Applied visualization methods for building information models with heterogeneous sources

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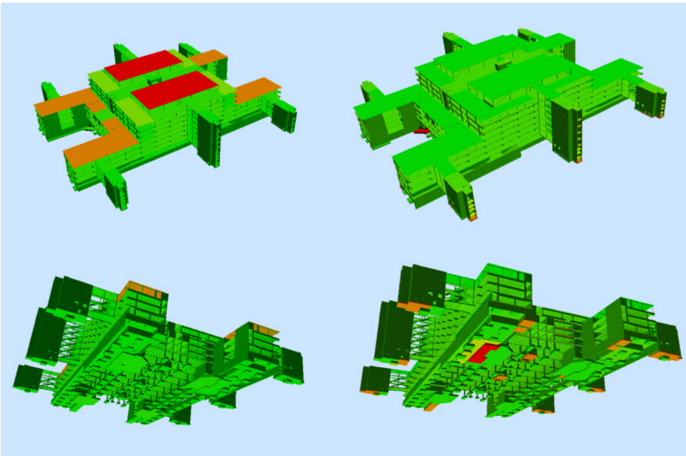
Abstract The advances in building information modeling gave rise to the explicit description of semantics formerly contained in drawings, diagrams and other visual representations implicitly. In this way information and visual representation became decoupled by intention, taking the loss of persistable and sharable visual representations.

The authors of this paper are developing a visualization framework for the recoupling of information and presentation in the area of building information models. The framework allows for the specification of arbitrary visualizations. These specifications are tailored to the application to heterogeneous interlinked models, consisting of 3D object model, construction schedule, cost and risk data and progress reports, among others.

Using the framework and a concrete use case with a complex information scenario, several advanced visualization components were developed. These examples and their generation are explained in detail, revealing the underlying concepts of the framework. The featured use case is the project management overview over the state of the building and the construction progress as the use case. In terms of visualization methods the paper concentrates on the application of color scales to different representation types.

Fig. 1 Different color scales applied derived from cost information: absolute cost values (left) and relative (sum of structural work) cost normalized to m³ (right)



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Objectives

The advances in building information modeling gave rise to the explicit description of semantics formerly contained in drawings, diagrams and other visual representations implicitly. This way information and visual representation became decoupled by intention, taking the loss of persistable and sharable visual representations.

However, architectural work cannot be reduced to the production of planning information (hence BIM data). An important part is also to present and communicate this information. The generic visualization framework developed by the authors seeks to recouple building information and visualization by means of an explicit visualization description. It intends to act as an enabling tool which should give back control over visual representations to the creative profession in the construction industry, thus reviving fading knowledge and skills.

This paper features an example use case, showing the complex process of generating visual representations from building information and the numerous options to choose from, even when focusing on a particular detail, namely color scales. In presenting an application use case, the paper illustrates the frameworks scope and supports its benefits. For technical details of its architecture we refer to Tauscher & Scherer (2012).

Tauscher et.al. (2011) have shown how known elementary visualizations can be combined into multi model visualizations. Of the three methods described there – interaction, embedding, blending – the latter is used in the examples shown here, focusing on the integration of information from secondary models by means of color scales. We are presenting two different visualization components, differing in the kind of the base mapping used to generate the graphical objects to be colored: 3D object mappings, schedule based Gantt charts and animated versions of both. Prior to this we are explaining the general approach to the visualization generation and discuss common problems arising in the mapping process.

Use case scenario and example data

The scenario for the visualization application is taken from the area of construction project management: Specifications, cost and progress control. In this area data from different phases of planning and execution cumulate, with different level of detail and different domains. The underlying information is based on the different multi models (combined models from different domains, Fuchs et.al. 2011) from the phases of tender, contract and progress reports. To guarantee efficient data access for the visualization application, all elementary and link models have been consolidated into a consistent multi model for the visualization.

In the milestone schedule for structural work in the model at hand there is only one related activity for each building element. We are assuming this to be a universal quality of milestone schedules, while more fine-grained schedules will have more activities per building element.

Progress reports cover a certain report time each. In the following reasoning, there will be no differentiation of finishing, reporting and billing date/time for simplicity reasons. Progress reports are arriving in intervals of one month. Furthermore for the progress reports there is the following restricting: they are always covering building elements in full - there are only two states. Thus a given building element at a given point in time is always finished or not.

Extraction and grouping of building information

The creation of the visualization model is carried out with the help of mapping rules, which create elements in the visualization model from the elements in the building information. The access of the data has to be oriented towards the structure of the intended visualization. Using multi models as a source, quite often this structure follows the structure of one of the elementary models, while additional visualization parameters like that of color are obtained from other elementary models. E.g. the crucial data for color coding in a cost control scenario is obtained from the specification of work and the bill of quantities, while for a progress control scenario they are taken from schedules and progress reports. These values have to be extracted, grouped, related and accumulated on the elementary model forming the base for the structure using the link model.

Fig. 2 shows the access structure, which is generated by joining elementary and link models. In doing so, the elementary model underlying the geometry is used as key model and all linked objects coming from other elementary models are related to the objects of the key model. Therefor the multi model container as well as its containing elementary and link models have to be parsed first, the link model has to be traversed and for every object of the key model a grouped link object has to be generated. All linked objects from other models are assigned to this grouped link object. The access structure and the data structure of the elementary models coexist, such that the relations between objects of the elementary model are retained and can still be used.

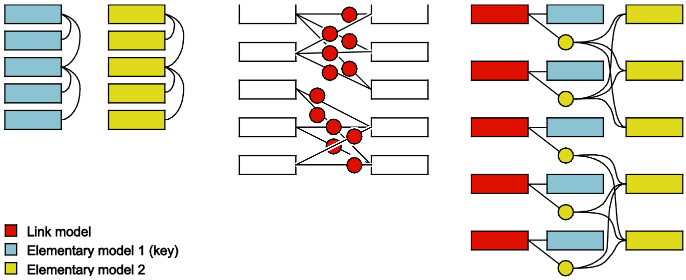

Fig. 2 Access structure for multi models - elementary models (left), link model (center) and grouped (right)

Mapping the extracted data to visualization parameters

In order to display the selected values in the visualization, the scale of the attribute to be presented has to be mapped to the scale of a visualization parameter. Scales may be metric (cardinal) or categorical (nominal, ordinal) on both sides of the mapping. Metric scales on the side of the attribute to be represented may be distributed differently, e.g. the gradient may be linear or algorithmic. If level of measurement and resolution of the scales correspond on both sides, information may be mapped and represented completely, otherwise either information can only be represented partly or the visualization parameter won't be fully used. Status information with few values, as for example 'open', 'started', 'blocked', 'finished', 'cleared' make up an ordinal scale, while price information with cent precision can be arranged on a proportional scale for example.

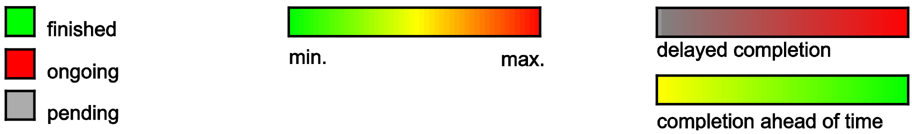

Fig. 3 Color scales from visualizations presented later: categorical (left), continuous (center), complex (right)

Most color models feature color spaces with a three-dimensional organization, as for example the RGB and HLS models. The range of values of the single dimensions covers in the technical implementation 8 bit each, hence values from 0 to 255, which is already exceeding the average human cognitive ability. In theory several attributes could be mapped to the single dimensions, thought in this case the HLS model would be more intuitive to read. The examples use RGB color space throughout and map only one single attribute to the color space. The dimensions of the color space are used as linear scales in a simplifying manner, not conforming to human perception, which can differentiate unequally well in various zones of the color space. Methods for the selection of suitable color schemes are also out of the focus of this article, and so is the testing of their applicability for specific tasks as it is presented and studied in Chang (2009) for example. Fig. 3 shows several color scales used later in this article.

As shown above, the possibilities to depict information with the color parameter, are quite limited. A more general quantitative study, involving also the potential of other visualization parameters and the information content of building product models is still pending.

Another question arising in the context of the visualization parameter color, is that about appropriate reference values. Fig. 4 illustrates the problems arising for the visual presentation with two possible solutions. If values (cost for example) are used as absolute values per building element, it is necessary to clearly show the boundaries between the reference units. Otherwise the statement of the presentation will be lost. Element boundary display however decreases the expense of intuitivity and clarity of the 3D-presentation.

Alternatively the values to be shown per color may be normalized using a common homogenous reference unit. An obvious choice for this would be the volume. Cost values are usually available with specific reference values depending on the building work concerned (volume, base area, surface shell, weight et. al.). The visual presentation may stay problematic nevertheless, namely if the normalized reference value (volume in this case) has a relatively high deviation from the display size. Display size means in this context the screen area of the 3D-element occupied in the final projected visualization. Significant deviation can come off for instance when huge parts of the element are masked by other elements or if the size perpendicular to the projection plane is highly deviating. One possible solution is the transfer of methods from the domain of cartography to that of building information visualization (area cartograms). First approaches to this have been studied in Tauscher & Scherer (2011).

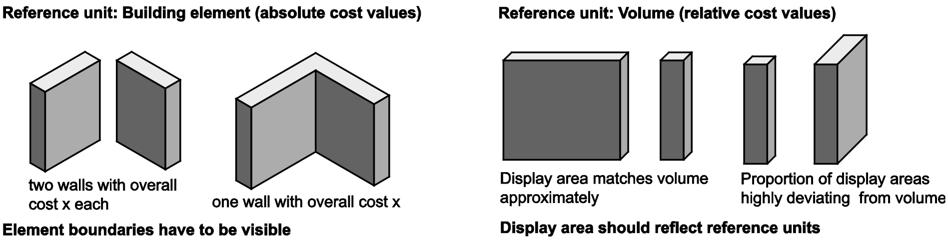

Fig. 4 Problem of reference units for the visualization of 3dimensional object display with color scales

The building information model may contain temporal information, as for example information about schedules or creation and modification times of documents. The information may concern different aspects of time, e.g. planned and actual sequences. As far as the medium used for visualization allows for it, the visualization can also contain a temporal dimension, hence it may change over presentation time. The problems of precision and reference do also exist also for temporal presentations. We can distinguish points in time and periods of time. Observations, measurements or remarks in most cases refer to points in time, namely those points in time, when they were made. However, as soon as a series of information is collected in fixed intervals, the information is usually related to events in the periods between these observation points. This can be seen as the resolution of the time dimension. The examples in this paper adopt time on the visualization side as discrete animation. Smooth animation with continually advancing changes could be implemented and studied, albeit the additional profit would be disputable.

Coloured 3D-presentation of the building

Colored 3D-representations of the building are a very descriptive and intuitive kind of building information visualization. Structure and geometry of the visualization objects correspond to those of the building as planned and are directly inherited from the elementary object model. Thus the object model forms the base of the visualization. Fig. 1 shows the application of a color scale based on absolute cost values per building element and an alternative visualization with normalized cost values, related to universal volumetric units. For temporal information it is also valid, that the most intuitively understandable kind of presentation is the one with temporal information mapped directly to temporal visualization parameters. Fig. 5 shows an application of such a direct mapping. The differently colored states of the visualization refer to different states of the building at certain points during production time: Red colored parts are under construction while green parts are finished and grey parts are not yet started.

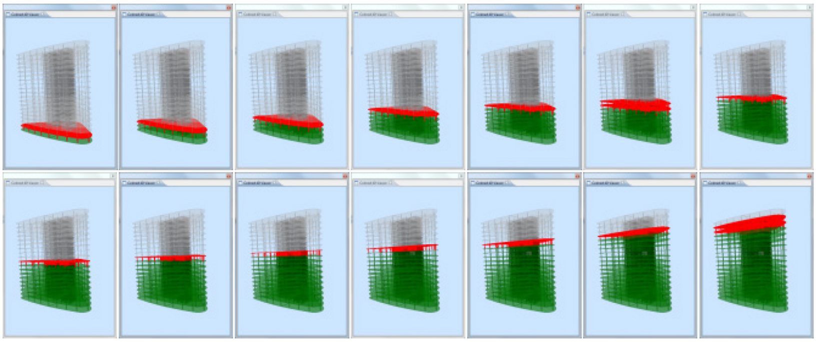

Fig. 5 Animated 4D view showing state of construction work at different points in time

Presentation of the planned and actual progress with a Gantt chart

For the animated Gantt diagrams graphical objects are derived from the activities. Hence for the grouping of information the activity model is used as the key model. Colors are calculated from information about the planned course of activities (expected values, milestone schedule) and the actual course of activities (actual values, progress report meta-information).

Fig. 6: colored Gantt chart at five points in time of the progress reports: target values (top), actual values (center), overlay (bottom)

For the Gantt chart temporal information is mapped to the x-axis of the two-dimensional presentation. Activities with duration in time are represented as horizontal lines or slim rectangles, with their spatial start and end points corresponding to their temporal start and end points. Different sorting criteria may define the order along the y-axis, e.g. earliest starting point, alphabetical sorting or position numbers. Status values (open, started, finished etc.) for each activity at certain points in time may be shown by applying colorings to the graphical objects representing the activity in question. In doing so, either the whole activity rectangle or part of it may be colored according to a scale. In the following we will show how to represent the planned and actual values using these color scales. The resulting visualization is shown in Fig. 6.

Calculation of target and actual values

Because the progress reports (which form the base for the actual values in the visualization) are not compulsorily happening at the activity boundaries, target values (derived from the activities in the schedule) have to be interpolated for the progress report points in time. To achieve this, an assumption has to be made regarding the distribution of the building elements to be finished over time according to the schedule. We are assuming a linear distribution in this paper, although with a non-linear distribution gradient more realistic visualizations may be achieved. Fig. 7 shows how the target and actual values at the progress report points in time are calculated, by means of exact indication (update), interpolation or prediction.

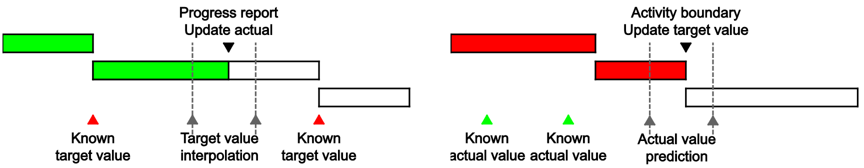

Fig. 7 Interpolation for target values (at progress reports, left) and predictions for actual values (at schedule boundaries, right)

The representation of progress for management purposes is based on a raw milestone schedule. This schedule summarizes multiple tasks in one activity. Quantification of the tasks is made through a quantity take off from the model based on different formulas including different dimensions of the building element (volume, surface, base area, weight etc). These can only be converted to comparable values regarding the temporal dimension with the use of effort numbers. In order to show the progress at the activities of the milestone schedule, multiple tasks with different quantity units have to be summarized. However, the leveling effort factors allowing for summarization are based on assumptions, estimations and experience. For the visualization shown here, we were using effort factors of 1 throughout. Progress control with this visualization is thus based on simple, but unrealistic assumptions. To make the presented visualization usable for management, those effort factors as well as the gradients for effort distribution over time, would have to be made configurable in the visualization. This way the visualization could help to gain a realistic insight in the progress. To be able to distinguish the effects of the progress reports from the effects of the assumptions, the effort configuration should be adaptable in real-time.

Colour scale by means of an expected and actual values overlay

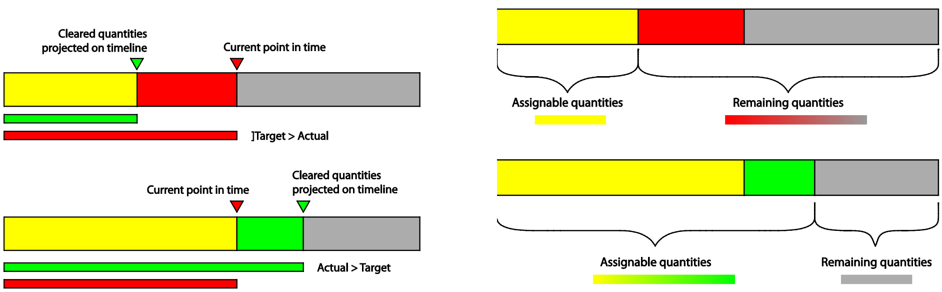

Fig. 8 Expected-actual-comparison color scale for the Ganntt chart (left) and for 3D building visualization (right)

The coloring of the Gantt charts is accomplished by overlaying expected and target values. Fig. 8 illustrates the principle: The expected and actual values for the respective point in time are first projected onto the time axis. Using the assumed even distribution of effort over the time of the activity, the expected value will be projected exactly onto the time of interest, using more realistic distributions this would not be the case. The expected value is assigned the color red and the actual value the color green. The overlay according to the RGB color model results in a three-colored scheme with the colors red, green and yellow. In this scheme yellow represents the amount of work carried out according to the schedule, hence the amount contained in both actual and expected quantity. Green on the other hand represents the amount of work actually carried out, but exceeding the expected amount. Finally, red represents the outstanding amounts, hence the amount which is contained only in the expected but not in actual quantities.

Applying the actual-expected colour scale to animated 3D presentations

As opposed to the coloured Gantt presentations the higher level reference in this visualization is not constituted by activities located in time, but by building elements located in 3D space. Thus the graphical objects are derived from and information is grouped according to the building elements. Activities, specifications and quantities are subordinated and assigned to the building elements. Because the schedule and the building model are structured differently, the relations between them are of cardinality n:m – one building element needs multiple activities to be completed and one activity affects multiple building elements. While before we have shown, how the status of an activity can be made up of the status of the respective building elements, we are now showing, how the status of a building element is made up of the status of different activities.

Again, the question of weighting the subordinated values (activities) is rising: One building element is touched by multiple activities, potentially overlapping in time. How is it possible to merge the status values of those activities into one status value for the respective building element? Is an arithmetic mean sufficient or do the activities have to be Figd into the whole with different weights? This question is analogous to the question about the distribution of particular building elements in an activity. Again, effort values could help to construct a more realistic distribution. For the sake of simplicity we are again assuming a linear distribution.

Another presentation problem arises from the fact that the milestone schedule is more coarse-grained than the building model and the progress reports, and that progress reports do not necessarily occur on activity boundaries (milestones), but with a regular interval instead. As shown before for an arbitrary point in time it is possible to determine the portion of building elements affected by the activity, which are supposed to be finished, using an assumption about the distribution. However, without a more detailed schedule, it is not possible to determine, exactly which building elements are expected to be finished. Such statement is only possible to be made at the activity boundaries. The actual information from the progress reports on the other hand are only valid for the respective delivery dates of the reports – only for these points in time a statement about the effectively completed building elements is possible. For points in time between the progress reports merely mean values or predictions can be made.

Target/Actual – Proportion Activity	Building element reported as completed	Building element not yet reported as completed
Soll > Ist	R,G,B = 1,1,0 Alpha=0	R,G,B=1,0,0 Alpha=(Soll-Ist) / (Vorgangssoll-Ist)
Ist > Soll	R,G,B = Ist/Soll,1,0 Alpha=0	R,G,B=*,*,* Alpha=1

Tab 1 Target-actual-comparison - color scales for animated 4D presentation

The resulting presentation problem does appear when expected and actual values are brought together for comparison. While in the visualization of expected values state changes at activity boundaries and in the visualization of actual values state changes at progress report points, in the combined visualization the state changes are staggered. Thus, some state changes can be related to concrete building elements, while others have to be related to the whole activity proportionally for the lack of assignment. In the latter case the calculated value cannot be visualized with a certain building elements but has to be illustrated with all potentially affected building elements.

Tab 1 and the right part of Fig. 8 show which color scales result from this reasoning: Similar to the scheme in the left part of Fig. 8, expected and actual values are blended. The progress report does split the bulk of all building elements into the group of those reported as completed and those not yet reported. Thus, actual values can be allocated to building elements and the respective 3D objects can be coloured directly. However, this does not apply to the expected values. The presentation of these values has to be carried out proportionally across all affected building elements. Instead of colouring concrete objects in green (completion reported, but not planned) or red (completion planned, but not reported), all potentially affected objects are coloured according to a scale from yellow to green or grey to red. Building elements completed too early related to the schedule cannot be identified in the bulk of all completed, thus all completed building elements are coloured according to the proportion of the early completed elements. Similarly the pending elements cannot be identified in the bulk of not-finished elements – thus all uncompleted building elements are coloured in red according to the proportion of uncompleted-but-scheduled elements. Fig. 9 shows the resulting visualization.

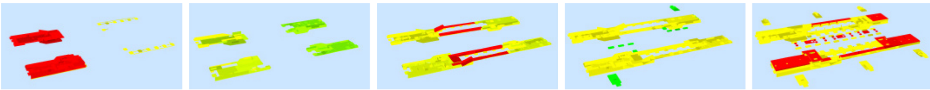

Fig. 9 Target-actual comparison based on the 3D object presentation

The fact that building elements may be partially completed, could lead to a further differentiation of the color scale. This would be the case, if some of the activities affecting a certain building element would be already reported as completed, while others are not. This special case was excluded for our present data. Also we have assumed that activities do not overlap per building element, hence there is only one activity active per building elements at any point in time, which can however contain multiple tasks from the specification. With a more fine-grained structure of the schedule according to the specification of work, this assumption could not be kept alive and the visualization in the presented form would not work anymore.

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