Europe-wide Design Space for Architecture, Engineering and Construction

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Summary

The paper introduces the eArecon client–server system, which offers a concept for the harmonization of the structural design software packages based on the Structural Eurocodes. The crucial points of the harmonization are the eArecon's middle data model, which is based on the IFC object sharing protocol and the prototype of the Eurocodes Foundation Classes (EFC). The Web-based eArecon system may be the Structural Design module in the more comprehensive vision of virtual building.

Keywords: Structural Eurocodes; CAD; virtual building; IFC; multi-agent architecture; collaborative design work; integrated design software.

1. Introduction

The comprehensive development of the computational technology gives strong basis to the new generation integrated software packages used for design of engineering structures. More and more commercial structural engineering software are available in the market. These packages offer high performance modeling and computation. All the European countries have one or more national packages, and some of them have strong marketing abroad. All the European countries have national standards which should be used for design of structures. The movement of "Structural Eurocodes" started 30 years ago and set a target to harmonize these national European standards New Eurocodes will be introduced by most of the European countries not later than 2010. This standard system provides uniform design rules, but the National Annexes will allow differences in application..

The harmonization of the structural design standards should lead to the "harmonization" of the structural design packages. There are at least one hundred structural design packages all over the Europe. These special products have relatively small market (relatively few licenses may be sold), consequently, most of them have been developed by relatively small teams. It is clear that the number of the commercial packages will decrease, but we do not know whether only some of them will dominate the market, or more "national" systems will form a colorful and multicultural space of European Structural Design. It would seem that the first way is probable in the architectural and constructional engineering. This statement is supported by the ArchiCAD's Virtual Building™ project [1], pioneered by Graphisoft and Tekla. This project offers many advantages to architects and designers: 3D representation of the building; superior visualization; automated documentation, calculation and estimation. The concept is based on the integrated 3D object model paradigm, and it is an effective technology for the life cycle support of buildings. The International Alliance for Interoperability (IAI) promotes an open, freely available, non-proprietary data model specification [2], known as the Industrial Foundation Classes (IFC). In structural engineering this type of integration seems to be improbable, at least in the near future, since the harmonized standards (as the background of the design) will keep on the national attribute. The structural engineering needs a middle-way solution which can offer the following advantages: IFC based integration of the structural design packages; linking to the virtual building concept (and later to the systems based on

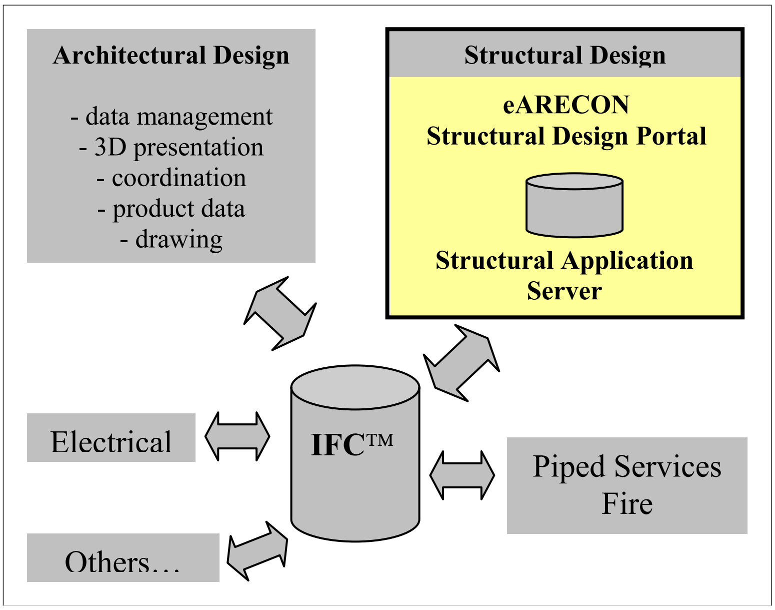

Fig. 1 *Location and function of the eArecon in the vision of virtual building concept based on the IFC object sharing protocol*

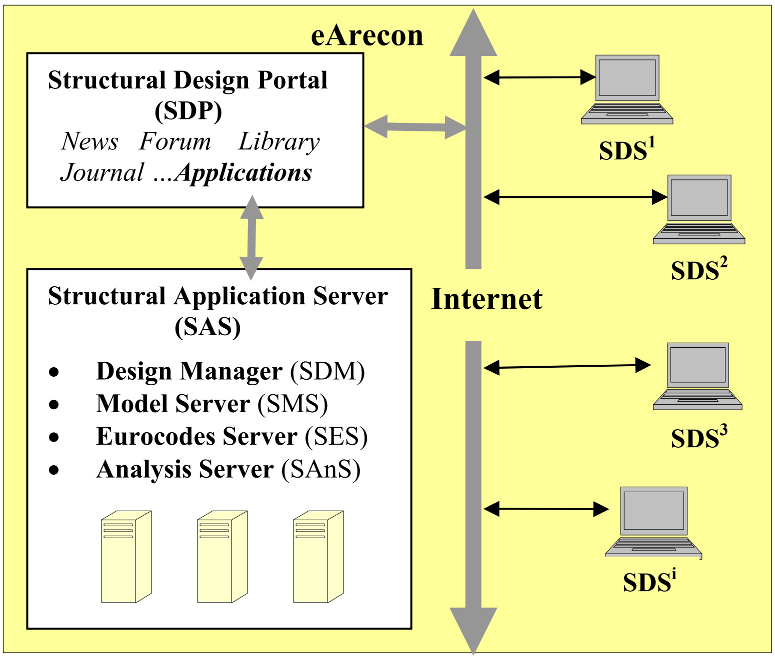

Fig. 2 *The functional model of the eArecon system*

this concept). This paper introduces the prototype of the eArecon system, which follows the above middle-way concept and aims to take part in the vision of IFC based virtual building technology, as it is shown in Fig.1.

2. The eArecon system

2.1 General

The comprehensive functional model of the eArecon system is illustrated in Fig.2. The different design programs (Structural Design Software; SDS) can link to the eArecon's Structural Design Portal (SDP) by Internet. The SDP's general services (News, Forum, Libraries, Gallery, Journal, e-Learning, etc.) are available freely. The advanced design services are available against password. Within the Structural Application Server (SAS) users can apply the services of the Design Manager (SDM), the Model Server (SMS), the Eurocodes Server (SES) and the Analysis Server (SAnS). These components are described in the following sections.

2.2 Structural Design Portal

Structural Design Portal (SDP) (www.earecon.com) is the Web-interface of the eArecon system. SDP is based on ASP.NET and programmed in C# language. This environment provides modern, scaleable, fast and stable facilities for the Web-application. Applying the Web standards the pages appear rightly in all the well known browsers (Internet Explorer, Netscape, Mozilla, Opera, etc.). The pages may be achieved by WAP and other tools using Pocket Browser. The portal offers all the well known modern services such as News, Forum, Library, e-Journal, Knowledge Base, e-Learning, and so on. The authorized users can open the page of Applications, where the data of projects are available and where the structural models are visualized by JAVA 3D. SDP links to the Structural Application Server (SAS).

2.3 Structural Design Portal

2.3.1 General

Structural Application Server offers the following services: Design Manager (SDM); Model Server (SMS); Eurocodes Server (SES); Analysis Server (SAnS). These services are described in the following points.

2.3.1 Structural Design Manager (SDM)

The main goal of the Structural Design Manager (SDM) is to support the engineering workflow of the individual work and the teamwork. The complex project can be divided into parts, and the parts can be recompiled to entire models. In the course of the division mechanically consistent sub-models are created, which can be examined and prepared individually by any of the engineers working in the project. The organization of the whole work is the responsibility of the chief designer. SDM visualizes the structures of a project according to the proper authority of the users on the Web services. However, the SDM is mainly a tool for the chief designer, who can execute the model division and the assignments of the work parts, approve and recompile the structural model on the visualized graphics. Helping this work a special data model is developed, which is able to describe all stages of this kind of design workflow in a standardized way. The structural model division and recompilation raise difficult engineering problems, the research and implementation of these problems was a key issue in the development of the SDM. For the sake of the solution a conception of Multi-level Structural Model (MSM) was introduced representing the two main design states during the workflow: Global Model (GM) controlled by the chief designer; SubModels (SM) to be prepared by the assigned engineers.

2.3.2 Structural Model Server (SMS)

The data management of the Structural Model Server is based on the ISO-10303. The EXPRESS Data Manager (EDM) developed by the EPM Technology provides all the tools, which are needed for the eArecon system. The STEP-toolboxes provide object-oriented data exchange on their uniform interfaces, which provide direct solutions for the low-level IFC data operations. For example to create/delete or open/close different models or different entities and aggregates within the models are extremely easy. However, EDM is a well developed but very expensive product. In the prototype system of the eArecon the data manager includes a built-in and a removable module. The built-in module is responsible for the data access between the system modules, while the removable module is a data base engine, which can be moved and replaced by EDM easily.

2.3.3 Structural Eurocodes Server (SES)

Structural Eurocodes offers a multi-level design methodology. The low-level methods provide design equations, where the design forces can be computed by simple stress analysis and other parameters (ex. buckling length of a member) are determined by the designer intuitively. Most of the commercial structural design packages follow this basic method. The high-level methods require advanced finite element analysis and use general design equations (ex. in case of the local buckling of irregular steel plates). eArecon has established the prototype of the Eurocodes Foundation Classes (EFC), where each class encapsulates a specific structural model and the adequate high-level design method. These classes can be available on the Structural Eurocodes Server (SES). The implemented classes of the prototype system are listed in Table 1.

Table 1 *Eurocodes Foundation Classes (prototype)*

EFC	**description**	**standards**
SECTION	Steel, concrete and steel-concrete cross-sections; Calculation of any type of cross-section properties; Calculation of resistances;	EN 1993-1-1 EN 1993-1-5 EN 1992-1-1 EN 1994-1-1
MEMBER	Steel, concrete and steel-concrete members; Simple calculation and FEA (beam-column, shell); Global stability resistance; Local stability resistance;	EN 1993-1-1 EN 1993-1-5 EN 1992-1-1 EN 1994-1-1
JOINT	Steel structural joints (end-plated, trussing); Resistance and deformation;	EN 1993-1-8

2.3.4 Structural Analysis Server (SAnS)

Structural Analysis Server (SAnS) provides high performance computation of thin-walled beam-column models and plated (thick shell) models, which are defined according to the IFC based eArecon’s middle-database protocol and stored on the Structural Model Server (SMS). These models can be analyzed by the SAnS in a direct way. The SAnS has two-way communication with the data base. A massage-governed task manager organizes the data access, the analysis and the save of the results.

2.3.5 Structural Design Software (SDS)

eArecon is available for any type of Structural Design Software (SDS) using Internet. The low-level integration can be achieved by the Web Open/Web Save functions, which can read/write structural models from/to the Model Server. This simple link can be realized in two steps: in the first step the free eArecon.dll should be implemented; in the second step an interface between the local data model and the IFC based middle-database protocol should be developed. The high-level integration means the direct use of the eArecon's services (ex. Eurocodes Foundation Classes; Analysis; etc.) in the design software. A low-level integration has been demonstrated in the FEM-Design software [6]. The high-level integration is represented in the ConSteel 4.0 design package (new version of ConSteel 3.2) [7], where the modules of the eArecon's server system (Model Server; Analysis Server; Eurocodes Server) were applied.

3. The eArecon's distributed multi-agent architecture

In Section 2 the eArecons's client-server system was described. The functions (services) of the system are mainly located in the servers but some of them in the client software. The physical realization of the system requires scalable, extensible and robustness (serving large number of clients) solutions. According to the research of system architectures these solutions can be achieved by a distributed multi-agent architecture.

3.1 The distributed multi-agent architecture in general

The agent is basically a piece of software, which can feel and realize. The multi-agent architecture is a dynamic system, in which the agents can cooperate with each other and can distribute their capabilities and purposes. Each one of the distributed system is represented by the agency. The agency forms a multi-agent system, in which the agents are responsible for the partial tasks of the procedure. The agency coordinates the agents taking their capabilities and loadings into consideration. The agents may be programmed in totally different languages and run under different operation systems. The agents can distribute the power of the processors with high efficiency. If a task needs high performance computation (ex. analysis of an extremely great finite element model), the corresponding agent distributes the task into several thread-information, and sends them to the agency. The agency opens a number of threads supplying them with information. eArecon's architecture is based on this technique [8].

3.2 Agents of the eArecon system

3.2.1 General

The agents of the eArecon system were defined and developed to cover all the functions described in Section 2. These agents are the following: I/O manager, Database, Web-connection, Analysis, Geometry, Macro, Section, Member, Joint and Integration. The logical relationship between the agents and the Structural Application Servers and the highly integrated Structural Design Software (SDS) are illustrated in Fig.3. The agents are described briefly in the following points.

3.2.2 I/O manager agent

I/O manager agent is responsible for the data store. It serves the import/export, open/save, new model and the new project functions. Each project has three levels: project, model and sub-model. The project is the highest object. Each project consists of more models and each model consists of more sub-models. Physically the project information is in XML files [9]. Each XML file has a scheme, which governs the presentation of the project on the interface. For example, in order to introduce new attributes or delete old ones, we have to just modify the scheme.

3.2.3 Database agent

eArecon is a platform for cooperation of the different parts of the structural design procedures (software packages). This capability requires a general solution, which helps the system components and the client programs to understand each other. This capability can be provided by a middle-data model, which is known by all the system components. The middle-data model ensures that the users can work with the same data but with different programs in the same time. The middle-data model provides a homogeneous data structure for the components, and the database system based on this model gives a distributed net-resources system application. The eArecon's middle-data model is based on the Industrial Foundation Classes [2].

3.2.4 Analysis agent

Analysis agent is responsible for the high performance structural analysis. It has the following layers and features:

- Connection Layer

  - message-governed task management
  - two-way communication with the database

- Finite Element Layer

  - unit-independent finite element module
  - unified coordinate system of finite element model
  - unified order of degrees of freedom
  - equilibrium control at each node
  - spare Column Storage matrix formula
  - parallelization of algorithms to shared memory architecture
  - parallelization of algorithms to distributed memory architecture

- High Performance Computing Layer [10]

  - symbolic factorization
  - solve positive definite linear equation system by blocked-typed Cholesky factorization [11], [12]
  - eigenvalue computation by modified Lánczos method.

3.2.5 Geometry agent

Geometry agent is responsibility for the internal world of the system. When the user defines a new object (plate, wall, support, concentrated load, etc.) on the graphical interface the system generates a NewObject message, which urges the geometry agent to create the graphical representation of the object. Besides the graphical representation the Geometry agent knows the common CAD functions (finding intersection points, select objects, etc.).

3.2.6 Macro agent

Macro agent involves the structural macros as plug-in modules. It is responsible for the administration, selection and serving of these macros. The structural macro is a tool to create simple structures or structural members by a specific set of parametric data. The submodels created by this way may be built into empty or existing models. Structural macro means an alternative way to avoid the time consuming graphical modeling. Structural macros may be created by anyone. For example the producers and the marketing managers can promote their products by corresponding structural macros.

3.2.7 Section agent

Section agent involves all the functions which are needed to form a complex program module. The module involves the complex modeling and computation of steel, concrete and mixed steel-concrete cross-sections, including the calculation of resistances specified the standards. Section agent uses a hybrid model, which involves the plate segment model [13] and the solid section model [14]. The plate segment model contains the design attributes which are specified by the design standard (ex. restraints of the segments; type of the shape; appropriate buckling curve; etc.). The solid section model is meshed by triangular finite elements; therefore it gives very accurate cross-sectional properties. However, steel cross-section objects involve both the plate segment and the solid section models. The formal model is used to calculate the cross-sectional properties for the analysis; the last model is used to compute the design properties.

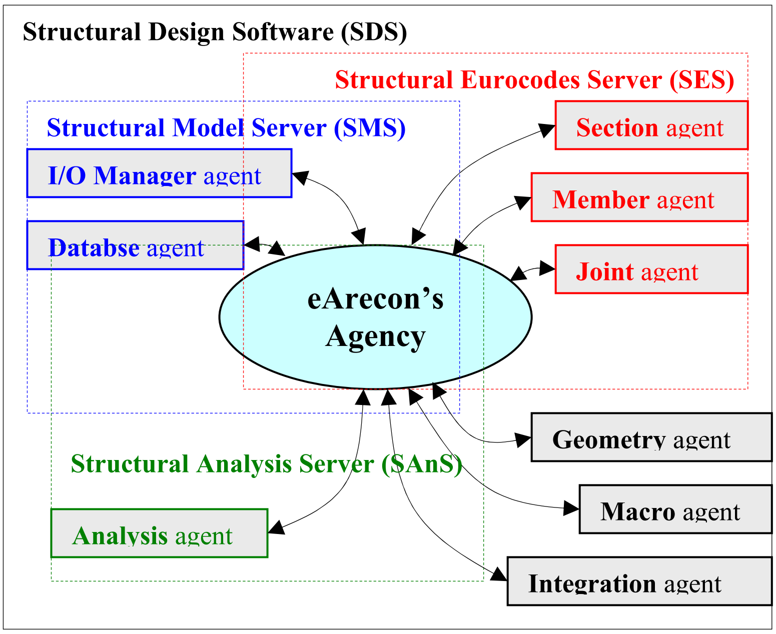

Fig. 3 *The logical relationship between the agents, servers and client software*

3.2.8 Member agent

Member agent consists of all the functions which calculate the global resistance of the steel, concrete and mixed steel-concrete structural members. These members can be beam-column or plated member. From point of view of origin the member can be freely defined or model-based. In the first case the member are defined directly by the user; in the second case the member is imported from a global structural model. From point of view of analysis the model of the member can be formal or real model. The formal model can not be analyzed, the design forces are given directly or imported form the global model. The real model is analyzed within the agent using the Analysis agent. The resistance of the member can be computed by two ways: using design interaction equations; using general formulas. The first way means the use of the basic-level design equations specified by the standards. The second way requires advanced finite element analysis and general design formulas. The method of the analysis can be the following: user defined; imported; beam-column FEA; thick-shell FEA. The previous classification leads to seven working schemes evaluated by the agent automatically.

3.2.9 Joint agent

Joint agent is restricted to the calculation of the resistances of the steel column bases, end-plated connections and welded truss joints according to the EN 1993-1-8. The joint may be imported from the global structural model and its properties may be exported into the global model.

3.2.10 Web-connection agent

Web-connection agent is simply responsible for the communication between the Structural Design Portal and the Structural Application Server.

3.2.11 Integration agent

The links of the different design software packages to the eArecon are supported by a universal program package, which may be used by anyone. The main module of the package is the eArecon.dll file, which provides the connection to the system server. The second module is the eDesign.lib file, which may be edited to the software package developed in Microsoft Visual C++ 6.0, 7.0 (.NET 2002) or 7.1 (.NET 2003) systems. The package may be used in both ANSI and UNICODE environments. The package works under C and C++ and the eDesign.dll can be used by other program languages.

4. Application

A simple, transparent and demonstrative structural model and design methodology have been chosen to illustrate the application of eArecon. The procedure starts with the architectural design using architectural CAD system, especially ArchiCAD (Fig.4). This software is not the integrated component of the system, therefore the product model is written into ifc2x2 file. The leading designer (LD) authorized in the eArecon system (for example using the SDP) imports the *ifc2x2* file into the ConSteel 4.0 design software (Fig.5). Here LD can divide the model into sub-models and can authorize associate designers (D1, D2, …), if it is appropriate. Then LD saves the project to the Model Server using Web-connection (Fig.6). D1 designer imports the project into ConSteel 4.0 and

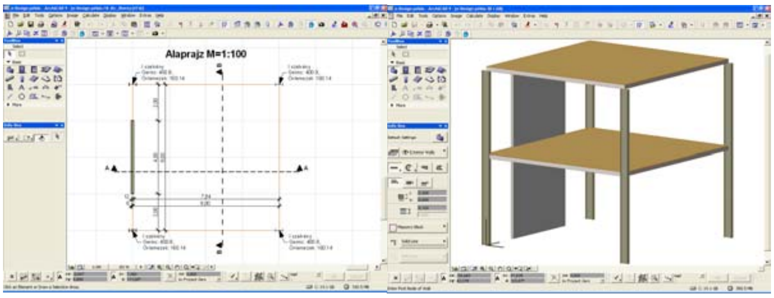

Fig. 4 *Architectural design in ArchiCad*

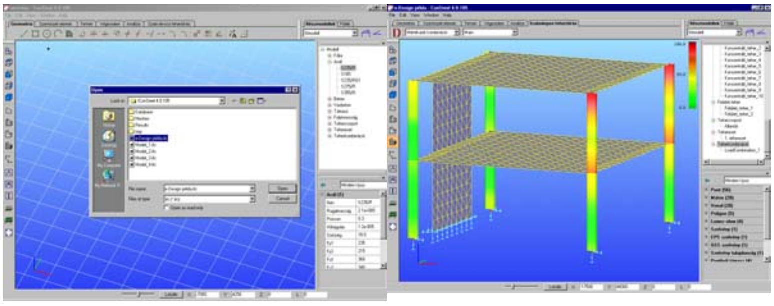

Fig. 5 *Web Open and design in ConSteel 4.0*

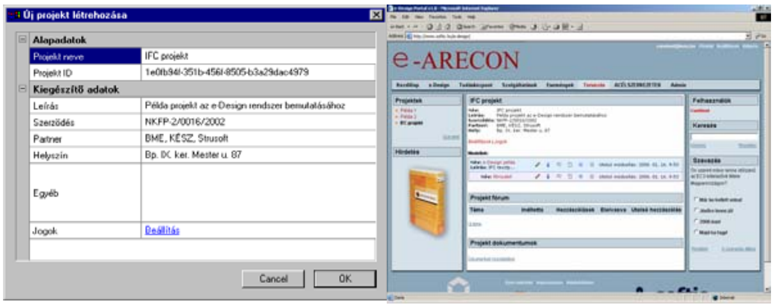

Fig. 6 *Project management in SDP*

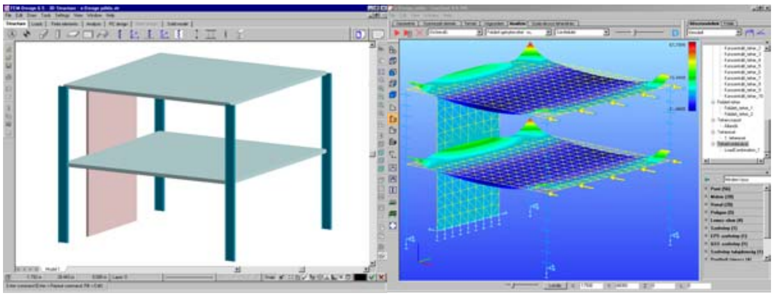

Fig. 7 *Web Open and design in FEM-Design*

designs the steel structural parts using 3D mixed beam-column-shell finite element analysis and general design method based on 3D elastic stability analysis (Fig.5). After the design of the steel structures D1 designer saves the model to the Model Server. Parallel to D1's activity, D2 imports the project into the FEM-Design program and designs the concrete structural parts using 3D mixed steel-concrete finite element analysis and design functions developed for concrete walls and slabs. (Fig.7). After the design of the concrete structures D1 saves the model to the Model Server. LD evaluates the D1's and D2's results, accepts (or refuses, modifies, reanalyzes) them, and saves the complex model to the Model Server. At the end of the procedure LD sends an e-message to D1 and D2 closing the collaborative work.

5. Conclusions

The harmonization of the European design standards raises the question of the "harmonization" of the design software packages based on the Structural Eurocodes. The harmonization covers the following problems:

- using middle data model which is known by any of the design programs devoted to structural design;
- linking design programs to design servers where collaborative design work can be organized;
- using high-level design formulas based on advanced finite element analysis.

eArecon's client-server system aims to demonstrate the possibility of this harmonization. The system is based on Web applications and uses the distributed multi-agent architecture. The same agents are used at both the server applications and the client programs. The low-level integration of design packages is restricted to the input/output Web communication between the application and the model server. The high-level integration means that the agents located on the server system are used by the client programs. The low-level integration is demonstrated by the FEM-Design software; the high-level integration is represented by the design program ConSteel 4.0, which was developed in the framework of the eArecon project. The working of the system is illustrated by a sample of collaborative design. The developed system may link to the more comprehensive vision of virtual building, which is based on the IFC object sharing protocol; however, eArecon may be the Structural Design component of the robustness vision of Europe-wide Design Space of Architecture, Engineering and Construction.

Acknowledgement

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