ARMILLA5 - Supporting Design, Construction and Management of Complex Buildings

LUDGER HOVESTADT
University of Kaiserslautern - ARUBI:CPE - Germany - lhov@rhrk.uni-kl.de
VOLKMAR HOVESTADT
University of Karlsruhe - IFIB - Germany - volkmar@ifib.uni-karlsruhe.de

Abstract: ARMILLA5 is a generic computer aided design system, which supports the cooperative design of complex buildings (such as labs, offices or schools) over multiple levels of abstraction. It follows the metaphor of a virtual building site. The designers and engineers meet at a spatial location on the InterNET and prepare the building construction by simulating the building site. This article describes the three essential components of the ARMILLA5-model: the geometric model which describes the spatial and physical aspects of the building site, the semantic model which implements passive building components as objects and active building components as applets or applications, and the planning model, which organizes the work steps of the individual engineers and their cooperation. The model is described using different software prototypes written in Objective_ C, CAD systems and HTML/JAVA.

Keywords: Dynamic Buildings, CAAD, CSCW, VRML, Casebased Reasoning, Facility Management, Augmented Reality

Figure 1: *The Swiss railroad's instruction building in Murten, CH in the MIDI construction system. Exterior and interior views, MIDI construction, detail of support column, assembly of interior wall system and suspended ceilings. All construction components used can be dismantled, and their configuration can easily be changed. The building was completed in 1982 and has been renovated four times since.*

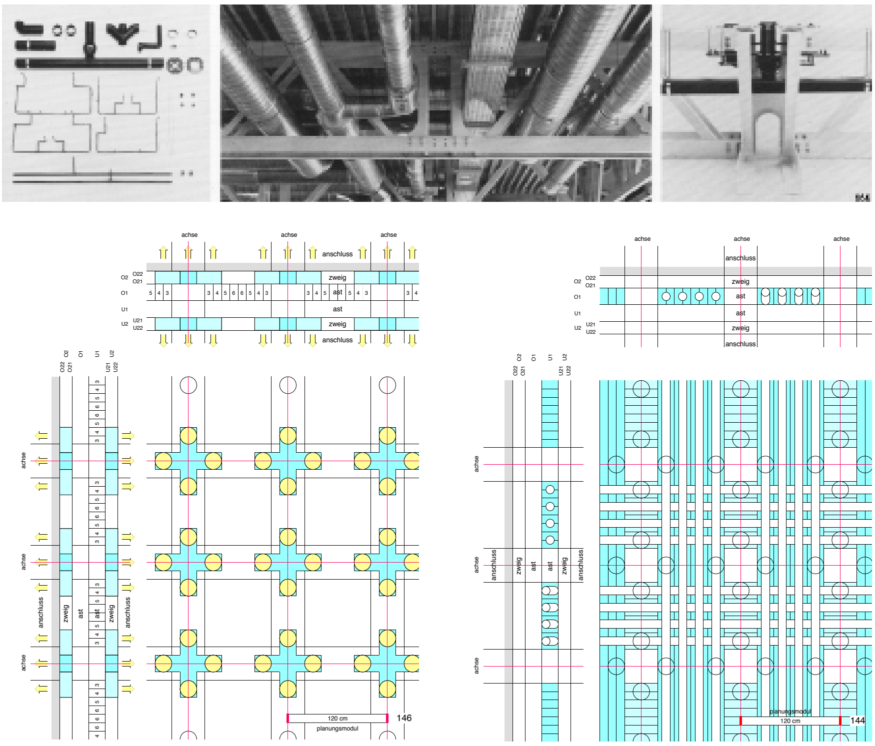

__Figure 2__: Views of the general installation model of ARMILLA. The goal of ARMILLA is to modularize the technical systems in dynamic buildings. The views in the first row show the integration of the constructive system (MIDI) and the technical system (ARMILLA) using the example of plumbing. The lower views show charts with planning rules that make it possible the designing of reconciled modules of the technical systems needed for a building [Haller 97].

1 The Context of ARMILLA5

ARMILLA5 is based on the construction modules MINI, MIDI and MAXI, which were developed by Prof. F. Haller in the 1960s and have widely been used in Switzerland [Haller 74, 88]. The main characteristic of this building is that it can be completely disassembled and reconfigured. The construction and use of the building is based upon a permanent design of a dynamic building. New construction is seen as a special category of remodeling.

These construction modules are supplemented by the generic installation system ARMILLA [Haller 85]. The goal of ARMILLA is the control of technical systems in complex, dynamic buildings (such as office buildings, schools and laboratories). ARMILLA is not a closed system, but rather a planning system that allows technicians to confer regarding numerous planning phases of their technical systems in a given building as building blocks. They attain a high degree of planning reliability, faster assembly and they can simply reconfigure their systems for a change in use without necessitating the destruction of building components.

The MIDI and ARMILLA systems are currently in use for new construction in the architectural firm of Prof. F. Haller, however without computer support.

ARMILLA5 is the fifth software prototype to result from the planning and building system of MIDI/ARMILLLA. In the concepts presented in ARMILLA5, examples of MIDI/ARMILLA are used, but the systems presented are easily transferred to other architectures. In the following, three different partial models of ARMILLA5 are presented: the geometric model, the semantic model and the planning model.

The geometric model (GM5) describes the geometric physical context of the building planned with ARMILLA 5 . As the lowest common denominator of all modelings in ARMILLA5, it also has the role of the integration model. It is supplemented as needed by the so-called subject models in the semantic model of ARMILLA5 (SM5). For previously modeled buildings, GM5 can be kept very simple: in a worldwide coordinate system, orthogonal spaces (containers) are assigned at specific locations - virtual construction sites. The semantic model of ARMILLA5 (SM5) describes in subject models how these containers are used with information regarding construction components, planning tools or representations of people. The planning model (PM5), as a third partial model of ARMILLA5, describes how these containers are configured and arranged on a “virtual construction site”, so that they simulate real construction sights in preparation and can assist in control of the real building. Descriptions of the various levels of abstraction are primarily required in order to do so.

2 The Geometric Model

Here the geometric model of ARMILLA5 is described with the editors of the prototype implementation of ARMILLA5 system: figure 3 shows the graphic editor of the ARMILLA5 system with a so-called personal planning section (PPS) in figure 4 by hyperlinks, for example from a mail system on a particular planning issue. By means of hyperlinks to PPSs, can not only planning issues be formulated, as in the example, but also new procedures for work processes or interactive tutorials can be created.

Figure 5 shows the graphic editor, produced by the hyperlinks mentioned above, tailored to a particular virtual construction site. Each hyperlink first creates an A5 navigator, represented at the lower left margin by the rectangle surrounding a small interface. Two A5 navigators are pictured in figure 5. In a second step, they create a link to an A5 InterNET server. A5 servers are installed by specialized planners and manage the various component systems of the ARMILLA5 building as an classification of subject models (see SM5). In a third step, A5 navigators load certain planning elements/containers into the graphic editor, where they can be

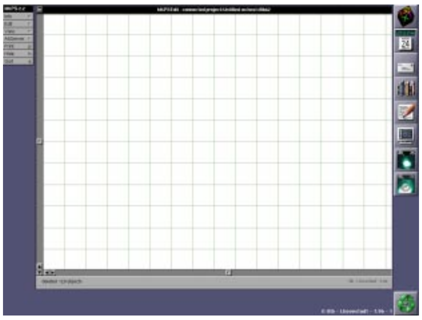

Figure 3: *The graphics editor of ARMILLA5 in the worldwide coordinate system.*

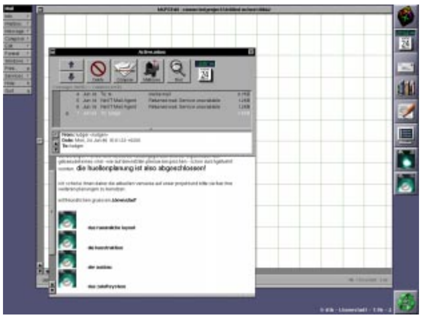

Figure 4*: The positioning of the personal excerpt of the plan, e.g., through the hyperlinks of a mail system.*

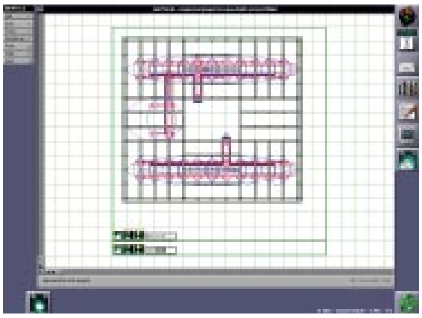

Figure 5*: A5 navigators build links to A5 Inter-NET servers so that construction components of the „virtual construction site“ can be edited. Here, two A5 navigators with links to a construction server and a return are server are installed.*

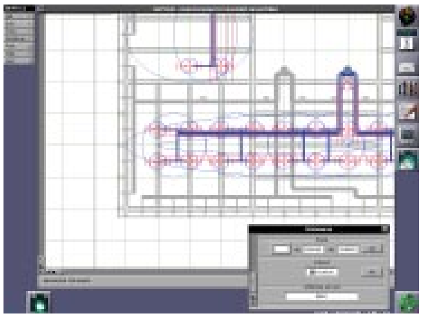

Figure 6*: The graphic editor is used here to enlarge an excerpt from the plan and to bring the construction components of the return air system to the foreground for editing.*

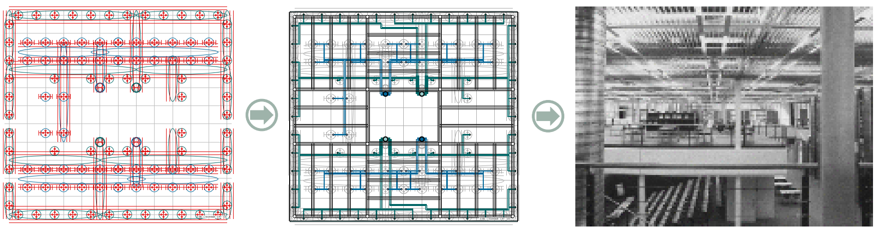

Figure 7*: ARMILLA5‘s geometric model describes buildings at various levels of abstraction. Shown here are: a strategic planning stage at the level of sketches in the virtual construction site, a more detailed planning stage of the virtual construction site, and, at the last level of detail, the real construction site/building.*

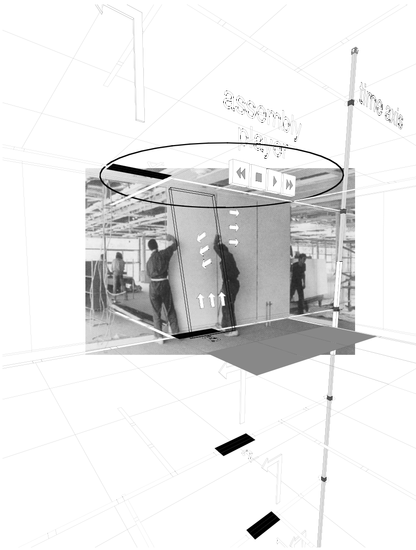

Figure 8: *The components of the virtual construction site can expand the real construction site through appropriate projection processes (e.g., semitransparent glasses with stereoscopic projections), here, for example, instructions for erecting walls.*

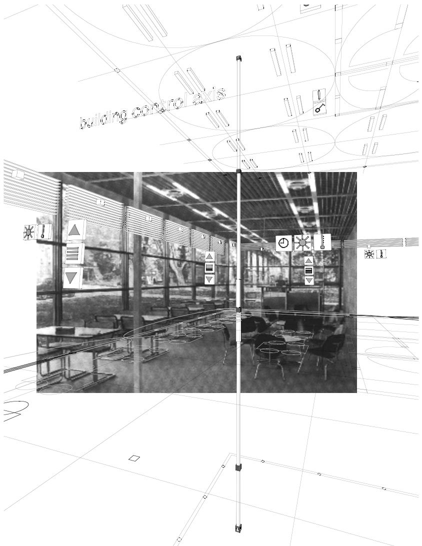

Figure 9: *With the same projection technologies, the virtual construction components can be used for, e.g., facility management. Here, for example, a janitor's view with various control and indicator elements.*

edited. In figure 5, links to the A5 servers of the return air and the load-bearing elements have been installed and planning elements have loaded an intermediate level of abstraction. During the work in the graphic editor, A5 navigators serve as „parent“ to their planning elements, make read/write access possible, and manage A5 server addresses.

ARMILLA5 is based on the concept that the virtual construction components are a preliminary simulation of the actual building process, and that the last concrete stage of the model represents the real building site (figure 7). Figure 8 shows how ARMILLA5‘s preliminary virtual structures can support ARMILLA5‘s real structures. Shown here is an abstract virtual construction component, which projects installation instructions into the real construction site. Figure 9 uses a Facility Management Application to show that ARMILLA5‘s virtual structures can also be meaningfully expanded even during actual construction. This conception is particularly useful for the idea of a „permanent construction site“ for „dynamic buildings“. ARMILLA5 formulates an expanded concept of architecture, in which real and virtual structures complement each other and can be treated in essentially the same way.
The ARMILLA5 model is not limited to proprietary software. With reduced functionality, it can also be implemented with a conventional CAD system (figure 10 and 11) or in the WWW (figure 12).

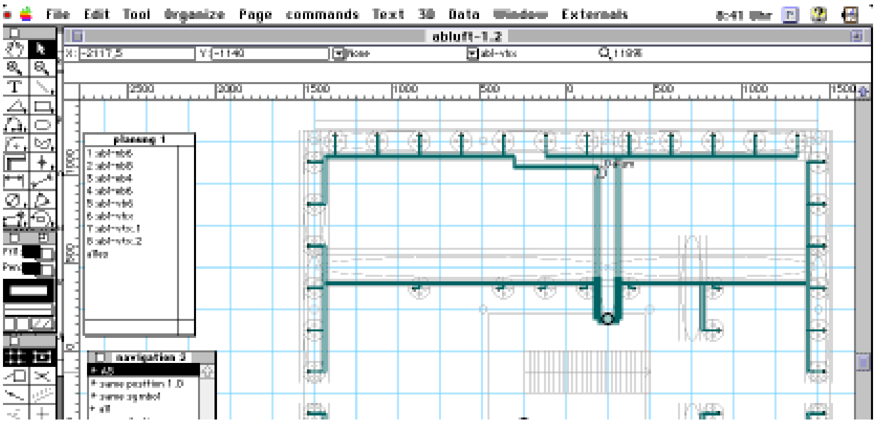

Figure 10*: View of a CAD system (MiniCAD, Graphsoft) on the ARMILLA5 model. The outcome of the planning model (PM5) is symbol, class and layer structures (upper panel at left), and the A5 navigators functionality is made available through a collection of smaller programs (here MiniPascal) (lower left panel).*

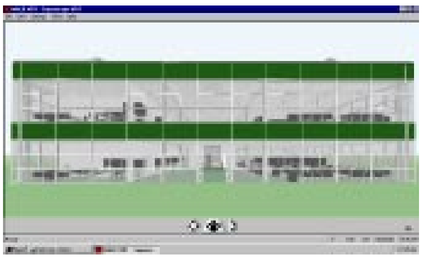

Figure 11*: A VRML view of an ARMILLA5 building.*

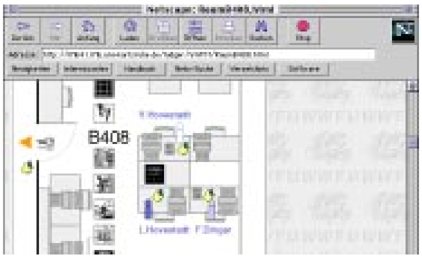

Figure 12*: This figure is an example for the same Facility Management System which in this case is usable in the form of maps in the InterNET.*

3 The Semantic Model

The semantic model of ARMILLA5 (SM5) describes the information filling the containers of the geometric model (GM5). SM5 employs an object-oriented modeling method using taxonomies, inheritance, polymorphism, relationships, etc.. Each of ARMILLA5‘s planning elements is anchored as a container in the geometric model and as a determinant in the semantic model. In contrast to the geometric model, the semantic model works from partial/subject models, since it does not seem realistic to develop a consistent model for all buildings. The examples in this article use the MIDI and ARMILLA subject models, which follow the systematology of the corresponding construction system. However, other subject models can easily be envisioned.

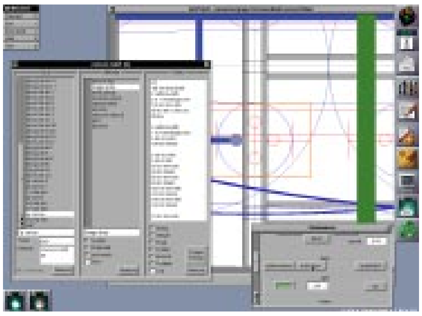

Figure 13: The semantic editor A5Browser, like the graphic editor, has access to the A5 servers. However, it shows a semantic view of the A5 server's contents, rather than a graphic view. In this example, the A5Browser is launched by the selection of a construction component in the graphic editor and the command „edit instance," and causes these construction components to appear and be displayed on the A5 server. In the first column, the semantic editor shows a list of all construction components of the A5 server; in the second column it shows the attributes of the construction component selected in the first column; and in the third column it shows the contents of the attribute selected in the second column. Selected here is the „object-instance" attribute that contains a reference to the class information of the selected construction component in another A5 server.

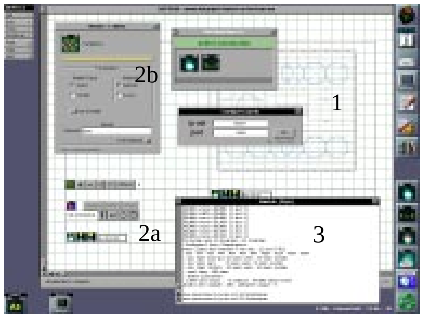

***Figure 14**: This illustration shows the three levels of semantic modeling in ARMILLA5. 1: Passive construction components are created as objects with attribute-value pairs and are treated as graphic objects. 2: Simple active construction components behave differently and offer the user several levels of interfaces inside (a) and outside (b) of the drawing surface. 3: Complex functions are offered on the InterNET server and are controlled by active construction components.*

Most of the semantic model's planning elements are passive objects such as supports or girders. A few components of the ARMILLA5 system are implemented as active objects: in addition to a graphical representation (which passive objects also have), they offer the planner interfaces with which other ARMILLA5 system planning elements can be edited. This modular concept is based on the idea that the planners go to the „virtual construction site" with their „tool boxes" in order to be able to carry out their planning tasks. Simple active components correspond to JAVA applets and are installed and implemented on the user's host. One example is the A5 navigator described above. In ARMILLA5, the A5 navigator is implemented with Objective_C under NextStep. Complex active objects are implemented as stand-alone applications (e.g., in CommonLisp or Objective_C) and installed on an InterNET host: As a server, they offer their services on the network and can be used as simple active objects. The A5 servers described above are one example.

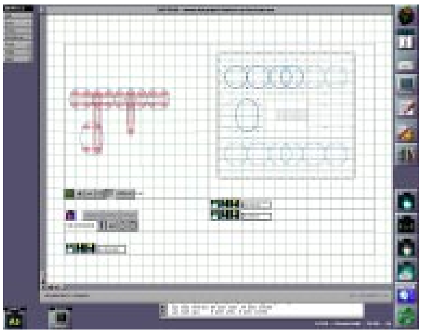

Figure 15: Case-retrieval and adaptation by ASM and TOPO

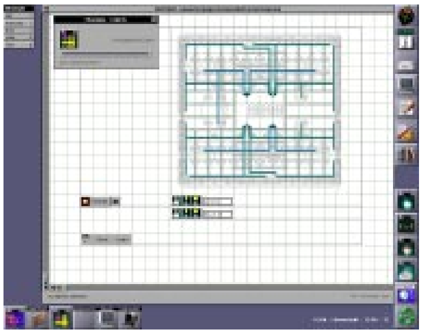

Figure 16: Arrangement of ducts and pipes in a given construction grid by ANOPLA.

In the FABEL project [FABEL 93 - 96], a large number of complex active construction components was developed [FABEL 93-96, Report 40]:

Retrieval Tools

- RABIT: A versatile retrieval system using similarity measures based on case attributes.
- ASM: A fast retrieval tool using an associative memory; the similarity is also based on attributes.
- ODM: Geometric arrangements of objects are retrieved by comparing object density maps.
- TOPO: Cases are transformed into graphs representing topological relations.
- ASPECT: Combines pre-computed similarities of stored cases with respect to different similarity measures (aspects) using the „fish and shrink“ heuristics to effectuate retrieval.

Adaptation tools

Retrieved cases will generally not fit as they are; some adaptation has to take place. This adaptation uses other types of knowledge in addition to the source case. Depending on the knowledge used, an adaptation tool may be more or less powerful, highly specialized or widely applicable.

- TOPO: After retrieving a useful case, Topo is able to transfer objects (of a given type) from the source case into the query case maintaining the topological relations between matching objects.
- AAAO: Arrangement of columns in a steel frame construction given a floor plan obeying static and aesthetic restrictions.
- SYN: Transfers branch lines (e.g. for return air) from clustered cases into the incomplete query case in order to connect the trunk pipe with the outlets.

Construction and assessment tools

Some tools work, or can work, without using source cases to design certain parts of a building. AAAO can also be classified here. Other tools find failures or inconsistencies in a complete or partial design. Topo can also be used for this purpose because it finds unusual relations in a given query case.

- ANOPLA: Arranges provisionally placed pipes so as to obey a given construction grid (template) and to avoid collisions.
- CHECK: This tool checks whether a set of topological predicates holds for objects of certain types; this knowledge was derived (learned) from cases.

4 The Planning Model

The ARMILLA5 (PM5) planning model describes the course of planning. It orders the planner's work through the various stages of elaboration of a plan and orders way in which the various planners can work together. PM5 describes the planning in the form of a tree structure: the roots of this structure indicate the total planning process (GP), and the leaves describe the basic planning steps.

Planning Scale

Overall planning consists of planning at various planning scales (PM). It begins with rough overviews and ends with fine details. Planning scales are the general milestones of planning and can be counterparts of planning phases, of the German HOAI, for example. Seven planning scales are currently formulated in ARMILLA5:

- In *Preplanning 1000* (v10), planning elements the size of main buildings and streets are brought together. This corresponds roughly to a plan on a scale of 1:1000.
- In *Preplanning 500* (v5), planning elements the size of secondary buildings and smaller roads are brought together. This corresponds roughly to a plan on a scale of 1:500.
- In *Preplanning 200* (v2), planning elements the size of stories and main exploitation are brought together. This corresponds roughly to a plan on a scale of 1:200.
- In *Preplanning 100* (v1), planning elements the size of use zones and corridors are brought together. This corresponds roughly to a plan on a scale of 1:100.
- In the *Line Plan* (lp), all construction components present are described in their approximate spatial location and are fitted together. This corresponds roughly to a plan on a scale of 1:50.

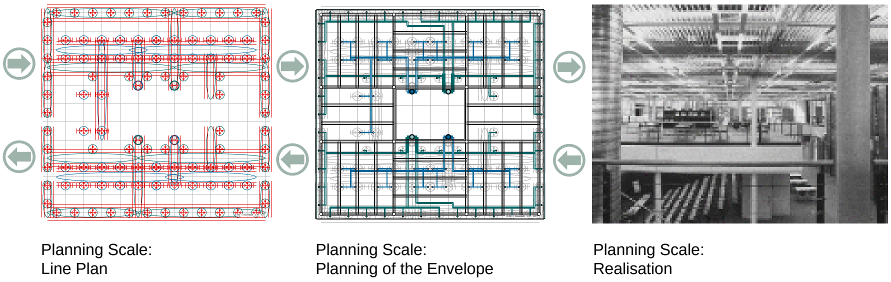

Figure 17*: An ARMILLA5 building is described in numerous abstraction levels.*

- Durin the *planing of the envelope* (pe), all construction components present are described in their exact spatial location and are fitted together. This corresponds roughly to a plan on a scale of 1:20.
- During the *planing of the components* (pc), the real construction components are chosen and arranged. This corresponds roughly to a plan on a scale of 1:10.
- With the actual building, the *realization plan* (rp) is the last stage of making the ARMILLA5 model concrete.

Planning Area

For planning in ARMILLA5, subject models must be used. They describe specific conceptions of architecture and construction in their components and development. In ARMILLA5, the following subject models have previously been used:

- *SPACE*: This subject model formulates the transformation of the space catalogue into a spatial layout.
- *MIDI*: This planning model is taking over the construction planning area.
- *ARMILLA*: The ARMILLA planning model describes the technical building features planning area.

The names of the planning areas arise from both the abbreviations of the planning scales and the names of the drafting models: e.g., „lp-midi“ planning area indicates the Line Plan (lp) planning scale of the MIDI planning model.

Planning Aspect

A planning area is worked on by several planners. They take on various component tasks called „planning aspects.“ (The term „planner“ is used here in a general sense. Naturally, it is conceivable and even possibly sensible for a single planner to work on planning aspects such as, for example, return air and exhaust or façade and lower slab. Cooperation of the various planners involved is described at the planning aspects level.

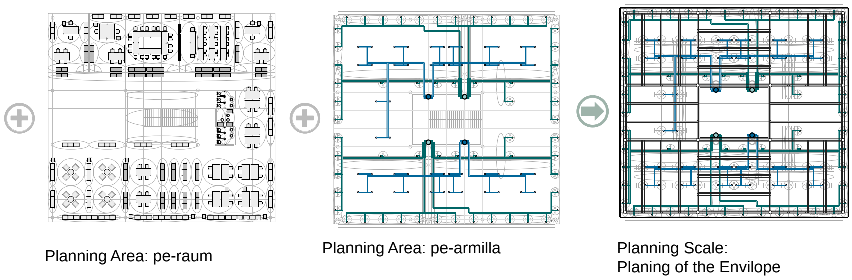

Figure 18*: The plans of a scale follow various subject models, here for spatial ground plan, construction, and building technology.*

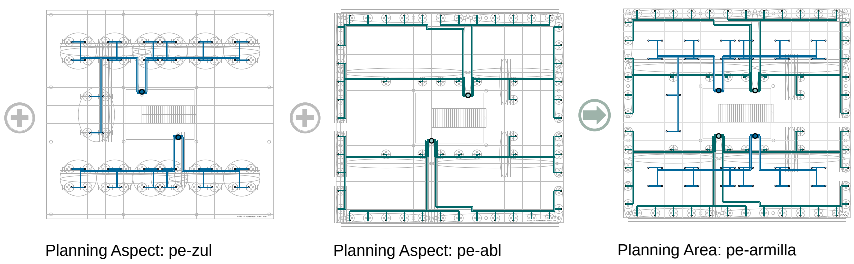

Figure 19*: A subject model consists of planning aspects, which define the work of the various planners needed.*

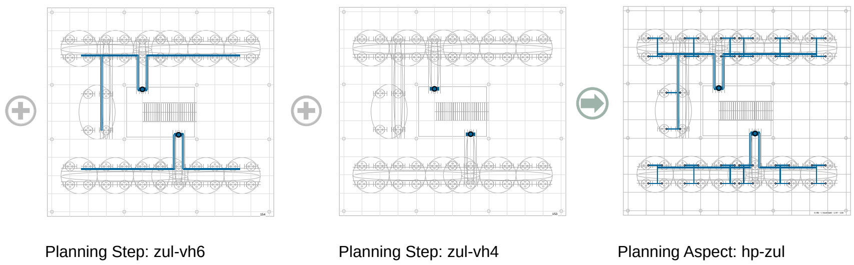

Figure 20*: The work of a planner consists of various planning steps. The basic planning elements from catalogs are classified and configured in a planning step.*

For the RAUM subject model, planning aspects are currently formulated as rau (spatial layout) and lct (lighting). The MIDI subject model formulates the planning aspects as bdn (floor), dch (roof), fas (façade), trl (stairs, elevator), trw (construction), udk (lower slab) and wnd (interior walls). The ARMILLA planning model consists of the planning aspects abl (exhaust), abw (sewage), zul (return air) and approx. 20 other technical systems. The names of the planning aspects are formed by combining the planning scale descriptor and the responsible party: lp-abl indicates planning for exhaust air (abl) at the Line Plan (lp) level of detail.

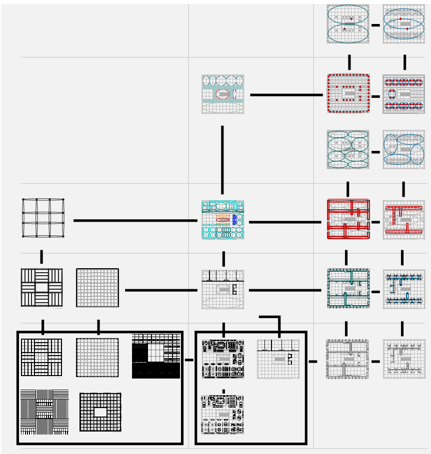

***Figure 21**: Excerpt from a chart with ARMILLA5's planning aspects, with which the collaborative work of the various planners can be coordinated.*

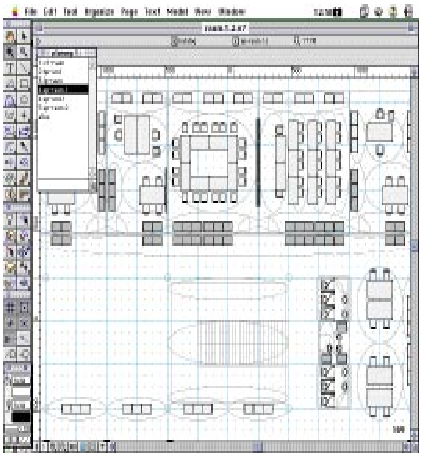

***Figure 22**: Resources and instructions for a planning aspect, presented on an HTML page.*

Planning Step

Each planning aspect consists of various planning steps. Planning steps are altered exclusively within a planning aspect. Planning steps include the tasks that can be performed with one operation and by one person.

Planning Element

By „planning elements" is meant the container/construction components familiar from the geometric and semantic models. They can be assigned to a single planning step and thus lie within the area of responsibility of a specific planner. The current version of ARMILLA5 includes approx. 600 different planning elements.

5 Tools of the Planning Model

Planning support tools can be derived from the described system for a planning model.

Figure 21 shows an excerpt from a chart on which the planning aspects of an ARMILLA5 plan and the tasks of the individual planners are noted. Horizontal links on this chart indicate that a planning aspect must be reconciled with other planning aspects. Vertical connections vertical links lead a planner through the various phases of his planning process. This chart can also give an overview of the actual state of development of a plan, since completed planning aspects are highlighted in comparison with the planning aspects which have not yet been completed.

Figure 22 shows a tool that complements the planning chart, produced in HTML. For each planning aspect, an HTML page is created making all necessary information, instructions, previous experiences, and resources available to the planner in one place.

6 Working Methods in the ARMILLA5 Model

Working With Catalogs

As shown, a single planning step can be assigned to several planning elements. Within a planning step, it is a planner's job to classify planning elements on the virtual construction sites, arrange them, and reconcile them horizontally and vertically with the planning elements of the neighboring planning steps. For this purpose, the possible planning elements are offered to the planner in a catalog corresponding to the planning step. This process is very general, technically easy to carry out, and theoretically possible for any plan. However, it has the disadvantage that, primarily in the case of complex planning steps, the use of the planning elements does not follow intuitively from the planning elements themselves. The planner must therefore be trained outside of the system and before actual planning takes place. Furthermore, the working method is reduced to many small actions and becomes nothing more than a search for the appropriate component in extensive catalogs.

Working With Cases

Another working method presents itself in the use of cases, which means that successful parts of planning processes or planning episodes are stored in a case database and, thanks to appropriate indexing, can be proposed as a solution for new but similar planning situations. Case-based inference was the research emphasis of the FABEL project. It was divided into „retrieval“ (how the appropriate case for a planning problem is found) and „adaptation“ (how a case can be adapted to the new planning problem). It can also not be decided whether a case must be divided into „problem“ and „solution.“ In the majority of cases, in FABEL, the path selected was that a case simply describes a large number of planning elements that can be approached as the solutions for a number of problem formulations, (arising from the planning interrelations of the current plan).

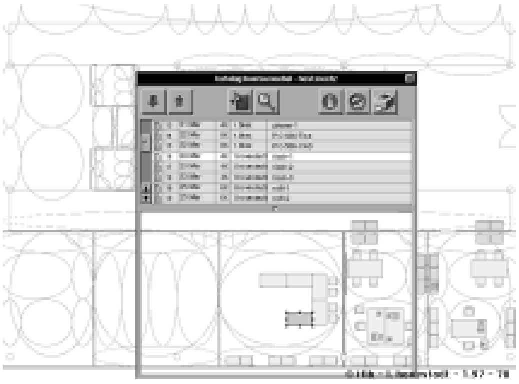

Figure 23: *A simple editor for working with catalogs in ARMILLA5. An active construction component offers the planning elements of a planning step on a list for classification and organisation on the virtual construction site.*

Cases have many advantages in comparison to catalogs:

- Planning can be carried out in larger, interrelated units and a planner need not carry out so many elementary actions.
- The planning elements of a case are already interrelated in a meaningful way (or, to give a negative example, in a way known to be detrimental). This interrelationship no longer needs to be explicitly formulated by a planner, but can be implicitly assumed.
- Cases are not offered as isolated cases by a retrieval process, but rather in a cluster of comparable cases for similar question formulations. A planner is thus informed about his possible actions and can make an informed decision about a solution.
- The user also has the possibility to learn by doing while working on customary planning structures. As long as he has the basic knowledge and works with positive examples, he can assume that he has made no fundamental errors. In this case, unlike that of catalogs, it is possible to work within defined planning structures, without learning them thoroughly before planning takes place.
- Because this technology allows work in outside models, case „marketplaces" for planning services can in principle be established from the models of various planners combined relatively freely. The CaseBank (figure 25) is an implementation of this concept on the InterNET, using HTML and JAVA.
- Cases are first and foremost a construct by which plans are handed down and by which planning processes can be established without models formulated before each planning process. In combination with conventional modeling technologies, their exceptional capability unfolds: to economically describe the basic framework of a plan through models in the form of catalogs and prototypes (see next page). With cases, the many exceptions and special cases that come up in general use are formulated and made available for later plans.

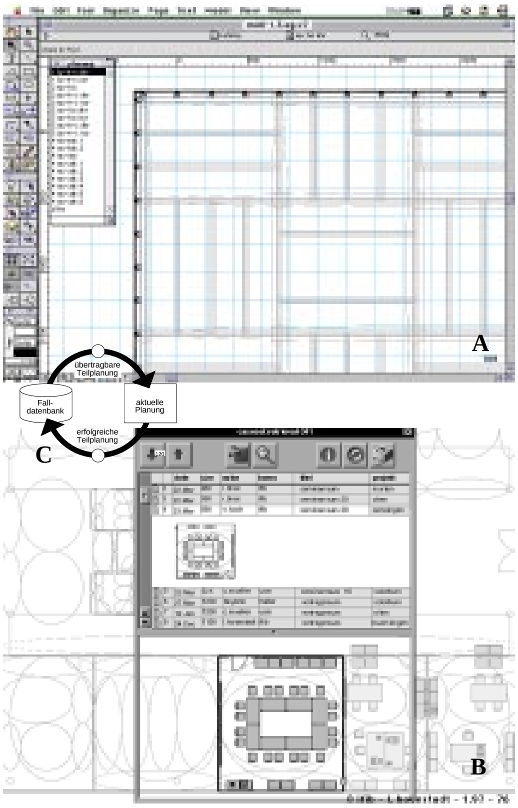

***Figure 24**: A simple editor for working with cases in ARMILLA5. A: On the basis of a selection of planning elements from the virtual construction site (corresponds to the problem formulation) from a case data bank (here, the ep-raum planning aspect data bank), an active construction component offers a selection of similar cases, determined on the basis of qualitative, quantitative, topological and other characteristics. B: A user can transfer one of these cases or parts of different cases to the virtual construction site and - possibly supported by a planning assistant - use them after adaptation as a solution to the current problem. C: The successful solution of the planning problem can then be put in the case data bank with the same tool, and will be available as a case for future plans. In this illustration idealized representations of the ARMILLA5 prototype are depicted.*

Working with Prototypes

A third form of working with complex models is the use of prototypes: completely planned-out buildings serving as models for a current plan. In this case, the actual planning does not consist of the creation and organization of new planning elements, but of a revision planning of this prototype building to make it match the requirements of the current plan. The prototype buildings are thus designed with the didactic goal of overcoming the greatest possible number of planning situations with a typical solution and to structure the revision planning as simply as possible. Even more than working with cases, this manner of proceeding makes it possible to use an „outside“ model for the prototype, without the latter having to be familiar with all of the details of this model from the outset. Seminars with students have shown that the effort needed to get used to complex models is substantially reduced through the use of prototypes in planning. Through this process, the use of complex models such as MIDI or ARMILLA by „outsiders“ is, for the first time, possible without excessive frustration.

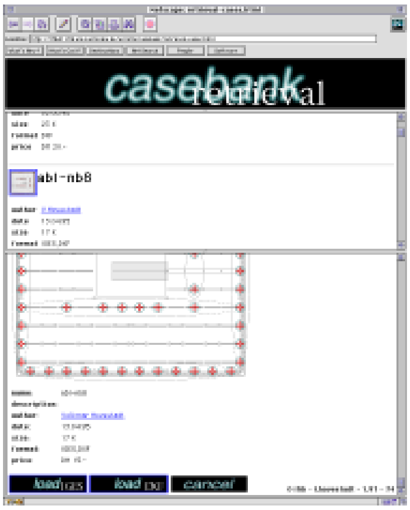

Figure 25*: The CaseBank is a concept, by which a „marketplace“ for partial planning services could be organized on the InterNET with case-based methods. Users could place successful partial plans in the CaseBank. These would then be distributed to other users with similar planning problems via the CaseBank.*

As an isolated process, working with prototypes could not find new solutions to structurally new queries. For this reason, it is only in combination with catalogs and cases that it becomes a powerful tool for the elaboration of adequate solutions to practically relevant problem formulations. The example building provided with the planning steps of the ARMILLA5‘planning model is a prototype in the sense described here.

In the last four years ARMILLA5 had been the domain of the FABEL project, titled ‚Integration of model-based and case-based approaches to the development of knowledge-based Systems‘ (contract no 01IW104 - BMBF) [Fabel 93 - 96] [Gebhardt et. al. 97].

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