Reinforcement Planning using Building Information Modeling (BIM) and SOFiSTiK Technologies

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FB3363 In this class you will learn how to create 3D reinforcement, 2D reinforcement plans, and bending schedules using Autodesk® Revit® software. We will show you how to use the design results of a finite element calculation effectively for creating reinforcement that covers the required calculated amount. A special emphasis will be made on the derivation of 2D reinforcement plans, including steel schedules.

Learning Objectives
At the end of this class, you will be able to:

- Use Revit for reinforcement planning
- Create 2D reinforcement plans in Revit
- Create reinforcement covering a calculated amount
- Include bending schedules on reinforcement plans

About the Speakers
Based in Nuremberg, Germany, Frank works as Managing Director at SOFiSTiK AG for more than 12 years. He is in charge for products and marketing at SOFiSTiK. Frank holds a ‘Diplom Ingenieur’ degree in civil engineering from the Technical University of Munich.

Andreas Niggl works as software engineer at SOFiSTiK AG in Munich, Germany, where he is responsible for the geometry and meshing kernel of the FEA package. In addition to this, he currently works on a software whose aim is to automatically generate 3D reinforcement from calculated design results. Andreas holds a doctoral degree in civil engineering from Technical University of Munich.

Based in Munich, Germany, Jochen works as Technical Specialists Engineer at Autodesk for more than nine years. Since Autodesk decided to market Revit in Central Europe in 2004, he presents, sells, trains and supports it to resellers and customers. Today he is mainly responsible for Revit Structure but also for all BIM products and solutions of the Building Design Suites. Jochen holds a ‘Diplom Ingenieur’ degree in civil engineering from the university of Lüneburg.
Overview about this Lecture

This lecture will discuss several areas where structural engineers can benefit from Building Information Modeling (BIM) and demonstrate the workflow using the current product portfolio of Autodesk® and SOFiSTiK®.

Autodesk® Revit® Structure integrates the analytical model of a building structure consistently with the real geometry of the architectural or coordination model and thus provides the basis for integrating structural analysis and design-related tasks into an overall BIM-workflow. As a company which offers software for finite element analysis as well as for reinforcement detailing, SOFiSTiK software perfectly fits into this concept.

The present lecture will give an overview about SOFiSTiK software and its integration into Autodesk Revit and will show how this matches with the possibility to create 3D reinforcement models in Revit. After a first overview of generating 3D rebar models in Revit in general, it will be shown how 2D reinforcement sheets and steel schedules can be automatically extracted from the 3D model. The latter is seen as an essential tool which is necessary to facilitate the usage of 3D reinforcement models in productive environments. Finally, an outlook will be given on a current development project at SOFiSTiK which aims to automatically generate a 3D reinforcement model from analysis results (required reinforcement).
Live Presentation: Reinforcement Detailing in Revit (learning objective 1, 2)

With the labs version of “SOFiSTiK Reinforcement for Autodesk® Revit®”, SOFiSTiK recently published a set of tools which allow to assist the automatic generation of 2D plans and steel schedules from a 3D reinforcement model in Revit. We see this tool as essential for the usage of 3D rebar models in current productive environments, since 2D drawings are still required and expected by practitioners in construction and design.

In contrast to a classic 2D workflow, where the generation of the reinforcement, bar marks and tagging will be performed roughly at the same time in a single step and usually by the same person in the 2D plan, we recommend a modified workflow when using our toolbox:

1. Designer prepares a rough reinforcement model with all necessary views and sheets.
2. Structural engineer adapts this model and inserts the structurally required rebars instead of creating complex sketches.
3. Designer completes the reinforcement sheets with bar marks, annotations, shape details, schedules etc.

Starting point of the generation of a 2D reinforcement schedule is an existing concrete building project in Revit. As a first step, all viewports necessary for the reinforcement plan as well as sheets with appropriate dimensions should be created.

The generation of the 3D reinforcement model is then carried out mainly using the tools provided by Revit. The real work for “SOFiSTiK Reinforcement for Autodesk® Revit®” starts with the creation of bar marks and tags. The picture below shows a completed reinforcement layout demonstrating how a plan could look like that is required for the checking engineer and on the building site.
In the schedule below you will get an overview about the functionality of SOFiSTiK Reinforcement for Autodesk® Revit®.

<table>
<thead>
<tr>
<th>Command</th>
<th>Brief description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Copy to Element</td>
<td>Copies the entire reinforcement to an identical or similar element.</td>
</tr>
<tr>
<td>Delete Reinforcement</td>
<td>Deletes the entire reinforcement of an element.</td>
</tr>
<tr>
<td>Delete Barmark</td>
<td>Deletes all rebar instances of a bar mark.</td>
</tr>
<tr>
<td>Set Barmarks</td>
<td>Sets the bar marks for the entire reinforcement in the project. You can determine a start number and an increment.</td>
</tr>
<tr>
<td>Renumber Barmark</td>
<td>Changes the number of a single position.</td>
</tr>
<tr>
<td>Barmarks per Sheet</td>
<td>Assigns reinforcement to sheets.</td>
</tr>
<tr>
<td>Settings</td>
<td>Sets the global parameters of “SOFiSTiK Reinforcement for Autodesk® Revit®”.</td>
</tr>
<tr>
<td>Tag All</td>
<td>Tags all rebars in the active view. Already tagged rebars will be deleted automatically.</td>
</tr>
<tr>
<td>Tag Missing</td>
<td>Completes the missing rebar tags in the active view. Existing tagged rebars remain unaffected.</td>
</tr>
<tr>
<td>Rebar Shape Detail</td>
<td>Places a detail of the chosen rebar shape on the reinforcement sheet.</td>
</tr>
<tr>
<td>Create Schedule</td>
<td>Creates a rebar and bending schedule in the SOFiSTiK Report Browser. It can be displayed on screen, printed and inserted into the drawing.</td>
</tr>
<tr>
<td>Insert Schedule</td>
<td>Inserts the steel and bending schedule on the active sheet. The schedule must have been created before.</td>
</tr>
</tbody>
</table>
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For further information and a download of the software please visit:


Additionally you will find an introductory video here:

http://www.sofistik.com/fileadmin/FILES/LabsReinforcement/Film/en/Preview_SOFiSTiK_labs_1.html

Automatic generation of 3D-reinforcement from calculated design results

One of the core features of SOFiSTiK are program modules for the design of reinforced concrete structures. Starting from linear or non-linear analysis results the software calculates the required amount of reinforcement for beam, plate or shell structures. These results of the design calculation often visualized by graphical plots are then handed over to the construction engineer who does the detailing of the rebars. This task however, is characterized by a large amount of manual work and thus consumes a large portion of the overall construction detailing work.

A recent development at SOFiSTiK now tries to support this step from the design calculation to the 3D reinforcement model by providing tools for a more automatic assistance. Two modules, called the “Reinforcement Generator” and the “Reinforcement Assistant”, which have been developed in a prototypic stage up to now, will be presented and explained in this part of the lecture. Both modules are implemented as extensions to Autodesk Revit.

**Reinforcement Generator for beams and columns**
The Reinforcement Generator automatically generates a 3D rebar model for beams and columns from computed analysis results. This 3D rebar model might serve as an automatically
generated recommendation which fulfills the required reinforcement and which can be modified and further refined by the user. Following picture shows the automatically generated rebars in a continuous beam.

One of the challenging tasks in this development is to capture the design intention of the construction engineer within the computer in order to allow an automatic process. Rebar design usually involves a multitude of different, possibly contrary, requirements which have to be fulfilled by the engineer. He has to consider the rules in the design codes, has to follow possible company or country specific demands as well as demands defined by construction schedules or economic needs. To a large extend the result and the quality of this work is based on the engineer's personal knowledge which he has developed during years of experience. This knowledge however is more or less 'stored' implicitly in the mind of the engineer and is thus not directly accessible by the computer.

One approach to access such kind of implicitly given knowledge is Expert System technology. Expert systems are regarded as branch in the area of Artificial Intelligence and are currently used in many fields of application like medical diagnostics or assembly layout of computers. One of the key assumptions in (rule based) expert systems is, that the knowledge of an expert can be expressed in IF … THEN … type rules. The system provides facilities to enter these rules by the expert in a very simple and accessible syntax, often similar to human language, which enables the expert to enter his knowledge without deeper programming skills. These rules are then processed by the expert system within the so-called inference engine in order to generate new conclusions or initiate certain actions.

The automatic generation of the 3D-rebar model in the Reinforcement Generator follows this approach. Each step in the generation of the rebar model, like the determination of the rebar
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layout in the cross-section or the calculation of anchorage and laps can be controlled by rules. For example, in order to control the diameter of the longitudinal bars in a beam, the user may define the following rules:

\[
\text{DiameterLongBar} = [8\text{[mm]}, 10\text{[mm]}, 12\text{[mm]}, 14\text{[mm]}, 16\text{[mm]}]}
\]

\[
\text{HeightSection} > 40\text{[cm]}: \text{DiameterLongBar} \geq 10\text{[mm]}
\]

The first expression initializes the range of allowed parameters for the diameter. The second expression restricts this range in the case that the height of the cross-section is larger than 40 cm. Based on these values, the application tries to find a distribution of bars within the cross-section which fulfills the required amount of reinforcement. According to the different requirements in the design process, there will also be different kind of rule sets for controlling the rebar generation. There will be rules for maintaining the design code regulations or rules which the user can define on a project or company specific basis.

As an example, below picture shows the rules for calculating the anchorage lengths of rebars following the definitions in the German Eurocode DIN EN 1992-1-1.

\[
\text{f}_{\text{bd}} = 2.25 \times \text{eta}_1 \times \text{eta}_2 \times \text{f}_{\text{ctd}}
\]

\[
\text{lb}_{\text{rd}} = (d_{\text{as1}}/4) \times (f_{\text{yd}}/f_{\text{bd}})$ \text{ $8.4.3 \ (2)}$
\]

\[
\text{lb}_d = \text{alpha}_1 \times \text{alpha}_2 \times \text{alpha}_3 \times \text{alpha}_4 \times \text{alpha}_5 \times \text{lb}_{\text{rd}} \times \text{as1}_\text{util}
\]

Such design code related rules will be provided by SOFiSTiK in different country-specific sets and there is usually no need for the user to apply modifications there. Other rules, however, for example those controlling the rebar layout in the cross-section cannot be determined.
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beforehand and are expected to be changed by the user. The user is free to add additional specifications and to provide his own set of rules. For defining the rules, we do not expect detailed programming knowledge. Each rule consists of an assignment expression and an optional condition separated by a colon ‘:’ and is usually defined in a single line. The rules can be entered in any specific order and any number. After parsing, the program processes all statements and brings them into correct order.

Currently, the rules may be entered via a text editor which can be opened from within Revit. In the long term, we are planning to provide special input dialogs in Revit which assist the user in writing his own definitions. Our aim is to enable the user to build up his own set of ‘design patterns’ which he can load into a project for controlling the automatic generation of the rebar model and which allows him to adapt this generation to his or his company-specific needs.

An important issue of such kind of automatic processes are facilities for explanation. The experienced user does not want to have a ‘black-box’ application which presents him a solution without any further information. He rather wants to know the basis on which a certain solution has been obtained. This gives him the opportunity to control the results and increases the confidence in the solution. In order to accommodate this issue, the Reinforcement Generator provides facilities for visualization of relevant parameters directly within Revit. Once the 3D-rebars in a beam have been generated, the user can visualize the required and the inserted reinforcement in a graphical layout similar to the well known moment-capacity diagram found in the design codes. These graphs are parametrically connected with the rebar model. Changing the rebar definition in Revit will automatically update the graph of the inserted reinforcement such that the user gets immediate feedback on his modifications. Following picture shows this distribution for the continuous beam shown above. The inserted reinforcement (blue) is compared to the required reinforcement (red).
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Reinforcement Assistant for slabs

The SOFiSTiK Reinforcement Assistant is an additional module used to monitor the inserted reinforcement in 2D slabs and walls in Revit Structure. The amount of physically inserted reinforcement can be displayed and compared with the required reinforcement, calculated beforehand by a Finite-Element analysis with SOFiSTiK. Whenever the user inserts new mesh fabrics or bars or changes the parameter of already inserted reinforcement the displayed values will be automatically adapted which gives him an instant feedback on his modifications.

The user can switch between visualization of the lower and the upper layer of the reinforcement and can display different kind of values:

- Total required reinforcement – which shows the statically required reinforcement calculated by SOFiSTiK
- Existing reinforcement – which shows the already inserted reinforcement
- Still required reinforcement – difference between required and inserted values
- Exceeded reinforcement

Technically, the representation of the displayed reinforcement values consists of a Revit AVF object: a set of a set of vectors that represent the reinforcement directions and which length corresponds with the magnitude of the amount of reinforcement. These vectors are distributed on a punctual grid that lies on the Revit analytical model. The values in each grid point are interpolated from the values calculated on the underlying Finite Element mesh created by SOFiSTiK.
By now, all the reinforcement representations are created on the active view independently whether it is a 3D or 2D view. The elements can be modified in any view and the results will be automatically updated. A single display style is assigned to the view, creating a color scale that displays the magnitude of the reinforcement configuration in each point.

The picture below shows the representation of the "still required" reinforcement on a slab. An analogue visualization can be created on walls as well.
The recognition of Revit reinforcement objects inserted in the target plate is limited to Area Reinforcement, Fabric Area and Rebar elements (when the layout rule is not set to “single”).

In the case of Area Reinforcement and Fabric Area, the direction of the reinforcement has to correspond to the direction of the local coordinate systems on the underlying Finite-Element mesh. For the Rebar objects, these have to follow the same direction, i.e. the driving line of the Rebar must be parallel to the reinforcement direction. Currently there is a tolerance of 2° to include the element on the set of inserted reinforcement.

The rebar objects are automatically assigned to the corresponding reinforcement layer in the slab (upper, lower) according to their relative position with respect to the faces of the host element. When the element is closer to the “top”/”exterior” face it is assumed that the rebar correspond to the upside and upside cross reinforcement layers depicted below in red. Likewise, when the “bottom”/”interior” face is the closer one, then the rebars assigned to the downside and downside cross reinforcement layers.