Building Design towards 5-dimensions

Meik Kabath, IEZ GmbH, 64625 Bensheim, Germany
(m.kabath@iez.com - www.iez.com)

Summary

There exists a big gap between the capabilities of current 3D-CAD applications and their actual usage in practice. Many architects and planners still prefer to draft in 2D because the benefits of 3D modeling are difficult to explain.

This presentation offers a basis to view the 3D building model not merely as the source for 2D plan generation. By adding extra dimensions like Time and Cost to the 3D building model it becomes possible to generate dynamic information on building construction progress with regards to used material, resources and cost.

These additional benefits are key elements to many planners and contractors and may therefore widen the acceptance of 3D building modeling in general.

1   The potential of a powerful 3D system

The following concepts are characteristic of modern CAD systems in the construction industry.

- The systems work model-oriented.

- Data storage and methods are encapsulated in a backend and thus independent of the graphic system used.

- Different vector-graphic front ends can be used as a graphic system and user interface.

- View filters control different display types depending on the features of the solid.

- Attribute filters make a rule-based transfer of specialized data to the graphic system possible.
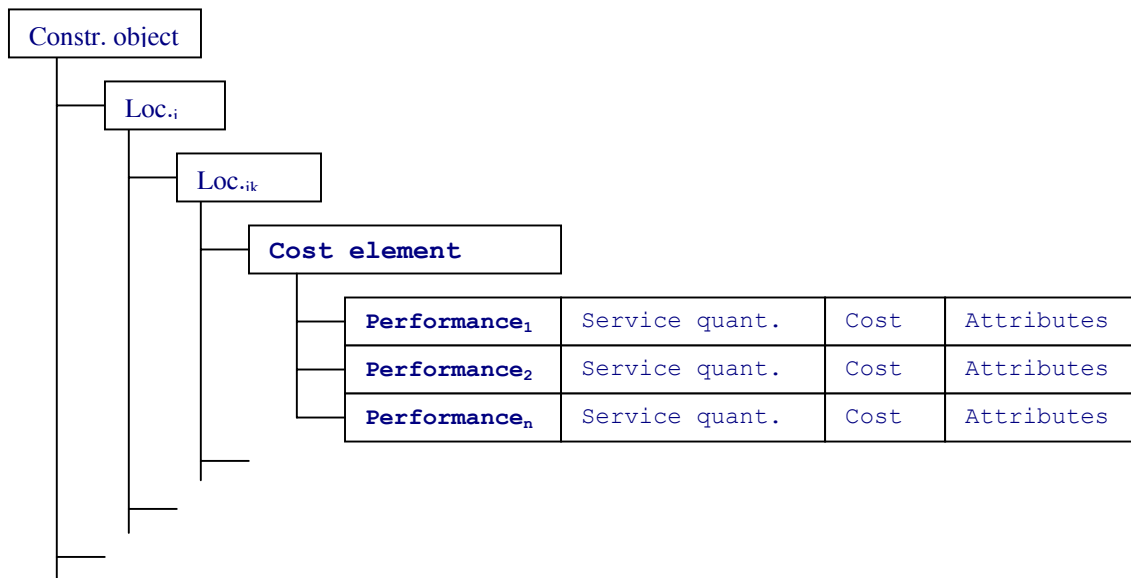
2   The 3D building model

Solids are defined geometrically, topologically and attributively. They stand in relation to one another. In addition to the solids, other structure elements are necessary to facilitate a subdivision into sub-models.

A building model is thus a structured, geometric model.
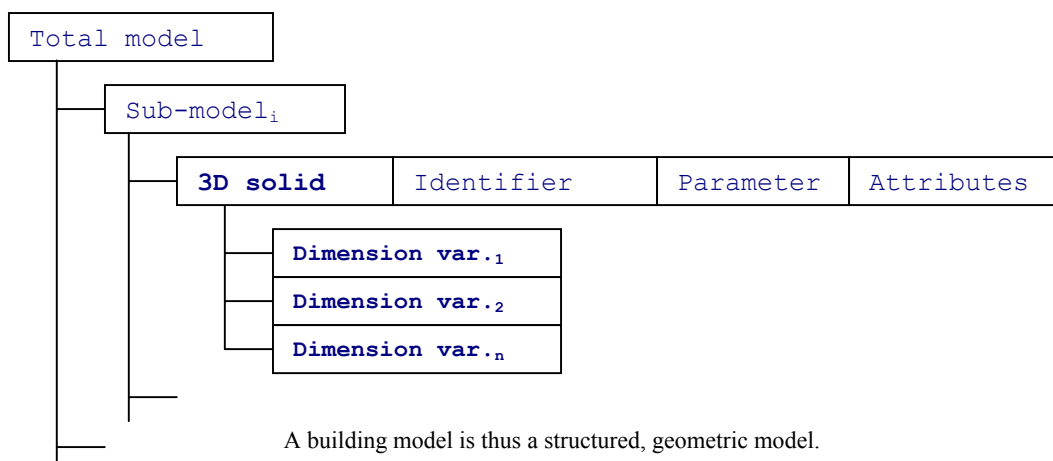
# 3   Transformation of the building model to the 4th dimension

Having said that however, a geometric model is not sufficient to describe a projected or real construction object. From the customer's point of view, the <u>Costs</u> incurred are a relevant aspect.

Costs arise from the required performance of objects at different locations in the building model [1]. The model is constructed from an abstract viewpoint. The topology provides the <u>Structure</u>, the performance, grouped into cost elements, represent the alpha-numeric objects. In other words, this is a four-dimensional [2] <u>element model</u>.

Constr. object
— Loc.$_{\cdot i}$
— Loc.$_{\cdot ik}$
— **Cost element**

Performance$_1$	Service quant.	Cost	Attributes
Performance$_2$	Service quant.	Cost	Attributes
Performance$_n$	Service quant.	Cost	Attributes

Obviously, there are parallels between the building model and this model. Both are built in a structured manner and consist of attributed data objects. The first step is to transfer the structure of the building model into the structure of the element model.

The congruent structure of the two models makes it possible to transfer certain information on the solid automatically from the building model via the cost elements to the element model at specific times.

3D solid$_1$	3D solid$_2$	3D solid$_n$

Cost element
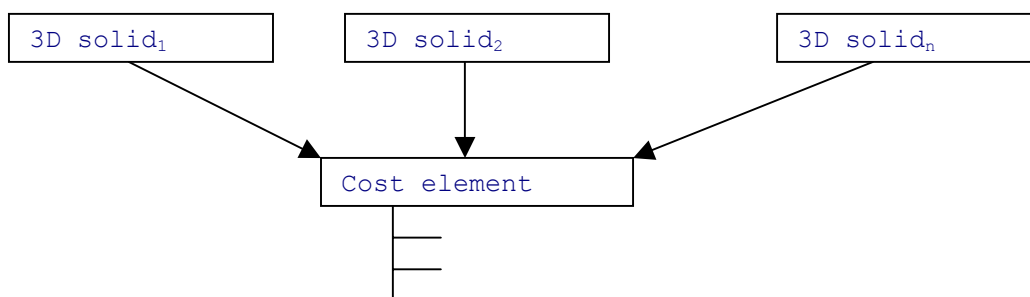
Taking into consideration that not all components of the element model can be stored graphically, part of the element model can still be automatically provided with information from the building model.

The building model can then be used to visualize stored values from the locations in the virtual construction object. It can thus be established that the element model is composed of an automatically quantifiable and visualizable part E_v originating in the building model and a non-visualizable part E_{nv}.

While E_v has references to data objects in the building model, E_{nv} does not. The greater the E_v/E_{nv} ratio, the easier it is to conduct a graphic plausibility check in the planning and building process.

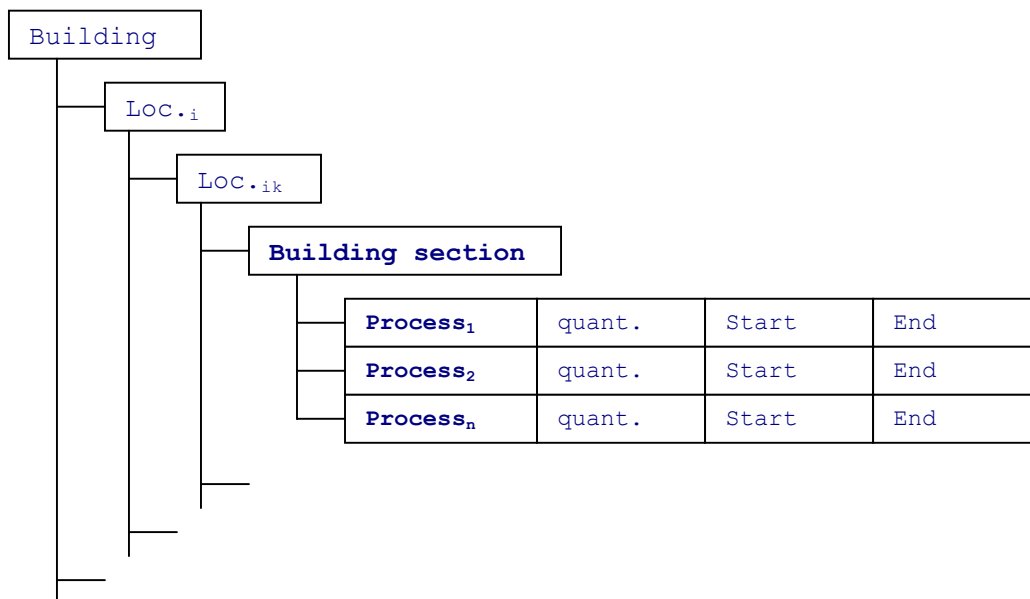> **The result of transforming the building model to the 4th dimension is a structured, quantitative model.**

[1] Other costs such as purchase costs, charges and fees are not taken into consideration.

[2] The term, 4th dimension, includes the costs in this case. Due to the sequence of the model transformation, the definition of the 4th dimension deviates from the conventional definition of the term.

4   Transformation to the 5th dimension

The construction schedule for the building requires a further dimension – time. Construction actions are provided continually by building section in a given sequence and in set time periods. Construction statuses provide schedule information at specific times.

By sub-dividing the element model within a technological grid building sections are created at various locations in the construction. The actions are proportionally allocated to these building sections. The duration of the actions are the result of the product of the proportional action quantities and the reference periods.

In this way, a time-based process model emerges from a quantitative, predominantly cost-oriented element model. Since the process model is based on the element model and this in turn contains a "non-empty" partial component E_v it is also possible to visualize building statuses in the building model.

```
Building
   |
   +-- Loc._i
         |
         +-- Loc._ik
               |
               +-- Building section
```

Process	quant.	Start	End
$Process_1$	quant.	Start	End
$Process_2$	quant.	Start	End
$Process_n$	quant.	Start	End

> **In addition to quantities and costs, the process model also includes time, thereby depicting a structured, process-oriented model.**

5   Status quo with contemporary systems

Today, specialized applications exist that are attached to either building models, element models or process models, and work with their respective methods.

Some of these applications have event-driven interfaces that enable two separate applications to communicate with each other, to link their respective data and thus work in parallel. Highly integrated computer workplaces are the result.

Practical experience has shown however, that because of the disciplinary and organizational division of these work areas, these systems are rarely used. It is equally difficult to make a technical drawer at his CAD workplace aware of the impact of linking his geometric inputs on construction costs or even on technological flows as it is to instruct a calculator or jobsite manager about the strict thought process behind a coordinate system or abstract parametric building element solids. Furthermore, an extremely document-based mindset prevails at CAD workplaces whereas the approach is more object or process-oriented in the actual construction and monitoring field.

6   The Building Book

The term, Building Book, is used to describe an application which

- stands between the classic CAD, tendering, contract-awarding and billing, and project management applications,

- provides an alphanumeric view of the building model,

- uses the core methods of a modern CAD system,

- performs model transformations up to the 5th dimension,

- uses the building model as a data source,

- derives data through calculations from it,

- provides reporting functions for documentation purposes,

- guarantees feedback to the alpha-numeric part of the building model,

- visualizes the building model in terms of quantity and time.

The building book depicts the structure of the building model in itself or in the form of an element model or process model, and facilitates easy access to individual or the aggregated data with the help of simple navigation. Attributes can be altered quickly by means of powerful selection procedures. Analytical functions based on the model geometry create in addition to conventional calculations, graphic logs which can be superimposed with the 3D model for monitoring purposes.

The application interface consists of a navigation area and spreadsheet type tables as well as a comprehensive graphical component called the Control Monitor.

6.1 Structure catalogs

Structure catalogs are used to transform the structure of the building model in the structure of an element model or process model.

Structure catalogs are formatted ASCII files and they describe the hierarchical structure of a construction object. Arguments can be optionally transferred to the sub-elements. These arguments contain structural components of the building model and link these with the sub-element of a structure catalog.

Example:

```
# define two buildings in an object
Element:'Construction object'
    Sub-element : 'Location1'
    Sub-element : 'Location2'

# define two floors for building1, arguments come from cad model
Element:'Location1'
    Attribute : <A_NAME>t>:='Building1'
    Sub-element : 'Ort1.1'
        Exchange : $A_FLOOR_PARTS:='1/1+1/2'
    Sub-element : 'Ort1.2'
        Exchange : $A_FLOOR_PART:='2/1+2/2'

# define an element with attributes on lowest level
Element:'Location1.1'
    Attribute : <A_FLOOR_PARTS>t>:='*'
    Attribute : <A_NAME>t>:='Ground floor'
```

The basic principle of this filter technology is to leave the data source unchanged. In other words, the structure catalog generates a new structure but does not alter the original structure of the building model.

The optional use of different structure catalogs makes it possible to create various hierarchical structures from a basic building model structure. Structure catalogs are open and can be modified by the user. A building model that is loaded via such a structure catalog provides the user with a new view of the model, the Building Book view.

6.2 Element filters

Element filters have logical rules with which to automatically link 3D solids with cost elements of the element model.

In so doing, the dimensions of the solid and the attributes thereof are compared with the criteria for issuing a specific element code. If the required features match, the element code is automatically written to the solid as an attribute. The element code provides the link between the 3D solid and the cost element.
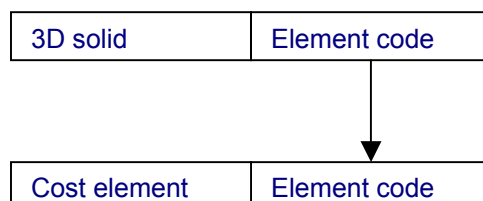
Example (excerpt from an element filter):

```
UNITS cm;

# assign elementcode W001
# to all walls with width=16 cm and material no.=400

WALL (a_width u 16.0) (a_type i 400)
     code 'W001' 'Wall, d=16cm, B25';

# assign elementcode F001
# to all walls and beams with width=50 cm and height=80 cm and
# material no.=400

WALL (a_width u 50.0) (a_height u 80.0) (a_type i 400)
     code 'F001' 'Strip foundation';
BEAM (a_width u 50.0) (a_height u 80.0) (a_type i 400)
     code 'F001' 'Strip foundation';
```

The example shows how an element code is allocated to the WALL solid on the basis of its thickness and material number attributes.

The example also shows how different inputs in the building model can be made uniform for the element model. A strip foundation can be modeled as a wall or as a beam. The same element code F001 is allocated in both cases however.

The graphic component of the Building Book makes an immediate visual check after a filter process possible. In this way, solids without an element code can be highlighted in color for example.

Example :

```
# draw walls without elementcode in red color
WALL solid (a_elementcode t '*') drw 'empty' 3 0 0 0;

# draw all solids with elementcode F001 in green color
WALL solid (a_elementcode t 'F001') drw 'empty' 2 0 0 0;
BEAM solid (a_elementcode t 'F001') drw 'empty' 2 0 0 0;
```

If one of the characteristics of a 3D solid changes, the original rules no longer apply in the event that the element filter process is repeated. The solid loses its element code and is either allocated a new one or is left without an element code.

Element filters are subject to the same syntax rules as view filters and attribute filters. They can be modified by the user as required.

Element filter technology also opens up a further useful option. The application of a different filter to the same building model makes it possible to allocate other element codes, with alternative construction methods and therefore other costs and time periods are found.

Example filter 1:

```
UNITS cm;
WALL (a_width u 16.0) (a_type i 400)
     code 'W001' 'In-situ concrete wall';
```

Example filter 2:

```
UNITS cm;
WALL (a_width u 16.0) (a_type i 400)
      code 'W002' 'Prefabricated wall';
```

The transformation of the building model into an element model is completed after all of the solids are linked with the right element codes.
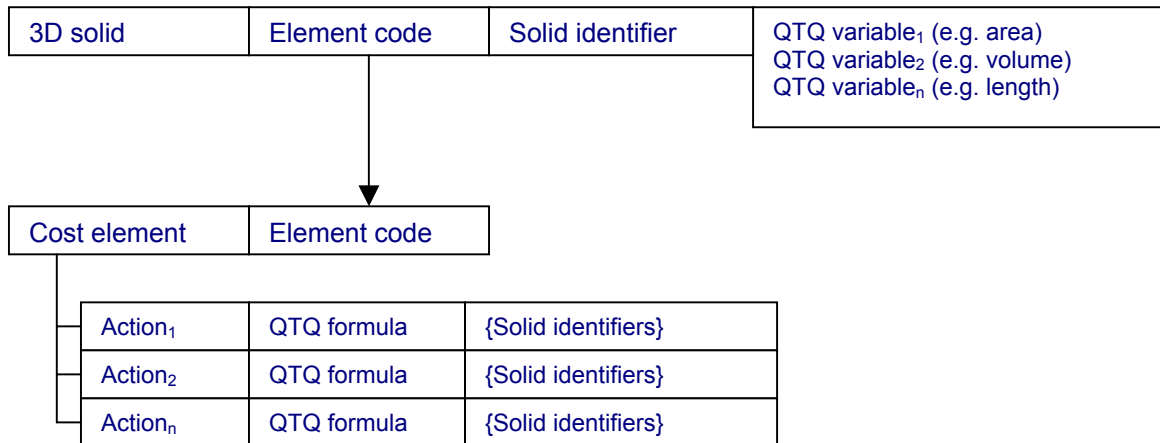
6.3   Calculation of action quantities

The solid-specific calculation of lengths, areas, volumes and pieces takes place at a point in time t_i in the building model. These model quantities are

- visualized in the Control Monitor,

- allocated to the time of the calculation and the element codes and

- saved in a database.

The building model is thus quantitatively fixed with reference to time. The calculation can be repeated at other times t_i+1 with other model statuses and/or other element codes.

The model quantities are transferred as starting volumes to the cost elements. From there, they are transferred further to the actions and offset against the action-specific values. The geometric quantities become action-performance quantities, so called performance quantities or QTQ values. They also inherit the identifiers of their original elements in the building model.

3D solid	Element code	Solid identifier	QTQ variable$_1$ (e.g. area) QTQ variable$_2$ (e.g. volume) QTQ variable$_n$ (e.g. length)

Cost element	Element code

Action$_1$	QTQ formula	{Solid identifiers}
Action$_2$	QTQ formula	{Solid identifiers}
Action$_n$	QTQ formula	{Solid identifiers}

Every QTQ variable of a 3D solid is characterized by the following features:

- Name
- Number
- Dimension
- Unit of quantity
- Calculation value
- Result

Example of the QTQ variable for the longitudinal area of a wall:

```
Name = WMF
Number = 10003
Dimension = 2
Unit of quantity = m2
Calculation value = 5.00*2.75
Result = 13.75
```

QTQ variables from the building model can be a component part of the QTQ value formula of a service.

Example of the calculation of the action quantity X by means of the QTQ formula of a service, e.g. 'Place wall formwork':

```
X=2*WMF
```

If, therefore, an action is evaluated from 3D solids, the quantity I is known by solid identifiers. This enables a graphic labeling of the affected solids of an action in the Control Monitor of the Building Book.

6.4   Generating processes by means of a technological grid

Building sections in connection with the building process are defined through the direct allocation of 3D solids or through the graphic inputting of construction spaces in the form of cubes. The outcome of this process is a technological grid in the building book.

The result is that a number of processes n, which take place in different building sections, emerge from a specific action respectively. Each process assumes a certain amount of solid identifiers I' and a proportional quantity X' from an action.
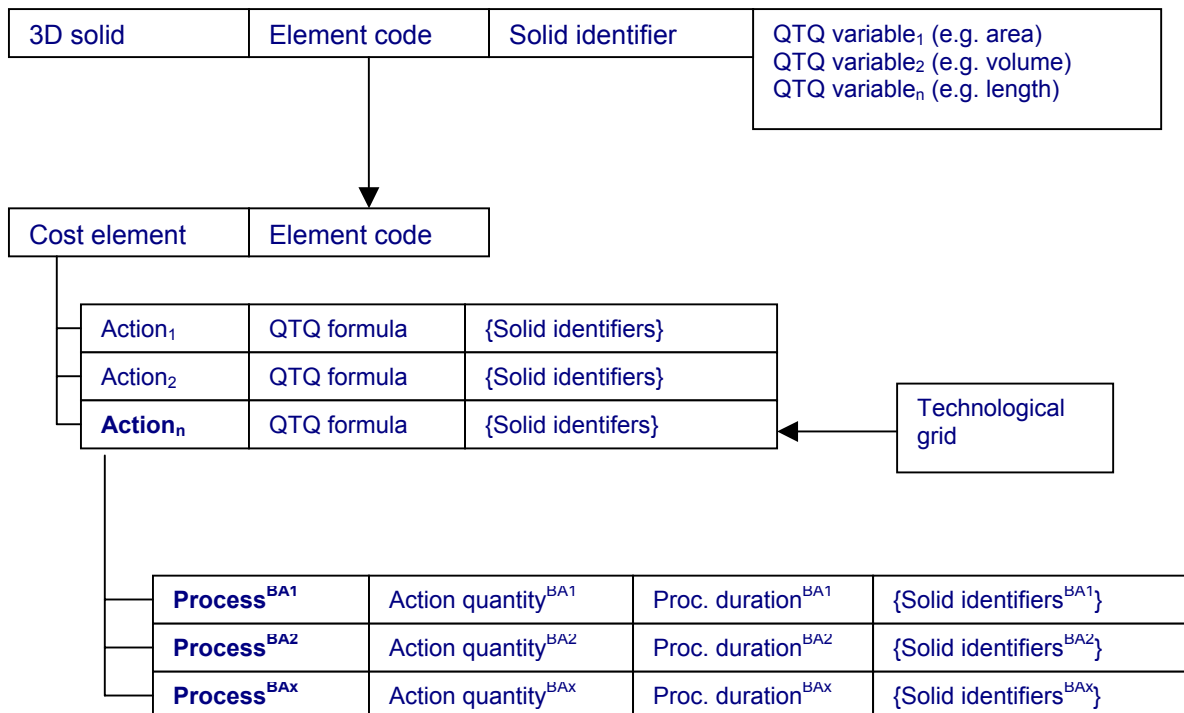
The construction schedule provides the start and end date for each process. The relevant procedure is not further detailed here.

ProcessBA	Process startBA	Process endBA	{Solid identifiersBA}

The two values for the process start AT_V and the process end ET_V are viewed as integers in a time unit and imported as attributes from the 3D solids in the building model.

View filters perform the graphic filtering of 3D solids,

- the process start and end of which are within a time interval or

- the process end of which is before a specific date or

- the process start of which is after a specific date.

Example :

```
# draw walls start and end between day 0 and day 30
# of building process (red color)

WALL solid (a_start i [0,30]) (a_end i [0,30])
     drw 'state1' 3 0 0 0;


# draw walls end till day 90 of building process (green color)
WALL solid (a_end i [0,90])
     drw 'state2' 2 0 0 0;


# draw walls start from day 60 of building process (blue color)
WALL solid (a_start i [60,*])
     drw 'state3' 1 0 0 0;
```

7 Added value thanks to the Central 3D Building Model

Based on a Central 3D Building Model, the Building Book supports the three different viewpoints resulting from the division of work in the planning, construction and monitoring of a construction object:

- the planning-oriented view of the architect,

- the execution-oriented view of the construction company and

- the monitoring-oriented view of the client.

1. The Building Book methods described above are proof that it is possible to create machine-supported calculations and building processes on the basis of a building model and to visualize these with the help of powerful, graphic procedures without the installation of a complete CAD system.

2. The use of VR software also makes it possible to derive simulations on virtual construction objects from the building model that is enhanced with attributes from the cost calculation and process schedule.

3. It becomes evident that a reduction can be expected in the obvious redundancy of activities by multiple disciplines in the construction process at the overlaps in the building, element and schedule model interfaces.

4. In terms of schedule and execution alterations made to the building model, changes in schedule and costs are consistently documented.

5. Automatic comparisons of alternatives can be made to a rough building model in the early planning stages thanks to the Building Book element filter technology.

❖