

Area cartograms in building product model visualization

A case study on the presentation of non-spatial object properties in spatial context with anamorphic maps

Helga Tauscher¹, Raimar J. Scherer²

^{1,2}*Technische Universität Dresden, Faculty of Construction Engineering, Institute of Construction Informatics, Germany*

^{1,2}http://www.tu-dresden.de/bau/cib?set_language=en

¹helga.tauscher@tu-dresden.de, ²raimar.scherer@tu-dresden.de

Abstract. Existing presentation of building information models is mostly based on a 1:1 mapping of spatial information to spatial visualisation parameters. This approach limits the presentability of non-spatial properties and can even produce misleading presentations. An area cartogram is a type of map where the size of the areas is tied to some non-spatial value instead of the real size of the object. We identified five types of cartograms, applied them to typical building geometry and evaluated the resulting presentations in terms of readability. Finally a use case scenario is given to prove the need of such formal studies and to provide the basis for further evaluation.

Keywords. Building information model; information visualization; area cartogram; spatial structure; building element structure.

Problem

Building product models contain spatial as well as non-spatial information. The type of visualization we are studying aims at presenting non-spatial information in spatial context. Visualization can be described as the mapping of data to visualization parameters. The number of visualization parameters is restricted due to human perception, with only a small subset of spatial parameters. In most cases spatial visualization parameters are directly mapped to the spatial properties of the objects in question. This approach has two problematic implications:

Spatial visual properties, especially the size of objects, have a high influence on the perception of the visualization. Whenever there is a huge difference between the size of an object and its importance regarding the represented facts, the interpretation of such visualization will be error-prone.

Furthermore direct mapping occupies more than half of the available visualization parameter set (position, shape and size). With only colour and annotation left, it is hard to show more than two additional non-spatial properties in spatial context. Even with only two abstract properties encoded into it, the visualization can become overloaded and difficult to perceive.

A piece of information is considered to be spatial if it describes geometric properties of the building. Consequently any piece of information describing something else is non-spatial. Examples for non-spatial information are for instance execution time schedules, expected or cleared cost values, physical material properties such as heat conductivity or light transmittance. The values may be planned, measured or simulated and aggregated by statistical functions (e.g. mean or deviation values). However in the scope of our formal analysis all these values are treated the same - as abstract non-spatial properties. The visualization methods described here are applicable for any of them. To prove usefulness, the last section outlines a use case scenario,

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showing how the arbitrary values can be replaced with values from a construction domain specific example.

Method: A formal approach to building product model visualization

In building product models information is aggregated in a way that increases interoperability of software tools. Consequently research concentrates on the semantic enhancement of the 3D building model, the integration of additional data (e.g. schedules, cost) with the building model and how this integrated model can be utilized by tools and algorithms. Often authors touch visualization questions within the scope of their analytical questions, in order to show off their results. Few authors tackle visualization problems explicitly though - mainly in the area of schedule (4D) visualization (e. g. Benjaoran et. al. 2009, Chang et. al. 2009). However there is no systematic research about visualization in order to support the human user in the exploration of building product models. The potential opened up by building product models for visual analysis of the product data remains idle due to the lack of more general approaches. On the other hand the established research in information and exploratory visualization avoids the special cases of spatial information and/or treats them as exotic, marginal topics.

Cartography is a domain traditionally dealing with spatial and non-spatial information as well. By this domain methods of abstraction were developed to highlight the meaningful information. One of these methods, called anamorphic maps, preserves only some spatial properties (position, shape and topology) of the original objects in the final presentation. Thus non-spatial object properties can be mapped to the unused spatial visualization parameters.

A well-studied subtype of anamorphic maps is the group of area cartograms or area-by-value cartograms. In an area cartogram the area of visualization objects does not reflect the spatial size of the data objects but a non-spatial property instead. This way area cartograms can adjust the visual weight of the presented objects, which is done either by a simple normalization or by encoding a non-spatial property into the area. The non-spatial property can be used as a reference value for a second non-spatial property which is then encoded in the colour parameter. Geospatial examples from the domain of cartography often use inhabitant numbers as reference values. Because the reference value is then distributed uniformly over the presentation area, cartograms are also known as density-equalizing.

In order to answer the question whether area cartograms are applicable for building models, we first identify and describe types of area cartograms including the algorithms to generate them. In a second step we describe the characteristics of building model geometry and apply the cartogram algorithms to a prototypical example of building geometry. The resulting visualizations are then evaluated in terms of readability.

Types of area cartograms

To obtain a representation with the targeted area value, the original spatial object can be scaled, distorted or replaced by a completely independent representation of the desired size. Each of these changes to the single visual object has an impact on its relations to neighboring visual objects and those affects topology and continuity of visual presentation as a whole. Position may be recalculated compared to the original position to keep the original topology as much as possible.

Thus area cartograms can be categorized according to the following criteria:

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- Continuity: Given a set of objects with spatial properties such that they fill the space continuously – does the corresponding group of representations fill up the cartogram area continuously as well?
- Preservation of topology: How much of the neighborhood relations are retained?
- Preservation of position: How closely is the position of the original objects matched?
- Preservation of shape: How closely is the shape of the original objects retained?

There is a strong interdependency between these criteria. They can't be equally fulfilled at the same time (see e.g. Roth et. al. 2010). Algorithms for the creation of area-by-value cartograms balance these criteria to achieve a reasonable trade-off. Some methods even relax the fundamental criterion of target area values by introducing a cartographic error. They allow for some deviation of cartogram areas from their target values to better satisfy the other criteria, producing an approximation to the value-by-area cartogram.

Scaling

Simple scaling of the objects preserves both shape and position absolutely, but neither continuity nor topology. Downscaling produces gaps, upscaling produces overlaps.

Gastner-Newman-Cartograms

The algorithm proposed by Gastner and Newman (2004) projects the original map onto a distorted grid, which is calculated such that cell areas reflect values of the objects on the grid cells. The algorithm maintains continuity as well as topology totally. However shape is distorted, but the characteristics of the shapes are retained partially. A special form of the algorithm introduces additional shape-preserving constraints. Tobler (2004) gives an historical overview about computational methods of displacement-grids for continuous area-by-value cartograms.

Dorling cartograms

Each data entity is represented by a circle of the appropriate size. The algorithm arranges these circles in such a way, that neighbourhood is maintained as closely as possible (Dorling 1996). The non-continuous cartogram maintains topology, but totally ignores the original shape of the objects.

Rectangular cartograms

This type of cartogram is similar to the Dorling cartograms, but uses rectangles instead of circles. It allows for better preservation of continuity. Van Kreveld and Speckmann (2007) present an algorithm to create rectangular cartograms.

Spatially ordered treemaps

Treemaps are a method to present hierarchical non-spatial values as the area of rectangles continuously covering a given canvas. For spatial data some of many possible layout algorithms are based on the position of the original objects. Spatially ordered treemaps maintain continuity, but are not capable to preserve topology in all cases. Shape is changed to rectangular. To come closest to the original shape, aspect ratio of the bounding box could be approximated. Wood and Dykes (2008) discuss an extension to squarified layouts which produces ordered treemap layouts with rectangle aspect ratios near 1.

Typical building geometry

Typical building geometry consists of horizontal levels and vertical elements, so that an orthogonal structure appears in vertical cross-sections. Floor plans also often show orthogonal orientation. Due to the nature of architecture the geometric structure of a building can be examined in terms of the enclosed spaces or in terms of the space-delineating building elements. In most cases one of both is sufficient and better suited to tackle a certain problem.

In order to focus on the basic issues the chosen examples are based on a very simple orthogonal floor plan layout with rooms, walls and openings, which also can be taken as prototypical for a vertical cross-section.

Spatial structure

The spatial structure consists of three-dimensional volume, continuously filling up the overall building volume.

Building element structure

Building elements are made up of walls and slabs separating rooms. These space delineating elements are of reduced dimensionality, one dimension is significantly smaller than the others. Furthermore there are openings (doors and windows) being part of the walls and slabs.

Case studies

Implementation

In order to produce comparable graphics (with unique aesthetics) the algorithms have been implemented using Java and processing. The input data of the floor plan layout was prepared with ad-hoc scripts to fulfill the requirements of the algorithms. Particular attention was paid to the topological integrity of the input data, otherwise Dorling and rectangular cartograms wouldn't be achievable. For the Gastner-Newman-cartogram preprocessing of the layout plan consists of the insertion of additional nodes along the straight course of the walls.

In the following each cartogram type is shown and discussed for the spatial structure as well as the building element structure of the sample layout with arbitrary area target values attached to the respective objects (Figure 1).

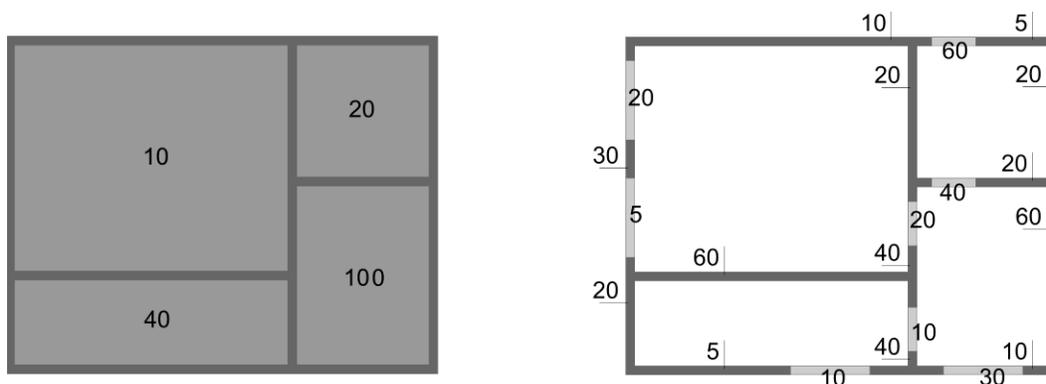


Figure 1

Sample layout with area target values for rooms (left) and building elements (right)

Cartograms applied to the spatial structure

Presentation of room areas in floor plans and vertical cross-sections is similar to cartographic maps in that the spatial objects are continuously filling up the layout. Area cartograms can be applied rather straight forward to the spatial building structure.

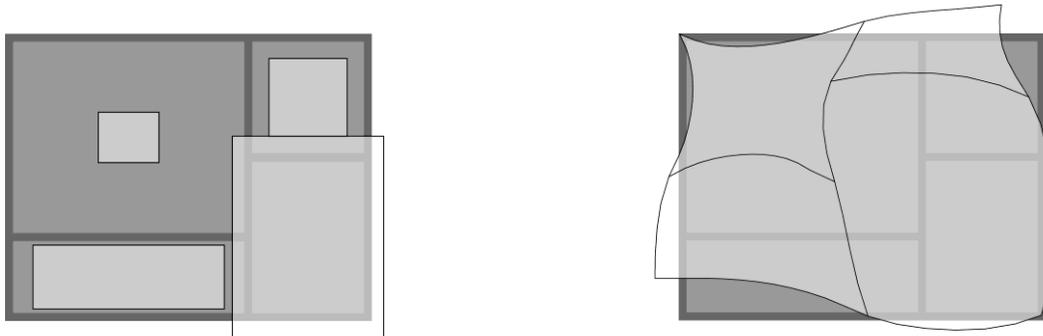


Figure 2
Simple scaling (left and Gastner-Newman-Algorithm (right) applied to spatial structure of the sample floor plan

1. Simple scaling: Scale is calculated to the maximal value which doesn't produce overlaps.
2. Gastner-Newman cartogram: The values in the examples have a high deviation from the size of the original area. Thus shape distortion is rather strong. Strong local distortion can lead to aesthetically unpleasant presentations, which are hard to read. However it can be very useful for smooth weighting of single areas (fish eye zoom).

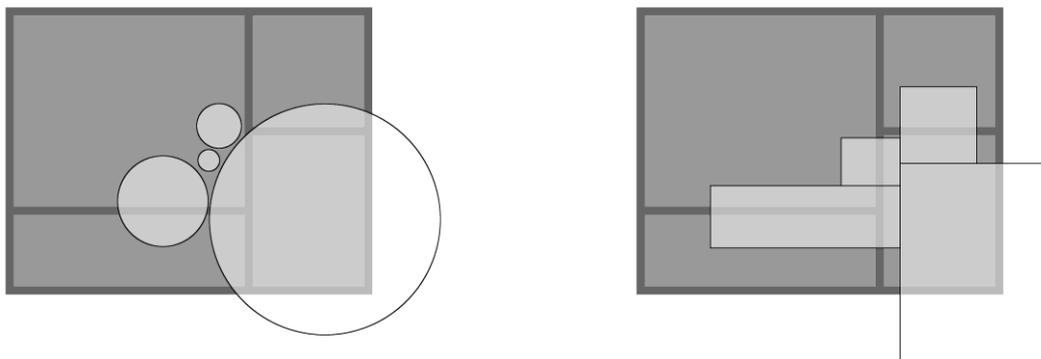


Figure 3
Dorling Cartogram (left) and rectangular cartogram (right) applied to spatial structure of the sample floor plan

3. Dorling cartogram: The high level of abstraction makes it suitable for an anamorphic presentation because it shows clearly, that this is not a real floor plan
4. Rectangular cartogram: Shape is maintained because the original is orthogonal, proportions can be retained as well in this simple case, but might be distorted in favor of topology for more complex cases.
5. Spatially ordered tree map: In this case shape is maintained, because the original geometry consists of rectangles as well. In contrary to rectangular cartograms proportion can't be retained, instead the abstraction of the outer boundary being a rectangle is

introduced, which matches the original geometry as well. Topology can be preserved in this case, but it might not be possible in more complex situations.

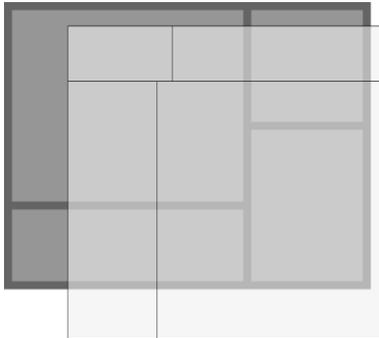


Figure 4
Spatial treemap applied to spatial structure of the sample floor plan

Cartograms applied to the building element structure

In contrary to the spatial structure the building element structure does not continuously fill up the presentation area. This simplifies the construction of area cartograms because the area of an element can be changed without influencing neighbour elements. However the elementation, neighbourhood and topology are more complex to define and describe in order to be preserved in the visual presentation. Another problem is how to normalize the areas of elements which are not directly comparable, because they refer to different base units, e.g. walls and openings.

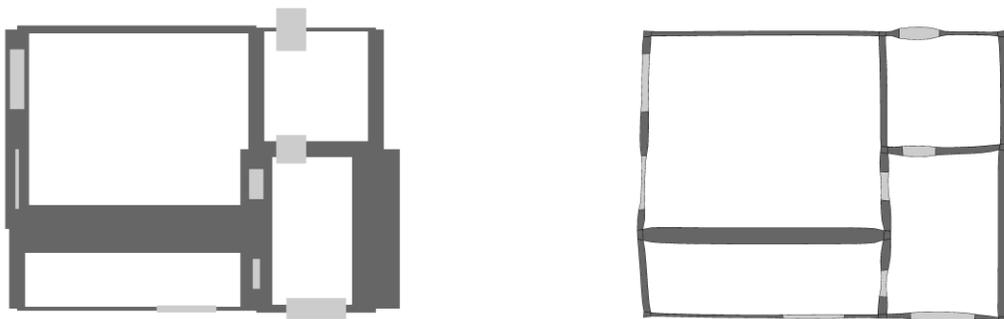


Figure 5
Simple scaling (left) and Gastner-Newman-Algorithm (right) applied to building element structure of the sample floor plan

1. Simple scaling: Because of the reduced dimensionality of the building elements, simple scaling can be applied to the reduced dimension without losing the original topology.
2. Gastner-Newman: The same arguments are valid as argued for the spatial structure
3. Dorling: The algorithm can be applied to the building element structure with the following definition of topology: Walls are neighbors when they are connected and border on the same room. Openings are contained in the walls. Although the rough position of the elements is retained, the visualization becomes hard to read.

4. Rectangular cartograms: A rectangular cartogram, when layed out for optimized preservation of topology, would look similar to the simple scaling solution.
5. Spatial treemaps are designed to show a continuously filled area. They can't be applied to the non-continuous building element structure.

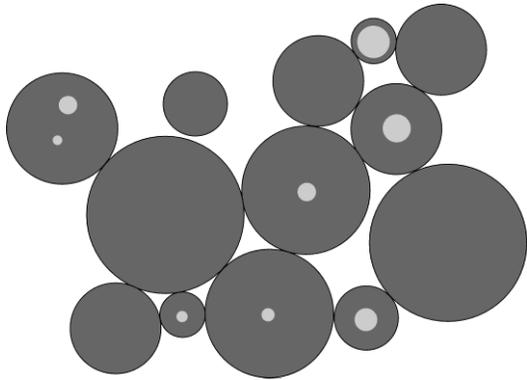


Figure 6
Dorling-Algorithm applied to building element structure of the sample floor plan

Envisaged application domain scenario

In the following a construction domain scenario is described in order to prove usefulness of the value-by-area cartogram approach for building product model visualization and as a basis for further studies. The scenario is placed in the context of execution design, contracting and execution of construction work. A visualization scenario consists of a task to be performed and questions to be answered by means of visual exploration. With the chosen task of cost control the non-spatial property to be visualized in spatial context is set to a cost property, retrieved from calculation, submission or invoicing. Questions to be answered are:

1. Which parts of the building will definitely have superior costs and therefor need special treatment in planning detail, careful supervision during execution or special attention during invoice verification?
2. What are the reasons for exploded costs? How correlate cost values to other key parameters, such as schedule irregularities or delays, trades and companies present on the site or the planned building use?
3. Which parts of the building are at risk of exploding costs and how high is the probability of excessive costs?

For the first question to be answered a single abstract value must be shown in spatial context. When the value is encoded by color, then small, but very expansive building elements or rooms might be dismissed. An area-by-value cartogram can be helpful, to prevent this misinterpretation.

The second question demands for visualization of the correlation candidates as a second value in addition to the cost value itself. By weighting the area according to the costs values, values of the candidate property which correlate to high cost values can be made visible.

In order to visually answer the third question the the height of potentially increased cost values has to be shown together with the probability of the occurrence of the cost-triggering events. The principle of the cost value as reference for a second value is similar to the visualization for the second question. However for the second question the users exploratory focus is on correlation of values, while it is on spatial clustering of values for the third question.

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Resume

It has been shown that the concept of areal cartograms is applicable for simple building geometries. 5 types of cartograms have been applied to an example of spatial as well as building element structure. While all of them are applicable to the spatial structure, rectangular cartograms and spatial treemaps turned out to not be useful for the building element structure.

In a next step more complex geometries will be fed to the algorithms. For cartographic models spatial information is sufficient in 2D or 2.5D. In contrary building product models rely on the full 3 dimensions. It will be analyzed whether cartogram algorithms can be adapted to 3D geometry.

A practical use case scenario for cost control was outlined to prove general usefulness of the concept. Case analysis has shown that the types of cartograms provide different levels of abstraction. Their appropriateness will be studied in the context of the drafted cost control scenario.

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