporal interval, but to an interval that is smaller than the temporal granularity chosen by the analyst. Researchers usually identify the temporal granularity that specifically fits their case study, and then can consider some events as the smallest time unit, and processes as overlapping several units.*

The overlapping of this grid of factors with contributions like [27], [30] or [25], who introduce typologies for uncertainty handling, is partial. Some differences need to be introduced for instance in concepts like accuracy or lineage (which need re-examination in historical sciences), at sub-categories level, and last but not least when attempting to type variables. In addition, recurrent practices in analysing the past, like generalisation, periodisation or analogical reasoning, have to be to either introduced or better defined. Finally, when handling ill-defined and ill-distributed (in time and space) information sets, specific uncertainty (and faulty conclusions) can also occur as the result of using statistics-based techniques such as clustering.

Yet a thorough analysis of the overlapping, the nuances and the differences would be irrelevant here. In the context of this paper, what needs to be said is that the above factors are taken into consideration in order to feed the subjective cognitive process that will lead researchers to interpret the information and deduce from it a scenario. But if we want to reason on the whole cognitive process (and not only on the clues we chose to privilege), then we need to visualise all the steps taken, all the choices made.

At this point, it is important to remember that what we want to depict is the evolution of an artefact. And the above mentioned factors are used to weigh pieces of information, not artefacts. Some kind of mapping of these factors into concepts and variables portraying artefact changes needs to be done.

In [10] we first introduced the following notions:

• We differentiate an artefact's evolution (overall lifetime) from its life cycles (switches from visible to concealed existence).

• We identify transitions - corresponding to changes of the artefact – as opposed to states - periods of stability, corresponding to results of transitions.

• Transitions are classified in general purpose categories – each transition may lead to morphological, structural or functional changes. The impact on the artefact is described by introducing a specific list of features for each category, with varying variable types.

These notions are here complemented with additional ones:

• Transitions also need to be analysed with regards to their relation to time, in order to differentiate key steps in the artefact's evolution from regular, "*everyday*" changes. We propose a hierarchy (with as initial division line key morphological transformations vs episodic transformations) that in addition differentiates positive from negative changes.

• The lifeline of an artefact is subdivided in time sequences, each sequence acting as an independent, partial, ordered time continuum, thereby allowing to represent multivocal and branching pasts.

• Uncertainty in dating represents a measure (through a lexical scale) of our confidence in the dating of events/processes.

• Confirmed alternatives (disjunctions) represent divergent options on what did occur, basing on indications that are duly established and related to the artefact under scrutiny.

• Unconfirmed alternatives correspond to indications that may be taken into consideration or may be not – when the information is unconfirmed, or more often when it is not directly related to the artefact under scrutiny but to a neighbour (or any semantic group it may belong to).

3.2 Understanding the nature of time

Both the information and its mapping into concepts and variables portraying artefact changes can clearly be related to what [3] call time-oriented data. And, as demonstrated by these authors, creating visual representations of such data implies "*considering the characteristics of the parameter time*". Describing how we consider this parameter in the context of our research will shed light on the variety of graphics to be presented in section 4. Our goal is to identify and distribute over time evidence about the evolution of artefacts so as to facilitate causal reasoning. To do so we, roughly speaking, spot events and processes affecting the artifact (e.g. a fire, a transformation, a change of owner, etc.) and contextual information (e.g. changes in law or rules of construction). Previous experiments like [10, 11] have shown us that the nature of the information we handle (uncertainties alternative choices, heterogeneous credibility and precision, etc.) implies that we rethink the basic ordered, linear, time model predominant in historical data visualization. Based on the terminology proposed in [23, 1, 3] the modelling choices we have made up to here can be described by the following list:

1. Linear time: Changes we report can be the result of unexpected punctual events / conditions (wars, floods, etc.) or of long-term processes (degradation of wood structures, decrease of economic power, etc.) but in all cases one can a-priori hardly expect to spot cycles. Furthermore, the data we use when identifying changes is strongly heterogeneous and questionable. In other words, not only do we have very unevenly distributed changes, but we also have very different levels of knowledge inside an artefact's lifeline, or across artefacts. As a result, the density of changes we derive from the data is extremely uneven across the collection of artefacts, and spotting temporal cycles very unlikely. In addition, would a cyclic behaviour be spotted, its interpretation could be misleading (typically if an inventory is carried out on a regular basis for tax calculation, and uncovers successive changes, well this does not mean the changes themselves occurred on a regular basis - and so what you will read is the cyclic nature of tax raising, not the cyclic nature of architectural changes). We therefore focus on linear time, although we do acknowledge that analyses of cyclic behaviours in historic architecture can be fully relevant in other circumstances[4].

2. Granularity and scale: experience shows that when dealing with historical data sets, and especially when going quite far back in time, a one-year time granularity is a reasonable choice. Most indications that are given to us cover several years, and can be mapped in a year scale even when they are somehow imprecise like "*last quarter of the XIVth century*", "*early XVIIth century*". Other indications like "*spring* 1657", or even "17 *September* 1854" may be a far less trustworthy indication than "last quarter of the XIVth century" – precision here does not mean credibility. We therefore consider a one-year granularity acts as a sort of common denominator well suited to the nature of the data we handle. But as can be seen from the examples given, by choosing a one-year time granularity we loose the capacity to order in time things that occur during the same year: "s*pring* 1854", "*late summer* 1854", "17 *September* 1854" all correspond to the same time point. Since the historical data is the way it is, we propose at this stage to substitute, inside a one-year chronon, ordinal time to discrete time (1854 is located in between 1853 and 1855 in a discrete time scale, but things happening inside 1854 are only positioned relatively to one another in an ordinal time scale when possible). If the principle appears promising, its implementation in the case of highly heterogeneous data sets however remains an open issue and requires further investigations.

3. Time points and time intervals: Because of the information's heterogeneity we chose as chronon – smallest time unit- a year. Events, processes, contextual information are described as time intervals delimited by two time points (start date, end date) with each of them weighed independently in terms of credibility (Figure 3, a). Events, processes and contextual information occurring within a year are given the same start date and end date. In other words we use time intervals as the basic temporal primitive (paradoxically, to the best of our knowledge, one of the closest approaches - the PlanningLines [2] - were developed to model future activities). Yet the concept of time point is duly present (see graphs of potential interactions, section 4.1) when we need to order in time events occurring inside a year - as a mean to integrate discrete and ordinal time scales.

4. Ordered time and branching time: In previous experiments like [10, 11] we clearly privileged ordered time. But as mentioned in section 1 we here try to consider, represent, and make visible alternative scenarios - in other words to connect a given time t with several different successors/ancestors. As will be shown in section 4.1, the graphics we propose integrate both ordered time (basic linear timeline paradigm with events reported one after the other) and partial branching time (forks located here and there along the timelines, depicting several possible branches). Noticeably, branches here all end up back on the main timeline (Figure 3, b) – a clear difference with the recurrent uses of branching time in the context of project planning[5].

5. Determinacy: There are cases when the data we handle just won't let us propose any kind of dating for one or several events occurring during an artefact's lifeline. We propose two different solutions: when what was before, and what is after, are both known the dating is considered as anchored, but indeterminate (Figure 3, c). When either what was before or what is after are not known, then the dating is considered as both unanchored and indeterminate (Figure 3, d). Specific glyphs are proposed so as to inform the user.

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[4] *Typically in cases like the iterative reconstruction – every 20 years - of the temple in Ise, Japan, of when dealing with use-related cycles –typically pilgrimages, and more generally when introducing natural cycles – avalanches in winter, floods in spring, etc.*

[5] *The term branching time that we use here may accordingly not be fully relevant.*

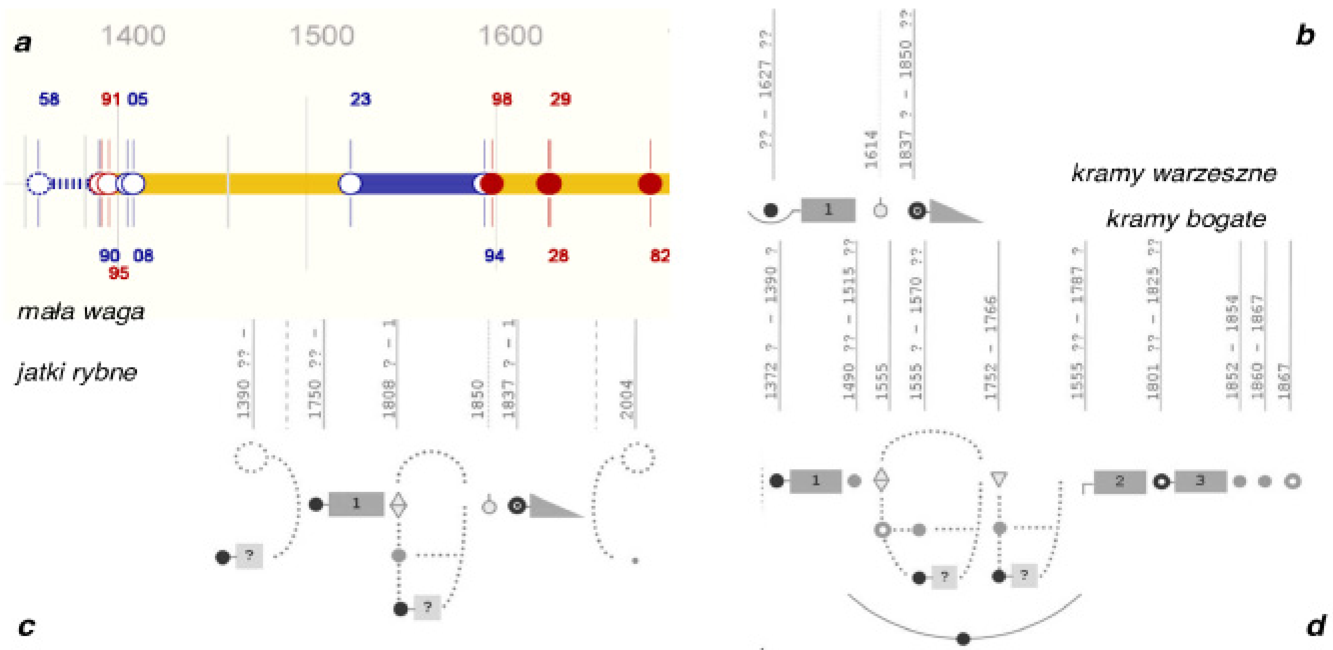

Figure 3. Mapping the characteristics of the parameter time. ***a*** - Colours are used to show stability (yellow) or change (red functional, blue morphological); outlines code the uncertainty parameter (dotted: most uncertain dating), and length the duration. ***b*** - The dating is unanchored and indeterminate for rectangle 1: a semi-circle below the first black dot informs the user. ***c*** - Alternative paths before, during, and after the lifeline of an artefact, marked visually by dotted forks. ***d*** - The localization in time of rectangle 2 (second stage of the artefact's evolution) is anchored (between rectangles 1 and 3), but indeterminate (dot and curve below the timeline)

4. The visualisation step

In [9] we introduced a description framework that focuses on the way artefacts get transformed, with a grid of notions giving the analysts the means to date, describe and order events/facts/elements of context that we consider meaningful in the understanding of the artefact's transformations. As a result, the analyst is given a set of graphics called chronographs (Figure 4, left), composed of three different visualizations (diachrograms that present the evolution of an artefact along a time axis, variograms that further detail the nature of the transformations and features visualisation disposals that foster comparisons). In a recent development [11], we proposed another visual solution called "*concentric time*" (Figure 4, right), based on the same grid of notions, and this time aimed at gaining insight on the whole collection of artefacts. Both these solutions have proven reasonably efficient: they help assessing causal relations and order in time sequences, events and consequences in a robust manner. However they have one major drawback: they imply a most likely scenario exists. In other words they do not identify those key time slots when the analyst chooses to favour an interpretation of sources over others. Moreover 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 introduce 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 (section 4.1). We in addition propose various solutions, inspired by classic examples like the "*small multiples*" principle (concept attributed to Scheiner's 1626 representation of changes in sunspots over time [12]), to visualise the collection of artefacts as a whole and uncover patterns in space or time (section 4.2). The visualisations are produced on the fly as answers to user queries, but do not introduce anything particularly original in terms if interaction: on one hand users configure the content to display (which artefacts? which visualisation? which granularity or clustering?) and on the other hand basically move, open/close components or query the underlying DB.

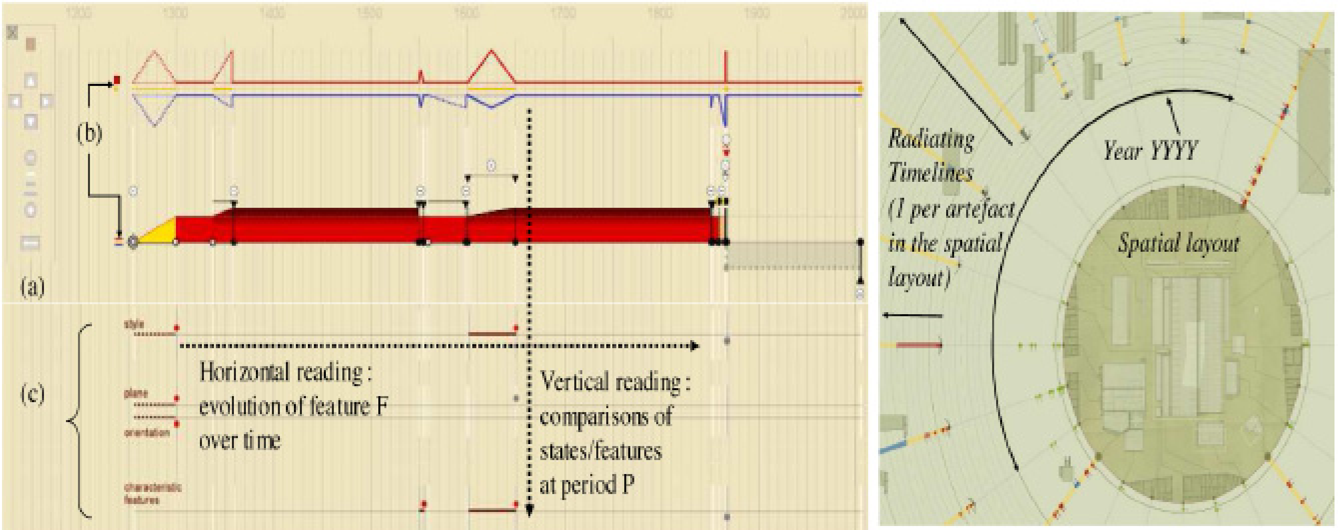

Figure 4. Left, the chronographs visualisation. From top to bottom a variogram, a diachrogram and the features chronology lines (partial view) with (a to c) interaction commands. Right, the “concentric time” experiment where time and space are combined in a context + focus visualization aimed at facilitating cross-examinations. The visualisation works more or less like a metaphor of a tree trunk section, with concentric circle radiating that represent distances in time. The central part is a regular map interacting with the radial timeline

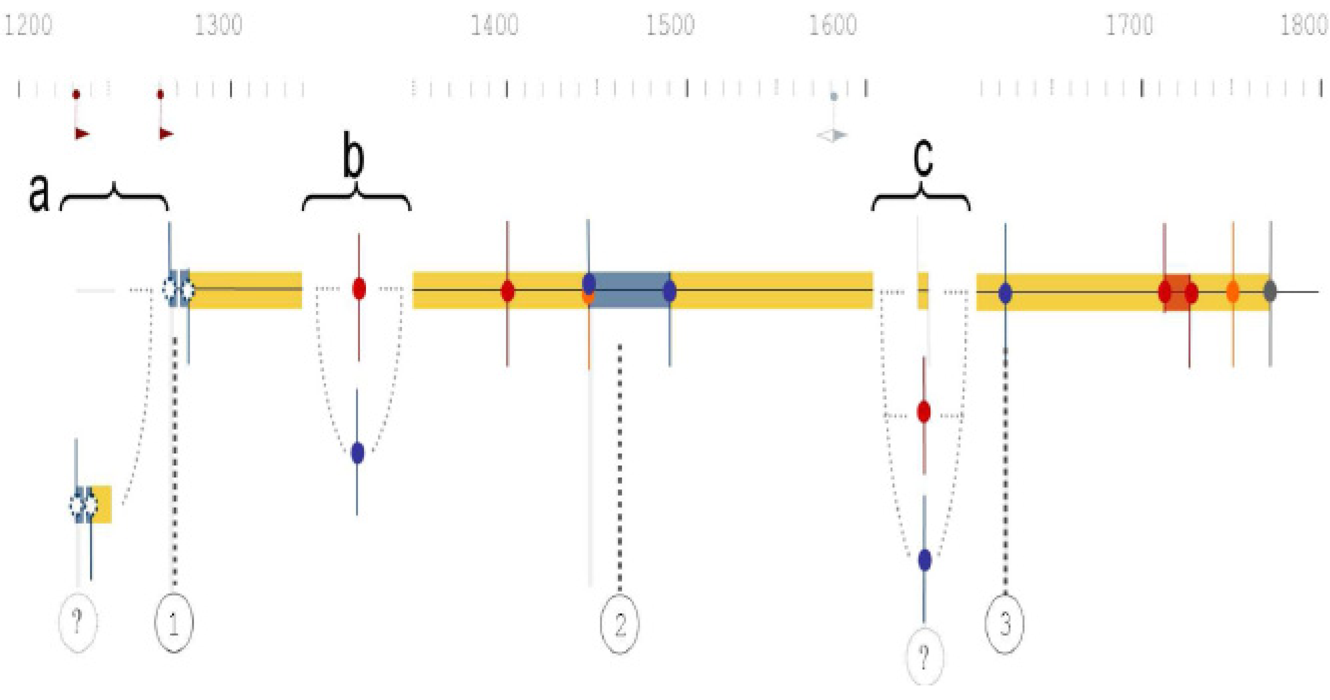

Figure 5. Multi-hypothesis chronology diagrams. Dots correspond to time points, lines to time intervals. The yellow line indicates a period of existence, and of stability. Blue lines and dots mean morphological changes. Red lines and dots mean functional changes. Dotted lines and curves are used to open/close alternatives in the storyline. These diagrams give indications on periods when alternative scenarios are possible (dating on the time scale), and on the nature of the options (**a**, possibly an early construction, **b** either a functional change or a morphological change **c**, either nothing, or a functional or a morphological change)

4.1 Visualising alternative scenarios of evolution of an artefact

Multi-hypothesis chronology diagrams deliver a quick, synthetic view on where alternatives scenarios exist (in time) and underline options the analysts face. From these diagrams observations and inferences can be made on relative durations, intensities or densities of events, acceleration or deceleration patterns, etc. Various overlapping patterns can also be questioned or formalised for instance using Allen's relations [21].

Multi-hypothesis chronology diagrams (Figure 5) localise states (number inside circles) and transitions (red or blue dots and lines) all along a real-scale timeline. Uncertainty in the dating is represented through outline and filling options. A thick yellow line stands for the overall evolution of the artefact. The line is interrupted every time a doubt on how to interpret sources appears – thereby introducing branching time slots inside the main ordered time visualisation.

Time is still represented in real scale, helping the analyst to weigh durations and densities, and to localise periods of doubt. But because numbers of interruptions may vary from artefact to artefact, lengths of timelines cease to be meaningful. Multihypothesis chronology diagrams show what options one can think about when interpreting sources, but they do not differentiate confirmed alternatives from unconfirmed alternatives. This is done through **graphs of potential interactions**, a linear diagrammatic representation along which successive states, transitions, alternatives are presented with brief texts summarising the underlying information (Figure 6).

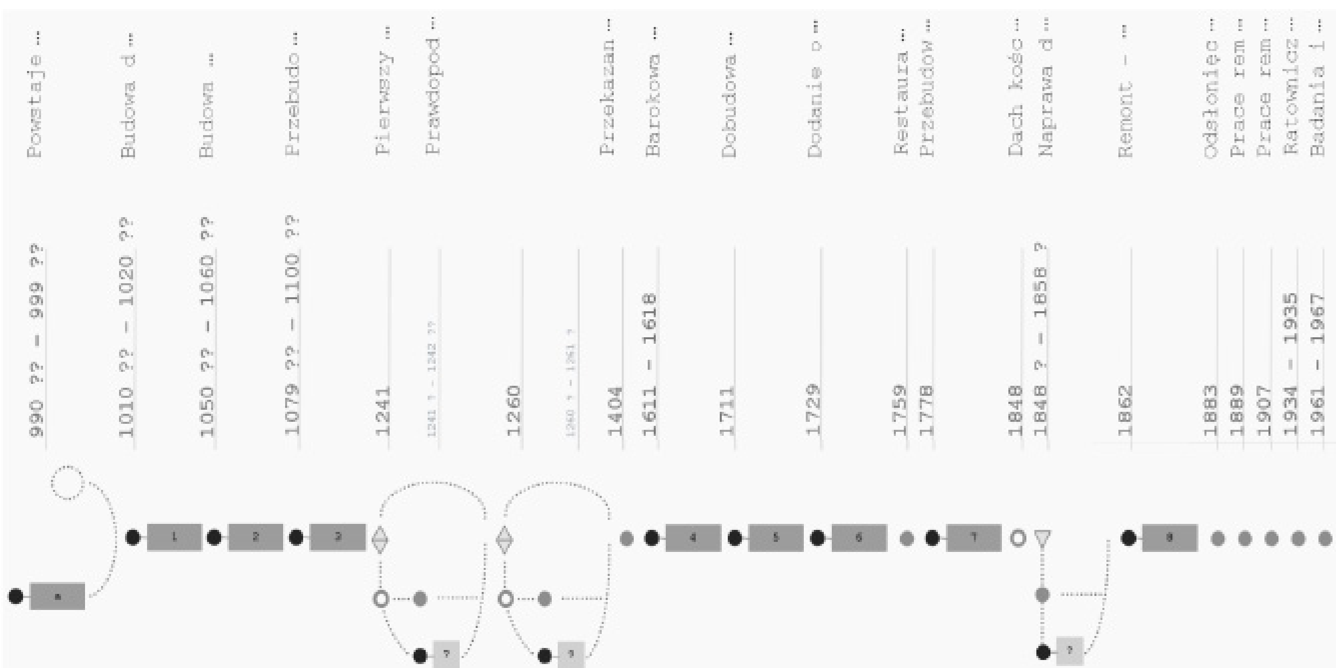

Figure. 6. Graph of potential interactions for St Adalbert's church. A main horizontal line, composed of circles (transitions) and rectangles (states) is interrupted by triangles (confirmed and unconfirmed alternatives). The path from rectangle 7 to rectangle 8 should be read like this: the event or process (vertical text) did occur for sure (triangle downwards) but either it has had limited consequences (light grey circle) or it lead to a morphological change (black circle, rectangle with question mark). The path from rectangle 3 to rectangle 4 is composed of two successive alternatives that should be read like this: the event or process (vertical text) may not have occurred at all (triangle upwards, dotted line straight to next step) but if it did occur (triangle downwards) then ... (back to the same situation as path from rectangle 7 to rectangle 8)

Contextual information (i.e. information that cannot be connected to a given change but that may help understanding some other aspect of the artefact's history) can also be integrated (Figure 7).

Differentiation between confirmed alternatives and unconfirmed alternatives is visible in the appearance of the triangle, as well as in the number of possible paths. In order to lower the visualisation's cognitive load, only shape and greyscale value are used. In this visualisation time scale is not used any more: only the order of states/transitions/alternatives is respected. Accordingly, durations and densities available in multi-hypothesis chronology diagrams cease to be readable. This visualisation focuses on relations of transitions to chronology and clues. Accordingly, other symbols (not present in the example given above) may be used to position specific events or processes such as archaeological surveys, reuse of parts of the artefact, etc.

The above graphs of potential interactions help visualising what an analyst does with each and every clue he knows of, including well-established indications. Accordingly, the resulting graphics may be lengthy, and appeared rather ill-suited to a synthetic comparison of levels of complexity of various artefacts.

We therefore developed a third visualisation, called **visual measure of complexity**, in which we withdraw from the visualisation redundant well-established indications. The diagram focuses on alternative paths: its main role for us is to foster comparisons across the collection. It is designed to underline different patterns of complexity - spatial, temporal, and semantic. Figure 8 for instance shows relative patterns of complexity of artefacts classified by what [21] call social use.

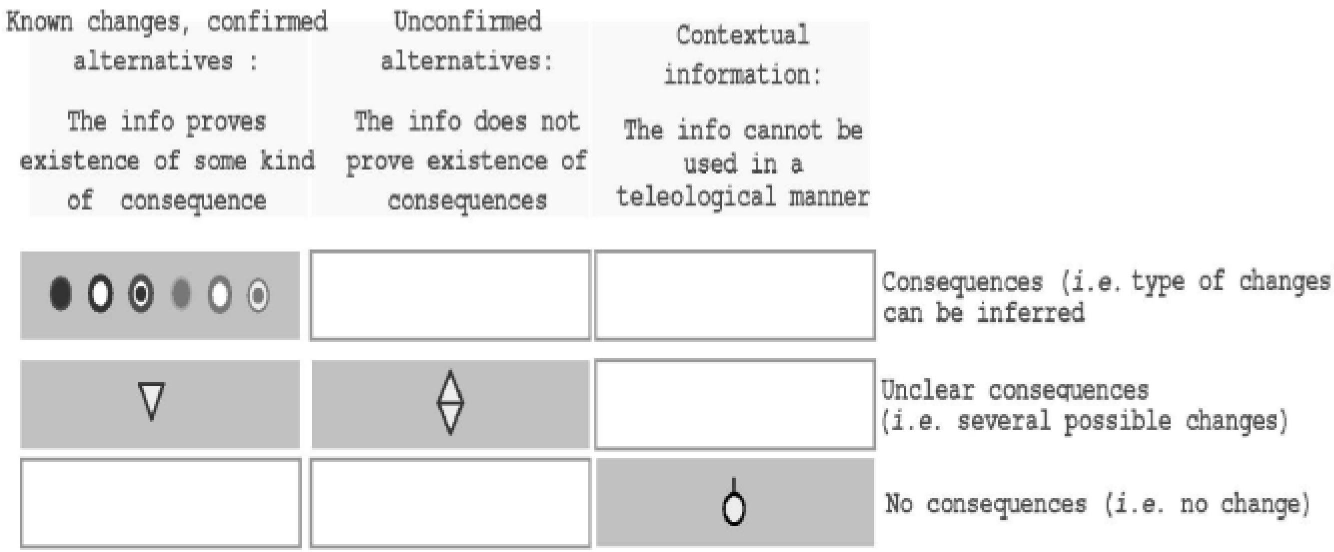

Figure 7. Relations of symbols to the nature of the information (columns) and to possible consequences (lines)

4.2 Visualising alternative scenarios in time and space across the collection of artefacts

The visual measure of complexity can be seen as a first step in trying to analyse, beyond individual artefacts, the collection as a whole. However it only supports complexity reading, and anyway remains a solution putting "*side by side*" individual cases. Considering we studied a total of 45 artefacts, Tufte's recommendation "enforce comparisons within the eyespan," might not be easy to achieve. Accordingly, we have evaluated various visual solutions aimed at summing up in an abstract manner all changes and alternatives for each artefact. Solutions like mosaic plots or time series were fist tested but turned out hard to read because of the number of cases, and of their variety in terms of life span.

We here consider that alternatives about the initial phases of an artefact's creation, before a first confirmed indication can be quoted to say that it did exist, raise specific issues (in particular long and very imprecise time slots, and a complex combinatory of possibilities that in theory could be extended further on). As a side-effect, doubts can be over-emphasized at visualisation time. So in this visualisation we therefore explicitly differentiate initial phases (represented by as many circles as there are possible initialisation points) from confirmed and unconfirmed alternatives once the existence of the artefact is clearly established, counted and represented as known changes are but with specific colours. We decided for a visualisation inspired by the "*small multiples*" concept in which we report for each artefact, the life span and the number of changes and of alternatives. The size of each square unit represents maximum values for these two parameters inside the collection (maximum life span is 1001 years - St Adalbert's church; maximum number of changes and alternatives is 28 – the belfry).

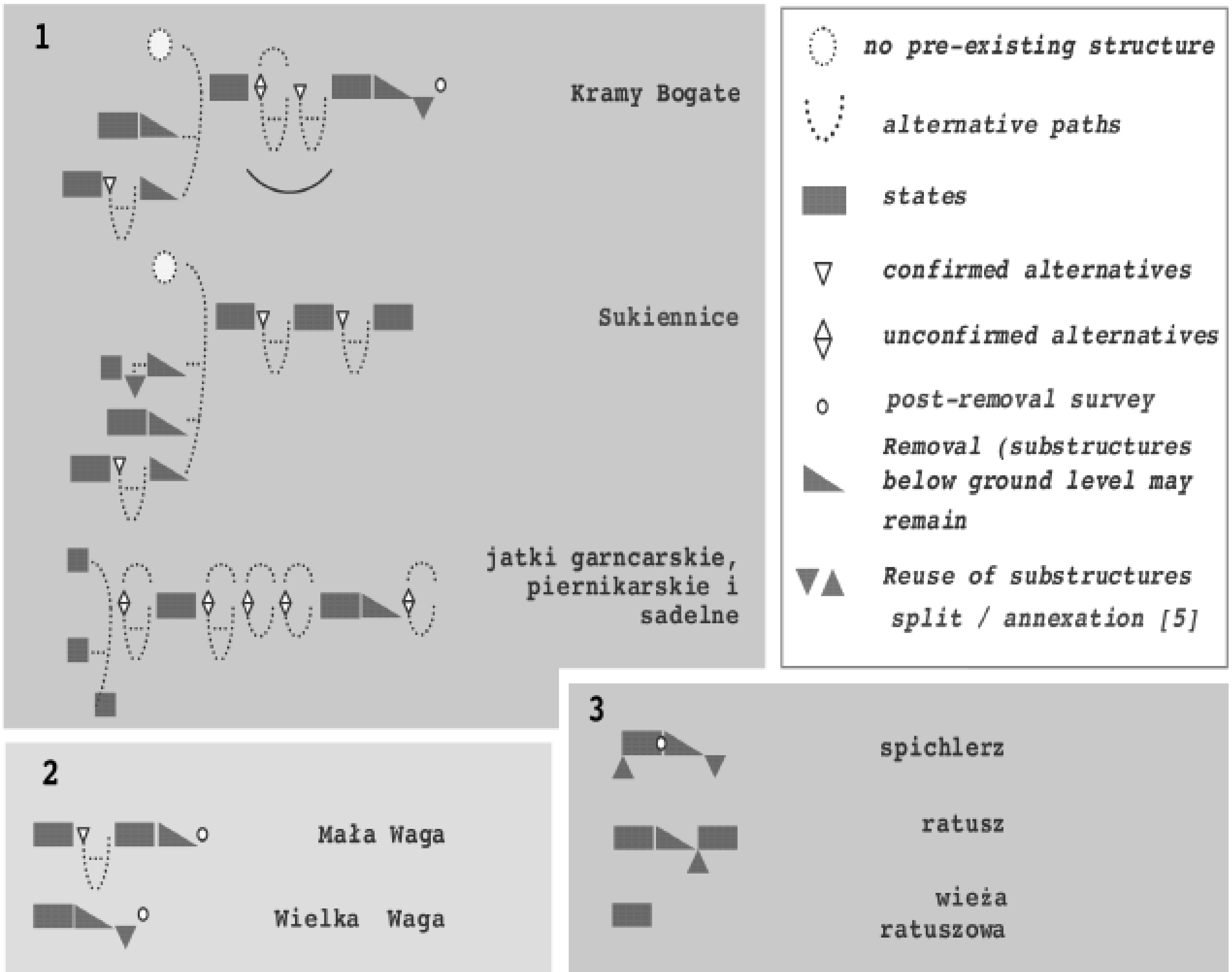

Figure 8. Relative patterns of complexity for artefacts (1) dedicated to private or semi-private trading; (2) dedicated to collective administration of trading (3), dedicated to the administration of the town. Note on the bottom right the simplicity of the diagram for Krakow's belfry. For this particular artefact we have spotted 28 successive transformations (a record across the collection). However since each of these transformations is rather well documented, and does not call for interpretation, the artefact's visual measure of complexity is limited to one rectangle

Diagrams in the bottom right corner of Figure 9 sum up the content of a graphic unit: (a) - the width of the square represents the maximum life span for our collection - 1001 years; (b) - the height of the square represents the maximum number of changes inside our collection; (c) - circles representing the number of alternative initialisation points; (d) - a white triangle stating an archaeological survey was carried out; (e)- a black triangle stating that parts of the artefact are now reused inside another artefact, with a new function; (f) - the x axis presents dates in real scale, and therefore allows the reading of absolute values for duration and time localisation; (g) - greenish rectangles represent confirmed (bottom) and unconfirmed (top, darker) alternatives; (h) - reddish rectangles represent (bottom to top), morphological changes, episodic changes, destructive changes; (i) - zeros represented by tiny lines.

Once a unit has been computed for each element in the collection, various combinations can be tried out to grab an understanding of the collection and spot temporal, spatial or other patterns. Figure 9 illustrates Bertin's vision of "*graphics as an answer to a question*", by showing no correlation can be established between the length of an artefact's life span, and the number of alternative scenarios of evolution. But it still puts individual cases side by side. Accordingly we developed a solution this time capitalizing on the concept of time series (Figure 10). On the x axis are distributed even periods of time (50 years) starting from the foundation of the city in 1257. On the y axis, we represent the overall amount of changes and alternatives for the whole collection are counted at each period. Circles are added below the x axis that represents the overall amount of alternative initialisation points for each 50 years period.

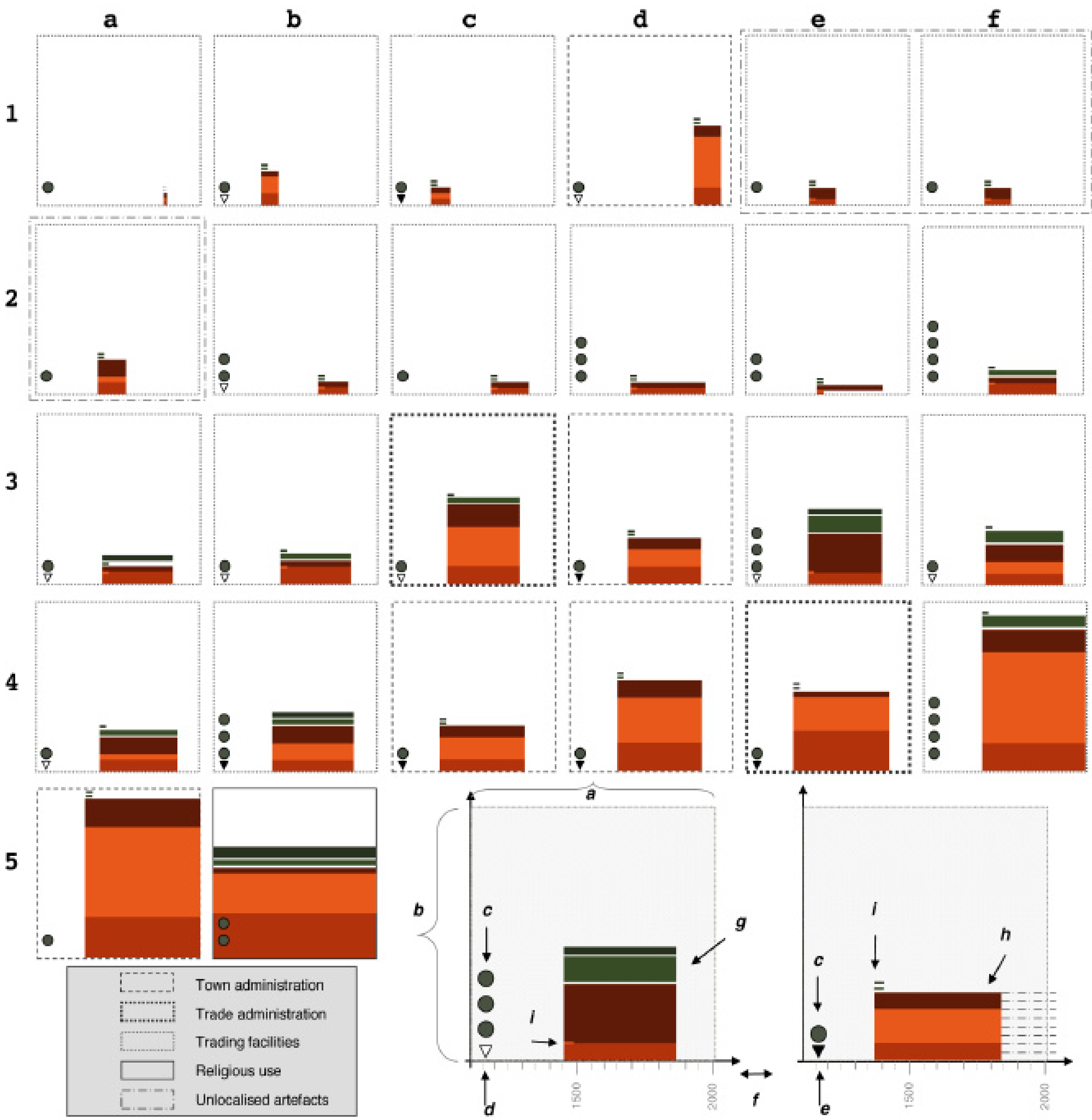

Figure 9. A combination of graphic units corresponding to 26 artefacts in our collection (classified by progressive lengths of life spans) with outlines of each unit corresponding to social uses. The visualisation corroborates some intuitive hypotheses – religious (b5) or administrative artifacts (c4, d4, a5) appear as lasting longer, with less alternative scenarios. It also underlines exceptions to this pattern: note, (f4), unit corresponding to the cloth hall - a long history, with several alternative scenarios, and a maximum value for alternative initialisation points)

The figure does suggest a number of interesting remarks. Note, unsurprisingly, that initialisation points concern early periods, but also, more surprisingly, that none are present in the 1307-1357 period, and that the maximum number of alternative initialisation points correspond to a period of low activity intensity (column 4). The visualisation also shows a sudden increase in density of changes at the beginning of the XVIth century, with during the 1507-1557 period a clear majority of destructive changes (dark red) and in the following periods a majority of morphological changes – an indication of the duration of transformations at that time. An interesting point is also made concerning the first half of the XIXth century (1807-1857). The period is known as the period during which most of the artefacts standing in the market square will be destroyed. But the visualisation shows that episodic changes widely outnumber destructive changes. This indicates that before deciding to tear down these artefacts, a number of solution were tried out to repair, transform, reuse them. In other words it clearly shows that the well-established "*pattern of destruction*" should rather be called "*pattern of renunciation*" in front of maintenance and repair difficulties. Finally, the visualisation underlines some clear patterns in the time distribution of alternative scenarios (green rectangles). Note for instance their density during the XVIth century, or their presence even during the supposedly well-documented XIXth century.

At this stage though it is important to point out that with questionable underlying data, with prominent subjective choices (typically the time span), this graphic does not prove anything. We consider it as just providing question marks that may help analysts know where to dig next.

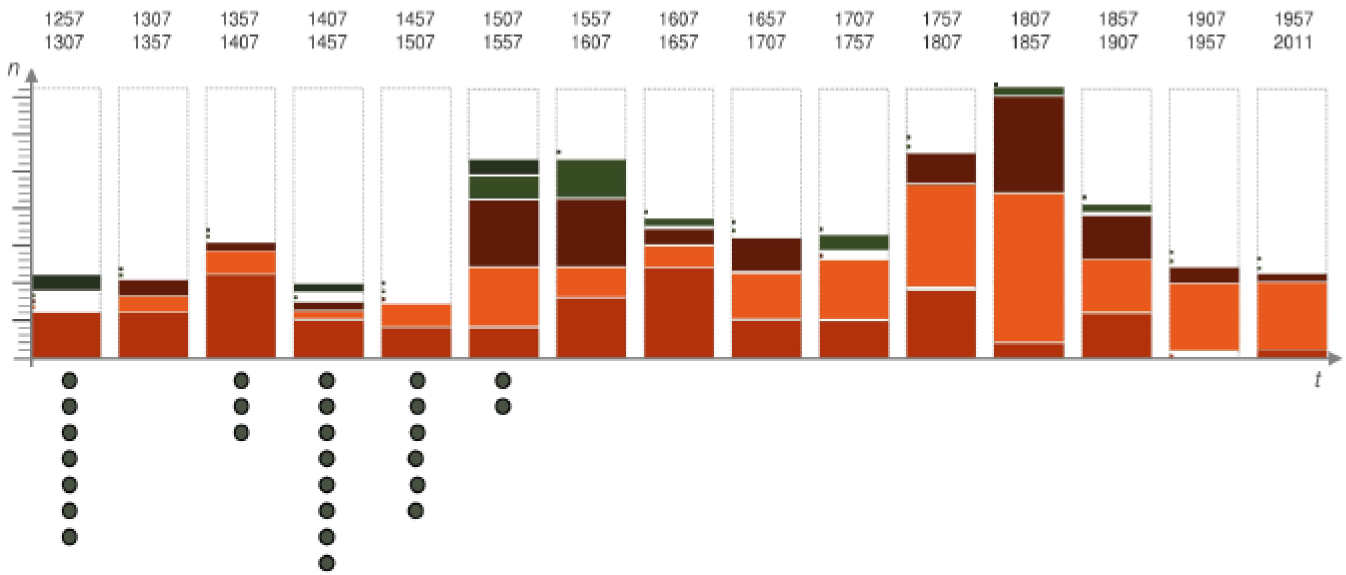

Figure 10. The distribution of changes, alternatives and alternative initialization points over time - with a fifty years time granularity (graphic codes are the same than for the previous figures)

4.3 Correlating changes and sources

The identification of changes, alternatives, or alternative initialization points results from an analysis of sources, each of which weighed in terms of credibility (see section 3.1). Consequently, changes and sources are de facto correlated, and any observation made on changes should be critically examined in the light of the background sources amount and credibility.

As an answer, we develop extensions of the above time series visualisation in which the space beneath the bottom time line is used to display variables relate to the sources used for each period of the time series. This however remains an ongoing part of the development, and we shall make here no claim on the comprehensiveness of the variables and graphics obtained. Instead, we illustrate on two examples what can be gained from helping analysts to correlate sources and changes using visual representations.

The first example (Figure 11) should be seen as a **measure of redundancy of sources**. Let us make this idea clearer: if we compare 5 changes identified using one single source, to 1 change identified using 5 different sources – well the latter is better known. It is therefore necessary for each time slot to try and weigh "*how many times a source is reused* ". This is simply done by counting on one hand the overall number of sources and on another hand reducing this number to unique values. Putting those two values side by side does shed light on the redundancy of sources at the various periods concerned.

The visualization for instance underlines a clear pattern: the more sources, the more reused sources (right column always unambiguously higher than left column). More interesting, it clearly demonstrates (compare couples of columns 1-1' 2-2') that there is no correlation between the number of sources, and the number of changes (although in general more changes imply more sources). Finally, some peaks and hollows in the distribution of unique and of overall sources over time appear clearly - this clearly questions the distribution of changes in time as it is known to us today.

In the second example (Figure 12) we basically correlate the amount/credibility of sources and the number/type of changes in

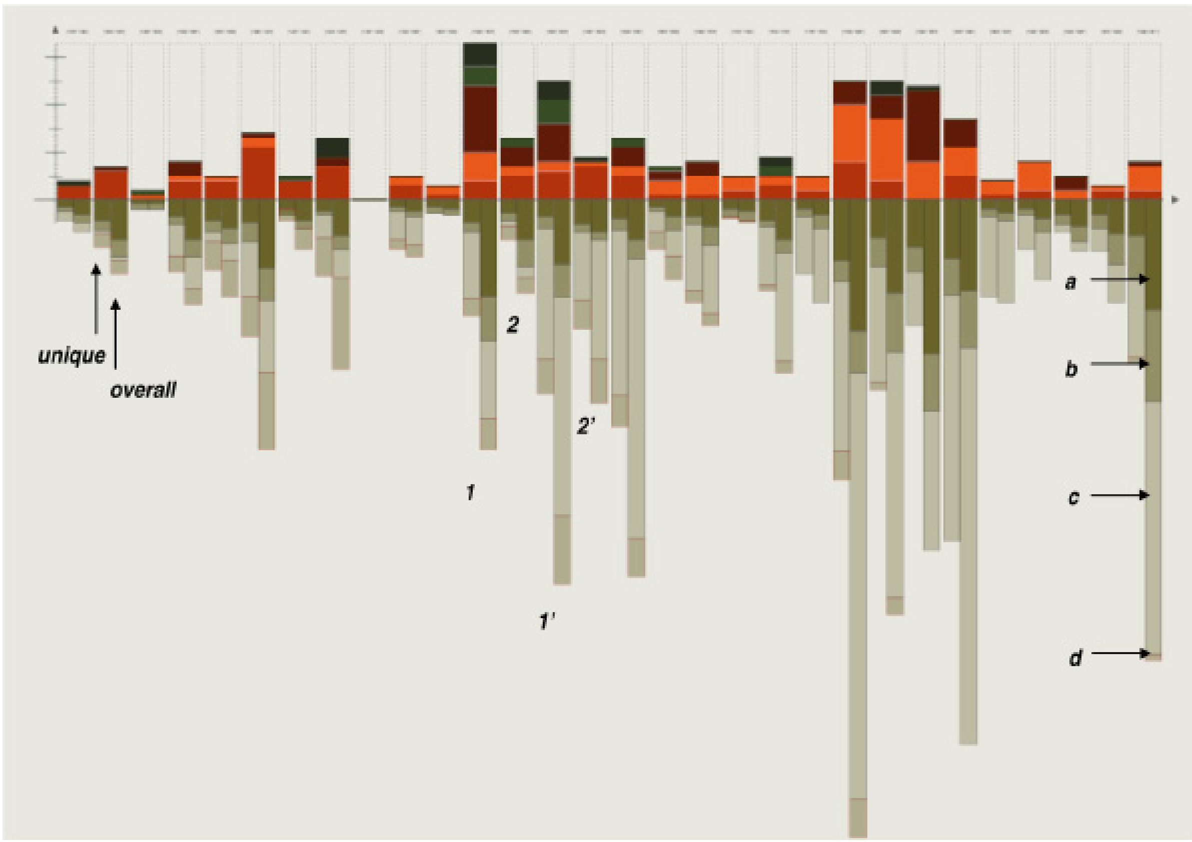

Figure 11. Visual measure of redundancy of sources - with a 25 years time granularity. For each time slot the left column represents the amount of unique sources for the period, and the right column the overall amount of sources for the period. Colour coding corresponds to types of sources : (a) sources used for dating (b) textual sources (c) visual sources among which (d) virtual reconstructions (contemporary or not)

a visualization that should be seen as a credibility or trustworthiness variability measure. This time the visualization focuses on the credibility that we attribute to the dating of each transformation (using a 3-values lexical scale). Sources are not directly present although the dating proposed is a direct result of the quality of sources.

The visualization shows (a, b) that there is no correlation between the credibility of the dating and the number of alternative scenarios, or denies common sense assumptions (c,d) : the oldest is not necessarily the least well known. It points out some patterns of the underlying data – note in (e) an indication of the sources' varying credibility - as well as interesting exceptions - note in column marked (c – period 1707-1732) the highest credibility level for all sources, as high as for XXth century sources. Read as a whole, the visualization naturally shows a correlation pattern between the amount of dates read in sources and the amount of transformations (size of columns over/under timeline). But the pattern is clearly broken with for XXth century period (f): this is due to the fact that archeological investigations are not counted as changes represented over the x axis, but are counted as dates represented below the x axis.

With these examples we believe we see the need for further investigations on how to evaluate objectively both historical data sets and what, as analysts, derive from them – and this is probably an interesting direction for future work.

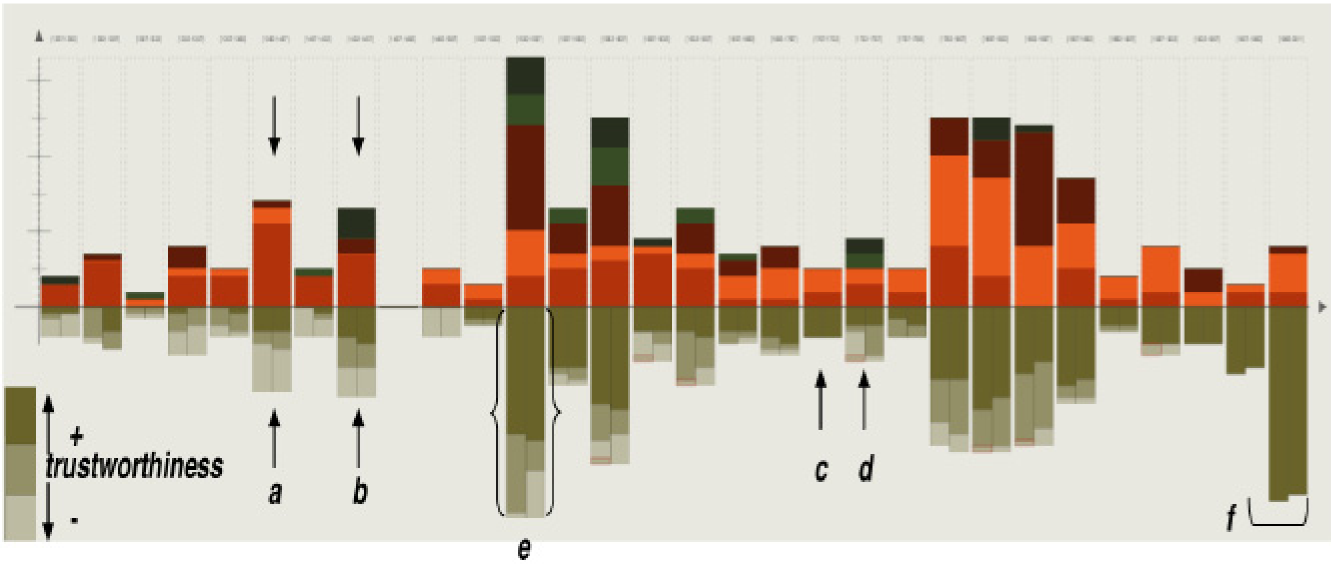

Figure 12. Correlation of number / type of transformations (above x axis) and amount / trustworthiness of dates read in sources (below y axis) - with a 25 years time granularity. For each time slot the left part of the downwards columns represents "*start time*" dating (things supposedly starting during the period) and the right column "*end time*" dating (thing supposedly ending during the period)

5. Implementation & evaluation

This development complements previous works on the same test field - the medieval heart of Kraków [9, 10]. Accordingly, the technical platform is the same:

• a description of artefacts as instances of a hierarchy of classes (in the sense of OOP), with persistence enabled through RDBMS structures,

• information sets structured and annotated through RDBMS structures, dynamic outputs (may they be visual outputs – 3D VRML or 2D SVG- or textual outputs –XML) produced by Perl scripts,

• interfaces produced by Perl scripts either as XHTML (in our first experiments) or as XML/XSLT datasheets.

For this development we basically extended our DB structure by introducing the concepts of sequences as well new descriptors of transformations and consequences. Sequences allow us to attach an ordered list of transformations to several artefacts, for instance in cases when two or more artefacts reuse parts of an older structure that cannot be attached to one of them. An artefact is described by a unique "*main*" sequence – roughly speaking the period when it was given the name under which it is now known. In addition, an unlimited number of "*init*" "*post*" sequences can be attached to the artefact, which represent lists of transformations that may concern the artefact, or may concern a neighbour, an ancestor, etc (Figure 13). Accordingly, an "*init*" or "*post*" sequence can be shared by several artefacts, facilitating the updating of the system as well as preventing information duplication.

SVG outputs are produced on the fly with rather limited interactions since graphics presented in this paper were originally designed for printing (this is why graphics illustrating this paper are for most of them redrawn from the SVG outputs). At this stage the implementation covers 45 artefacts, 66 sequences, 357 transformations, 161 consequences as well as the 538 historical sources thanks to which they were identified. Naturally, the whole system is flexible to incremental data update - still the implementation is as can be seen a rather basic one, and calls no particular comment in the context of this paper.

In terms of evaluation, we first needed to understand to which extent the graphics leave room for ambiguities and misinterpretations, and to which extent they may foster knowledge sharing. This was been done by questioning non-experts a group of 20 third year students (computer graphics / physics) during the off-hours of a summer school, on aspects like readability and cognitive load.

Participants were asked 6 groups of questions covering all the graphics presented in section 4 (Figure 14). The session lasted

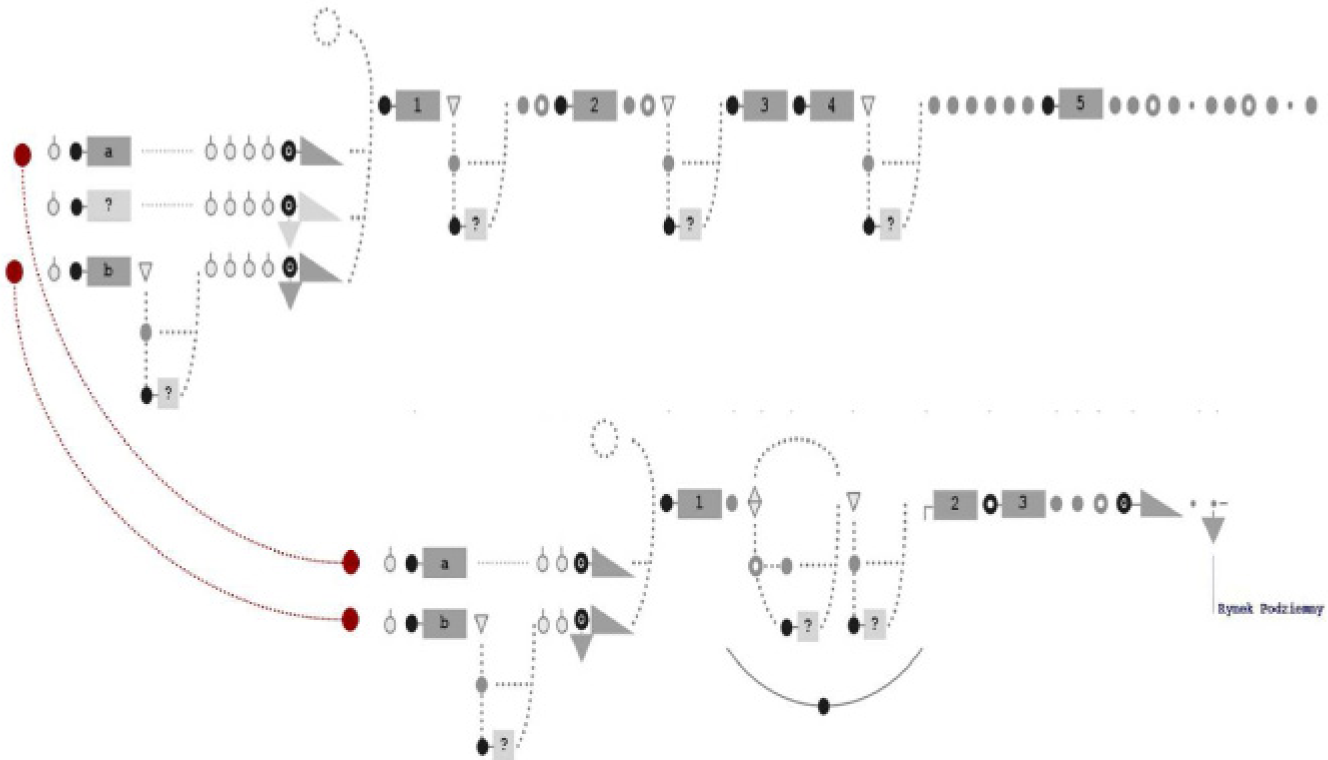

Figure 13. Sequences present both in the lifeline of the cloth hall (Sukiennice, top) and of the rich stalls (Kramy Bogate, bottom) as "*possible ancestors of either the former or the latter*"

for a little more than two hours, and the participants were confronted to both the computer version and a paper version (as mentioned above the graphics are supposed to be used as visual material in a printed book). The session started with an introduction to the modelling layer (types of changes, notion of branching time, etc.), but no explanation was given at start on the actual visual encoding.

Participants had to carry our various tasks that ranged from completing the legends of the visualisations to making some sensible comment on the evolution of the Market Square as a whole. At each step of the evaluation process answers were collected, and time left for us to get some less formal feedback.

The evaluation showed that there are still clear lacks in the proposed set of visualization, but whether the graphics themselves, their number, or the underlying concepts should be charged remains an open question. In other words, the evaluation did not fully hit its target… Yet we could identify three main weaknesses:

1) Generally speaking the browsing and navigation capabilities of the computer version are insufficient (zooming is too basic since it is an essential task considering the load of graphics, legends should be called on demand on this or that glyph, objects are not movable, etc.). The technical platform chosen, and the output expected at start (paper version) are here to be charged. Because the visual outputs we propose are basically different, in role as in scope, what we need to do here is to rethink globally the way interactions between the artefact and its information space are dealt with (and not only improve this or that functionality).

2) Besides, participants clearly regretted being shown that many visualisations in a short time, when they apparently were unfamiliar not only with heritage architecture, but more surprisingly with infovis. Classic visual solutions (i.e. parts of the scientific legacy associated with infovis - time series and small multiples) apparently confused participants. In short, our graphics were seen as competing visualisations more than anything else, which is clearly a question mark. We draw here two lessons for a future evaluation: concepts behind what some view as classic visualisations are not necessarily obvious, and should be made clear prior to tests; and asking too many questions can mean getting too little answers...

3) Through comments more than through formal answers, participants made clear that providing during the test both a paper version and a computer version was awkward and uncomfortable. Should we conclude from this observation that multimedia (paper + computer) visualisations are out of reach? We rather think at this stage that we need to build better evaluation settings before reaching to a conclusion.

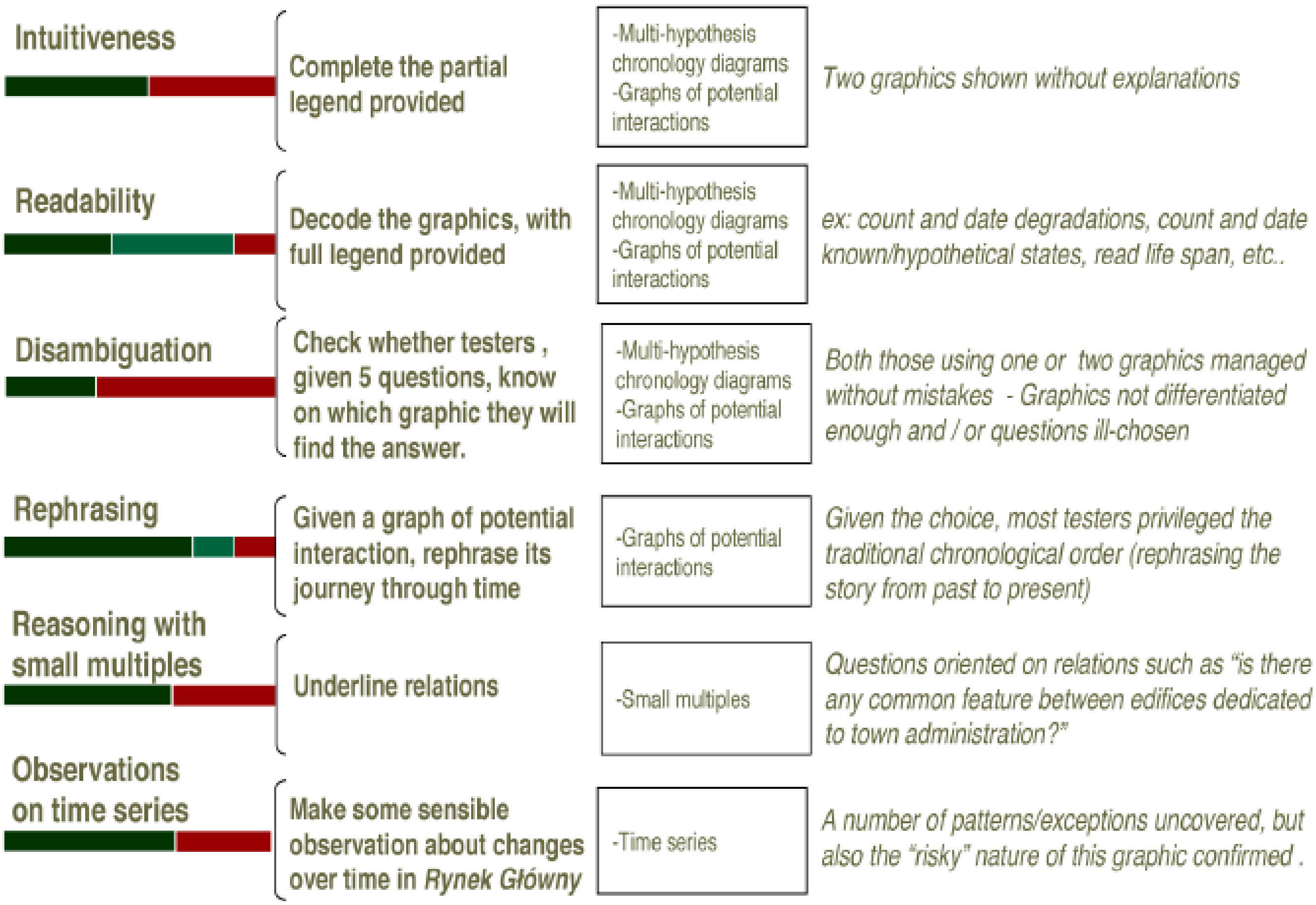

Figure 14. A summary of the evaluation steps. From left to right group of question and raw result (dark green - correct answers, bluish - acceptable answer, red - errors), objective of the test, graphic concerned, comment or examples of questions

Still, it is important to stress that participants did uncover a number of patterns/exceptions, and, basing on them, as we expected, did work out a wide range of faulty explanations (blaming wars when there were no wars at the time for instance). The bottom line of our approach is that visual analytics can usefully apply to historic architecture analysis, but we believe it is vital to understand the "*risky*" nature of such graphics when the underlying data is what it is in historic sciences – and our evaluation does point this out. Finally, the evaluation underlines the inherent limit of tests that are not targeted at people familiar with the discipline the graphics are supposed to serve. One frustrating thing with attempts to bridge gaps between scientific fields is that you often end up telling experts things they already know very well, whereas non-experts will argue these things are irrelevant in their field. Well we acknowledge our evaluation might look precisely like that: for infovis / visual analytics experts it will appear trivial and weak, while others (in historical sciences) may not understand why we bothered with such a boresome effort. From our point of view, this evaluation is far from being convincing, both in terms of method and in terms of outcomes, but thanks to it we hope we at least had some non-experts come to rethink the way they picture the use (and evaluation) of graphics.

In a forthcoming evaluation, we also wish to understand if the framework acceptable as it is for people whose professional practices do not always include a strong investment in computer technologies, and in visual analytics in particular (namely, historians, archaeologists, etc.). This will be done, in collaboration with colleagues who have thoroughly analysed some of the case studies presented here, by checking how alternatives spotted in this research match their doubts.

6. Conclusion

This research sought to provide analysts of historic architecture with means to visualise interpretation difficulties, i.e. visualise alternative scenarios that can be derived from sets of information. We have briefly commented on the nature of their cognitive process – hypo-deductive, reductive, non-inductive. We have shown that it is necessary to try and support this process with graphics highlighting alternative explanations so as to avoid unjustified assumptions.

We have analysed factors that need to be weighed when interpreting the underlying sets of information, and developed various visual solutions that help analysts keep trace of doubts, and give them means to perform some reasoning on alternative scenarios of evolution:

• 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, through which we introduce a classification of architectural consequences. These graphs position alternatives in time, help understanding their relative density 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;

• visualisations dedicated to collection reading in which we report for each artefact, the life span and the number of changes and of alternatives.

The results we report show that a number of faulty inferences can be fruitfully uncovered by analytical graphics – provided these graphics do take into consideration the nature of the data handled in historical sciences, and the nature of the analyst's cognitive process. The visualisations, applied to Kraków's Rynek GBówny, helped us reach some interesting conclusions on this case study. They for instance clearly deny "*common sense*" assumptions such as "*the more information the less doubts*" or "*the most recent the most well known*", etc.

However results also show that when handling questionable information (historic sciences), analysts should remain cautious if drawing conclusions from a visualisation: with distorted input, one should expect distorted conclusions. Given this precaution, we believe the contribution draws attention on the necessity to further investigate interpretation steps in historic architecture, and more generally on the complexity of the challenging complexity of simple visual thinking. But we consider that one of the contribution's main achievements is to show that analysts in historical sciences – often driven towards solutions stemming from geosciences – can greatly benefit from an investment in the infovis community.

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