Case Based, Self Learning Assistant for FEM Analysis in the Design Process

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Summary

A new assistant system is described, that works in the scope of integrated CAD/FEM/PDM. Significant is the processing of knowledge in form of real practice FEM analysis cases. The system learns fully automatically by capturing case knowledge from the processed FEM projects. It assists those, who search for solutions or skills, by providing context sensitive knowledge. Additionally it standardizes methods, supports large heterogeneous teams and communicates in the designer's language.
The research project is shared by industry (Dr. Wallner Group) and research institutes (Technical University of Darmstadt). At present it is in the phase of initial implementation.

Keywords

Knowledge-based design, FEM Assistant, FEM Feature, Case Based Reasoning, Expert System, Wissensbasierte Konstruktion, Wissensbasierte Berechnung, FEM Assistenzsystem, Fallbasiertes Schließen, Expertensystem

0. Introduction

Knowledge and experience, which result from using FEM Analysis, are mainly stored only in the heads of specialists [1]. Many approaches to make this knowledge available for others, lead to an extraction of rules. The concept under consideration alternatively uses the more modern method called “case based reasoning” (CBR), that has not been applied for FEM expert systems until now. The very successful application and adaptation to several other disciplines, including medicine or law, s. [2] lead to positive expectations. Significant for this method is, that the main context of knowledge remains and an interpretation is performed.

This new concept acts as a framework, that has to be adapted to a company’s needs. Such integration and adaptation work can be applied without problems, provided a CAD, a FEM and a PDM system are already in use. The prototype under consideration works in conjunction with EDS/iMAN, EDS/Unigraphics, AI/DesignSpace and UG/Scenario for Structures.

The concept will be most effective for large teams, consisting of FEM experts as well as beginners. Such constellations more and more appear in large companies, s. [3]

The research project is shared by the technical University of Darmstadt and the Dr. Wallner Group.

1. Concepts for Knowledge Reuse

In this part concepts for knowledge management, which play a role for the considered assistant system, are explained.

Systems for knowledge based product development can be classified in three categories [4]:
a) Product configuration systems.
b) Process modellers, navigators and wizards.
c) Systems providing the actual knowledge in context to the actual stage of design.

The system under consideration belongs to the third category.

1.1 Problem Solving using Rule Based and Case Based Concepts

Case based approaches for knowledge based methods are often seen as an alternative to rule based approaches. While rule based approaches contain knowledge as rules, case based approaches contain cases of projects of the past in the knowledge base.
Problem solving in rule based systems is provided by applying the given rules. Case based systems are searching for the most similar case of the past and adapt it to the actual problem.
As a way of artificial learning, capturing new knowledge for the knowledge base in the ruled based approach is provided by applying new rules or modifying the given rules. The case based approach applies new cases to the knowledge base.

1.2 Significances of Case Based Approaches

Several aspects vote for case based approaches against the rule based ones, s.[5]:
The main point for rule based representation of knowledge is, that experts formulate their knowledge mainly by defining rules. But expert interviews show, that with increasing problem solving competence their ability to put knowledge into rules decreases. (“Knowledge Engineering Paradoxon”), s. [6]. The knowledge representation seems to change by increasing expertise. Beginners and experts differ in the way they represent knowledge, s. [7]. So the case based approach is nearer to human thinking.

Also the case based approach is nearer to human behaviour with regard to learning techniques. The beginner learns from rules. If he can successfully apply the learned rules in real practice, the cases will be stored as experience in his mind. With future problems he will first search for a similar case in his experience. He will try to adapt the most similar case to his actual problem. If he won’t find a proper case, he will use the rules.

You can also see the disadvantages of the rule based approaches in the system’s ability of learning and by means of maintainance: We have seen, s. [5] that applying new rules to the knowledge base can easily destroy the consistency of the hole rule tree, if at any location a conflict is provoked. So, large consistency checks have to be performed for applying new rules. The case based approach simply allows adding new cases. Consistency checks are not necessary.

A case represents knowledge in an interpretable form. The knowledge is not filtered before. As a disadvantage, the knowledge has to be interpreted at each runtime (generalisation) and transformed to the actual situation (re-specialisation). This is contrary to the simple application checks (unification) for rules.

1.3 The Method Case Based Reasoning (CBR)

Actually strong expectations are set in CBR methods, s. [2]. The simple hypothesis for CBR is: "Similar problems have similar solutions" or "You can use the solution of a similar problem to solve your actual one".

A widely accepted model for CBR is the following:

1. <u>Retrieval</u> of relevant cases in the case base.
   As a coarse selection such cases are selected, that potentially can provide the given task. The retrieval is a searching problem, properties of the given task are compared to those of the cases in the case base.
2. <u>Selection</u> of the most appropriate case or cases out of the relevant cases.
   As a fine selection this or those cases are selected, which shall be used for solving the task. The main problem is the definition of an appropriate similarity measure.
3. <u>Creation</u> of a solution by transferring knowledge. In this step a solution will be adapted.
4. <u>Test</u> of the new solution. This can be done for example by searching for contrary examples.
5. <u>Validation</u> of the solution by questioning the user.
6. <u>Saving</u> the solution in the case base.
   After a successful problem solving, the question of saving the case in the case base has to be answered. In general this is recommended, if the case contains information, which is not already stored in the case base.

1.4 Knowledge Management using Semantics and Features

In the scope of CAD/CAM systems, semantics manage meanings in a characteristic way. A weld point, that is represented by beam elements, provides poor semantic information. With the beams being grouped and the group having an attribute "weld-point" and in addition containing information like strength requirements, tolerances, costs, manufacturing processes and experiences, semantics of higher order will be applied. As an advantage, the weld point will be recognised and processed sensitively to the application.

Today's CAD/FEM systems differ extremely in the way of processing semantics. As a rule, FEM tools, which work in the design context, are processing higher level semantics.

Features, in the scope of CAD/CAM, are using semantics to store and transfer information together with geometry, see Fig. 1, [8], [9]. A feature "Hole" for example, can contain the geometric faces, the parametric expressions as well as appropriate tool parameters. CAD systems have partly established feature processing, FEM systems are still behind.

The following methods for processing features are available:

1. Interactive definition: The user has to define feature information manually.
2. Feature recognition: Algorithms or expert systems perform pattern recognition.
3. Feature based modelling: Building up models by the use of features.

We try to reach a digital model by application of generally useable features. Some integrated CAD/FEM systems for example provide generally useable features for connections: The mating conditions out of the assembly module supply knowledge for creation of boundary conditions in the FEM module. In a similar way, the kinematics module extracts knowledge for joint creation out of the mating conditions.

A typical FEM feature is the function „bold load". It contains the applied faces, a direction as well as the amount of the load. The distribution of the load is automatically calculated. This information is stored encapsulated, having descriptive attributes and are futurely modifiable. So the feature represents a design characteristic. An analogue of CAD and FEM features is shown in Fig. 1.

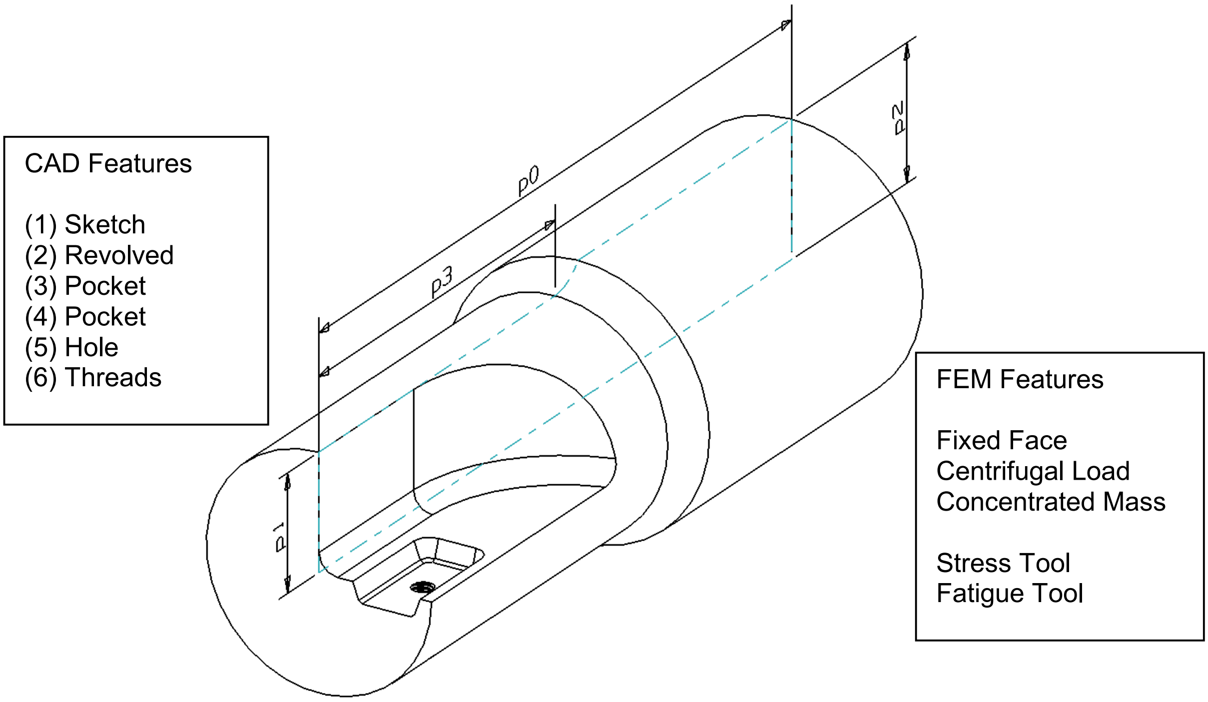

Fig. 1: Analogue between CAD and FEM features. Both of them model design characteristics.

2 Analysis of Cases from Industrial Applications

A collected edition of 100 FEM application cases serves as a base for the following studies. The goal is to find a method to classify the application cases or their knowledge, as well as to develop an information model for the knowledge representation. In future studies a more advanced similarity measure shall also be developed, which allows implementing an efficient search algorithm.

The application cases are adopted partly from industrial projects, partly from FEM consulting and from trainings. The training examples are completed by documented methods and best practice guides. The collection contains linear static, thermo-transfer, as well as modal analysis examples of components and assemblies. In some cases there are non-linearities like contacts, non-linear reversible plastics and large displacements. The cases are extracted from a wide range of different industries, including automotive, mechanical engineering, production industries.
Each FEM analysis is based on CAD models. The following systems have been used: CAD: Unigraphics, FEM: Ansys, Nastran, DesignSpace, UG-Scenario. As documentations there are the usual CAD/FEM Files available, as well as reports in some cases.

The FEM cases have been analysed relative to the ability of knowledge reuse. The following aspects are of special interest: Which type of knowledge is included? Can tasks and solutions be found? To which elements is the knowledge connected? Can it automatically be transferred? How complete is it? Can incomplete knowledge be interpreted? Can the knowledge be structured?

2.1 Study of Characteristics

In this study reappearing characteristics have been extracted and classified from all analysis cases. The found characteristics feature to be members of either one of two groups: FEM specific- and design specific characteristics. FEM specific characteristics result from the principles of the finite element method and show theoretical, abstract aspects. Examples follow:

- Discretisation of space or time
- Element formulations: Solid, shell, plate, ring, beam, point
- Material models: Linear elastic, non-linear elastic, …
- Given values at nodes:
    - Displacements: suppressed, defined, coupled

    - Forces
    - Temperatures
- Resulting values at nodes: Displacement, reaction force, temperature
- Transferred values: Strain, stress

Contrary to the FEM specific characteristics the design specific ones result from real world problems and design means. Examples follow:

- Component Part: Geometry, material properties, surface properties, history
- Connection / bearing:
    - to fixed ground / to other part
    - by shape, by medium, by friction
- Influences: Gravity, acceleration, applied force, displacement, moment, pressure, temperature,
- dynamic stimulation, touching
- Other Effects: Eccentric load, vibration, tightness, fatigue
- Interesting properties: Eigenform, frequency, temperature profile, displacement, reaction force, strain, stress, life duration

Then the analysis cases have been structured in a way, so that each task was registered with the corresponding solution. It turns out, that any of the tasks behaves analogue to one of the design specific characteristics. In the same way any of the solutions behaves analogue to one of the FEM specific characteristics.
In the following the notations design specific / FEM specific characteristic will be used synonym to the notations task and solution.

2.2 Hierarchy of Design Specific Characteristics

For further studies of dependencies between design specific characteristics they have been analysed in an order scheme. This method, see [10] arranges the same characteristics in rows and columns. An attachment is assigned, if a characteristic is included in another one. By this way a hierarchy can be established.
It turns out, that some tasks show a detail nature. Others behave in higher order, because they assemble the detail ones.
As an example, the assembled task “beginning of plastic flow” can be assembled by the detail tasks “stress analysis” and “material properties”.

2.3 Representation Forms of Case Knowledge

Afterwards the case knowledge shall be analysed by ordering all detail tasks against all solutions in an order scheme. An attachment is assigned, if a solution has been used for a task. It results, that the elementary case knowledge is represented in three different forms, while also mixed forms are possible:

- Some tasks are clearly assigned by one solution. Such tasks have a specific solution.
  Example:
  Task: “Gravity Load”
  Solution: “Give forces at nodes”
- Other tasks are assigned by more solutions. The assignments can exist separately (*or*). Such tasks can be solved in different ways. Example:
  Task: “Pinned bearing to fixed ground”
  Solution: “Give displacement to nodes, suppress specific degrees of freedom”
  or
  Solution: “Non-linear solution, use contact condition”
- The third type of task can only be solved by a combination of solutions (*and*). Example:
  Task: “Component Part”
  Solution: “Discretisation of Space”
  a*nd*
  Solution: “Element formulation”
  a*nd*
  Solution: “Material Model”

A last form for representing case knowledge results from the higher order assembled tasks:

- The fourth type of tasks can be solved by assembling elementary tasks.

The representation forms of case knowledge are mirrored by the structure of the information model in chapter 4.1, see Fig. 2.

2.4 Interpretation of Case Knowledge

When performing FEM projects, only a part of the full knowledge is documented in the appropriate CAD/FEM files. The other part stays in the users' mind and will not be documented. You can see this at methods, which don't have reasons. ("Why did he do it this way?")
Example: A sheet metal bracket for automotive has to carry an aggregate of 3Kg. The user applies a load of 24Kg, because he takes an acceleration of factor 8 for pavement crossing into consideration. This information is not stored in the case documents.

In many cases missing knowledge can be completed by interpretation of the case context. An advantage of FEM in context with CAD is, that the case context is more transparent. The case context is even more transparent and interpretable, if CAD and FEM are integrated in a PDM system, see [11].

2.5 Ability to Transfer Case Knowledge

To use case knowledge effectively, the possibility of transferring it to other problems is required. So this study proves this requirement. Here the case based reasoning method (CBR) is manually performed.

Therefore users are confronted with FEM problems, for instance the creation of a seam weld over several faces of a sheet metal part. Several projects of the past, which analyse different sheet metal parts, are demonstrated to the users.
It turns out, that the users quickly select an analysis case, which meets the requirements at best. What follows is an interpretation of the analysis case within the database. If accepted, the case (or maybe some details of the case) becomes a pattern.
As a disadvantage it turns out, that stored cases contain solutions (the seam weld), but sometimes the method for reaching the solution is hard to find. So sometimes the training documentation had to be used additionally.

3. Motivation for a Case Based Assistant System

The Motivation to build a new assistant system results from the clear deficits of actual methods for knowledge reuse in the scope of FEM. In this chapter those deficits are described in conjunction with corresponding requirements.

3.1 Provide Context Sensitive Knowledge

All approaches for knowledge processing as demonstrated in the first chapter, have been actually poorly performed. Rule based methods are actually standing out. Wizard technologies restrict creativity and the effect of learning. Case based methods are neglected. Especially in the scope of FEM there are no approaches or implementations for case based user support.
The assistant under consideration shall dynamically transport knowledge and experience and also provide it sensitively to the context as well as filtered to other users. The concept shall also support single persons by finding information, which has been forgotten.

3.2 Standardizing Methods without Forcing the User

The analysis of representation forms of case knowledge demonstrates, that in some cases the same problems are solved by different methods. For flexibility requirements it is necessary, that this possibility remains. The new assistant under consideration will lead the experienced users to create methods in form of their application cases. Users with few experience trust in the experts and force searches to the experts' solutions. In this way methods are standardized in a forceless way and best practice guides are developed automatically.

3.3 Support of Large Teams with Heterogeneous Expertise

For a long time FEM analysis completely was a domain of specialists. Those specialists use their own special tools and data structures. The increase of FEM applications at the designers daily work, especially in large companies, see [3], demonstrates more and more the necessity of knowledge transfer, because an increasing number of non-specialists use FEM.

The assistant under consideration shall support the increasing number of designers and non-FEM specialists, who work in large teams. Parts of the experts' knowledge shall be provided for beginners. The larger the team and the more the expertise differs, the larger will be the expected effect.

3.4 Force Database Oriented Methods

PDM and PLM systems shall organize product data. In fact they only organize design data. They organize the data, but they do not know anything about it, see [12]. The knowledge, that is produced while developing products, is not provided structured. It cannot be reused. An important part of it is lost. The new assistant requires and forces the use of a PDM System.

3.5 Meet the Designers Language

Up to now, FEM systems have not established the processing of features. A feature for each design specific characterization, that has a meaning in FEM, should be the case. For example a feature "press fit" could contain all necessary information for design and analysis of a press fit.
The assistant under consideration shall process such design specific characteristics, even if the CAD/FEM system does not provide an appropriate feature. So the assistant system shall communicate in a design specific language, that meets the designers requirements.

3.6 Reach High Level of User Acceptance

In order to reach a high level of acceptance, the assistant under consideration shall need only a minimum of user interaction. This applies especially to the support of the case base and also the comfort by retrieving knowledge from cases.

4. Concept for an Assistant System

The considered concept extracts a pattern of the case knowledge when inserting a new case into the case base. When searching for knowledge, a pattern recognition in the case base is performed. So the system belongs to category three of the classification in chapter 1.

Important elements within the concept are knowledge representation by an information model, knowledge acquisition and the similarity measure.

4.1 Information Model

By storing an analysis case, the representation of the included knowledge is already realized. This advantage significantly simplifies the information model, because it only has to register the included case knowledge and reference the corresponding case. So the knowledge representation is limited to references of the included knowledge. See Fig. 2.

The concept schedules knowledge elements, which represent a detail (detail knowledge element), for instance a load type, as well as knowledge elements, which represent administrative and procedural information of a case (admin knowledge element). A third type defines an assembly of several detail knowledge elements, which represent higher order semantics (assembled knowledge element). So the knowledge elements build up modules of the information model, see Fig. 2.

Knowledge elements are classified and described by attributes. The underlying class structure is oriented by the types of design specific characteristics, as described in chapter 2. The knowledge representation by the references is as far as possible oriented by means of the STEP information model (AP104, 209, 214). Because some of the information is not included in the STEP norm, new definitions are created.

4.2 Knowledge Acquisition and Capture

The most simple form of knowledge acquisition, the manual questioning and inserting of knowledge by the user, is not acceptable. Automatical methods are required for capturing knowledge, so the CAD/FEM files have to be filtered for knowledge elements. High order semantic processing of the CAD/FEM system simplifies the filtering process considerably, because the main problem is the recognition of design specific characteristics.

Confronted with poor semantics, a preparation of information is necessary. The following concepts are possible, see [8]:

- Manual definition of semantics by the user. The user has to assign groups, attributes and classifications.
- Automatic methods to recognize semantics. Algorithms or expert systems recognize patterns. Actually there are no methods for pattern recognition in the scope of FEM semantics available.

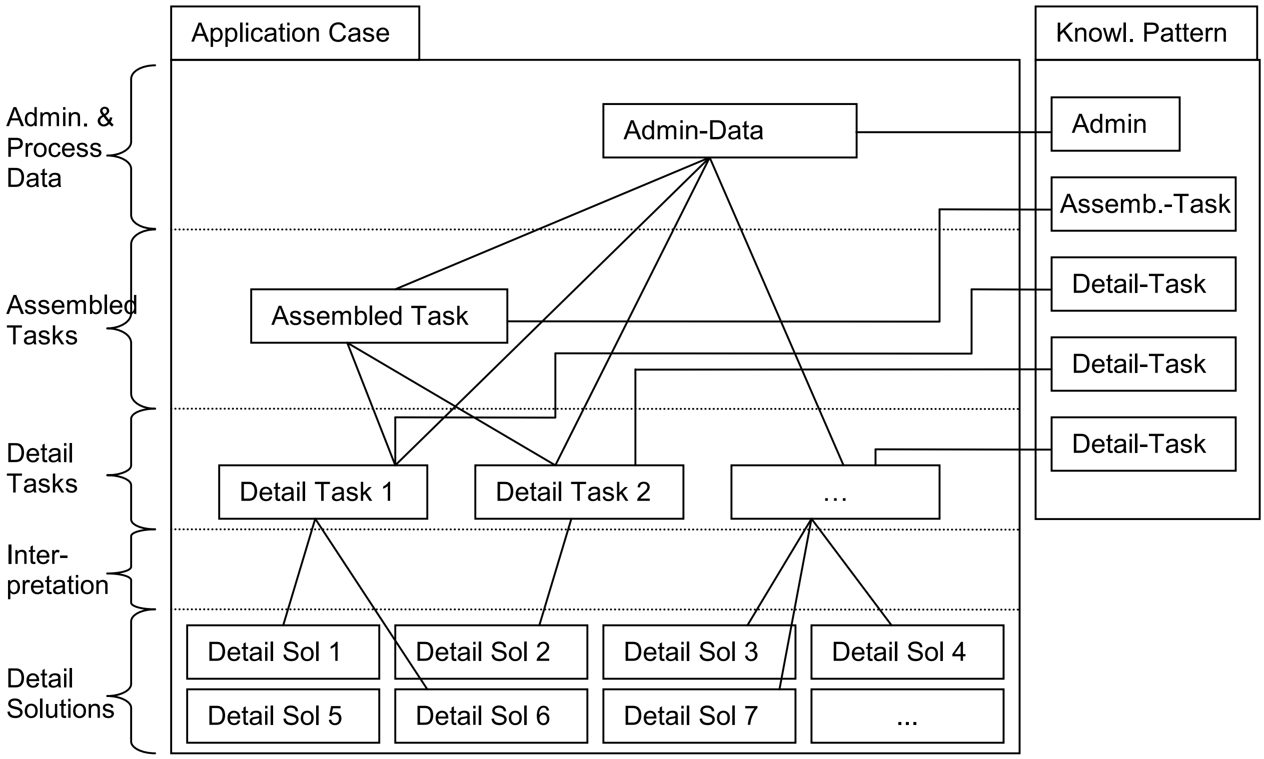

Fig. 2: Architecture of the information model. Knowledge elements represent case knowledge. References register included knowledge elements and support pattern recognition for similarity measures.

4.2.1 Automatic Acquisition by Feature Validation

Features register design specific characteristics or tasks. The corresponding solution can also be included in the feature, otherwise it can be found in the interpretation of the case knowledge. Ideally each design specific characteristic is registered by a corresponding feature. If the concrete analysis case contains features, they clearly register knowledge elements. So the extraction of high order features builds a pattern of the case knowledge, see Fig. 2.

In some cases FEM features are created fully automatically. An example are contacts, which result from assembly mating conditions. The knowledge quality of those features should be classified smaller than the one of explicitly created features.

4.2.2 Manual Preparation of Semantics

Higher order design specific characteristics sometimes have to be assembled by several elementary features. For example you may use temperature strain to apply pre stress. Corresponding features would be possible, but are not available. Thus the user has to manually define such complexes in form of assembled knowledge elements. As far as possible this should be avoided to keep the acceptance of the user.

4.2.3 Capture of Knowledge „On The Fly“

Often case knowledge is not complete. To complete incomplete knowledge you can use methods, that capture ideas of the user. As a disadvantage such methods disturb the user in his work and lead to

decreasing system acceptance. An optimal concept extracts maximum information and causes minimum disturbances.
The concept under consideration performs context sensitive classifications, that are processed by one mouse click. Those classifications are performed directly after creation of a feature. By using this way the disturbing effect remains small, because the user has this idea in mind, which the system asks for. In addition a classification disturbs less than a request for text input.
To keep such classifications flexible you need lists of values, that suggest values, but also are able to process new values. The new values have to be suggested the next time too.
For instance the concept under consideration classifies connection features effectively in this way. The user selects from those classes, that the STEP norm [13] suggests for connections:
Bolted Joint, Brazing, Clasping, Clinching, Clipping, Doweling, Flanging, Foam Injection, Glueing, Laser-Welding, Press-Fit, Riveting, Sewing, Spot-Welding, Stapling, Welding.

4.3 Similarity Measurement

The assistant system supports the user while working on a concrete analysis case by demonstrating examples, that are similar to the actual problem. The similarity measure quantifies the similarity between the actual problem and the cases in the knowledge base.
The considered concept performs pattern recognition when searching for similar cases. Patterns describe the included knowledge in all analysis cases of the case base, as well as the concrete problem. The similarity is measured by filtering attributes and classes for congruencies. This method will be extended in the future.

5. State of the Project and Open Issues

At present, the project is in the state of initial implementation.
As a global system architecture, we chose the client server model based on an iMAN-Web Portal. EDS/Unigraphics serves as the CAD system, AI/DesignSpace and UG/Scenario for FEM Analysis. Users can access the system by iMAN-Web Clients via the www. A common query server manages the case base by means of a case retrieval net. In addition to starting a retrieval process, every user is allowed to maintain the case base by providing new cases via the www.
At present, the users are limited to the consultants of the Dr. Wallner Group. They act from four different locations, see Fig. 3. In future, the system will be opened to support integrated CAD/FEM trainings. In the next step it will be available for use by customers.

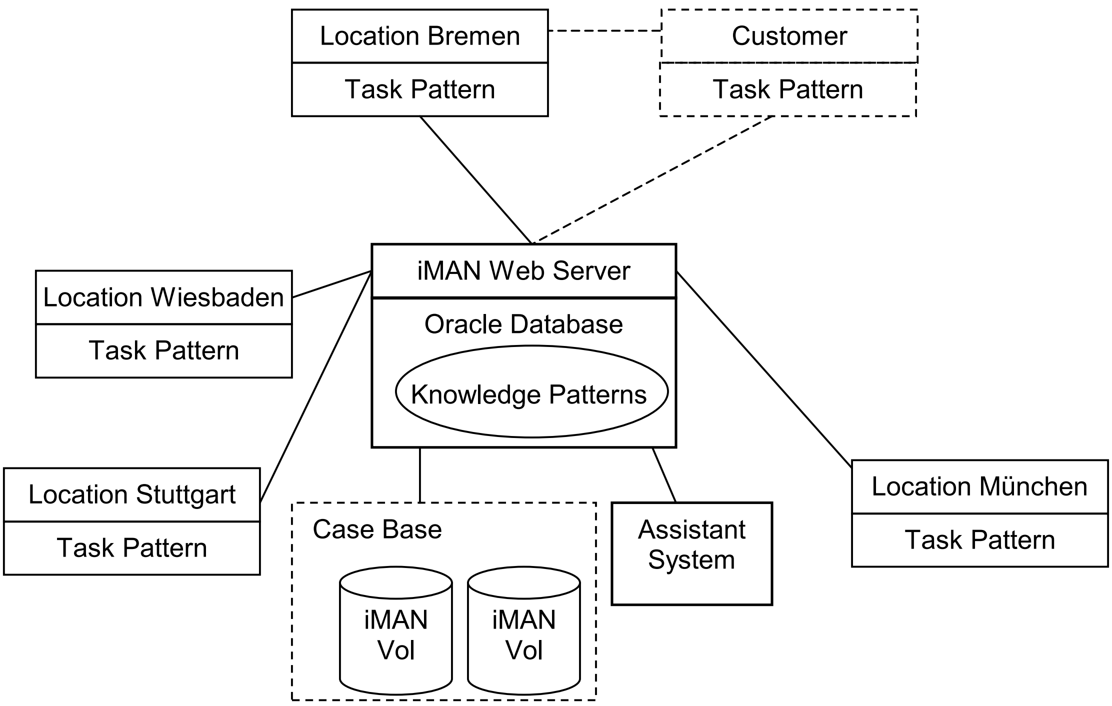

Fig. 3: Architecture of the present implementation of the assistant system. Four locations are provided via an iMAN Web client-server model.

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