White Paper

Interoperability for BIM: a structural engineering viewpoint

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In construction projects there are always many parties involved; the project owner, architects, engineers, contractors, authorities, suppliers, etc. "Many parties" mean a lot of redundant communication and repetitive transfer of data (design review and changes, details, bill of material …). An effective method of gaining efficiency and improving quality in the construction process is to make use of digital sharing of data. This is the essence of the BIM (Building Information Modeling) process and must prevent re-entry of data; this process is also described as Product-based Model Design (Fig.1). Most software vendors have implemented methods to share the data of their models with other parties.

But the question remains: are the available technologies effective enough from the viewpoint of the structural engineers? In this paper, we discuss the various levels of interoperability, the position of the structural engineer in the interoperability processes, the practical implementations and our viewpoint. For a correct understanding of this paper, it is assumed that the construction project is in an advanced stage (execution planning); the interoperability between architects and engineers and others will then bring maximum benefits.

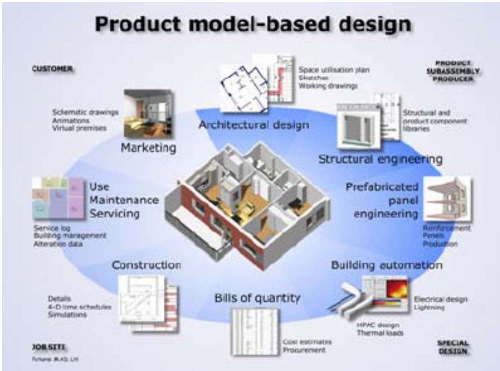

Fig.1

Interoperability in general

There are several levels of interoperability.

* The basic level is to **enable users to export and import data in their application software**; e.g. a CAD application – let us say for reinforcement drawings – must be able to read the design data from a CAE software – the required necessary reinforcement as in structural members. AutoCAD and Revit® Structure, both Autodesk products, interoperate with import/export of files. Likewise the CAE application Scia Engineer imports the DWG files as a grid for modeling or even as a background for reviewing. Allplan (Nemetschek) does also import required information's from other structural packages. In most cases the data exchange concerns pure geometrical non-intelligent data (points, poly-lines, planes, 3d volumes). Each software has its proprietary data storage, which imposes that this interoperability is from one program to another.
The longtime existing technique of import/export requires manual interaction to place correctly the imported data. Every time changes or revisions are required, the import/export operation has to be re-done. For huge projects with several thousands of drawings, this is an impractical working method. Adding the fact that different parties use different products, this level of interoperability becomes cumbersome.

* A second level is the ability **to use standard exchange formats** in order to enable users to read and write data to a large number of programs. In this work-flow the IFC (industry foundation classes) exchange technology is the most capable industry standard. Two aspects are new: all major software programs agree to the same format and accept to be certified for it, the exchange concerns well-defined objects and associated data (not drawings). It is an agreed international standard based on product modeling. The IFC format - Industry Foundation Classes offers a multiplicity of information: one works with intelligent 3D-CAD building objects like walls, windows or slabs. These objects contain specific and approved properties and attributes, which give the user a high level of flexibility.

In addition to the exchange of 2D and 3D geometrical data, the structural relationships and positioning between the elements is managed. Thus, the IFC format allows to reach new levels of collaboration and productivity in the building industry, even with the use of different CAD systems. The current implementation level is named IFC 2x3; it is supported by many suppliers of the AEC community: Nemetschek with its product lines Allplan, Archicad (Graphisoft), VectorWorks and Scia Engineer, but also Autodesk with Revit Architecture, Bentley with its building applications and more. There exist several independent tools (some of them available for free) to visualize and check IFC files, reinforcing the interoperability and the quality control of the exchange format. Scia is the first and only CAE supplier with a level 2 IFC 2x3 certification for its structural analysis program as of today (fig.2).

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IFC does have limitations: the data format provides for a static geometric definition attached to a collection of static properties. The functional relationship between the geometry and the properties is not preserved unless both the transmitting and receiving application take pains to register, attach and use the same functional data on both ends. This functional data can be carried by the IFC file but may go well beyond the 'standard' property set provided for in the IFC standard.". Even being a product model, the information on objects does not automatically incorporate the rich application content of the various software packages. An IFC file is logically a subset of a full BIM model where obsolete data are filtered in function of the application software. Any file conversion method has the chance for higher model degradation.

* The most advanced level is the **direct link between different software applications**: data are shared between at least two programs. For example, 'Round-Trip Engineering', by which a structural model is shared between a CAE and CAD program, in this case Scia Engineer and Nemetschek Allplan. This operability mode can also be described as integration (fig.3).

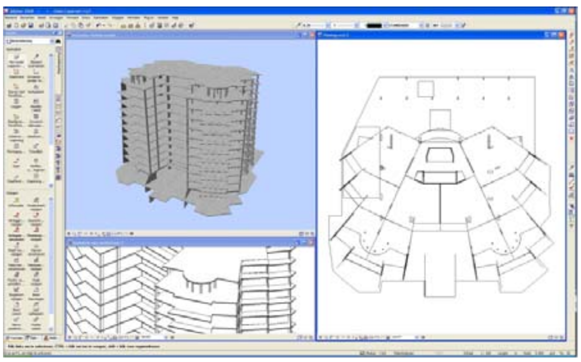


Fig 3 a Allplan Building Model

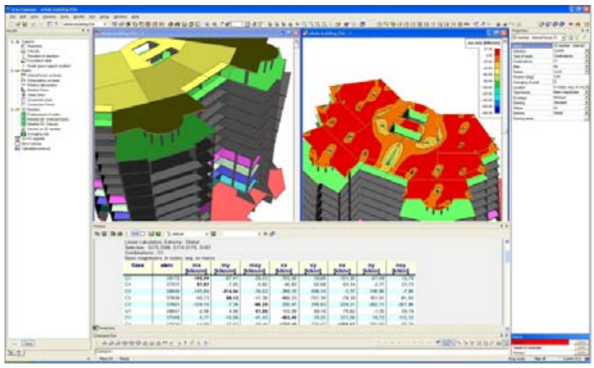


Fig 3 b Scia Engineer analytical model

Other examples are: linking Revit Structures to a CAE software like Etabs, Robot or Scia Engineer by using a direct API link (Application Programming Interface). It is a 1 to 1 intelligent relationship between two programs, with great efficiency since data re-entry is no more required. The level of intelligence is specified in an agreed protocol. The different features of these links will be shown further.

Data are often re-entered on purpose, because one fears mistakes and conflicts, either caused from the previous workflow, or caused by the engineers themselves. Adopting automatic workflows does not mean that one loses full control. As we will show later, plausibility checks, warnings and reports will be used in the process.

But what about the position of the structural engineer?

Every construction project is unique and will involve the expertise of a number of professional people including a structural engineer. The specialist skills of a structural engineer will include calculating loads and stresses, investigating the strength of foundations and analyzing the behavior of beams and columns in steel, concrete or other materials to ensure the structure has the strength required to perform its function safely, economically and with a shape and appearance that is visually satisfying (ref. "What is a structural engineer?" - Institution of Structural Engineers).

Building Information Modeling is essentially creating, communicating and reviewing information on a construction project, from concept up to fabrication, construction and maintenance. Engineering Design concerns the use of data from an architectural model and adding engineering analysis and design information to specify the structural work (delivering analysis and design notes, detailing drawings, revisions, changes …).

The role of the structural engineer in this process is important: his decisions will largely influence the cost and construction sequence of the basic structure. Will he propose or recommend a steel frame, precast concrete slabs or walls, in situ concrete, etc.? The sizes of the elements are determined; in high-rise buildings, the choice may result in a bonus of an extra storey if floor thicknesses can be reduced. The structural engineer needs a subset of the entire building model: a structural model, in which unnecessary information is no more represented. High quality architectural software has filtering and mapping capabilities to deduce a structural model from an architectural model: e.g. details on windows, doors, floor coverage, plaster, … are eliminated; a schematic rectangular section can represent a specific steel profile.

The structural work is the ultimate model for the structural engineer. It forms the backbone of a construction. The engineer determines the concept, the structural member positions and dimensions and the required details (reinforcement, section types, connections …). For these tasks the engineer uses two virtual models: the structural model and the analytic model. The difference between the two models lies in the necessary assumptions the engineer has to take to be able to analyze the structure according existing theories and building codes. As an example: a floor may be a two-way supported plate or a one-way supported slab or a structure of beams or any other structural system. The qualified structural engineer makes the acceptable simplifications in the analytical model. E.g. axes of members will be assumed to be coinciding while in reality there are small eccentricities. Sound qualified engineering judgment is necessary to understand and accept automatic conversions of a structural model to an analytical model.

The historical and current practice is that most engineers will individually work out an analytical model directly and separately from any other model (structural or architectural). His work leads to dimensions and detailed design data, e.g. required reinforcement in a concrete beam. The ultimate detailing i.e. working out drawings with the positions of the reinforcement is then the work of structural draftsmen.

Hereafter we propose interoperating processes, where the re-entry of data is drastically reduced by sharing or linking model data.

Practical implementations of interoperability around the Scia structural design software

1. Allplan Round-Trip Engineering

Especially for reinforced concrete structures a highly integrated solution is very effective. Between Allplan Engineering and Scia Engineer an innovative “Round-Trip Engineering” methodology is implemented.
Starting with an architectural model, a structural model is derived and transferred to Scia Engineer. There the analysis model is generated, the analysis is done and reinforcement designed (and optimized) and detailed (practical reinforcement schemes). This reinforcement is passed to Allplan to be further detailed and completed (Fig. 4 and 5). It is also possible to exchange the reinforcement scheme as detailed in Allplan with the design software to check for crack-width and real deformations. This level of integration has a very high benefit for quality engineering work.

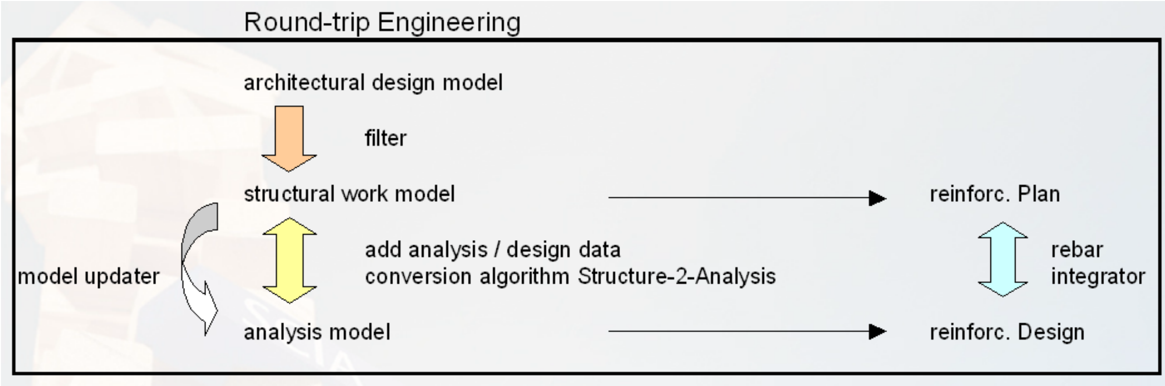
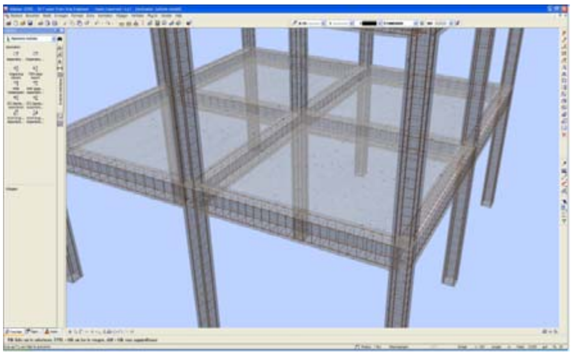
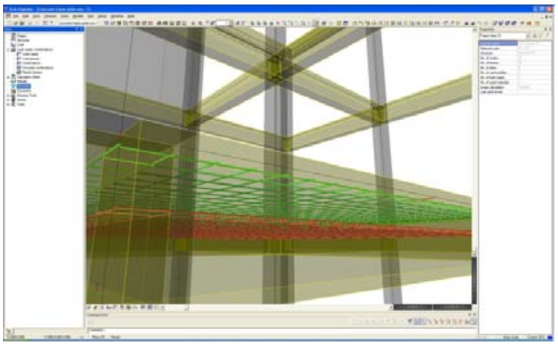


Fig. 4


Structural work model in Allplan Including reinforcement scheme


Structural work model in Scia Engineer including reinforcement scheme ***Fig. 5***

This advanced level of interoperability was realized using the API’s of the two programs to keep the structural objects compatible. Scia Engineer has a BIM Workgroup toolbox, consisting of the automatic conversion routine between structural and analysis model, the sharing of projects within workgroups with update and merge assistance and the member recognizer that converts geometric solids to linear or plane members, and plane members to linear members.

2. IFC based Structural Work Link (SWL) valid for Archicad and Vectorworks

A classical split concerns the work division between an architect and an engineer, mostly applied for buildings. The architect will filter his architectural model, to create a structural work model, which is then sent to the engineer. This is the method which is implemented by example between Archicad and Scia Engineer, as seen in the scheme hereafter (Fig.6).

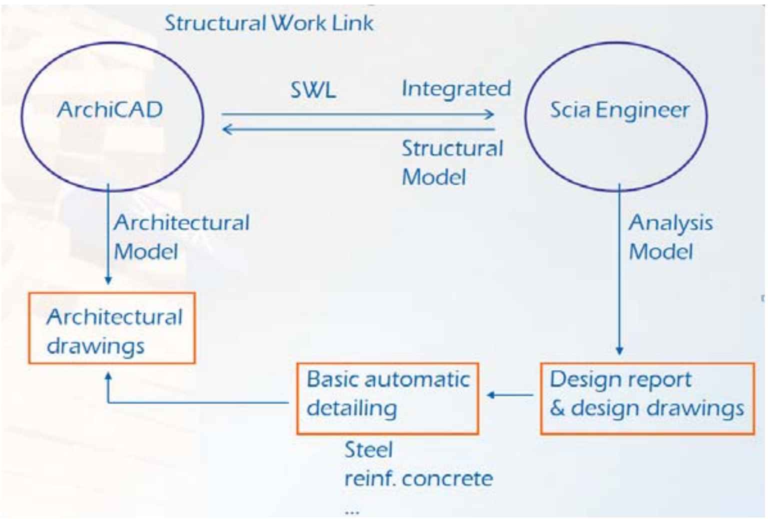


Fig.6

There is a clear distinction between the work of both professionals. The architect has a comprehensive software to work out a full virtual model with corresponding architectural drawings and lists. The Structural Work Link is the interface between the filtered architectural model and the structural model. The engineer remains within Scia Engineer for modeling, analysis, design and basic detailing drawings. The drawings can be combined in one project drawing for the purpose of workflows such as "interference checking" between the final structural and other building systems (e.g. HVAC ductwork) or be exchanged with other detailing software (e.g. specific for general reinforcement lay-outs, etc.).

The data from the structural engineer cannot automatically change the architectural model data; change proposals from the engineer must be accepted by the architect for his model. And more changes from the architectural to the engineering model are to be managed through a revision BIM workbench (see further) to prevent restarting engineering work on loadings, support conditions, structural geometry, design set-ups, etc.

3. REVIT Structure interface

In the first approach, the architect creates the architectural model without having to be concerned about the structural aspects. When this architectural model is ready, it is passed to the structural engineer. He will import the model into Revit Structure and modify it as required and generate the analytical model. With the plug-in for Revit Structure, the structural engineer is then able to export the analytical model into Scia Engineer. Once the model is imported into Scia Engineer the analytical model is automatically meshed into a finite element model allowing the structural engineer to start with his main task of calculating the structure with all added loads. In short: in Revit Structure the basic analytical model and loading is worked out, then passed to Scia Engineer where further design data (e.g. on loading, analysis type etc.) is added. Changes to the analytical model, initiated by Scia Engineer, are handled within Revit. The design work which is done within Scia Engineer (e.g. steel connection, Rebar) is not linked to Revit.

Using the alternative approach, the analytical and structural model is created within Scia Engineer and then exported into Revit Structure. It enables the Revit Structure user to continue with the tools provided by Revit Structure. There is no “Round-Trip engineering” on the level of reinforcement schemes (bars, meshes) between the two programs.

In either approach, the structural engineer is able to check, modify, correct and update the analytical model in Scia Engineer with the necessary analysis data, including seismic information, stability information etc. using the necessary tools developed for the daily work of the structural engineer. The structural engineer can then, after the design is done, update the Revit Structure model as appropriate (Fig.7).

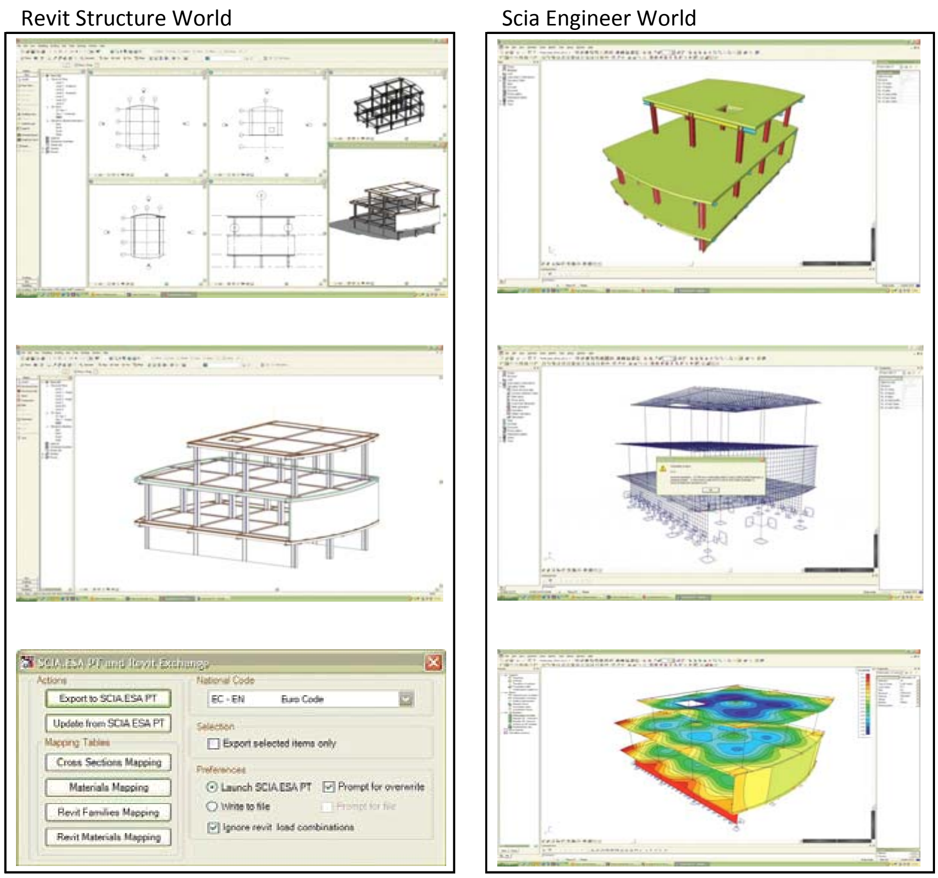
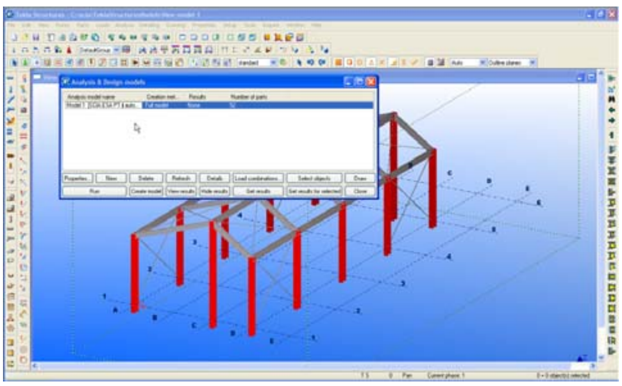


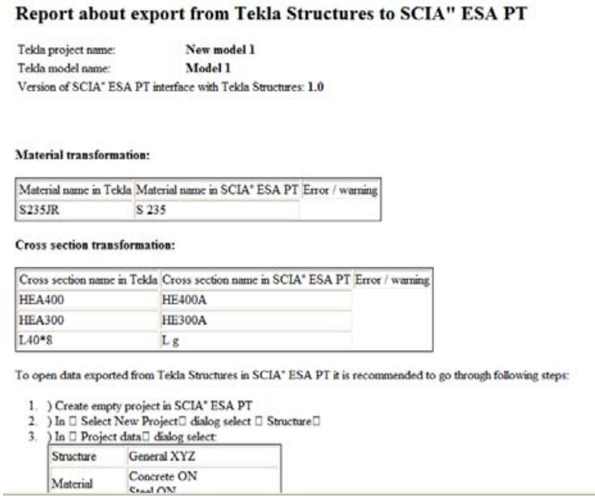
Fig. 7

4. TEKLA Structures interface (based on Tekla API)

The concept of this interface works in one way: The Tekla user creates the model and when this model is ready, it is passed to the structural engineer with a plug-in for Tekla Structures. He is able to create and export the analytical model towards Scia Engineer. Inside Scia Engineer the analytical model is again automatically meshed into a finite element model allowing the structural engineer to start with his main task of calculating the structure with all added loads.

The following screen copies illustrate the link (Fig.8). There is report on the export from Tekla to Scia, explaining the transformations.





Report about export from Tekla Structures to SCIA" ESA PT

Tekla project name: **New model 1**
Tekla model name: **Model 1**
Version of SCIA" ESA PT interface with Tekla Structures: **1.0**

Material transformation:

Material name in Tekla	Material name in SCIA" ESA PT	Error / warning
S235JR	S 235	

Cross section transformation:

Cross section name in Tekla	Cross section name in SCIA" ESA PT	Error / warning
HEA400	HE400A	
HEA300	HE300A	
L40*8	L g	

To open data exported from Tekla Structures in SCIA" ESA PT it is recommended to go through following steps:

1.) Create empty project in SCIA" ESA PT
2.) In □ Select New Project□ dialog select □ Structure□
3.) In □ Project data□ dialog select:

Structure	General XYZ
Material	Concrete ON Steel ON

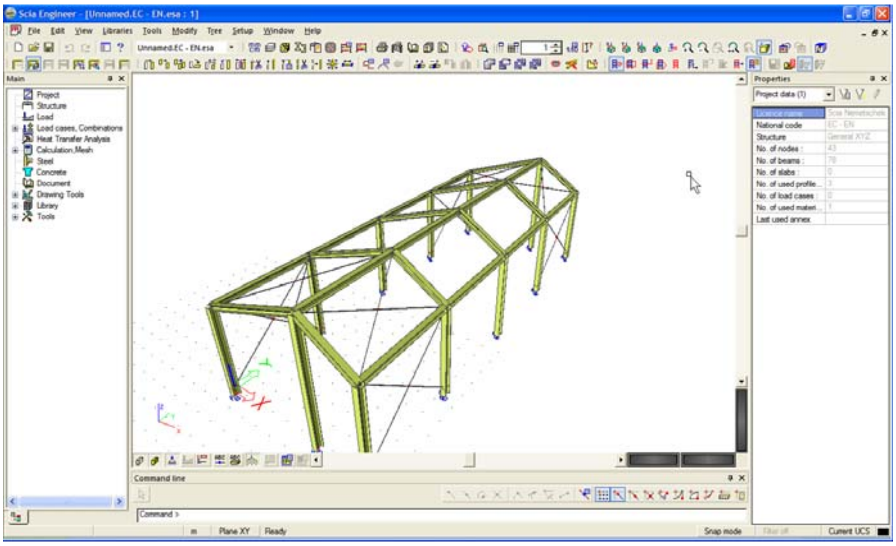


Fig.8

Basic analysis data can be added within Tekla (e.g. hinges, supports, loadings, combinations) and is exported with the geometry. Within Scia Engineer additional design data (loadings, connection types, structural members, combinations, …) can be added to the model. The analysis, design and engineering detailing (e.g. connection details) is done entirely within Scia Engineer. The design changes to all cross sections initiated by Scia Engineer are sent back automatically to Tekla Structures. Other design functions of Scia Engineer such as new members, deleted members, connections, etc... are not linked to Tekla as the current Tekla API does not support it. The fabrication detailing is done fully in Tekla Structures.

Beside this API link (from Tekla Structures to a CAE program) there is also the possibility to import and export standard files for the geometry, based on IFC 2x3 which both software vendors Tekla and Scia are supporting.

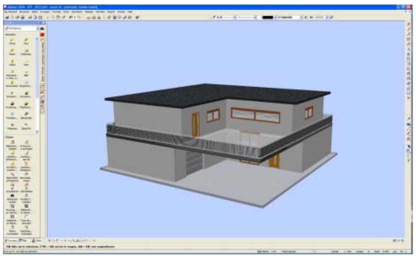
Work is going on to add steel fabrication detailing geometry (as required to steer CNC machines) into future IFC implementations (ref. Chuck Eastman / Atlanta on moving CIS/2 to IFC). Currently users have to use other existing data interfaces such as CIS/2 and DSTv/PSS ("Produktschnittstelle Stahlbau" of the "Deutsche Stahlbau Verband", a German standard).

Overview table of operability functionality

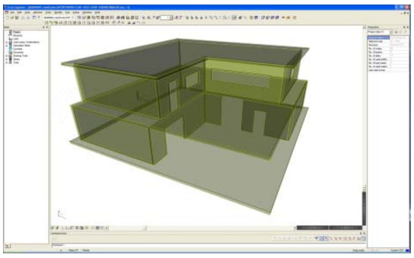
CAD modelling sw vs Scia Engineer implemented interoperability functions	Scia Engineer	+	Allplan Roundtrip Engineering	Archicad Structural Work Link	VectorWorks Model Link	Revit API link	Tekla API link	General IFC 2x3
architectural model			X	X	X			X
filtering architectural model towards structures			X	X	X	X		
structural model	X		X	X	X	X	X	X
analytical model	X					X	X	
detailing model			precast				steel	
alignment algorithm	X					X	X	
conversion solids into structural members	X							
automatic update of changes	X		X					
revision management	X							
visualisation of changes	X		X			X	X	
exchange of part of a model	X		X			X	X	

The detailing model is focusing on the work-preparation mainly for prefabrication (precast concrete industry, steel fabrication). It requires the understanding of how structural member parts will be manufactured (e.g. hollow core slabs on tables, steel profiles and plates cut, welded and/or bolted).

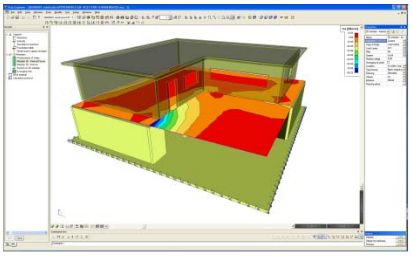
Basically there are 2 workflow scenarios for a seamless digital transfer from an architect to the structural engineer (CAE user):



Architectural model

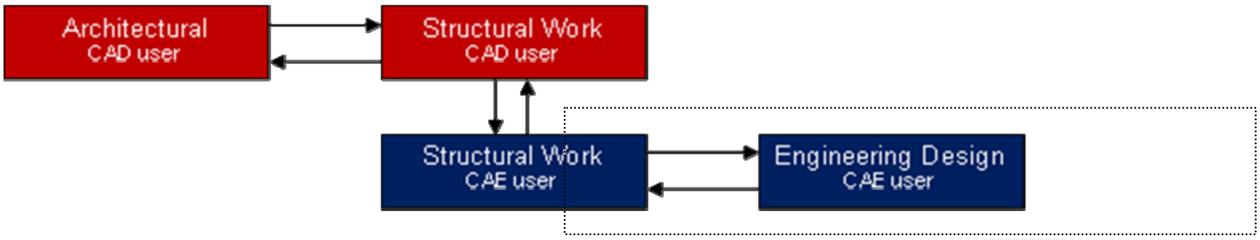


Structural model

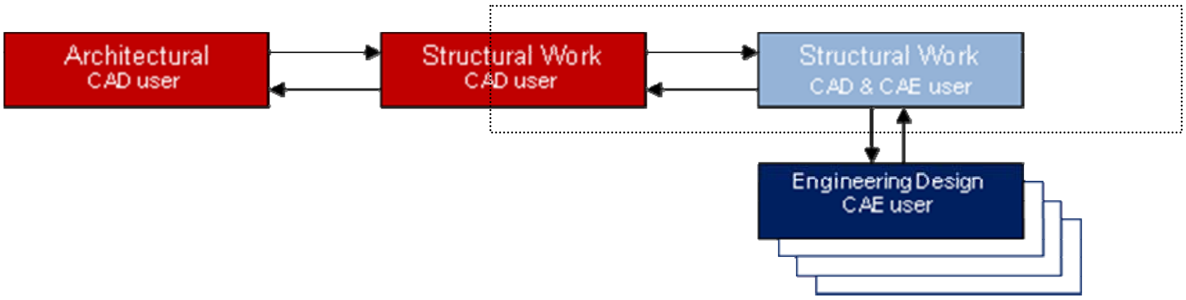


Analysis model

Scenario 1 : one CAD user and one CAE user (2 programs) (implementations 1 and 2)



Scenario 2 : one CAD user also has to work-out the analysis model (implementations 3 and 4)



In practice the adopted scenario will depend on the available resources and competences. For the Scia Engineer software both scenarios are possible.

Key factors for successful interoperability for structural engineers

In the scheme below, the different views (architectural, structural, analysis) of a 3D model are sketched. To the right one sees the different between a structural model and an analysis model; the engineer has to decide if the members are plates or beams. The conversion is possibly done automatically, as long as the set-up parameters can steer the automatic conversion process (Fig. 9).

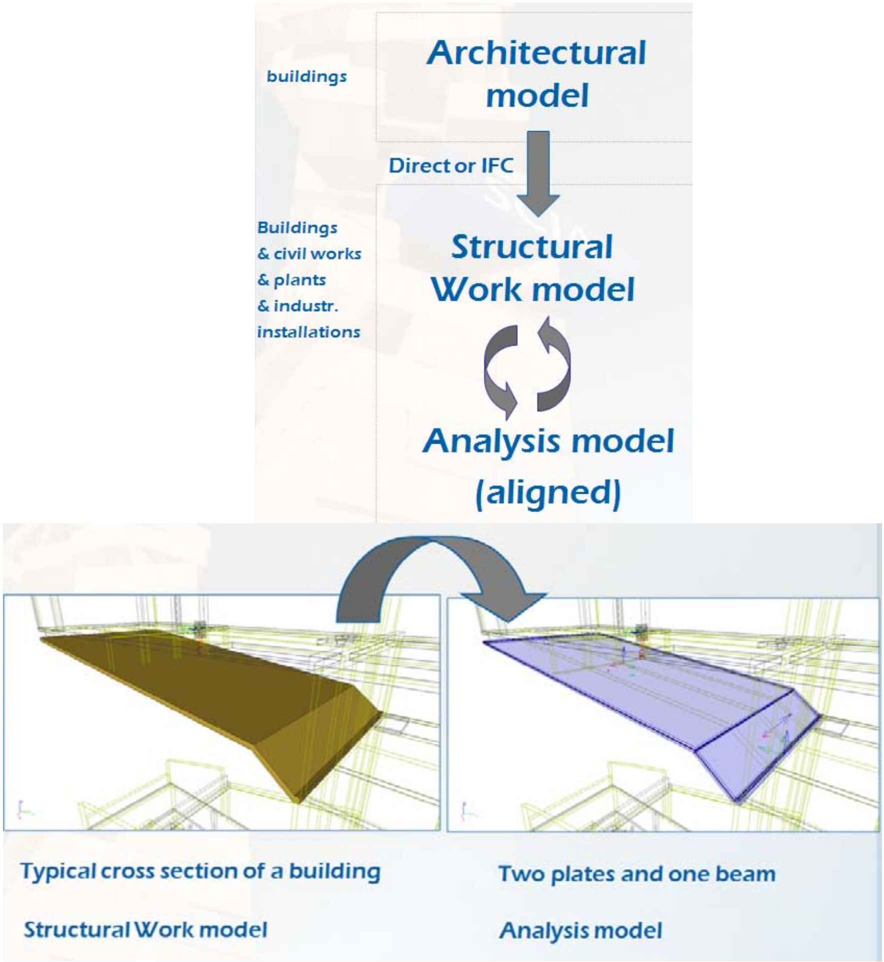
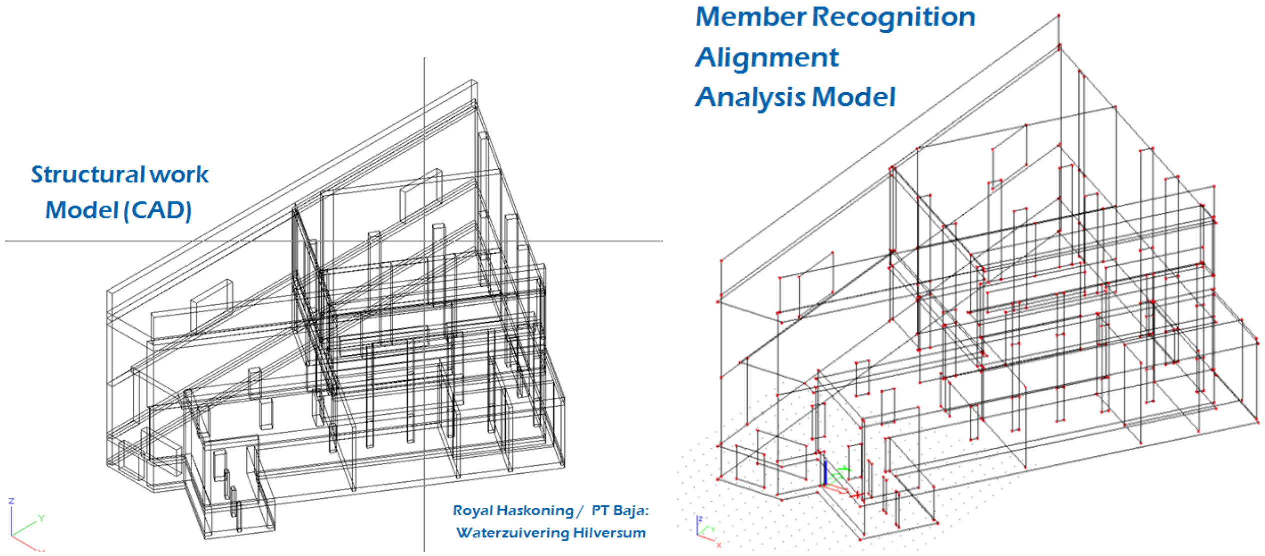


Fig 9

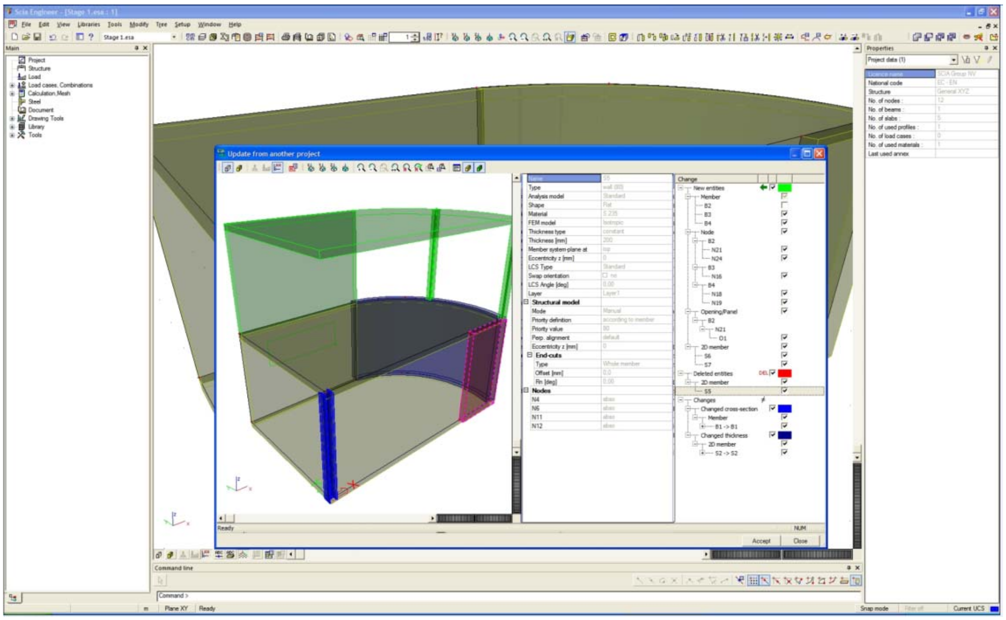
The keys to practice in linking an architectural model to an engineering analysis model are algorithms for member recognition and automatic alignment. An example is given hereafter where one sees how in practice an architectural model must be reconstituted to an analysis model by shifting the neutral planes and axes such that a practical calculation is possible (Fig.10). Doing this manually is impossible; it is the main reason why – in the past – the data transfer between architects and engineers did not happen, except for having an architectural drawing as background to redraw the structure.



Allplan structural model sent to Scia Engineer ***Analytical model generated in Scia Engineer*** ***Fig.10***

Another important requirement is the capability to manage the revisions and changes. The iterative design cycle imposes to keep track of changes, e.g. of geometry (but it could also be loadings, support conditions, …) (Fig.11).

A BIM workbench was implemented in Scia Engineer to manage the revisions (changes, additions, deletes). The process of structural analysis, code compliant dimensioning and engineering detailing is strongly supported by this BIM workbench. It enhances the control of the automatic processes for the structural engineer, when linking with other programs as the mentioned ones for architecture (Allplan, Archicad, VectorWorks) or for engineering (Allplan Engineering, Revit Structure, Tekla Structures) .



One entity has been deleted (red color), two entities were changed (blue) ***Fig.11***

Our concluding viewpoint

The construction industry is highly driven by cost reduction, yet the progress of innovation is far too little. Quite a number of publications mention the drawback in efficiency in construction as seen in the last decennium. The shortage of skilled engineers is equally known, which imposes to better exploit the scarce engineering resources with new design tools and processes. It is more than time to promote these new tools.

Interoperability is a key issue for introducing BIM process changes in a company or in-between companies. Each supplier of a corner stone in the BIM chain should offer several solutions of operability, with various functionality. Whatever level a user wants to adopt, the supplier must offer adequate BIM process supporting software.

Although the BIM technology for structural engineers is now at an advanced level, more work is still required to cover all practical aspects. Important changes to the structural work due to technical interventions, e.g. due to pass-through for HVAC / MEP or due to entirely new architectural building parts, might require stronger management tools to consolidate the work on building parts of the various models.

Not all techniques for communication between construction partners have been discussed in this paper. Lately the use of 3D PDF’s to better communicate the design to others and material take-off from the model for more accurate estimating has proven very valid.

For a discussion of legal issues and risks we refer to the paper by Lachmi Khemlani “BIM Fundamentals Seminar for Structural Engineers” published in AECbtes on Oct. 18 2007.

By all means BIM is a new way of working for all involved in construction. For the structural engineer this technology provides a lot of value to improve his efficiency and his collaboration with other design and fabrication partners.