The ARMILLA project

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Abstract:
ARMILLA describes a major agenda for a variety of different CAAD research projects at the Institute for Industrial Building Production (IFIB) at the University of Karlsruhe. This paper provides an overview of the research and development of ARMILLA over the past 10 years. A discussion of the ongoing implementation efforts is included with a summary of current research.

Keywords:
Product model; Building systems; Object-oriented design; Virtual building components; Augmented reality

Fig.1. The building component system MIDI of Prof. F. Haller marks the beginning of the ARMILLA project.

1. The building component system MIDI, 1974

The elements that form the foundation of the current ARMILLA project are the building component systems MINI, MIDI, and MAXI developed by Professor F. Haller (Fig. 1) during the 1960s. They were especially used in Switzerland. These preengineered systems are designed to facilitate complete disassembly and reconfiguration. The buildings thus formed by the component systems can be called flexible and dynamic. Their design is never finished and is closely linked to the building management during the whole life cycle. This sort of design can be called a permanent design of dynamic buildings [5,7].

2. The installation model ARMILLA, 1985

The main obstacle to the flexibility and adaptability of buildings stem from their technical systems. This is especially relevant in highly complex buildings like laboratories or office buildings. These buildings can only be adapted to different needs, if their construction components and their technical components obey to an overall system of design.

In 1977 Prof. F. Haller started his research on this field of integration at the University of Karlsruhe. The research resulted in the general installation model ARMILLA. This model describes a methodology for the spatial coordination and the cooperative design of the technical assembly of complex buildings, The general installation model has to be adapted to specific buildings. These adaptations are called special installation models. Fig. 2(1) illustrates the adaptation of ARMILLA to the construction system MIDI.

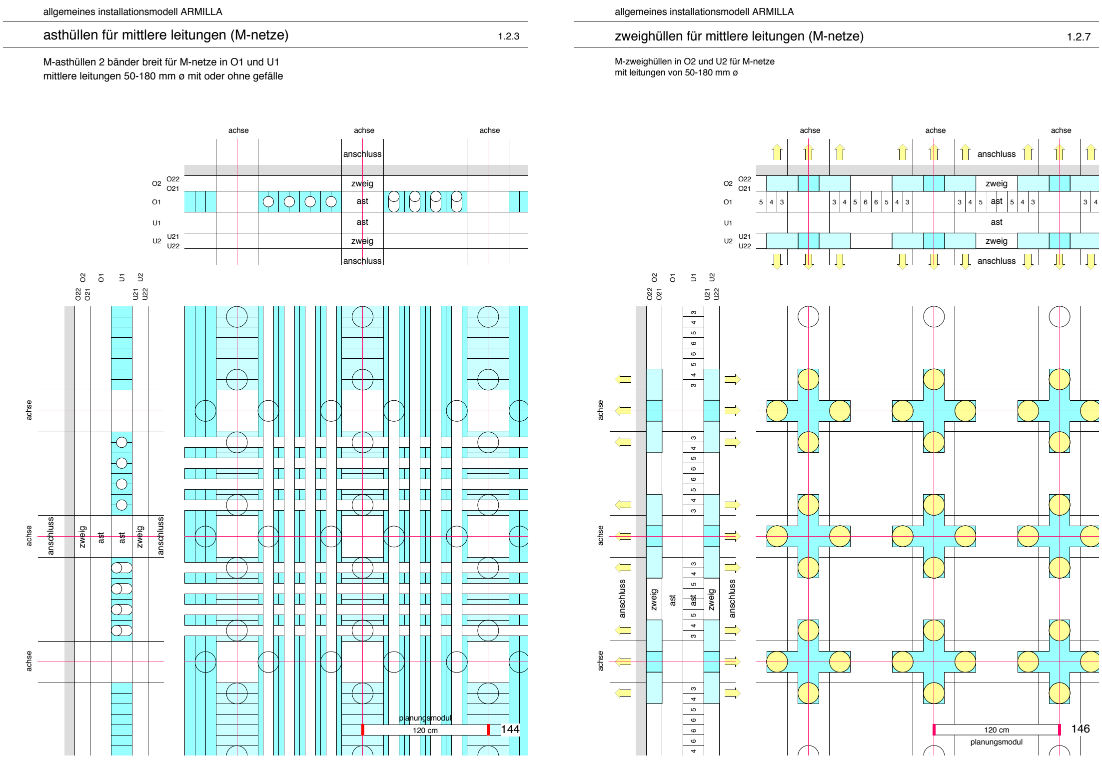

Fig.2. (1) Integration of construction systems (MIDI) and technical systems (ARMILLA). (2) Plan view of possible pipe lines. (3) Pipe line possibilities in the z direction.

In order to answer to questions of diverse application, ARMILLA was conceived as more than simply a kit of prefabricated building components. ARMILLA, therefore, attempts to support its modular design on different levels of abstraction, from early sketching phases through specific construction details. It describes how an arbitrary technical system can be designed modularly with respect to the other systems of a building. Fig. 2(2-3) illustrate these concepts. As an example, at a medium level of abstraction ARMILLA describes a spatial network of potential positions (referred to as ‚lines‘) for the different installation systems. Fig. 2(2) shows the possible ‚lines‘ for medium-sized pipes (10-20 cm diameter) in the x and y directions. Fig. 2(3) shows the lines of these pipes in the z direction [8].

The first version of the ARMILLA model was completed in 1985. It is still in development and in use in the architectural practice of Prof. F. Haller [6].

3. ARMILLA1: design automation, 1986

To manage the complexity of the installation model ARMILLA the research concentrated from 1985 on its support by computers. The first software version entitled ARMILLA1 was finished in 1986. It follows the idea of ‚design automation‘. The system demonstrated, that the implementation of the ARMILLA model as a computer aided design tool based on objects and rules is possible.

However, the experiments using KnowledgeCraft made clear that even large rule-based systems could not work on small parts of the design without fault [15]. ARMILLA1 was implemented in Pascal and later in CommonLisp. Frames and rules were used for knowledge representation. On a PDP11, sequences of planning steps ran on different abstraction levels without the possibility of user interaction. The system had a capacity of approximately 50 objects [15]. Fig. 3 illustrates two design steps within the first prototype of the ARMILLA project.

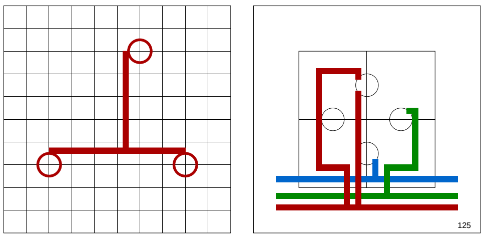

Fig. 3. Two design steps within the ARMILLA 1 prototype.

4. ARMILLA2: blackboard system for the coordination of planning assistants, 1988

To address the shortcomings and lack of flexibility inherent in design automation, the second version, ARMILLA2, pursued the idea of design assistants. The research concentrated on the iterative and multistage design process. ARMILLA2 was implemented with KnowledgeCraft as a blackboard system with a simple-to-use, CAD-like, user interface. A particular emphasis of ARMILLA2 was the design of an effective dialogue between users and expert systems on several levels of abstraction [1].

Fig. 4(1) illustrates the layout of the building and its components. In Fig. 4(2) the installation requirements are formulated. Fig. 4(3) illustrates the third step in which the so-called ‚Linienplanung‘ (line planning) for each technical system is developed. In this case, the figure highlights a strategic pipe layout for an air-supply net. The design decisions on this planning level have a fuzzyness of ± 1.20 m and therefore exhibits the character of an architectural sketch. In the next planning level, ‚Astleitungsplanung‘ (planning of the branch pipes), each technical system is localized inside a definite space [Fig. 4(4)]. To ensure success, this design step requires mutual collaboration. The next planning level, shown in Fig. 4(5), is called ‚Zweigleitungsplanung' (planning of the twig pipes). Here the branch pipes, that were the result of the ‚Astleitungsplanung,' are joined with the appliances. The spatially complex geometries of the twig pipes makes it possible, that both the location of the appliances as well as the location of the branch pipes may be moved within boundaries, without influencing themselves. These boundaries are defined in the previous line-planning level. A planning session using ARMILLA is completed by creating the individual, specific elements as shown in Fig. 4(6). On this level the physical components are ordered within the boundaries that were reserved for these systems during the earlier stages of the design. The illustrations included in Fig. 4(1-6) are taken from the ARMILLA film [10].

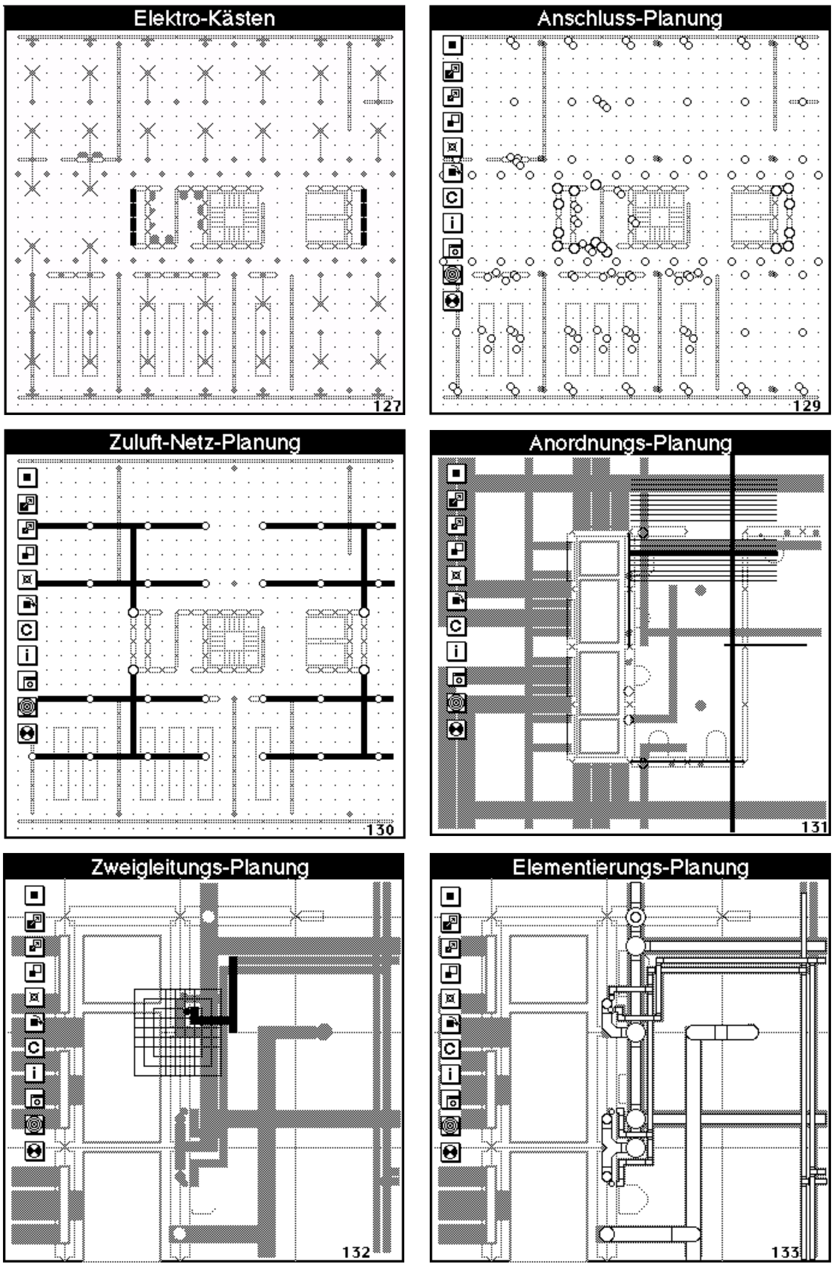

Fig. 4. (1) Building and component layout. (2) Formulation of installation requirements. (3) Line planning for technical systems. (4) Branchpipe planning in definite space. (5) Twig-pipe planning and connection to appliances. (6) Creation of individual, specific components.

ARMILLA2 was implemented in CommonLisp and KnowledgeCraft (Frames, OPS5 and Prolog) on a micro VAX and later a SUN3 platform. On the basis of a blackboard structure, one expert (air supply, sanitary facility, etc.) at a certain abstraction level (area, bounding box, element) corresponds to one knowledge source. Each knowledge source may be represented through a graphic window. This window displays the specific view of the expert on the respective abstraction level to the data of the blackboards. The user may alter the graphics and, therefore, manipulate the data of the blackboards in the role of an expert. Knowledge sources also incorporated OPS5 rules, which could take over regular user interaction (construction) or the classification of data (classification). The particular interest of ARMILLA2 has been the dialogue between users and rule systems with graphics that are easily understood. These graphics help to mediate the complex data of the blackboards. It was also important, that a user could freely navigate between the knowledge sources, that means between the experts and the abstraction levels and the rule systems, to correspond with the iterative design process. With this blackboard system approximately 250 objects could be processed in a single-user mode. The implemented rule systems referred to the design of the waste-water systems [1,9,10].

5. ARMILLA3, RETEX and A +, 1993

After several unsuccessful attempts to incorporate more realistic data quantities and multiuser functionality into the concepts and implementations of ARMILLA2 (ARMILLA3) alternative system architectures were considered and tested.

The RETEX project combined the object-oriented database ONTOS with the CAD-system AutoCAD for a multiuser design environment [3]. The system was implemented and tested without Al functionality.

The A+ project implemented the rule sets of ARMILLA inside constraint based Al tools. These tools could be instantiated and incorporated in the design as prototypes and there could be adjusted to different demands by the user [2].

6. ARMILLA4: designing in a multidimensional design space, 1994

The ARMILLA4 prototype utilizes the concept of containers placed in a multidimensional design space [11]. The ‚containers‘ can store any type of information, from simple graphic descriptions of building components like columns or beams, to attributes, such as catalogue numbers, prices or weights. Additionally, the containers can store simple functionalities of application components, for example the building control, as well as complex Al functions that support various design tasks.

Within the container model, all components of a building and all tools needed for designing and constructing it are treated structurally in the same way. ARMILLA4 uses the above described containers for the virtual assembly of a building. A multiuser and multitasking functionality is also realized in ARMILLA4 through the principle of location: Containers (and thereby users, who are also represented in the system as special containers) are forced to interact when they collide spatially with each other. In other words: If two containers do not collide, users can work independently without mutual collaboration.

In order to implement a real cooperation and communication model for the architectural planning process using the principle of location, the area, in which the containers is located, must be multidimensional. This area distinguishes between criteria, which are important for planning and construction processes: the geometry, the time, different abstraction levels, different views and versions. The dimensions of the design space are accordingly: x, y, z, time, timetag, aspect, morphology, resolution, scale, user and composition [11].

6.1. ARMILLA4 (UNIX-AutoCAD-KnowledgeCraft)

With the concept of data containers in a multidimensional design space ARMILLA4 abandoned the blackboard systems. In the first implementation of ARMILLA4 one UNIX file corresponded to one data container. Analogous to frames, the attributes and values of the containers were put in ASCII format. The axes aspect, morphology, resolution and scale of the design space were implemented temporarily as UNIX directories. The axes x, y, z, time and timetag were managed by small C programs. Through the use of UNIX the containers could be processed by several programs simultaneously. For the graphic input and output the CAD-system AutoCAD was used. The rules were written in KnowledgeCraft. There have been tests with five AutoCAD and five KnowledgeCraft environments, which worked simultaneously on the same containers. With this version of ARMILLA4 about 3000 containers could be processed manually. With more containers AutoLISP became too slow. Furthermore, the graphic possibilities of AutoCAD have proven to be insufficient.

6.2. ARMILLA4 (Objective_C, NeXTSTEP, ObjectStore)

The second version of ARMILLA4 was implemented in Objective_C under NeXTSTEP. NeXTSTEP offered the most potential for the development of a productive and ergonomic graphic editor, with integration of other media, such as pictures, text, sound, video, telephone etc. The administration of the containers has been realized in Objective_C. With these implementations a building with 10000 objects could be designed and managed easily. The potential of this implementation is limited to about 50000 objects which is still to few for the design of a building design of reasonable scale [12]

In a parallel development, the container model was implemented in the object-oriented database ObjectStore. The primary goal of this implementation was the optimization of data access with respect to particular demands, especially from the iterative and cooperative design process. A secondary goal was to expand the functionality of the ARMILLA4 prototype with the inclusion of dynamic linking of expert models and constraints into the container model. In particular, the localization and limitation of functionality within the multidimensional area of containers could facilitate the checking of consistency in complex design and construction environments [13,16]

In the ARMILLA4 prototype, the research field was expanded from construction tasks to building management. The user can enter a building remotely and get an introduction to it with multimedia techniques [Fig. 5(1)]. The user can move' through the building and make use of various services [Fig. 5(2)]. An example of such a service is the reservation system for the seminar and lecture rooms [Fig. 5(3)]. By leaving the floor and moving to the ceiling the user reaches the ARMILLA system - the construction of the technical systems at different levels of abstraction with the participation of different designers [Fig. 5(4-6)]. Different views of this construction process (in this case the air-conditioning system and the spatial layout of the furniture at different levels of abstraction) can be displayed simultaneously [Fig 5(7)]. User interfaces for the building control are displayed inside the building model [Fig. 5(8)]. These user interfaces can be addressed from a modern working table [Fig. 5(9)].

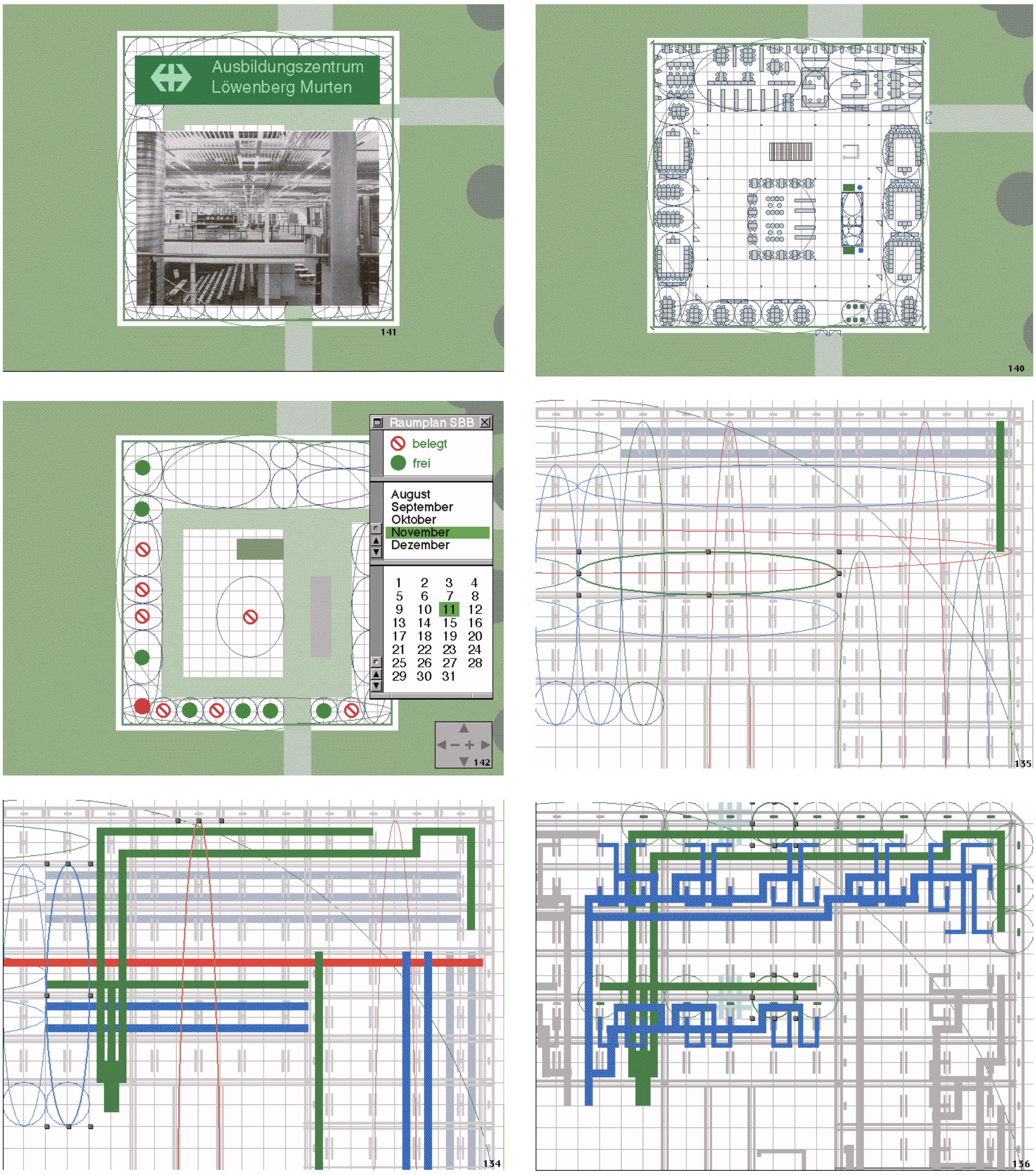

Fig. 5. (1) Introduction to the building site. (2) Services available. (3) Reservation of seminar rooms. (4) Technical systems, abstraction level I (line planning). (5) Technical systems, abstraction level 2 (planning of the branch pipes). (6) Technical systems, abstraction level 3 (planning of the twig pipes). (7) Air-conditioning and furniture layout. (8) User interface for building control. (9) The ‚working table.‘

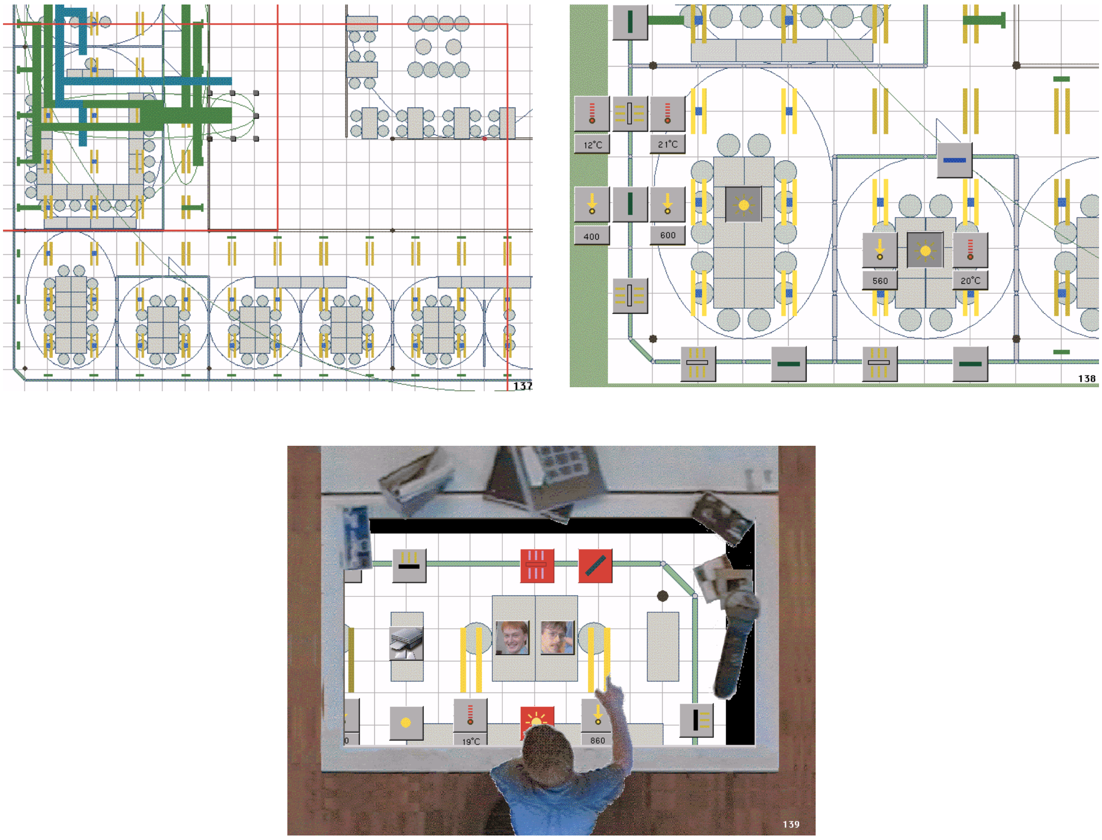

Fig. 5. (Continued).

The sequence of figures makes it clear, that designing, constructing, controlling and managing tasks can be integrated with all their necessary functionality within one complex building model. Electronic building models become a fundamental part of the dynamic building concept and accompany them over their entire life cycle. The figures are taken from the ARMILLA4 film [12].

7. ARMILLA5: cooperative design and management of buildings through the Internet

The ARMILLA5 prototype generalizes the ideas from ARMILLA4, the spatial cooperation and communication between data, tools and designers within a multidimensional design space, and sums them up under the metaphor of a ‚virtual construction site.' Different designers meet each other on the Internet at a certain place on a worldwide coordinate system to design a building. The designers are supported by tools, which they can access via the Internet as well. These tools, and the data they create, are encapsulated inside multidimensional containers. All containers of the virtual construction site are called the ‚virtual building components'. Progressing through the different levels of abstraction these virtual building components are ultimately transformed into physical building components. In this last design step the virtual construction site becomes the real construction site.

Virtual building components accompany their physical building component counterparts during their entire life cycle. This dual existence of a virtual and physical construction site facilitates building management (Facility Management) and becomes a constant and essential companion of a dynamic building.

ARMILLA5 distinguishes between three different classes of virtual building components. The first class represent plain data. The second class integrates simple standalone functionality, like text editing, calculation, 3D visualization etc. The third class integrates complex functionality based on clientserver models. Two virtual building components of this class were implemented in ARMILLA5.

One tool focuses on constraint management. By assigning constraints to virtual building components the applicability of constraints can be limited within the design context to multidimensional areas. The expense for the rule examination and the proof of consistency could be reduced effectively. The individual formulation of constraints has been realized as a general constraint language [13,16].

Another focus evolved from the desire to reintroduce strategies from previous efforts into the design. These tools facilitate the repatriation of knowledge by implementing a mechanism for case-based reasoning methods. Planning episodes, or cases, from earlier designs could, therefore, be reused for solving current problems. Cases can be distinguished by different granularities: small cases with only a few design elements offer support in specific construction and configuration tasks. Large cases with many elements offer support in strategic decisions [4].

ARMILLA5 places organizational, geometrical and semantical editors (tools) at the users disposal.

(a) The organizational editor organizes the cooperation of different users. In Fig. 6(1) an electronic mail message describes the end of a milestone of the design process. Links within the message refer to the corresponding geometrical editors.

(b) The geometrical editor functions much like a conventional CAD system [Fig. 6(2)]. Two links are installed. One link refers to an expert model dealing with the domain of the air supply, while another refers to the domain of the building structure. Links within the geometrical editor are represented by special containers called A5-Navigators. A5-Navigators possess user interfaces. A user can navigate with them through the design space and through the data of the different expert models. This data can be localized on different servers on the Internet.

(c) The geometrical editor can display the elements of the ‚virtual construction site‘ referring to different abstraction levels and different views simultaneously [Fig. 6(3)]. The large ellipses mark strategic design decisions as sketches, which are gradually refined to the ultimate specific descriptions of the building components. The different views of the users are represented by different colors. By keeping certain elements editable in the foreground and others protected from changes in the background, all design decisions of the different levels of abstraction and views can be coordinated geometrically through all phases of the design.

(d) Another view to the design data is realized by a semantic editor [Fig. 6(4)] With a browser a user can navigate semantically through the data of expert models localized on A5Servers in the Internet. In this example the expert model refers to the domain of the air-supply net.

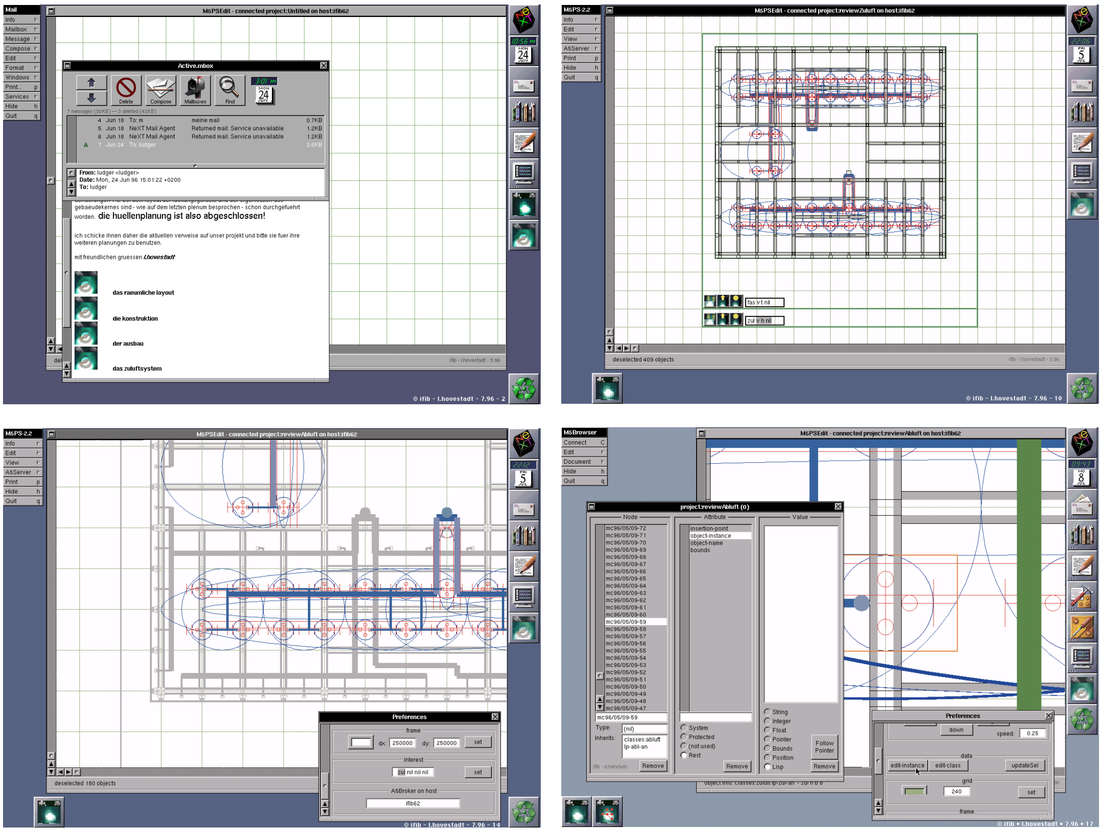

Fig. 6. (1) The organizational editor. (2) The ‚CAD-like' geometrical editor. (3) Design within the virtual construction site. (4) Semantic editor and browser.

The concepts of an integrated system for the planning and the organization of complex buildings could be realized only insufficiently with the presented closed and proprietary implementations of ARMILLA4. To satisfy the demands of a distributed database, an opening of the system to different commercial editors (CAD systems, spreadsheets, electronic mail systems, etc.) and a conceptual integration into the Internet would be necessary. This attempt has begun with the ARMILLA5 prototype.

The ARMILLA5 model is realized on five different levels of implementation (Fig. 7). Located on the first and upper level are the worldwide, distributed users of the system. On the second level various editors for the different views on the ARMILLA5 model (for example semantic, geometric or organizational views) are offered to the user. On the third level the contents of the ARMILLA5 model are coordinated through the idea of ‚virtual construction sites‘ on a worldwide coordinate system. On the fourth level expert models are described in distributed databases, which contain the data of the virtual building components. On the fifth level a worldwide cooperation of models and users is realized on the Internet. The ARMILLA5 prototype was implemented in Objective_C under NeXTSTEP. The distributed database uses the Remote_Objects from NeXTSTEP 3.0. The constraint component was implemented in C++ inside the object oriented database ObjectStore [16]. The AI functionality - case retrieval, case adaptation etc. - was implemented in Allegro Common Lisp [4].

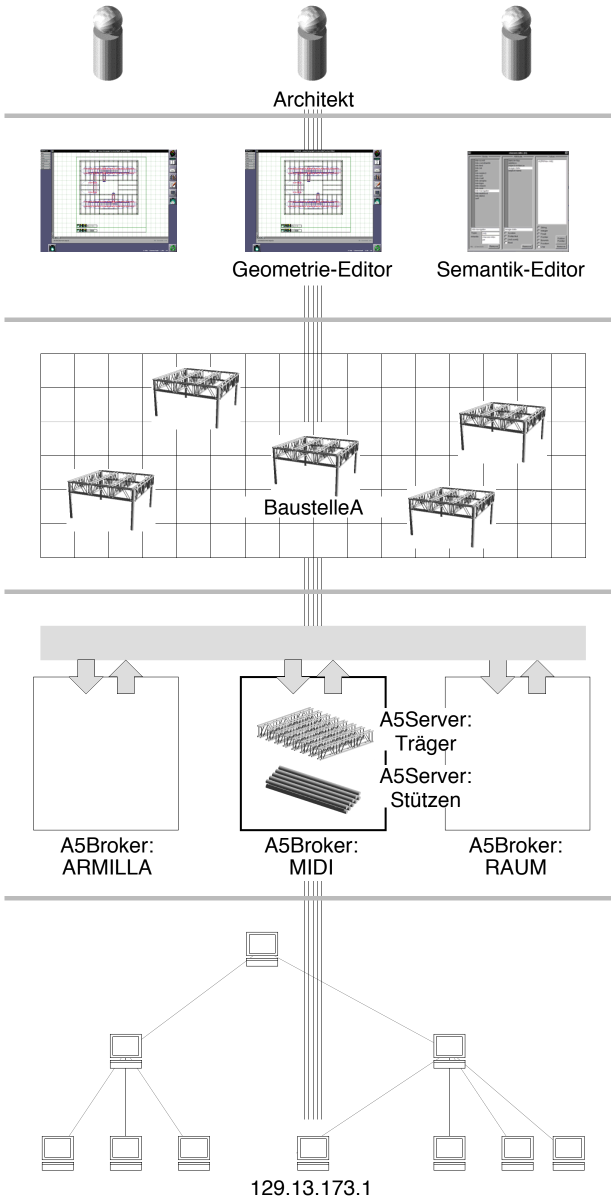

Fig. 7. The five implementation levels of the ARMILLA5 prototype.

8. ARMILLA6: expanded architecture

In the context of the ‚virtual construction site‘ further developments are discussed in the current prototype of ARMILLA6.

8.1. Expanded reality

Following the idea of a parallel world of virtual construction sites and dynamic buildings, special projection techniques can be used, which can integrate the virtual building components into the real buildings homogeneously and ergonomically (Augmented Reality). The possibility exists in the use of video-see-through displays/glasses, in which - corresponding to the perspective of the user - the virtual building components are projected. For example assembly instructions [Fig. 8(1)] or user interfaces for the building control [Fig. 8(2)] can be integrated in the real environment [14].

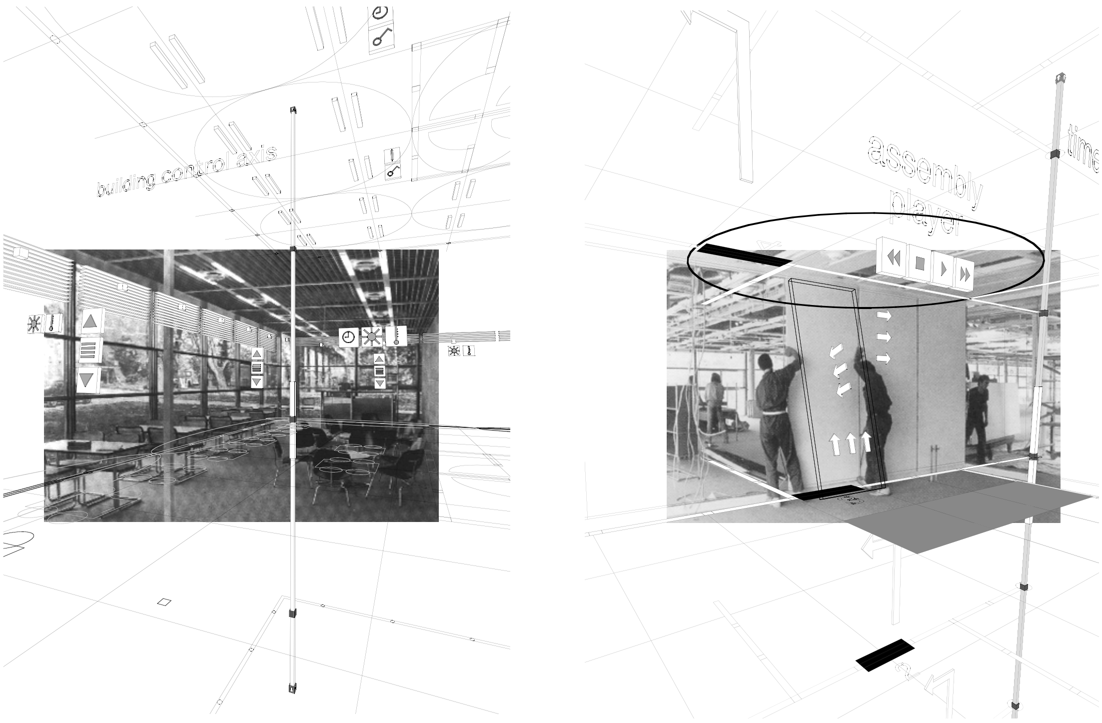

Fig. 8. (1) Assembly instructions displayed sensitive to place and time in the real construction site. (2) Software user interfaces for the building control, expand the functionality of physical displays and switches.

8.2. Expanded architecture

Under the spatial metaphor of the virtual construction site it is possible to design virtual architecture without thinking about physical architecture. In this manner, for example, it is possible to design a virtual office building for staff members that are distributed worldwide. Through the metaphor of the virtual office building and corresponding telecooperation techniques, the staff members are able to work independent of their physical presence in always the same organizations, structures and architectures. This metaphor works especially well if the virtual architecture corresponds with the real architecture. This means that both, physical and virtual building components should be modeled neutrally as modules, so that the different virtual building components may be integrated homogeneously into the physical environment (Fig. 9) [14].

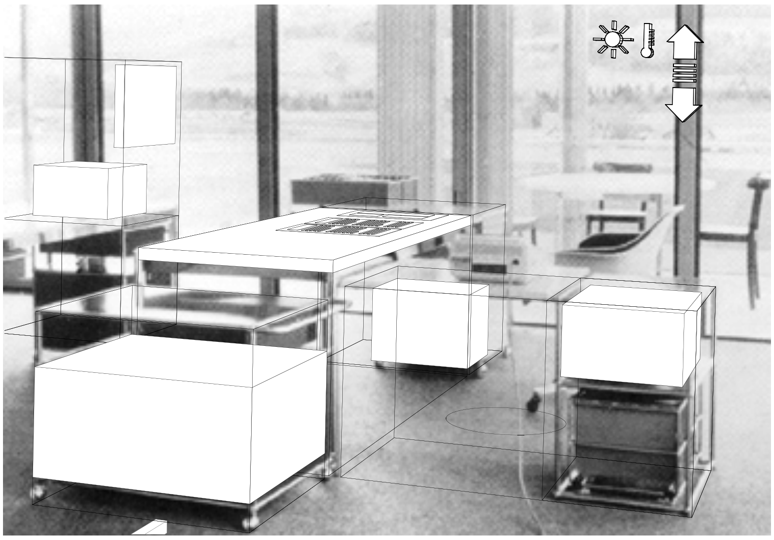

Fig. 9. Example for a modular and neutrally designed environment, in which virtual structures can easily be integrated as ‚virtual building components‘ with the techniques of the Augmented Reality.

With these considerations we return to the starting point of the ARMILLA project. The building component system MIDI and the installation model ARMILLA describe buildings neutrally on the basis of components. They can serve as a ideal physical platform for the integration of virtual building components in an expanded architecture.

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