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Use of BIM Technology and 3D-Modeling to Automate the Paperless Reinforcement Production

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ACKNOWLEDGEMENT

This is a Master project prepared by the Department of Construction, Faculty of Engineering Sciences at University of Agder, summer 2018.

This project was conducted by prior knowledge of *Building Information Modeling*. The *Automation of Reinforcement Production* using *Building Information Modeling* technology is a worldwide topic that can improve the paperless reinforcements' drawings and make a cost-effective and time saving process of reinforcements fabrication. *3D Reinforcement Modelling* in the field of *BuildingSMART* and *Building Information Modeling* are also relatively new concept, and it is challenging to refine the theory when it is mostly connected. Therefore, there will certainly be instances where the reader is expected to conduct further studies on the topic.

The assignment has been an independent work, supported by Statsbygg, and Department of Construction, University of Agder at Grimstad.

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Sara Jalali

Abstract

Although, Building Information Modeling has flourishing development for reinforced concrete, still there is a long way to achieve efficient performance throughout reinforcement supply chain. Statsbygg through the use of 3D reinforcement of digital construction project (Gol Traffic Station), desires to achieve a full paperless drawings and documentation project. There is also a strong ambition to standardizes those codes that are not mentioned in the official bending lists.

This project has two-part and, follows these objectives:

1. Automate the production of reinforcement, production by direct export from model, avoiding manual work in the form of official bending lists and minimizing incorrect production / deliveries.
2. Reinforcement of cast in site structures by model and avoiding traditional reinforcement drawings on building sites.

In this study, current tools' capacities and performance from these prospects is evaluated. The flow work for 3 reinforcements over its data exchange is considered. This process demonstrates the importance of selecting the proper method of extracting outputs from the model, and its influence on the path from modelling to the production section for BIM tools to operational support and perfect the whole reinforcement modelling.

BIM tools are considered in four sections: design and modeling; editing, updating and optimization, interoperability, project and construction management. This assessment demonstrates development trends in the BIM software industry according to concrete 3D-reinforcement. It is attempted to simulate a small section of Gol project to get a better understanding of work flow.

In this assignment the focus would have be on the workflow and improvement or optimization of this purposes.

- Consider how we can standardize the workflow using file formats (excel / BVBS). Pros / Cons of these.
- What are the challenges with quality assurance? How to set status on objects?
- What parameters must be included in the model?
- Which standard views must be included in the production / assembly at the construction site

Explanation of Abbreviations and Concepts

BVBS	BundesVereinigung der BauSoftwarehäuser E.V.
CAD	Computer-Aided Design
CIP	Cast-in-Place
IDM	Information Delivery Manual (IDM)
IGES	Initial Graphics Exchange Specification
ISO	International Standards Organization
JIT	Just In Time
LOD	LOD-Level of Development
MMI	Model Maturity Index
MVD	Model View Definition
NBIMS	National BIM Standards
NC	Numerically Controlled
PPS	Production Planning and Scheduling
RFID	Radio Frequency Identification
SBC	Safe Bearing Capacity
SDC	Strategic Development Council

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1. Introduction

1.1. Why 3D reinforcement is interesting?

According to observation of Strategic Development Council (SDC) there is not inclusive use of BIM in design, commissioning, and fabrication of precast concrete or even cast-in-place concrete.
BIM has generally lower adoption to contractors and reinforcement manufacturers compared to other specialists like architects and engineers. Many companies apply BIM significantly for visualization and constructability checking and don't utilize other important capacities of BIM that can improve the efficiency of design and fabrication. BIM-assisted reinforcement detailing or manufacturing models are considerably used for design, visualization, documentation and adaptability checking aims. In the field of reinforced concrete, BIM potentials usually are not extensively used for the purposes, such as conflict detection, code adoption checking, estimation, scheduling, and project coordination [6].
Although, Building Information Modeling has got flourishing development for reinforced concrete, still there is a long way to achieve efficient perform throughout reinforcement supply chain.

1.2. Cooperation Partners

Statsbygg in construction project (Norway's first Digibygg: Gol conservation station and day-care center), attempts to obtain a full digital drawings and documentation. Gol Consumption Station project plays a very important role for all involved parties as this will be the first of many Digi-constructs. The digital solutions will be measured and evaluated to take further experiences to future Digi-construct.
High ambition level Statsbygg has signaled that to provide both drawing space construction, 4D time planning, Radio Frequency Identification RFID tags and use of VR, in implementation of the project.
In this project, Statsbygg in cooperation with NTI, SYMETRI and the other software providers, tries to provide the following possibilities regarding 3D reinforcements.

1. To automate the production of reinforcement. Production by direct export from model. Avoid manual work in the form of official bending lists and minimize incorrect production / deliveries.

2. Reinforcement of cast-iron structures by model. Avoid traditional reinforcement drawings on building sites.

Figure 1.1Digibygg-Pilot Gol [1]

1.3. Background of reinforcement supply chain

Developing support systems to rectify construction costs specially by implementing lean and Just-In-Time (JIT) production principles were considered by several studies by the aim of to reduce lead times, inventories, and material and product waste, and to manage site work more favorably[1].
Additionally, an activity-based costing was developed to upgrade rebar cost information on processes and cost drivers[2].
A number of researches evaluated production planning and fabrication automation. Some have addressed to automate extraction of rebar design data and production planning employing Numerically Controlled (NC) rebar production. This was carried out by computer integration and feature-based design concept. Detailing data are provided by integrating Computer-Aided Design(CAD) data and production planning [3, 4].
For the purpose of increasing precise and real-time production, details applying data-rich rebar identification and pursuing methods are important issues. Therefore, attempts have focused on improving Radio Frequency Identification (RFID) systems for effortless rebar quality control inspection, inventory, and Transportation management [5]
In some studies machine learning techniques are employed to extend a flexible control system for automated rebar bending[6]. Other studies have improved knowledge systems to more appropriate identification and obtain rebar constructability issues during the design phase [7, 8].
Some studies have revealed the best practices to improve the workability of various rebar supply chain activities such as classifying best practices for slab mesh design to design the more applicable

reinforcement, [9], prefabricated rebar assemblies has employed extensively as an economic friendly method by many reinforcement institutes in developed countries[10].

Bar marking, and development of codes and standards for rebar bending schedules helps to upgrade the productivity of reinforcement supply chain. It is important that, steel reinforcement materials, production processes and improvements in corrosion resistance have ongoing progression causes to improve their performance and application[10].
Dominant of researches about concrete reinforcement has addressed to production planning, fabrication, transportation and site work, and consideration the role of BIM in the design, analysis and detailing stages are neglected. Bending patterns based on 2D drawings has considered by CAD-CAM integration in which there is lack of rich scope, and detailed information in design objects. According to conclusion of Tommelein and [25], Governing business processes can improve the supply chain activities. The effective actions must be creating error-free information, smooth exchange of information, and reducing nonimportant adding activities such as document production, correction, and revamp[10].
"Chalmers Technical College of Higher Education" in Gothenburg provided an extensive survey of, where on the implementation of reinforcing on the building site led to, wasted time[11].

Simple measures

To optimize the time consumption, Chalmers came up with some suggestions for a more intelligence flow of goods and better management of the reinforcements.
Through long-term and early cooperation with the supplier, for example, the degree of pre-production is developed, and deliveries are planned better. By this way deliveries also are done at the right time and interlayers and the moving of unmanaged reinforcement are prevented.
The school also recommended clarifying responsibilities, focusing more on progress and building outside the core time as much as possible. By taking further control of the process through 3D modeling, you could also save significantly on time on simple things like correct assembly instructions and obtain more appropriate quality assurance. These simple measures could decrease totally the cost and decrease construction time, says Hansen[11].

An idea takes shape

In Celsa Steel Service, the seed was sown. A project began to find an advantageous solution that could correct all the investigations in the survey from Chalmars. It is the result of this project that has now revealed itself in a full-fledged solution for modeling and ordering pre-manufactured reinforcement directly from the model, that is based on IFC and openBIM.
At this stage possible errors and failures can be investigated by help of a complete BIM from the basis made by construction advisors, that would create delays, stops and costly waiting time at the construction. For those, who are well-educated and preferably create the BIM itself, it is essential to cover virtually any format. However, it is construction advisor’s responsibility to control the model

according to the determined BIM basis for ordering, so it is essential that the model be approved, before ordering by construction advisors, "said Hansen[11].

Delivered "as a village"

As part of the service a model of the designed reinforcement job, can be obtained. A model, that can include the desired information about the bar sizes, divided into different dimensions, bending types and concrete volumes. The model can be employed as a fundament through the design and possible clarification discussions with construction advisers. When the 3D model is completed, there is an optimal tool for finding the solutions to save time and money, says Hansen[11].

Increases the quality

Prefabricating foundations, columns and beams edge, raise the quality. All production carried out under controlled and stable indoors conditions. Through the cloud-based digital arming logic solution - also known as "QR" - whatever is needed is prepared and there’s always a fresh and up-to-date status for what's ordered, delivered, used and assembled. Everything is updated in the cloud, says Hansen [11].

Color codes on the construction site

The BIM model is created based on color codes. The color marking not only makes it easier to add reinforcement, it also offers better overview of the construction site and more precise storage compared to what is used [11].

Physical reinforcement iron with colored labels that correspond to specific items in the model, is an added security and makes the whole reinforcement job simpler and clearer for the individual executive. In addition to orders via IFC and openBIM, uploading of XML / XLS bucket lists can be supported and a separate QR API that integrates with Tekla Structures, concludes Hansen, can be provided [11].

2. Society Perspective

Even though BIM tools in modeling of reinforced concrete have improved considerably, there are still some unresolved technical deficiencies. These deficiencies prevent us from reaching error-free and streamline use of models during design, production, and project management processes.
Required time for providing shop drawings and Material Take Off is considerably shortened when BIM technology is used. Since all the changes that are time consuming for designers, are applied directly to the models, shop drawings are generated almost automatically. On the other hand, the duration of design can be reduced to the point, where more components can be prefabricated earlier in a longer time among the contract date and the start date of on-site building. The use of electronic building model eliminates long distances as a hindrance. Design, analyses and engineering can be performed by geographically dispreading teams. BIM technology enables companies to develop preassembly and prefabrication for any piece of building by removing or limiting efforts of producing drawing. Since, BIM fabrication model starts to dominate the logistics, accounting other management areas, the need for paper drawings is dramatically reduced resulting in paperless construction.

Improving the efficiency of information flow between different disciplines and across project stages certainly leads to sufficient capabilities of internal modeling and increases the value of 3D parametric models. Economical communication and data transportation between various field-specific BIM tools, which is realized by software interoperability, does not need any area expertise for users. There is a growing demand for 3D reinforcement and drawing-less process of ordering, manufacturing and assembly. For this purpose, an automated data collection system is required that provides the correct information, enhanced collaboration, and higher data availability, creates better structure to the project, offers higher safety in the project, improves efficiency and provides more time for value added through creative work, quality assurance and new opportunities, smoother information deliveries/handover (no data" stuck" in documents) [12].

Skanska was the entrepreneur of ASKER TEK project as shown below. This project involves an office building of approximately 20,000m², 9 floors of which 2 with parking, building technology, steel core piles for mountains, free-standing base plate, single-sided soil pressure on 3 floors, prefabricated construction, approximately 470 tons of 3D reinforcement. ASKER TEK project indicates that drawing-less reinforcement provides better understanding (nodes) and helps to control quantities (avoids miscalculation), to take their own cutting. Additionally, it generates layout plan with correct mounting order, prefabricates reinforcement cage, prepares bending list directly from model to bending machine, and determines rebar status as ordered-mounted[13]

Figure 2.1Asker Tek [15]

3. Theory

Physical and functional features of a building can be digitally demonstrated by Building Information Modeling (BIM). BIM may be defined as a technology or a process, which generates, analyzes and communicates building models. The digital objects produced by a BIM model cover graphical information related to design and detailing, construction, logistics, maintenance, budgets, schedules and so on.

Plenty of benefits are achieved by parametric 3D modeling when integrated with different application domains. Spatial coordination with all other 3D objects is obtained by parametric 3D modeling, which supports automatic layout or shapes, and 3D reinforcing based on rules that picture the best practice. It also leads to more effective project planning and enhances digital tracking. Parametric 3D modeling for the fabrication-level detailing of steel structures was presented a decade ago [14], and is now in common use [15].

Three-dimensional modeling can be applied in both precast concrete and steel structure and can be carried out through the design, fabrication, and construction stages. Although, there are available commercial BIM tools for design, provision, fabrication, and erection, the parametric 3D modeling for construction of cast-in place CIP reinforced concrete structures is still exclusive to schematic modeling of structures [16, 17].

The thesis consists of two parts. The first part deals with general information about cast in place reinforced concrete as an option for creating an effective 3D reinforcement BIM model.

The second part deals with a modelling, and the best method of data extraction, which is structured in a test model later. This section is important for understanding, reinforcement supply chain, and the benefits and challenges associated with BVBS and IFC formats, in which models are transferred to the fabrication and compared with other alternatives.

3.1 Cast-in-place reinforced concrete

The BIM tools that have developed for steel, and precast concrete construction are not appropriate for production modeling of cast-in-place (CIP) reinforced concrete structures. The basic reason is that CIP is a completely onsite system and CIP structures are inherently monolithic. This means, that at a member's intersection, the concrete volume is evaluated as a part of one or a part of other members' join framing. This should be specified according to the reporting obtained by *join's geometry* feature of Revit structure. Another example is the intersection between beam and column, where standard cases parameters set beam to be always shortened. In other words, it automates this property to give a priority to a member type over another. The same rebar may also have a particular functionality within one member and another functionality within joints. Similar to a top steel in a continuous beam, that is employed for withstanding against shear crack within the span and functions simultaneously as a moment reinforcement over the support [12].

To gain real-time updates of models, interfaces of construction management in BIM tools should be present through web services. The internal model of CIP reinforced concrete should be modeled in detail. The procedure requirements of CIP concrete includes, structural analysis, the measuring of concrete volume, determining and reports of rebar shapes for production and placing [12]. CIP concrete is performable in complex curved geometry, with curvature in one or two axis directions and different thicknesses. To construct non-uniform multicurve surfaces like domes, any modeling software should be able to model such surfaces and the solid volume they enclose and provide their descriptive geometry. Partitioning of CIP concrete structures for analysis and design differ from fabrication [12].

The locations and breaks of pouring model should be determined, such that the extraction of pouring specifications such as reinforcement, concrete material volume, weight and so on, be simplified. Placing drawings consists of detailed drawings of CIP concrete that represent crucial information of reinforcement installation on construction site. Placing drawings are created directly from production exchange model. Beside design details, placing drawings should also contain the layout and requirements of rebar supports and ties, rebar caps, form accessories, and favorable placing sequence. Even though, geometric modeling of the accessories might not be needed, the functionality is required to determine their layout and material take-off information for the defined work packages by BIM tools [3, 10].

The cast stop locations are usually specified on the site and do not always support the product sections, as predicted by the designers. However, if the members are employed for both construction management and design, pouring models should be prepared through both methods given on the site and/or by designers. Any of these methods have their own unique Multiview to modeling target, that is provided by most BIM software. This BIM software recently offer some functionality for CIP concrete modeling.
Revit construction gives an essential option of switching between distinct, but, internally consistent displays of 3D concrete geometry, and idealized components for structural analysis. Composite systems such as unit and mullion systems, column cover and spandrel systems, and panel (strong back) systems, require precise assembly and segment manufacturing details as well as to be intimately coordinated with a structure's other systems [12].

As one of the most substantial parts of any building model are curtain walls. Those are center of all construction performance analysis except that of an entirely structural analysis (thermal, acoustic, lighting). Any computer simulation that can be run on a model will need the related physical specifications of the curtain wall system and its elements. Besides its geometry, models should also be designed for local wind and dead load structural analysis for the system components. Most routines of curtain wall modelling that are found in architectural BIM systems enables initial design only and have no ability for detailing and manufacturing. Moreover, some software applications such as the DeMichele Group and Fenesoft package, predict modeling of any windows or details of curtain wall sections without considering them in the entire building model. Some mechanical parametric modeling platforms, such as Solidwork and, Autodesk Inventor, are more effective in the case of using steel and aluminum profiles in most curtain walls. Some other existing software such as Digital Projct Catia, Tekla Structure Revit Building, Allplan Architect, Graf iSOFT ArchiGlazing, and Soft tech v6 are also applicable[12].

3.2. Design and Detailing

Alongside the proper internal modeling potentials, gaining optimum value from 3D parametric models depends strongly on smoothing data flow between different disciplines and across project stages. Software interoperability offers the intentions for cost-effective communication and data exchange among various domain-specific BIM tools.

Shiva Aram a, Charles Eastman b , Rafael Sacks [10] studied the process of designing models for understanding reinforcement information creation and exchange throughout the project lifecycle as shown in Figure 1. First, the structural engineer designs the primary reinforcement types, according to the building code necessities and with Example Model EM.1. Then, producing reinforcement information in models often begins during the design developing stage and exporting Example Model EM.2. This model contains illustrating design purpose and geometric information.

The structural design model is brought back to an architect for checking and to a steel reinforcement detailing engineer for primary layout of reinforcement design, demonstrated as EM.3. In design improvement and the following phases, different model generating and sharing rounds are accomplished.

The reinforcement structural design and detailing models of reinforcement are completed during the next phases such as construction documentation, procurement and product development. These are respectively shown by EM.2, 5, and 7, and EM.3, 6, 8, and 9 in the following Figure [10].

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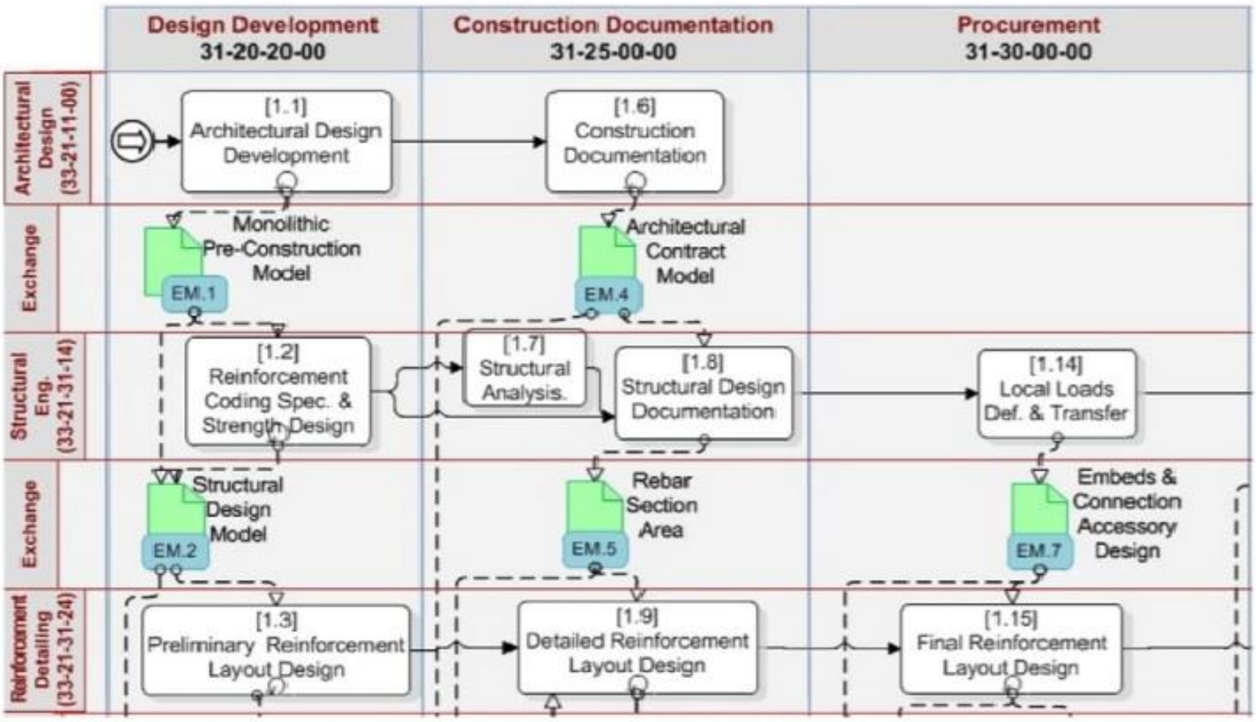

Figure 3.1Part of the developed process

3.3. Standards

Standards such as **Eurocode 2** should be satisfied for structural design and detailing activities. These define code requirements for concrete design and construction, and rebar bending schedule standard such as **Eurocode 2** [18].

Reinforcement regulations for reinforcement and strain reinforcement

1)The rules on rods, netting and tension reinforcement are predominantly exposed to static strain should be fulfilled on two critical parts that are given as following:

- structural parts that are subject to dynamic load caused by seismic effects or vibration from machines
- structural parts where specially used reinforcement rods are coated, with epoxy or zinc

2)The requirements for minimum concrete overlay must be observed.
3)Additional rules for easy-to-use concrete must be concerned.
4)Rules for structures exposed to fatigue loading must be satisfied.

Distance between the reinforcement rods

1) Distance between the reinforcement rods for easy concrete casting and compressing should be checked.
2) Free distance (horizontal and vertical) between parallel single bars or horizontal layers of parallel bars should be concerned.
3) It should be noticed where the rods are in separate horizontal layers.
4) *Allowed* diameter through bending of reinforcement minimum diameter helps to avoid damage to reinforcement for welded bent reinforcement and netting bent after welding.

According to **Eurocode 2** [18] the structural engineer's must specify reinforcement elements' anchorage length and rebar splicing type – lap, mechanical or welded – and location [19]. The structural necessities of reinforcement integrity in critical places like links of beam-column should be also provided [10]. More accurate reinforcement models give the locations of reinforcement elements, show assemblies in the physical model and describe the details needed to produce and locate elements like hooks, hoops and ties.
Moreover, places of the rebar splicing based on mill lengths should be prepared. Rebar splicing requires auto-splicing features in BIM tools to streamline the process. The detailing engineer is required to confirm that the reinforcement conforms to the geometric boundaries of the concrete elements and to construction restrictions such that the reinforcing elements can be accurately placed on site [20].

After design and modelling the concrete pads, the appropriate types of reinforcements were allocated to the foundation. Each set of rebars were applied through rebar configurations in the structure panel. Reinforcement schedules were set up according to Construction Drawings Simplified representation of concrete reinforcement (**ISO 3766:2003**). The bar schedule is the document used to determine and identify reinforcing bars. It is divided up into shape schedules. When applying shape codes, bending schedules) and combined schedules special mat schedules or weight schedules are also possible. Every schedule shall contain a title block containing elements in accordance with Calculation, Standards to support the problem and practices [21].

A shape schedule shall contain the information corresponding to member (characterization of the structural member in which the bar is located), bar mark (unique reference of the bar), and type of steel. The bar's quality and profile can be designated by a single letter if it is properly defined, and the bar diameter (nominal diameter), in millimeters should be determined in the shape schedule.
The information of other parameters, such as bar cutting length for bends or end hooks, number of members or number of sets of bars, number of bars in each member or in each group, total number of bars, total length e) x h), in millimeters or meters, bar shape (shape code), and definition of end hooks, bar-shape parameters (bending dimensions, and modification index of member are also specified. According to **ISO 3766:2003**, letter shall be stated, (e.g. A, B, C, …,). If one or more lines are modified and a new schedule is distributed, the same letters shall be stated in.
Bending schedule should be create as like as dimensioned unscaled sketch of the bending shape.
Combinations of shape schedules and bending schedules are also possible. A weight schedule may be drawn up separately or else a column stating the weights may be added to the shape or bending schedule[21].

Regulations for drawing and data transmission

The sight of data exchange is considered in the effort of new National BIM Standards [22], which is presented in **SN / K 257** BIM standardization in Norway.
the one hand, it reflects Norway's "voice" in European and international BIM standardization. On the other hand, the committee will pursue the activities of **ISO / TC 59 / SC 13** Buildings and Civil Engineering Works - Organization of information about construction works. It follows up on work of **CEN / TC 442** Building information modeling in special, and Norwegian BIM standardization in general. Moreover, **SN / K 257** is a route for Norwegian construction industry that can offer new standardization projects in CEN and ISO [22].
CEN/TC442 Standardization is applied in structured semantic life-cycle information for the constructed environment. It contains an organized set of standards, characterizations, and reports which determine methodologies to define, describe, exchange, monitor, record and securely categorize asset data, semantics and processes with connections to the external data such as geospatial data [23].
Another standard that provides a conceptual data schema and an exchange file format for BIM model is **ISO 16739:2013**. In EXPRESS data specification language, the definition of conceptual schema is provided. Based on the conceptual schema, the standard exchange file format to share and exchange, employs the Clear text encoding of the exchange structure. The other optional exchange file formats can be applied if they verify the conceptual schema. It also offers an open international standard for BIM data that is exchanged and shared among software applications applied by the various actors in a

building construction or facility management project. This standard is additionally offered as an EXPRESS schema specification, and reference data, provided as definitions of property and quantity names and descriptions [24].

The other regulations regarding the Building Information Modelling that are employed in Statsbygg BIM manual are developed by the following standards.

The Framework for BIM Guidance (FBG) is given in **SO/TS 12911**.

BIM Information delivery manual, Part 1: Methodology and format (IDM) is provided by **ISO 29481**.

ISO/PAS 16739:2005 offers the Industry Foundation Classes, Release 2x, Platform Specification (IFC2x Platform) (A revision is being developed) (IFC).

ISO 12006-2 and **ISO 12006-**3 contain respectively Building construction Organization of information associate with construction work Part 2: Framework for classification of information and Part 3: Framework for object-oriented information (IFD). The **NS 3451** contents roughly correspond to element tables such as 'OmniClassTable 21 –Elements'.

NS 3940 determines the areas and volumes of buildings and **NS 8351** Building drawings - Computer aided design (CAD) –Layers[25].

A recent addition to open BIM standards is "BIM Collaboration Format" (BCF), established by Tekla Corp.n and Solibri Inc., now supported by buildingSMART and getting support from other participants (Autodesk, DDS, Eurostep, Gehry Technologies and Progman, etc.). The BCF format determines means by which designers and other stakeholders are able to relate messages, action items, viewpoints and snapshots to determined components in a BIM and transmit them to other players. The receiving party then employs this information in its own BIM authoring tool to recognize and place the component(s) and view them from the same viewpoint established by the sender. Status reporting from the involved players is supported, so that it can be applied in BIM processes[25].

A section of an International Standard that is applied for information management is **Iso19650-1-2**. The information management utilizing building information modelling (BIM), consists of exchanging, recording, versioning and organizing for all users participating in every working environment.

This standard provides a solution for organizations to obtain higher standards of quality and greater re-use of available knowledge and experience. A collaborative environment offers the potency to communicate, re-use and share data efficiently without loss, contradiction or misinterpretation.

This International Standard is suitable for all sizes and all levels of complexity of construction assets and projects. Part 2 of this International Standard provides the particular requirements for information management during the delivery of built assets, according to the concepts and principles through this document [26].

3.4. Data Exchange

3.4.1. Generation of IFC files

Standards for data exchange are the most successful solutions, that have been presented over the years. The initial versions were national and concentrated on geometric data exchange. These standards consisted of SET in France, VDAFS in Germany and the Initial Graphics Exchange Specification (IGES) in the USA. Later, on the International Standards Organization (ISO) made a considerable effort to create one International Standard for all approaches of technical product data. It was named STEP, which stands for the Standard for Product Model Data[27]. This format demonstrates a general-use solid model, to display a 3D object. This general- use extruded and swept solids, wireframe, Boolean initial modeling, and many other modeling paradigms [28] that make it complicated for the needs of the Additive Manufacturing community [29].
The types of systems that use STEP are illustrated in Figure 3.2.

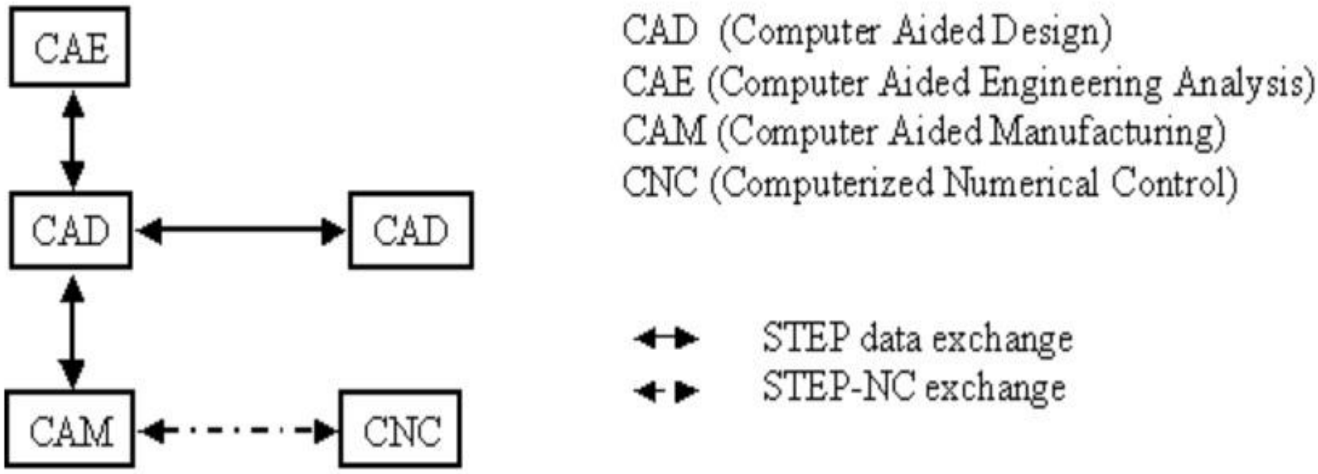

Figure 3.2 Standard for Product Model Data[28]

The header data of an IFC file are schema and translator version, file name, date and time, preprocessor and translator that can be applied to transfer data history. Headers show that Digital Project and Bentley Architecture have both adopted ST-Developer software as their fundamental STEP tool kit for improving their IFC translators. Revit Building uses EURO-STEP and ArchiCAD uses EDM from EPM Technology. There are several systems in design and production, that are employed to manage technical product data. Since each system has its own data formats, the same information must be entered multiple times into multiple systems resulting in redundancy and fails. Besides the manufacturing, a more critical challenge is that, design data are complex and 3D, leading to increased scope for fails and misunderstandings between users. The National Institute of Standards has determined that data incompatibility costs billion dollar problems for the production industry [30].

Y.-S. Jeong a, C.M. Eastman a,∗, R. Sacks b, I. Kaner evaluated whether each BIM tool can import and/or export data files. Hence, a benchmark test was applied to investigate the current state of- the-art of data interoperability between architectures and fabricators through exchange file formats such as IFC and SAT [31]. The ACIS SAT format is broadly applied in CAD packages for boundary-representation (B-Rep) objects. Since the whole format turns around its internal topological data structure, it becomes complicated and inappropriate for an exchange format [29].

Benchmark test modeling was carried out once by using architectural BIM tools and then by applying the other fabrication engineering BIM tools with a look into the domain of precast concrete architectural facades. Additionally, different types of design elements made of steel, CIP concrete and precast concrete were included in their benchmark test model. In order to test the dependability of exchange of convex and concave curved surfaces, a set of complex geometric appearances were also designed [31].

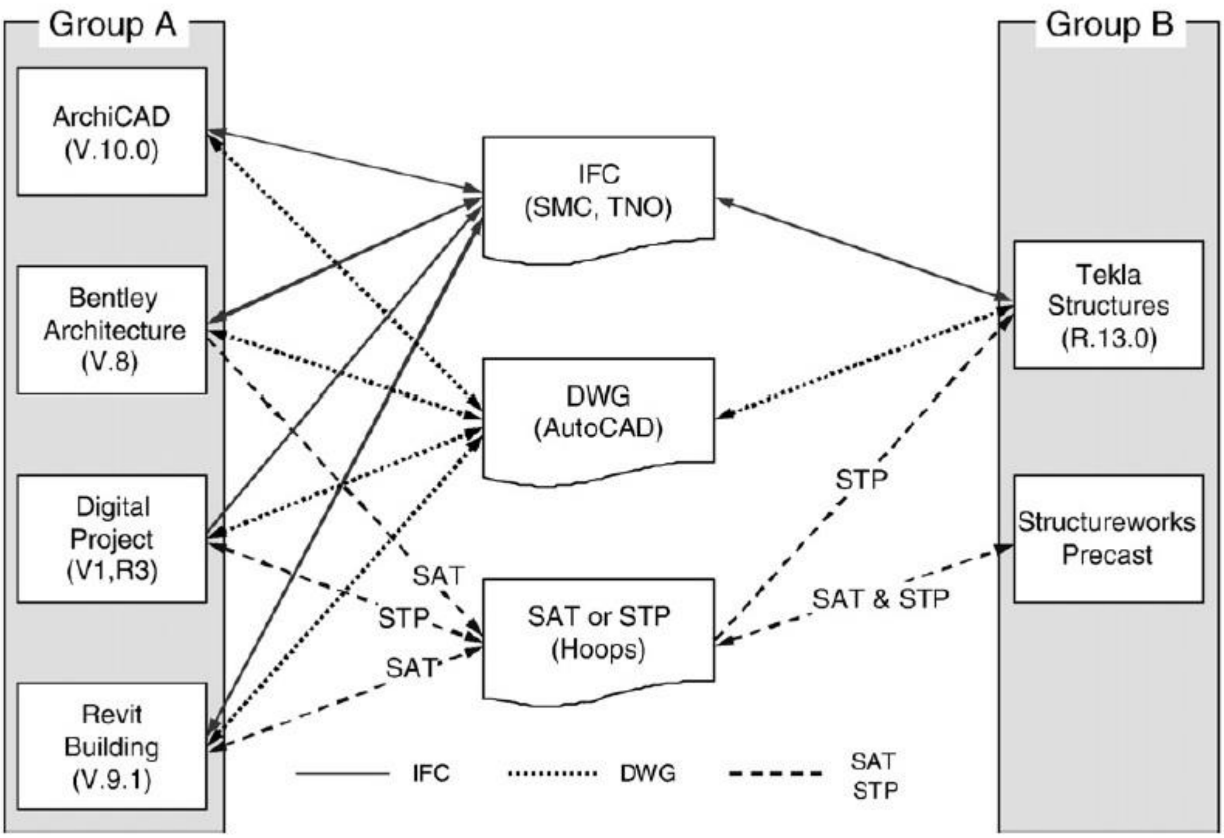

Figure 3.3 Detailed file exchanges. Missing links denote the lack of exchange capabilities between different formats. Arrow directions, especially those that are one way, similarly reflect [32]

Import and export functionality of IFC, DWG and SAT file format are shown by continuous, square dot and dash lines with arrows in the diagram of Figure 3.3, respectively. The each arrow's end determines whether the BIM tool can import and/or export data files [31].

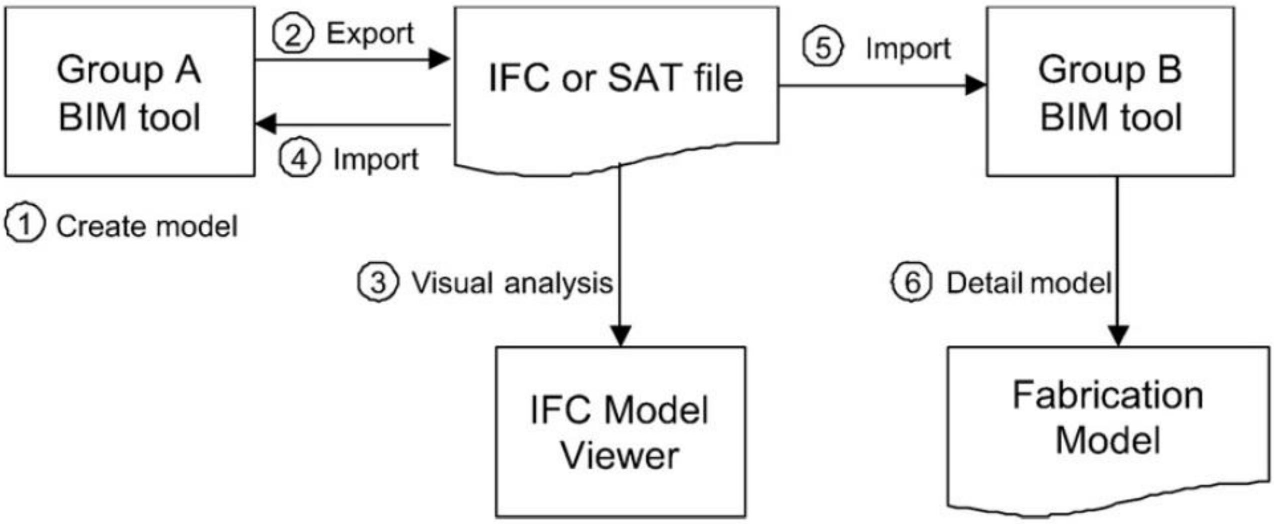

Figure 3.4 Experimental methods and processes for testing exchange translator support [32]

Y.-S. Jeong a, C.M. Eastman a,⁎, R. Sacks b, I. Kaner , conducted their observation of methods and processes for testing exchange reader support in four steps, as shown in Figure 3.4:

1) Step 2 contains a round trip data exchange test. As shown in Figure 3.4, the model creation is completed in Step1 by applying each architectural BIM tool. In Step2, the model is sent out to an IFC. The IFC files are examined using independent viewer software in Step 3 [31, 32] and then in Step 4 brought the model back to each architectural BIM tool.

2) Step 5 involves measuring the amount of data that is transferred from Group A tools to Group B tools. This measurement was performed by importing each of the IFC files, which was sent out from the architectural BIM tools of Group A. A main target was to measure the amount of data that can be exchanged without data loss or deviation.

3) In Step 6, the BIM tool of Group B precast production. Then to produce fabrication level models, reinforcing bars, embeds and details of connection are appended to the concrete structural members of Unit 1, 3, 4 and 5.

The roundtrip export-import test of each tool, shown above in Figure 3.3, was carried out as a first data interoperability check. After building the benchmark test model, each modeler produces an IFC data file. Each exported file was then imported back into the same tool. The roundtrip test stands on three main issues[31]:

- Required time for remodeling of benchmark test mode,
- Restoration grade of geometric shape data needed, and
- Restoration of indigenous object types.

The building models were built by using each one of the architectural BIM tools that were transferred to the fabrication modeling tools. The main approach was data interoperability. Several restrictions were imposed on exchanging both geometric shape information and other semantically information. The most difficult challenge was that none of the exchanges could be completely transferred by the whole geometry. The exchange failings happened in both export interpreters from the architectural BIM tools, and the import interpreters to the precast fabrication BIM tools. Results were also evaluated based on the piece structure within the data exchange. These were limited to those of the architectural BIM tools to the tool, that is able to create IFC import interpreters. All exchanges were found to be defective, with most challenges induced by the lack of uniformity in the way the internal object data were traced to IFC objects and properties [31].

Because of the difference in semantical defining objects of the BIM tools, and the difference in the modelling done by architectural practitioners of BIM tools, the IFC file exported from each BIM tool was recorded individually into IFC. Also, the variety of building elements, which can be modeled by BIM tools, is not fully covered by the IFC product model. These observations clearly demonstrated the demand for a mutually agreed upon standard that defines how precast architectural facades should be modeled and traced to and from the IFC schema [31].

In the NBIMS perspective, exchange workflows are characterized and recorded in an Information Delivery manual (IDM). An IDM determines the necessary information for particular exchanges defined in the various life-cycle stages and between various players. These are then recorded and identified as IFC Model views and prepared in a related Model View Definition (MVD), that should eliminate the type of problems observed at this stage. The tests of IFC import into BIM tool B1 were done using by files sent out from all the architectural BIM tools. Difference in the type or geometry of all components was determined by a precise visual and data inspection. This examination indicated, that of the 52 obvious specifications examined, Revit's IFC file perfectly showed 50 features (or 96%), Bentley Architecture's 41 (79%), ArchiCAD's 31 (60%) and Digital project's 11 (21%) [31].

The SAT file format is used by a tool that lacks IFC translators. In the considered exporting programs that supported SAT, the export application provided geometry that, when imported, could simply be edited in the receiving application. This practice made errors flexible without any need to completely remodel the objects and work could directly continue using the imported geometry without rebuilding. This study confirmed that the IFC format is the unique choice for applicable exchange of geometry, segment structure and other significant information. However, much still remains to be improved before everyday production work becomes practical. Establishment of a standard for exchange requires two urgent steps. One is Information Delivery Manual and Model View Definitions, and the second is instructions for appropriate function of precast concrete modeling within the BIM tools. There is still a need, for the objects, relations, and corresponding identification of architectural precast concrete objects be clearly classified within IFC standards. Some applicability challenges in the cut and bending rebar supply chain is due to the information flow between designers, constructors and rebar fabricators, and stakeholder's interplay.

To import and export the data between design and production, different standards are applied [33]. The IFC schema can be employed to create an applicable integration of the rebar production process alongside the BIM workflow, upgrading data exchange and minimizing the need for manual intervention.

3.4.2. Generation of BVBS format

After providing bar bending schedules, it is the turn of bar fabrication. In the past, the determined reinforcements were usually cut and bent on the site of small projects. Recently cut and bent reinforcement that provided by rebar fabrication facilities, are typically delivered to the field for installing. All the reinforcement data from 2D CAD or 3D reinforcement modeling software can be translated by a few software packages in specific digital file formats like BVBS or SDI. This software cause a high reduction in material waste by locating the reinforcement depending on maximum stock length and assign exclusive tags for each rebar mark [10].

BVBS (BundesVereinigung der BauSoftwarehäuser) is numerical file format that cause a quick digital data transfer between 3D modeling tools for cast-in-place concrete structures. It is performed by CAM controlled bending machine or Production Planning and Scheduling (PPS) software [34]. Reinforcement fabrication machinery is conducted without any manual intervention. The current procedure is that first the details of reinforcement details such as the splice, standard hook, bending radius, etc. are modeled in the 3D modeling tool. Then all the data will be sent to shear and bend machinery. However, geometry, and some references between detailing and locating rebar drawings restrict BVBS format. Moreover, the supplementary information of order and delivery date under the contractor's task are not provided.
The possibility of the interface, which requires collaboration between the engineering firm and fabricator should also be studied. This link is influenced by the general contractor that acts as an intermediary. [10] has pointed out into the necessity of existing interfaces improvement or development of new standards for the meaning of limiting the manual intervention by the [17] fabricator.
However, it should also consider interfaces that enable the reuse of data generated along the design, detailing, planning and procurement phases and causes the collaboration between all stakeholders. Todays, the progress of existing standards retaining compatibility with available cut and bent industrial reinforcement plants can be taken into account as an excellent choice to be used associated with the development of new standards.
To get a solidified and non-dedicated format for information exchange in the AEC industry, the Industry Foundation Classes (IFC) become a useful option beside rebar supply chain. Further, the necessities for exchanging reinforcement dataset in BVBS standard are discussed to reveal how this data are set on IFC schema. Besides the reviewed new entities published in IFC4, the geometric appearance of reinforcing bars, and a comparison of forms in some structural BIM tools to send IFC files are given, [34].

Digital interface between design and production

Although the integration of CAD-CAM has been in use for many years, the central part of standards and file formats have been upgraded according to a CAD field by a look into bending patterns based on the 2D drawings errors. This solution is advantageous especially when fabricator has control over both detailing and fabrication. Otherwise, it needs a secure communication among the users.

Table 1.List of some standard files formats used for digital interface [33]

Name	Developer	File format
BVBS	BundesVereinigung der BauSoftwarehäuser E.V.	abs
ProgressXML	Progress Maschinen & Automation AG.	pxml
Unitechnik 7.0	Unitechnik Systems GmbH	uxml
Unitechnik 6.1	Unitechnik Systems GmbH	.cam
Rebar Data Exchange	Applied Systems Associates, Inc. (aSa)	.rdx

There are different standards and files formats on the market, as shown in Table 1. the transcription of the data included in the reinforcement detailing design in a digital format become possible by these standards. Some formats are proprietary while others are created jointly by the cutting and bending rebar supply chain stakeholders.

BVBS standard among the existing formats provides the significant use of automation of cut and bend rebar manufacture for CIP industry. In precast industry, generally for the creation of precast wall panels and floor slab, ProgressXML and Unitechnik standards are extensively utilized.

Some BIM authoring tools have native protect for these standards, while others need a third-party plugin to perform the design-production digital interact. 3 BVBS interface The *BundesVereinigung der BauSoftwarehäuser* standard (BVBS) [35]was improved in general agreement by bending machine factories, construction software companies, reinforcement bending works, steel manufacturers and academic institutions to streamline the data exchange between rebar detailing software and CNC controlled bending machines or PPS software without any manual actions. The BVBS characteristics a data structure from the designer's viewpoint regardless of the manufacturing machine which will be utilized. Moreover, it may also be clear without authoring CAD/BIM tool [33].

Through an ASCII encoded text file and, as other CAD-CAM formats, the information of reinforcement is exchanged, and BVBS is focused on 2D drawings. These files are generated by a data string divided into blocks and preceded by an identification code applied to put the shape type group, which can be: two-dimensional rebar (BF2D), three-dimensional rebar (BF3D), spiral links (BFWE), mesh (BFMA) or lattice girders (BFGT).

The identification code additionally permits the machine to check if it can create a particular shape. The blocks in the file are configured as following instruction[33]:

1. Header block (H): creates data related to the bar's identification and characteristics. It is divided into three groups of information [33]:

    - Identification: project number (j), drawing number (r) and revision number index (i);
    - Material properties: steel grade (g), bar diameter (d) and bending diameter (s);
    - Quantity Sets: bar length (l), item quantity (n), weight per bar item (e);

2. Geometry block (G): defines the geometry of rebar's shape bending,
3. Chair mesh block (A): describes the locations of the chair mesh concerning bars.
4. Bar block (X/Y): employed only for the mesh to determine a diameter, bar origins and length,

5. Private block: utilized for the project or other inward information,
6. Checksum block (C): for a checksum quantity.

Alongside being a standard that is extensively used in rebar's CIP industry, BVBS selection is made because it provides the data needed by CNC controlled bending machine. It can be utilized either straightly at machine via USB or via a barcode as a mass fabrication workflow, via PPS software. 33rd International Symposium on Automation and Robotics in Construction (ISARC 2016) Even though this standard consists a broad variety of reinforcements kinds like spiral links, standardized meshes or engineered meshes.

Each bending shape has own data, independent of the geometry (such as drawing number, item number, quantity, 0). This information is all located in the header block (block identification H). Different data fields can pursue the opening block character H. Each data field is opened with a lowercase letter as field identification (a..z) and is closed with '@' as field terminator. The end of the header block is demonstrated when a field terminator '@' is continued by an uppercase letter (A ..Z). The regularity of the data fields in the block is placed and constant. However, fields can be left out.

The geometrical data follow in an additional block (block identification G). This block can have multiple fields as well. Each data field begins with a lower-case letter and ends with '@' as field terminator. The regularity of the data fields in this block is changeless as well. The field recognition characters (a..z) are correct in connection with their block recognition. In the block H the field identification 'r' represents drawing number, on the other hand in block G represents for the radius. The data string is resulted with **CRLF** (ASCII13+10)[35].

Geometric block requirements

Shape group makes the coordinate system accepted by BVBS to define the reinforcement bar geometry. Contrary to the BF2D (2D rebar), that applies to polar coordinate, the BF3D (3D rebar) is described in Cartesian coordinates. The shape dimensions depend on external length, conformity to the pattern, given by some detailing standards as American ACI 315[36], British BS 8666 [37]or European ISO 3766 [21]. BF2D geometry is determined by the leg length (l) and by the angle of the corresponding bend (w) as shown in Figure 3.5. The bending diameter demonstrated in the header block define each bend and for all transitions is distinctive.

The radius of the bent element (r) must be placed on the geometric block when different bending diameters are demanded. The coordinates of the bar's vertex (X, Y, Z) should be presented to describe the BF3D geometry[33].

The geometry block reads:
Gl400@w90@l600@w0@

The complete string therefore reads:
BF2D@HjTestPDF@r417@ia@p1@l1000@n10@e0.888@d12@g500S@s48@v@
Gl400@w90@l600@w0@
C88@CRLF (83 characters)

Example 2:

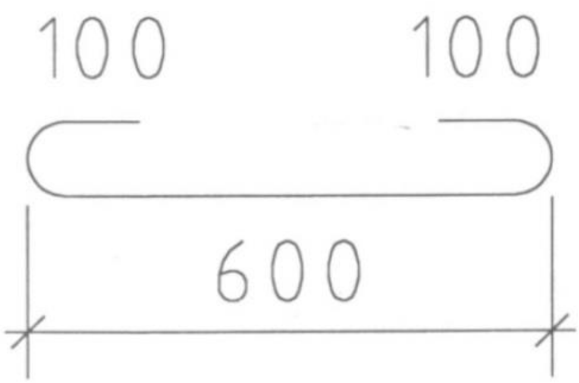

Figure 3.5 BVBS example for a two-dimensional reinforcement bar [36]

How is the workflow of the Reinforcement production?

Skanska's workflow of 3D reinforcement production is given as follows in Figure 3.6. At the beginning Revit model is generated, the data extracted in BVBS format and transferred into the cut and bending machine. The internal control and quality assurance of Pdf documents are evaluated. If both construction consultants and constructors approve the documents, it will be delivered to the construction site. Otherwise, it will be returned to the building consultants to apply some necessary revisions.

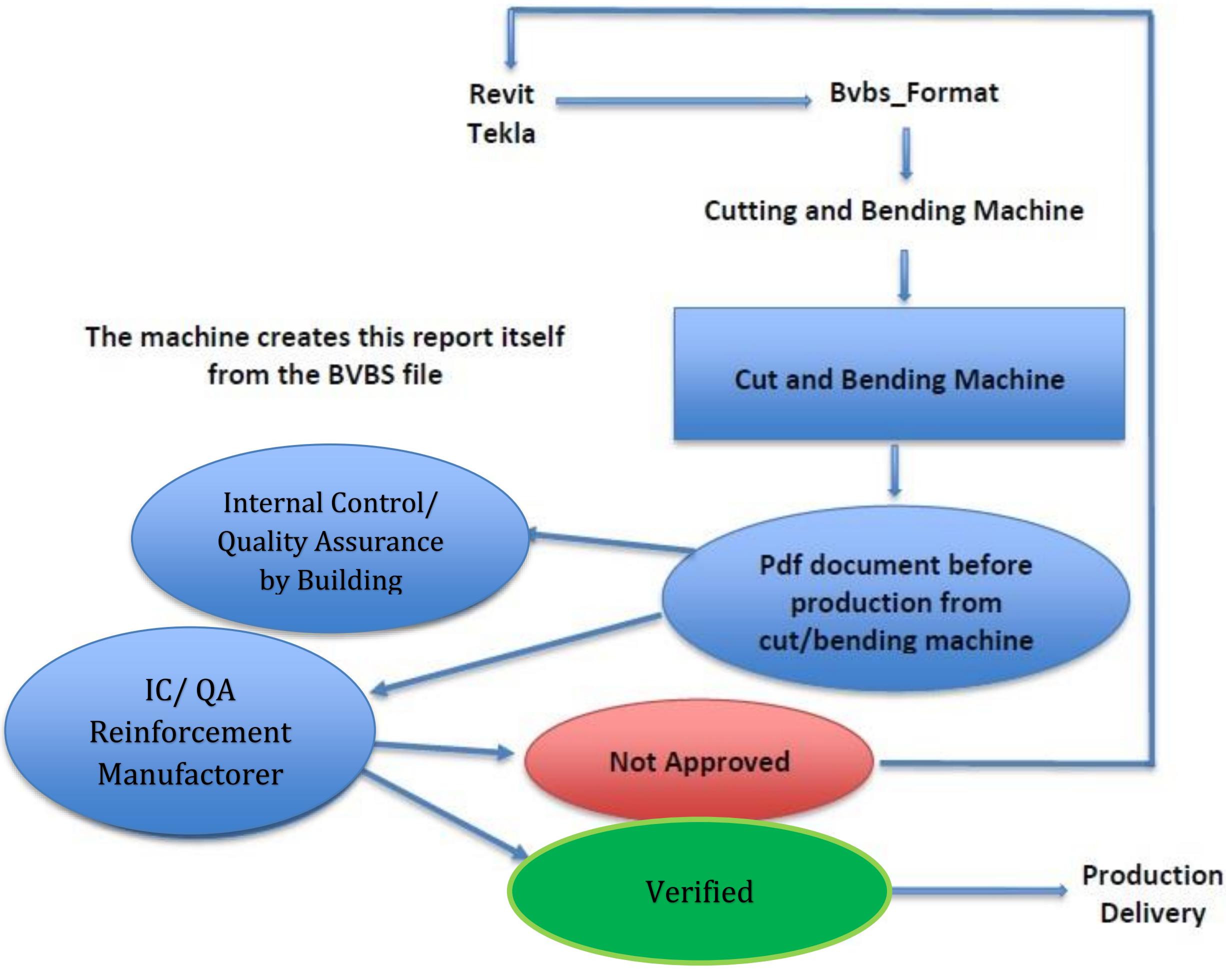

Figure 3.6 Celsa Workflow of transferred construction model from creation stage to the fabrication stage [39]

According to the meeting of Celsa and NTI about Statsbygg‘s Digital Construction, held on 27/11/2017 prepared by SFK, Celsa’s Machine parks with ten years of production is quite old, and has outdated software. Celsa's system and BVBS as an old format do not work well enough. BVBS not only applies to geometry, but it also refers to a presented form code. BVBS should connect to a form code located in the system. Since no production software that is able to read all form codes, which can be standardized and be common to all, it will stop in machine software at fabrication stage [38].
Data extracted from Tekla / Revit in the format of BVBS works well so that parameters can be controlled, and it may vary if it is desired to export all bars. They can also change based on production stage.
Imported BVBS file from Tekla to LP Production Software functions fine for all known form codes. However, the problems are the variations in 99 codes. LP recognizes all rebars that have known form codes in LP. BVBS also struggle with couplings and anchoring plates. It seems that BVBS is not appropriate to be applied as this is outdated and it does not respond to complicated rebars’ shape.
However, is there any interest to base an old format?
According to the interview carried out with Celsa steel production company, all the workflow is based on IFC model. The model should be cleaned up and organizes own tabs for reinforcement, Color codes on status or classification of the different phases such as ordered, delivered, and so on.

Moreover, the process should be divided into production reconnaissance step. The construction advisor is more involved and should define the stages in close collaboration with contractor and reinforcement production [38].

Parameters that are taken into account contains production steps, with serial number, the traditional postal number that is now the same location or production step. Additionally, it should cover parameters such as cc, unit (pcs or lm), form code, material, diameter, total number, hooks, a, b, c, d, e etc.

Exports are from IFC to excel or ITO and have a spreadsheet that sorts the measurement of cost per meter reinforcement based on dimension and with cut or bend (pcs) at the end. Next step is to import excel sheet from contractor to Celsa QR, where they require primarily to modify some defects like errors in the excel lists.

Even though the IFC model characterizations satisfies a remarkable part of the required information, its implementations into practical applications have shown several serious deficiencies mentioned as following:

1) Because of the variety of information contained in different software products, it is impossible to retain all the data when transferring a model among various software applications.
2) The large models have time-consuming transferring of the model, however usually a small segment of the model is changed, and there was no need to transfer the whole model if the bounded exchange would be available.
3) It is impossible to version and control actor rights in file exchange [39]

According to a phone interview carried out with Carl Petter Simonsen from Smith Steel in 25/01/2018, the Norsk Stål, Celsa, Smith Steel covers 95% of reinforcement production in Norway.

The machine park, software that controls the machine, is made ready for BVBS. BVBS is a European Standard Equipment Providers. To get access to a European market in production, will be reasonable to put data on BVBS's structure/layout.

Biggest Challenge in Norway Market is to standardize the BVBS file, where machines can only read 2D stirrups. In Germany, there are several types of research on 3D stirrups. If there is a new shape code, it must be allocated to match into the standard forms, found in LP.

As general feedback on BVBS, constructor wishes that BVBS be applied as a valid standard.

LP is a production software that Smith Steel uses for their machinery, which can interpret BVBS file.

3.5 Collaborating

The success factor is the cooperation with the contractor and adviser, requires a mutual interest from both sides. Challenge as a driving force, as the pilot, and the solution will be developed throughout the construction phase. Revit, Tekla, IFC, BIMEye, Solibri, BIMsync, SimpleBIM, BIM360 are useful software products for modeling and visualizing 3D reinforcement.
BIM360 Glue and Solibri are products and hardware were mostly used by Skanska and Rambøll in the *Asker Tek* project to visualize the model on the sites and the different views generated by designers.
Logistics and deliveries to produce this period's construction parts were also carried out by modelists. They solved it practically and summarizes molding stages, with status in the Revit schedule. Furthermore, they specified model delivery plan in Revit and prepared checklist or Schedules for quality control.
Bugs in Onenote or Screen dumps are detected with comment and corrected date. Quality assurance per casting and revision was conducted. Position, stage, location, diameter, number, center were parameters included in the essay [40].
Active cooperation requires motivated employees, who involve challenges, and not intimidated. In the collaboration between entrepreneur and construction consultant, should have an expertise and a desire to join. They should also notify challenges, take questions/problems into account WITH A TIME, and be a solution-oriented BIM coordinator.
In the following, Figure 3,7 shows the workflow of 3D reinforcement production. Construction consultants begin the process of creating the model using Tekla/ Revit and exporting data in an IFC file. Then, the entrepreneur must prepare work package, check positioning number, inspect views and forward the extracted BVBS file to the supplier to run bending machine and fabricate reinforcements at the building site.

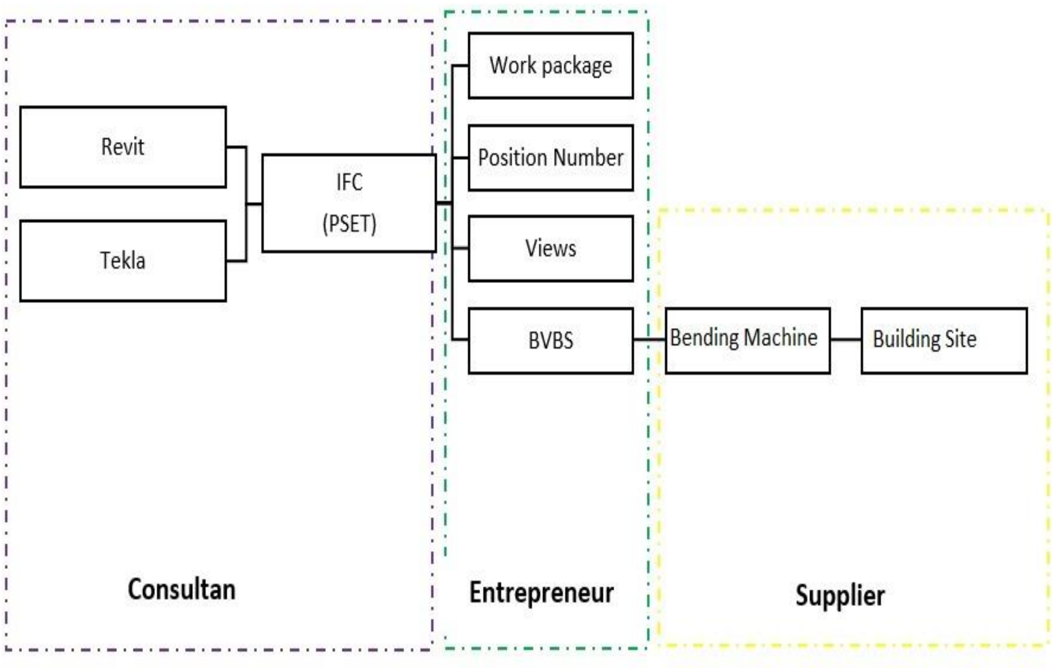

Figure 3.7 work flow of 3D reinforcement production given by Statsbygg [41]

3.5.1. Solibri

During coordinating the architectural and structural models, everything should be considered to ensure that the models match, Solibri allows the user to know if they do not. It is the only program that helps us to detect deficiencies. Overlapping walls and reiterative columns looks fine in CAD. However, Solibri then addresses, if it is not.

In addition to clash detection, quality control, and handling sophisticated models well in various ways can be carried out by using Solibri. It leads to time-saving, and the client's money as users get improving with the tool.

There only the architectural model is created at the beginning, and it becomes the initial point for other disciplines. Using Solibri results in less environmental waste and the associated drawing software to fix mistakes before the construction begins [41]. The architectural model of Gol Traffic Station project is given in Figure 3.8.

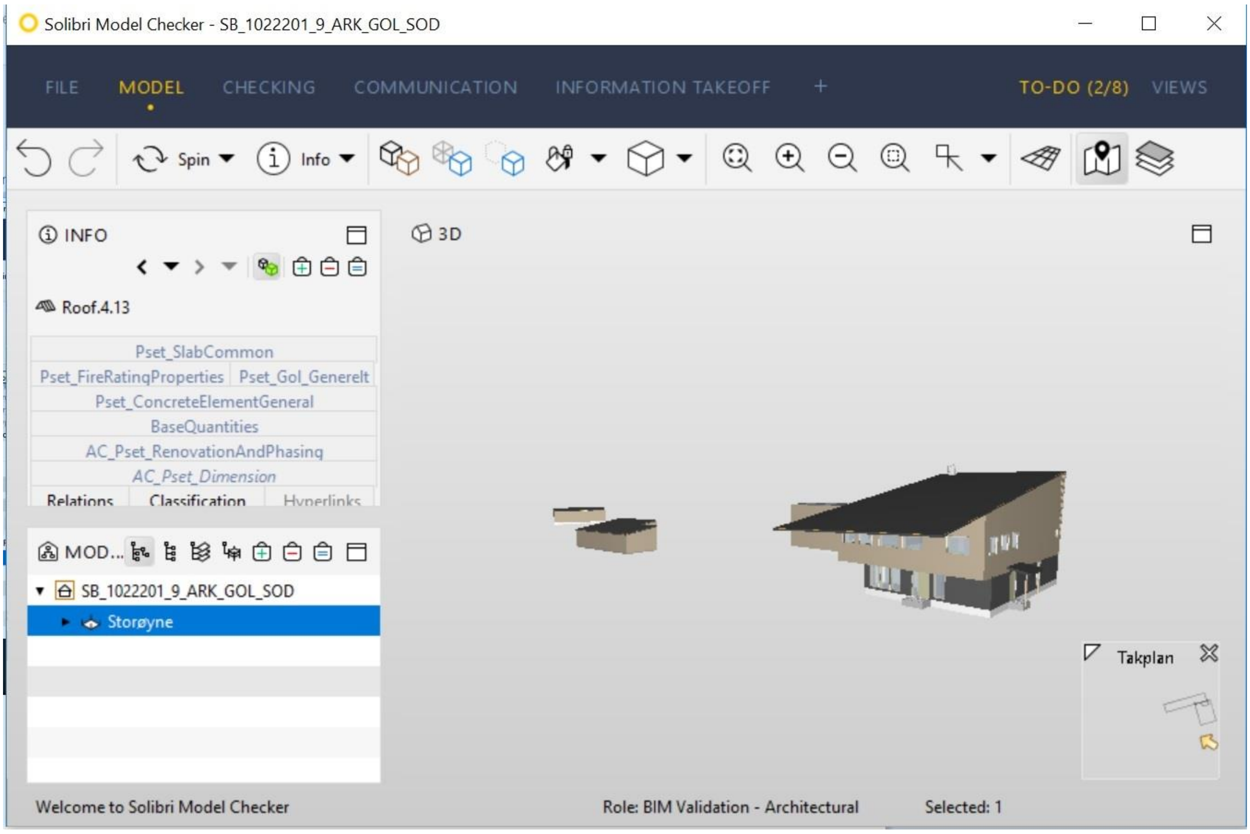

Figure 3.8 Architectural model of Gol Traffic Station Produced by Rambøll

Solibri Model Viewer assists to make a comparison of IFC-models with required content of IFC-model. Solibri Model Viewer is a free tool that simplifies reviewing over IFC-models. This program is appropriate in the case that IFC-format model should be checked. However, there is no need to perform reviews. Solibri Model Viewer presents the information associated with any selected component. Demonstrating members only of one classification is possible. For instance, it shows an element under the category of only walls, or only slabs, or only foundations or columns [42]. Below a selected element of Gol Traffic project is illustrated in Figure 3.9 under classification of Footing.

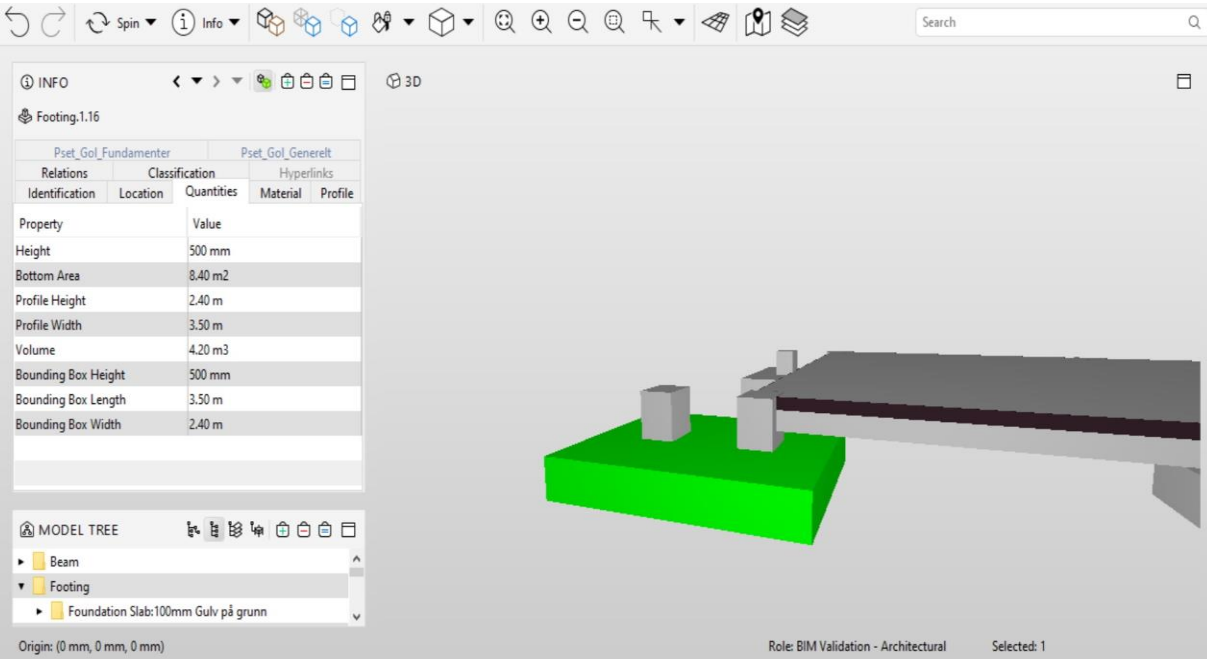

Figure 3.9 A selected element of Gol Traffic project is shown under classification of Footing Produced by Rambøll

Solibri performs former design checks as indicated in Figure 3.10 before delivering to the construction company or building owners. By the help of Solibri earlier mistakes correction is carried out and less time is spent later with complex changes, all these lead to higher customer satisfaction. Solibri enables the entrepreneur to check the model and find out the probable conflicts or defects, get the Information Take off easily and fix them through communication with building consultants.

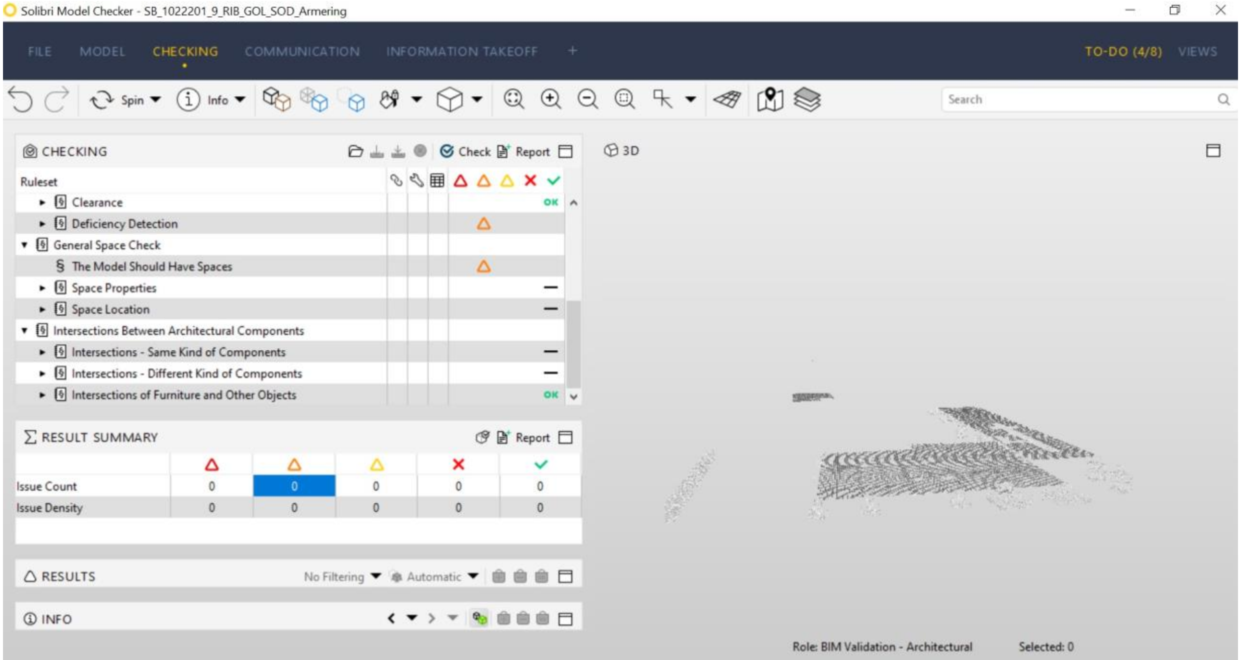

Figure 3.10 Solibri design check done by Rambøll

Solibri has a module called Information Takeoff shown in Figure 3.11, that enables the user to have structure and view of IFC models directly from exported specifications. The takeoffs can use all IFC data exported with the components, and this, in turn allows the user to isolate model reinforcement, using something that seems like a Rebar Schedule.

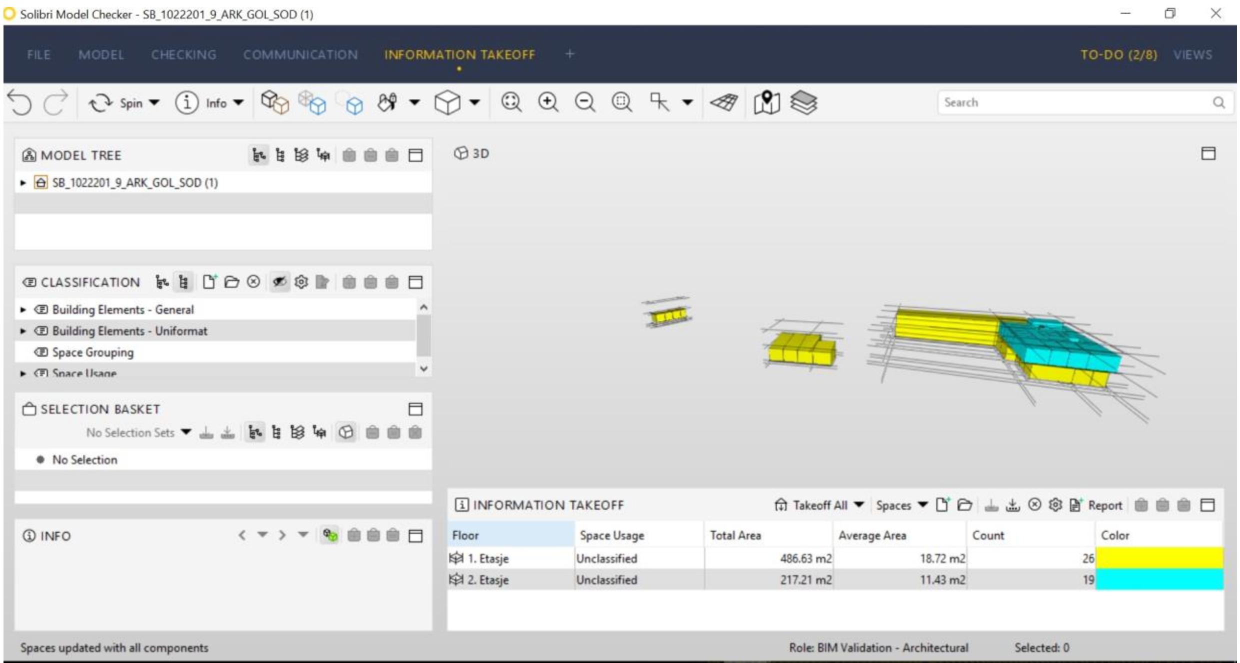

Figure 3.11 Solibri Information Takeoff Module by Rambøll

It is also worth noting that the Classification tool in Solibri will allow any user to add properties to IFC elements. These properties will keep their values as long as IFC GUID's are retained in the exported models. To keep tracking of project deliveries, the typical labels are used such as "ordered", "partly ordered". "delivered" or "installed." Tekla BIMsight and BIM 360Field /Glue are another IFC viewer that can arrange and filter construction information.

There is many works with sorting out the correct parameters in Solibri to keep track of reinforcements model by setting correct status. Solibri is usually a good choice used on the sites.

Usually, through email, it is notified, that, for example, a new model is posted on status D means that reinforcement is ready to order. Later once the build is in progress, numerous changes usually take place. Busy architectural practices prevent using resources to rework old project, and this is economically beneficial. On the other way, confidence about the knowledge that designs will be realized based on is with less environmental impact. SMC Information Takeoff can be utilized to order the correct amount of material [32].

3.5.2 BIMeye

Regarding the Statsbygg meeting with SYMETRI Addnode Group on the date of 05.03.2018, BIMeye was presented as software, which allows collaborating and refining BIM data by the apps in it, even without awareness of the origin design system. It enables engineers to sync their model directly from Revit, ArchiCAD, and Tekla or any other software using IFC. BIMeye lets the engineers, who are working on building site to survey easily through the Revit model and BIMeye and share their comments or change the statuses on the Revit original 3D reinforcement model. It offers easy access to quality assured BIM-data, which is accessible on building site.
The chance of becoming familiar with the mechanism of BIMeye caused that, besides Solibri, it was also applied as an alternative tool for exchanging data belonging to project test model. Below in Figure 3.12, the model information which can be transferred into BIMeye are shown.

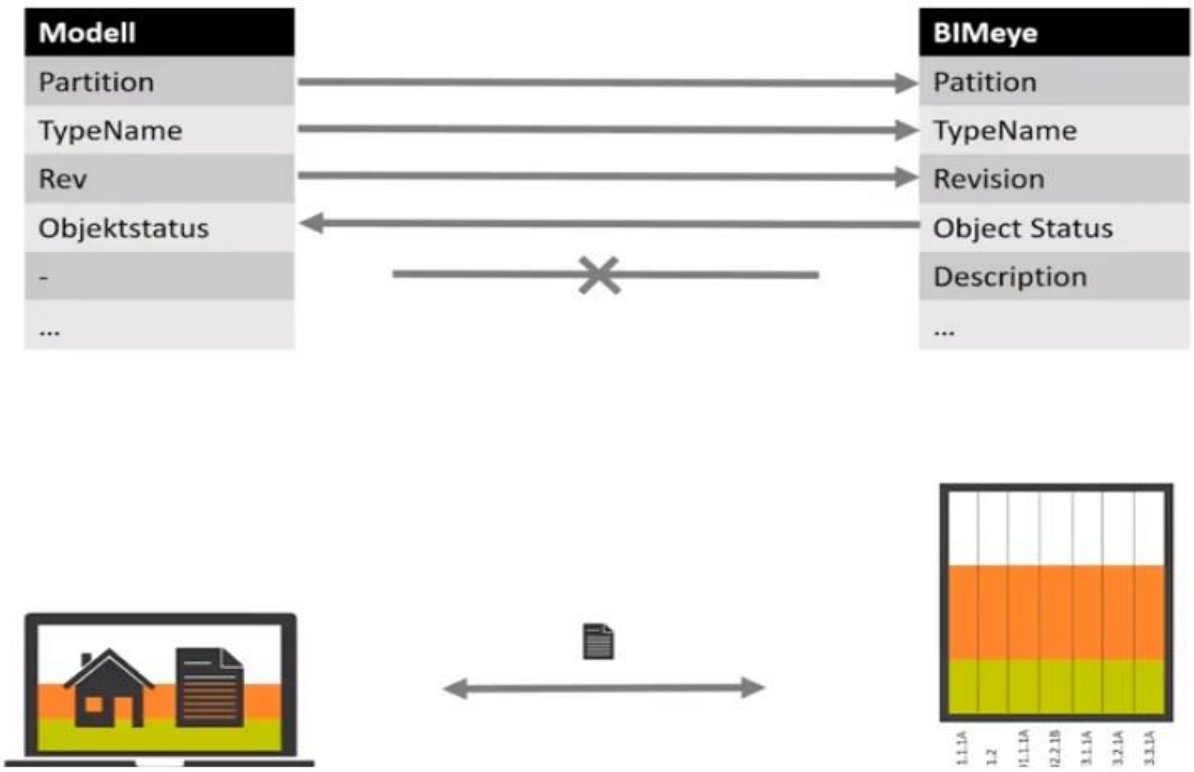

Figure 3.12 Model information that is selected to transfer into BIMeye [44]

Following the organizational flowchart is shown, in which provided data of bar schedule through PDF, file and serial interface cable, can transfer to the bending machine or prefabrication factory. According to BVBS guidelines and Exchanging Reinforcement Data, each data provider/receiver require creating one converter (software interface) as shown in Figure 3.13.

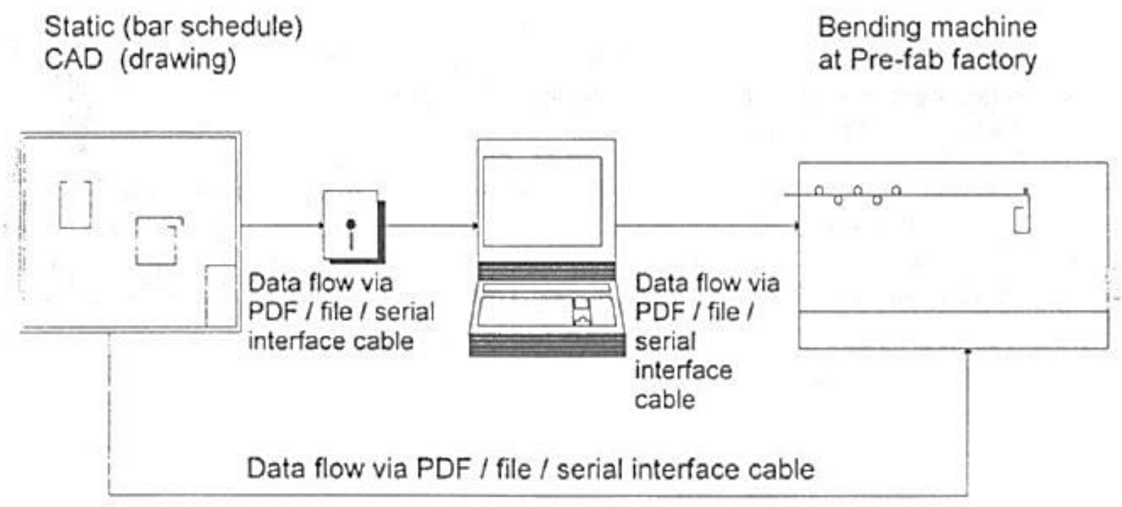

Figure 3.13 Workflow of Creating BVBS and the Role of Converter (software interface) [36]

Interface prerequisites

The following requirements should be satisfied by this interface.
The data format must:

• Be as flexible, transformable, and expandable as possible
• Include only data known to the designer irrespective of the machine
• Be dense, and tighty and neatly packed together, (no more than 1000 characters per item)
• Be clear and explicit even without CAD.

The reinforcement shapes will be divided into groups, owing to the changing geometric possibilities. Each of these groups has its identification code. In this way, it is possible, for example, for a 20-bending machine to distribute instantly if appropriate data is created without analyzing the whole data string. The subsequent identification codes will be employed [35].

3.5.3. Quality assurance and Set the status

Quality Assurance:

The BIM manual requires BIM model to be used for quality assurance in the design.
Models are shared not only with other design disciplines but also with the construction disciplines in the project. They are typically exchanged for one or more of the following purposes:
(a) compliance with standard code and conformance checking of contract and design purpose
(b) conflict and clash control
(c) coordination in decision-making by all disciplines during design and construction phases
(d) Duplicate using of information in the parallel and subsequent project activities.

The structural consultant usually prepares the controlling of standard compliance for reinforcement design. It is documented to ensure the accuracy of the reinforcement layout according to regulations and specifications. The owner and general contractor consider the conformance of design purpose for the contract conformance[10]. Usually, structural consultants improve the models and detailing after receiving feedback from construction suppliers like the reinforcement fabricator, concrete subcontractor, and general contractor.
Applicable constructional inspection needs proper cooperation between project players involved in both design and construction side, to inspect possible conflicts and clashes among all interaction in the project, which are mentioned as following:

- High accumulated reinforcement spaces such as connections and member borders
- Between reinforcements segments such as multiple layers of rebar mountings, splices, meshes, and tendons in one building member
- Among reinforcement and appliance which stabilize reinforcement in concrete, including rebar caps, support chairs and ties, and formwork appliances such as various types of ties and spacers
- Between reinforcement and intersection of components belonging to other building systems such as conduits, pipes, and sleeves in the MEP systems, or wall penetrations of the building facade
- Between reinforcement and connecting objects particularly at junction spaces with members of different structures [10].

The purpose of the process is to facilitate workflow for design and correcting work mappings for production. A plan shall be established in the quality assurance plan of a BIM model, which contains dates for deliveries and work tasks in the process against one coordinated and flawless assembly model.There are different programs like Revit for modeling, and iConstruct add into Navis that used to control various parameters that are mentioned as following. Color codes of any position number in iConstruct should be checked. The division of reinforcement into casting stages or production packages should also be controlled. The parameters for the status of reinforcement (A, B, C, D for Ramboll D means for work drawing) should be determined as well. The auditing parameters on each rebar should be Considered, and the layout plan shown in the video with position number and color code should be controlled [40].
Quality assurance of the model contains classifications on different casting stages, rules for duplicates, and visual inspection and checklist for model processing technology using Solibri. Checklist for

quantities, from Solibri to excel /BVBS should also be carried out as what has done in ASKER TEK drawing-less reinforcement Henning Habbertsad/ Rupert Hanna [13].

Status tagging of objects:

By using status marking of objects, they have a detailed overview of how far in the design the other disciplines have come in defined areas of the building. Knowing about the other disciplines' works prevents an unnecessary working with other disciplines substrates that are not sufficiently complete. The temporary document "VDC in Skanska" describes that it is possible to add status (LOD-Level of Development and MMI-Model Maturity Index) that simplify it for all parties involved to extract information on the development of the project [43].
Status of the objects of A, B, C, D (D means that it is ready for ordering as drawing), statuses such as ordered, delivered, mounted as a classification in Solibri can be identified. In many projects, the objective is still solved with DWG substrate laid in Solibri [40].

3.7. Production

Detailing models should offer complementary and organized information of reinforcement properties. Extracted information should be attached to the right elements or mounting-hierarchy level so that constructors be able to get directly accurate reports and drawings like bar bending schedules, and quantity take-off reports. These products of models represent essential information for provision, production planning, and fabrication proceedings. The bending schedules should cover the characteristics such as shape, grade, size, length, volume, and bar mark of all the reinforcement types, which applied in the model. Material take-off for reinforcement classifies similar reinforcement components regarding size and shape according to the material grades and adds weight information to each category. Material take-off option makes it possible to calculate the total weight of various reinforcement material grades. By use of rebar bending schedules and material take-off reports, the management of ordering, production planning and control, and manufacturing of reinforcement, are carried out.

Within the entire of supply chain, various identification systems are applied. The most significant ones for reinforcement are mentioned as following:

- bar mark, to represent the bar size and number
- The type of concrete component (for example, beam, column, etc.), and the floor,
- (B)Tag or label of the mill, which covers both the producing mill data and the structural properties like heat number
- (c) rebar package tag (release number) allocated by the manufacturer demonstrating sizes, lengths, grades, bar marks and rebar segment numbers in the package
- (d) mesh style symbol represents the spacing and size of longitudinal and transversal wires [10]

Within production planning, bar mark is applied to plan fabrication and delivery bundle. Accommodation of automated bar marking properties should be according to the standards used in production.

As mentioned before, the locations of casting concrete and breaks should be shown in the casting model so that, player be able to draw necessary information out. Detailing drawings of on-site reinforcement installation are produced directly from production models. Geometric layout and material take-off information for the defined work packages should be provided [10, 44]

After placing and examining reinforcement, onsite information should be considered to ensure the conformity of design with the on-site building.

Also, in cases of change incidence within the site construction owing to various unpredicted conflicts, models should be updated. By this way, correct as-construct models will be created so that the building models can be immediately used during facility management proceedings [10].

Today, manufacturers try to improve the productivity of rebar production. This aim is achievable by integration and automation of the data exchange among the various process stages. The design data created by drawings software is stored in an electronic format. The process for further manual dataflow is costly and error-prone. When the designers automate the process, they can implement the optimization algorithms on the large amounts of design data based on plan production. This production planning restricts the machine set-up times and to removes the most of material scrap. The assortment of NC RCB machines is based on the parameters such as their raw material, supply system,

their mounting principles, the rebars diameters, they process, and the length of the final product or its type[4].
Current bending Machine tool have a capability to save reinforcement and bending information to an ASCII file. The data can then be transferred to a task setup program for bending machines. The file format is compatible with the BVBS reinforcement interface guidelines. The machine tools can be downloaded with 2D bar code (BVBS standard protocol). Editing of the 2D bar code on labels for downloading of manufacturing data is possible directly to the consoles of the machine tools. This raises productivity by diminish the data entry time and risk of error [45].
The BVBS is used in rebar's Castin-Place industry because it offers the required data for CNC controlled bending machine. It can be used by a production machine is readable without authoring CAD/BIM tool. It can be utilized either straight at machine by USB or by barcode as a mass production workflow, using PPS software [33].

How is the process that sets reinforcement to production? Who defines the work packages or work area?

The workflow of 3D reinforcement production can be followed both in IFC or BVBS format. Contractor defines the work packages and routines to make casting stage, determine work area, packaging and return them to construction consultant so that they implement the section in the native file [40].
Below Figure3.14 classifies the workflow of IFC and BVBS and the required information, which should be extracted from each stage, as explained earlier.

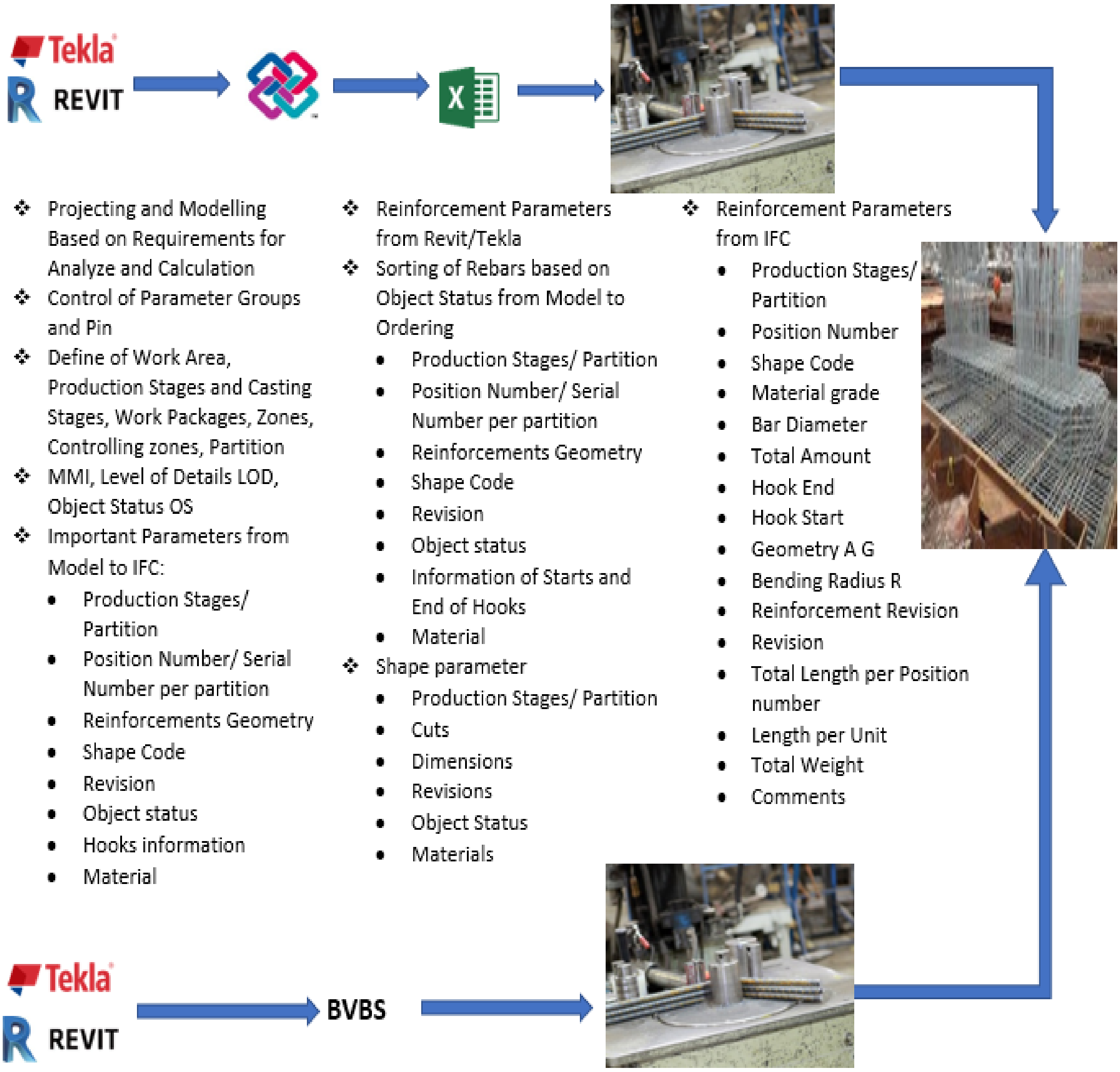

Figure 3.14 The work flow of IFC and BVBS Associated with Required information [41]

For improving the productivity of rebar manufacturing integration and automation of the data transfer between the different process stages are performed, the design data is created today using graphics systems, it is stored in an electronic format. Current procedures for subsequent manual data handling is costly and error-prone. Moreover, by automating the process, optimization algorithms can be applied to the massive amounts of design data to plan production. The production planning results in the reduction of machine set-up time s and almost elimination of material scrap. The automatic creation and transfer of machine programs to the NC RCB machines eliminates the setup time required for manual machine programming and program verification. The RCCS is an integrated and automated system. This system is achieved by the automatic flow of data from the design stage to the actual production, and by automating production planning and the production itself. A schematic view of the system is depicted in the *design* module of the reinforced concrete.

4. Research Question

The response to following questions made the major intention of this Master thesis. These questions formed the initial idea of this study so that all the basics of that stands on these questions.

- How can we avoid traditional reinforcement drawings on building sites?
- How to select an appropriate method of data exchange, and extract outputs from the model in the formats of IFC or BVBS, to achieve an automated production of steel reinforcement in a concrete structure?
- How can export of BVBS/IFC-data to a reinforcement production line, through a sample model, be considered?
- How can the workflow be standardized or optimized using file formats (excel/BVBS)?
- What are the advantages and disadvantages of each format and what leads to the best possible workflow?
- Is there any loss of information during the exchange procedure and can it be restored?
- What are the challenges with quality assurance and the way of setting status on the considered objects?

5. Method

The methodology of this assignment can be considered as a combination of Literature Study and Case Study. This study attempts to explore the existing knowledge about the 3D reinforcement supply chain, and It attempts to detect the meaning of events and researches for those who experience them and tries to represent a validated interpretation or understanding.
The case study is also applied to the understanding of information flow process, and preparation of a section of Gol project as a test model. Then export/import tests were conducted by utilizing the model. This method helped to test the current potentials of modeling and exchange.
First, the flow of information within the concrete reinforcement supply chain was illustrated, then the required information for the model creation was identified. The resulting information enabled the researcher to compare the content of created model, requirements and processes with the current capabilities of BIM tools, and so to identify and analyze strengths and weaknesses of exported data formats.
A brief investigation of the main BIM tools supporting reinforced concrete was prepared. The research includes the process of creating and modifying concrete reinforcement model, abilities to exchange models through other disciplines' programs, and finally specifications to apply the created models in fabrication activities.
To evaluate the properties of Solibri as a selected BIM tool in more detail, several test models created by BIM vendors (Rambøll), were studied. Moreover, during several educational meetings the process of data exchange through BIMeye by modeling samples provided by SYMETRI, was extensively studied. These enabled the author to obtain further information about their incorporated features and player interfaces. The author studied the project, in which BIM is successfully used in the concrete reinforcement supply chain. This provided the author a clear perspective about the development of BIM's capabilities contribution in the reinforced concrete projects and production.

6. Case Study

One of the most simple and common types of foundations that used, when columns carry the load of the structure, is Individual footings. Usually, each column has its footing. The selected footing in this assignment contains a rectangular pad of concrete with dimensions of 3500X2400X500 mm with two smaller rectangular pads standing on it with dimensions of 500X500X600, on which the floor and column sit. For the meaning of getting an exact estimation of the size of the footing, usually the total load on the column is calculated, and it is divided by the safe bearing capacity SBC of the soil. For instance, where the SBC of the soil is 10 $\frac{T}{m^2}$ and column carries a vertical load of $10T$, the footing area will be $1m^2$. In this study, Revit was used as the leading software to present parametric modeling of a simple individual foundation of Gol Consumption Station project. Below in Figure 6.1, the whole foundation model of Gol project along with a single target foundation are illustrated.

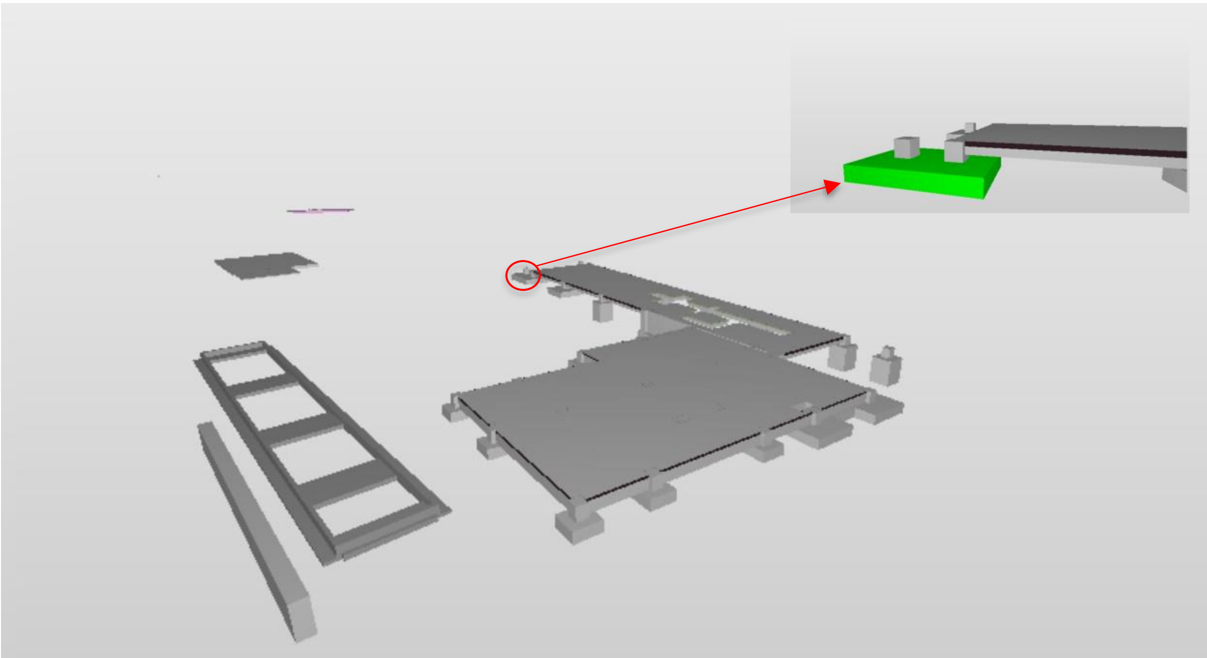

Figure 6.1 Foundation Model of Gol Project by Rambøll

7. Result

This section addresses the reader to the results got from following subjects:
1. Rebar Modelling in Revit
2. Exporting Data Using Solibri Model Checker Program
3 The instruction of exporting data through BIMeye

7.1. Rebar Modelling in Revit

A small part of a chosen foundation belonging to the Gol project was modeled in Revit. The geometry and dimensions follow the data provided by Rambøll's documentation. The first step in reinforcement modeling that was done before placing single rebar in a project was to add and allocate some Rebar Covers through the Structure Tab and Reinforcement menu and clicking on Rebar Cover Settings as shown below in Figure 7.2.

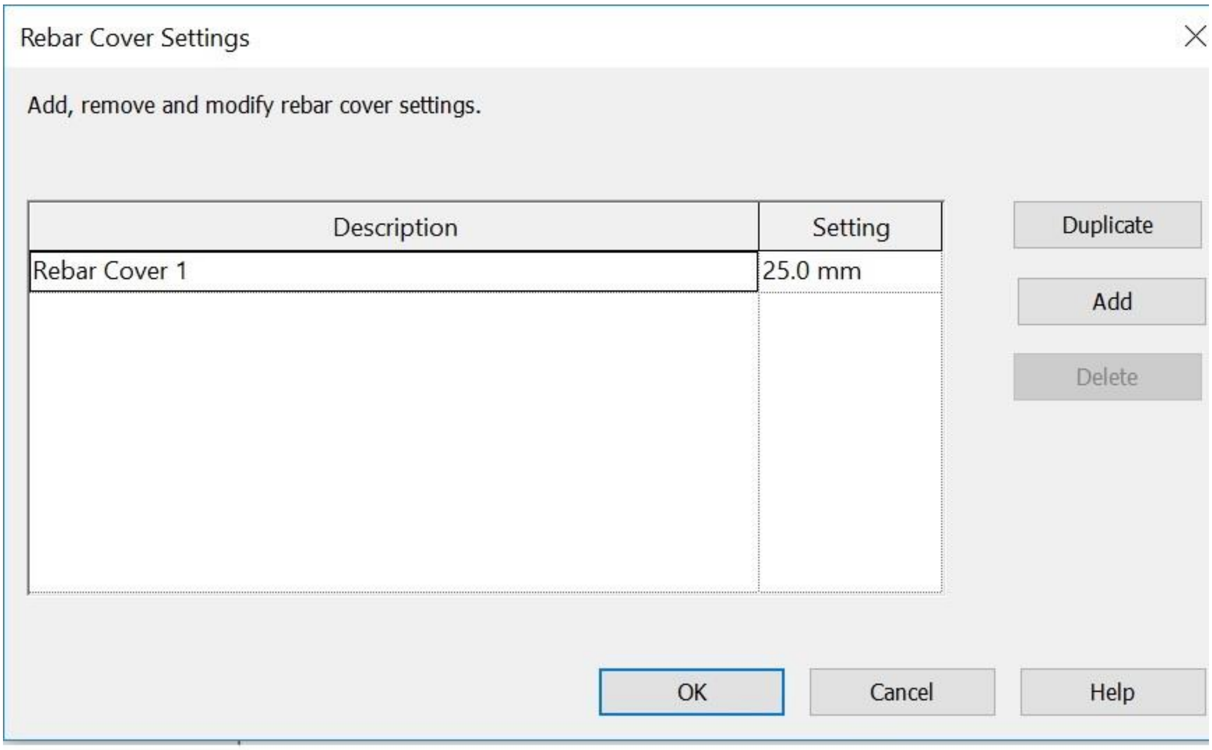

Figure 7.1 Rebar Cover Settings (produced by the author)

Rebar could be added to an object in many ways. However, the approach was used in this project was to draw a reinforcement section perpendicular to the target element, the element was clicked, and "Rebar" from the Modify Tab was chosen. In the following Rebar Bar (diameter), Rebar Shape and Placement Orientation were specified as shown in Figure 7.3.

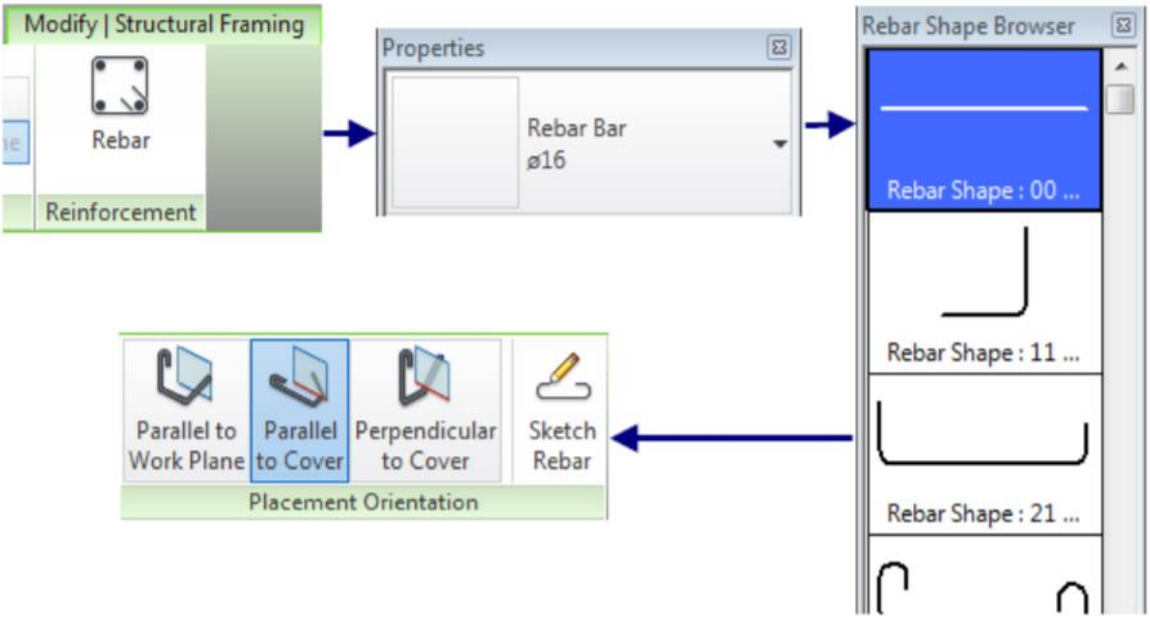

Figure 7.2 Rebar Shape and Placement Orientation [46]

A perpendicular plane to the element, obtained by selecting *Parallel to Cover* that puts a bar perpendicular to the view and choosing *Parallel to Work Plane*, which draws a bar parallelly to the section view, shown in Figure 7.3.

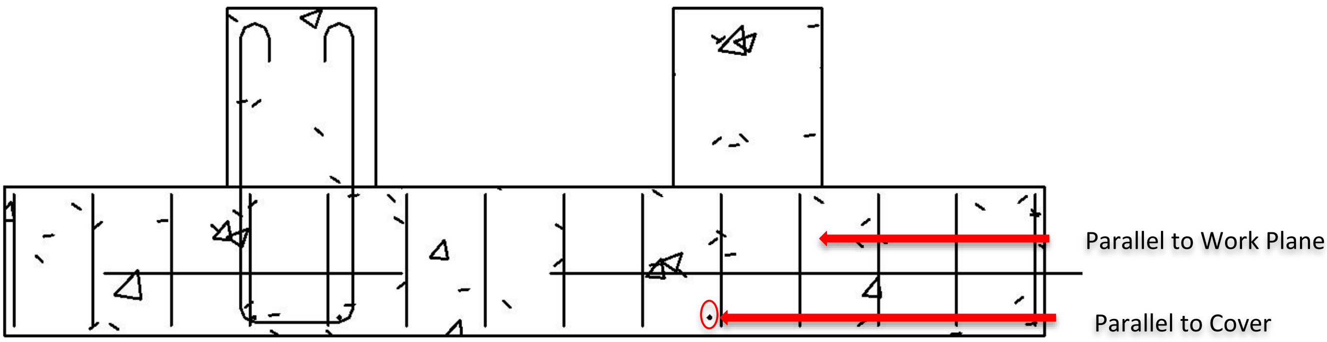

Figure 7.3 laying Rebar (produced by the author)

These parameters will place the Rebar Set perpendicular to the rebar *shape plane* as is illustrated in Figure 7.4. A prevalent problem that could not be solved in vertical sections was the horizontal reinforcements that were located vertically in objects and did not cross the current Work Plane. A typical instance is stirrups in vertical columns that were implemented merely by adding a Reference

Plane that crosses the column, naming it and allocating it as the current work plane in the addressed plane view in which the column cross-section is shown.

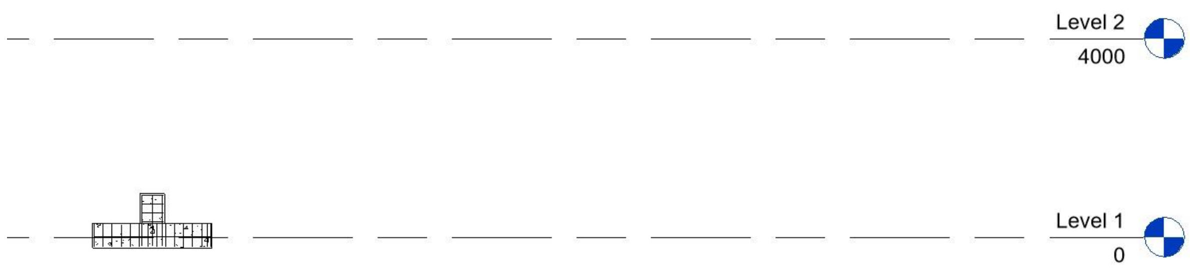

Figure 7.4 Placing Rebars in Wes Cross Section Plane (produced by the author

To assign the rebar name in *Rebar Bar Type Properties* as indicated below in Figure 7.5 is very considerable. It is essential to let the *Bar Diameter* parameter of a *Rebar Bar family* represent the Type Name. In the target case, the *Bar Diameter* parameter was only used for naming. However, naming is simple because all regular reinforcement in this defined geographical area were generated from the same material (B500C).

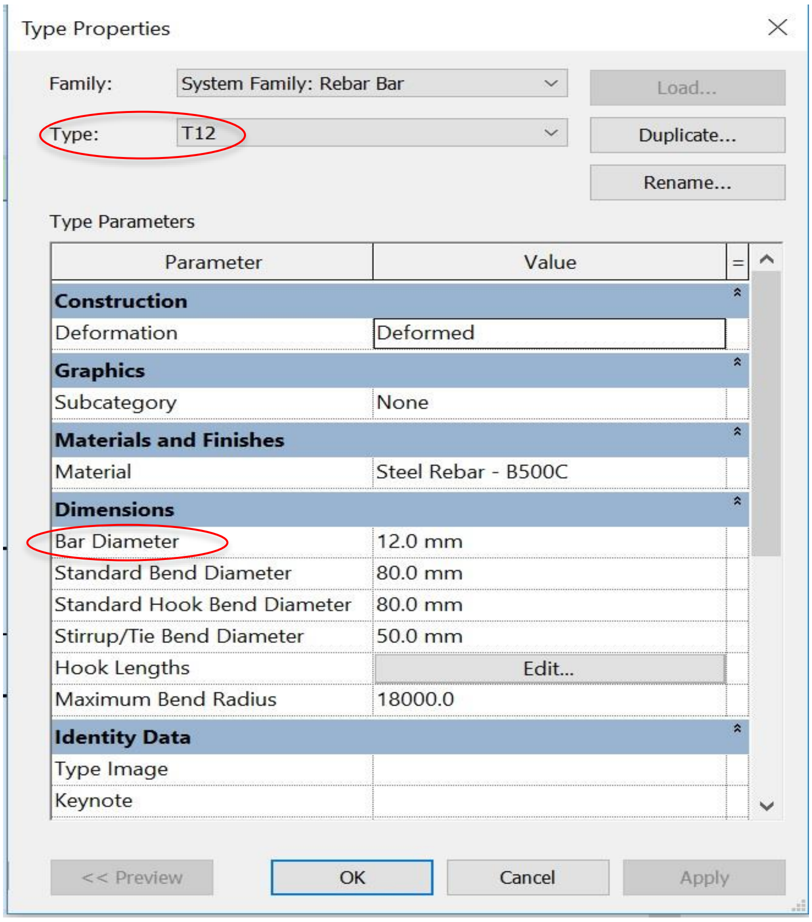

Figure 7.5 Placing Rebars in Wes Cross Section Plane (produced by the author)

Rebar Hook

Like the Rebar Bar system family, the Rebar Hook family is equally direct and easy. There are, however, some skillful parts that should be concerned. For include or exclude Hook definitions in the Rebar Shape families there is a feature as displayed in Figure 7.6, that makes European hook definitions possible outside Rebar Shapes [46].

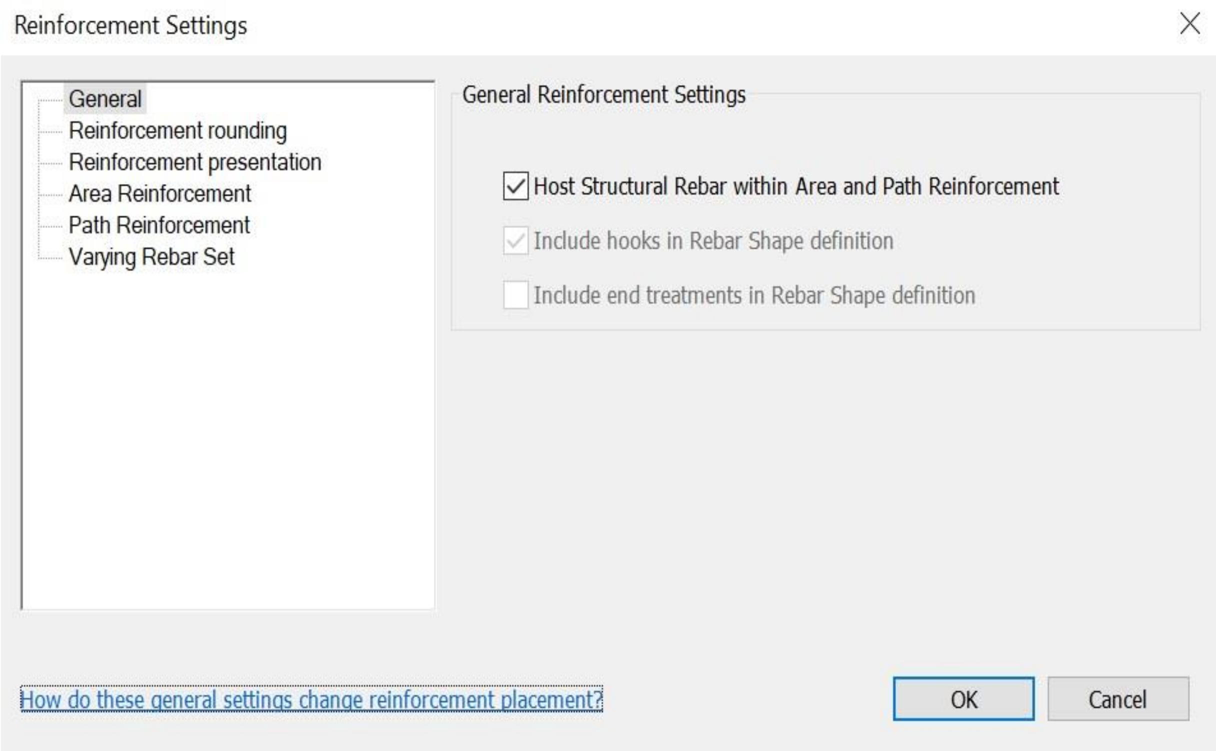

Figure 7.6 General Reinforcement Setting (produced by the author)

By this way, hooks by deactivating it users can change hooks using the Structural Rebar Properties. If hooks are considered in Rebar Shape definitions, it will make troubles while changing the hook definition inside the project space without having the available suitable shape families. Thus, the shape that was previously selected will be redefined and renamed to something like "*Rebar Shape* 1". If a project contains several *Rebar Shape* 1's, 2's and 3's designer will lose track of design very soon. The solution to this potential problem is to predefine and loading the shape families with all the hook definitions that are required[46]. Figure 7.7 shows *Hook Properties.*

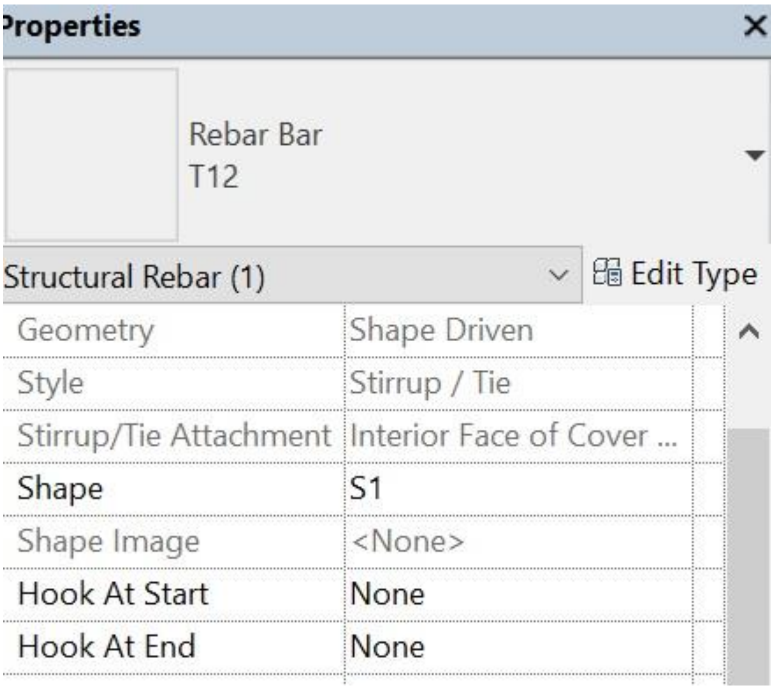

Figure 7.7 Hook Properties (produced by the author)

In the case of using European hook definitions and exclude hooks from *Rebar Shapes*, it is arbitrary to change the start and end hook conditions freely without modifying shapes [46]. In this model, hooks were considered in *Rebar Shapes*. Below Figure 7.8 demonstrates the window of Rebar Hook lengths.

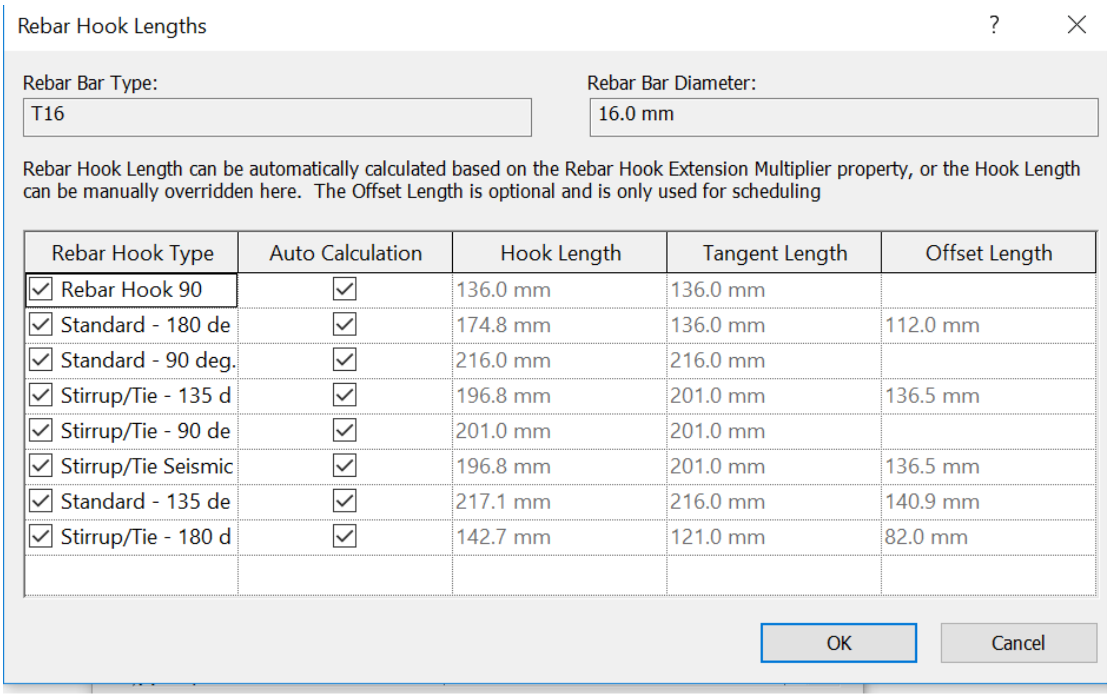

Figure 7.8 Rebar Hook lengths (produced by the author)

The designer looked practically at many different factors before providing a construction design for a footing. In Revit program, all parameters were filled out, proper coverage, and number, status B, C, D, dimensions, and position were determined as is illustrated in Figure 7.9.

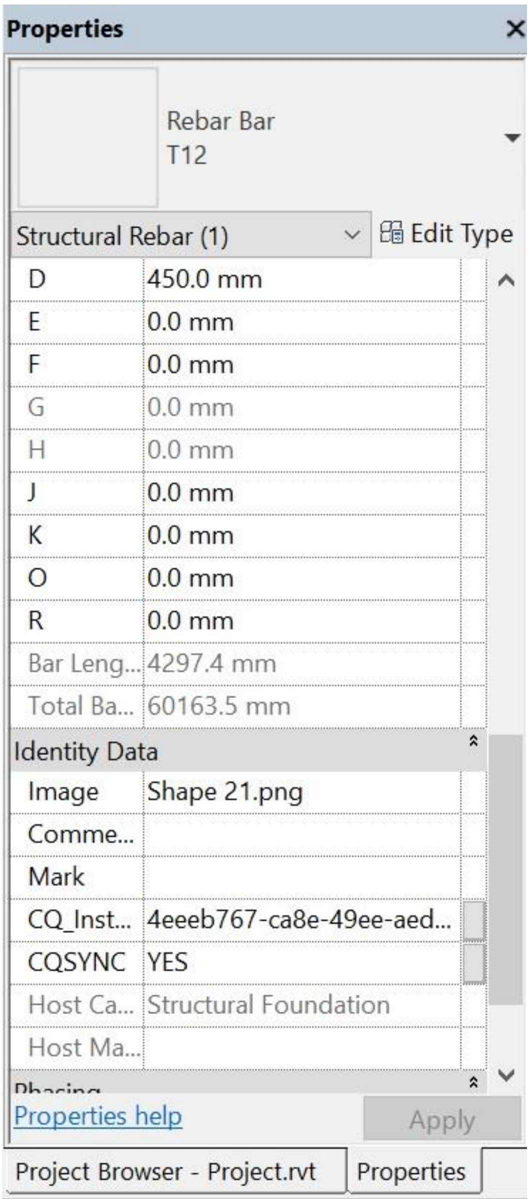

Figure 7.9 Dimensions and Identity (produced by the author)

As illustrated above one more modification done continuously, was due to make Rebar Shapes report, according to the exact need information of Rebar Schedules, Shape Code and Hook information. The presented values are national standards. The main point is that these locked text parameters can report something that the out-of-the-box parameters cannot. The following picture 7.10 indicates the way of making Rebar Schedules.

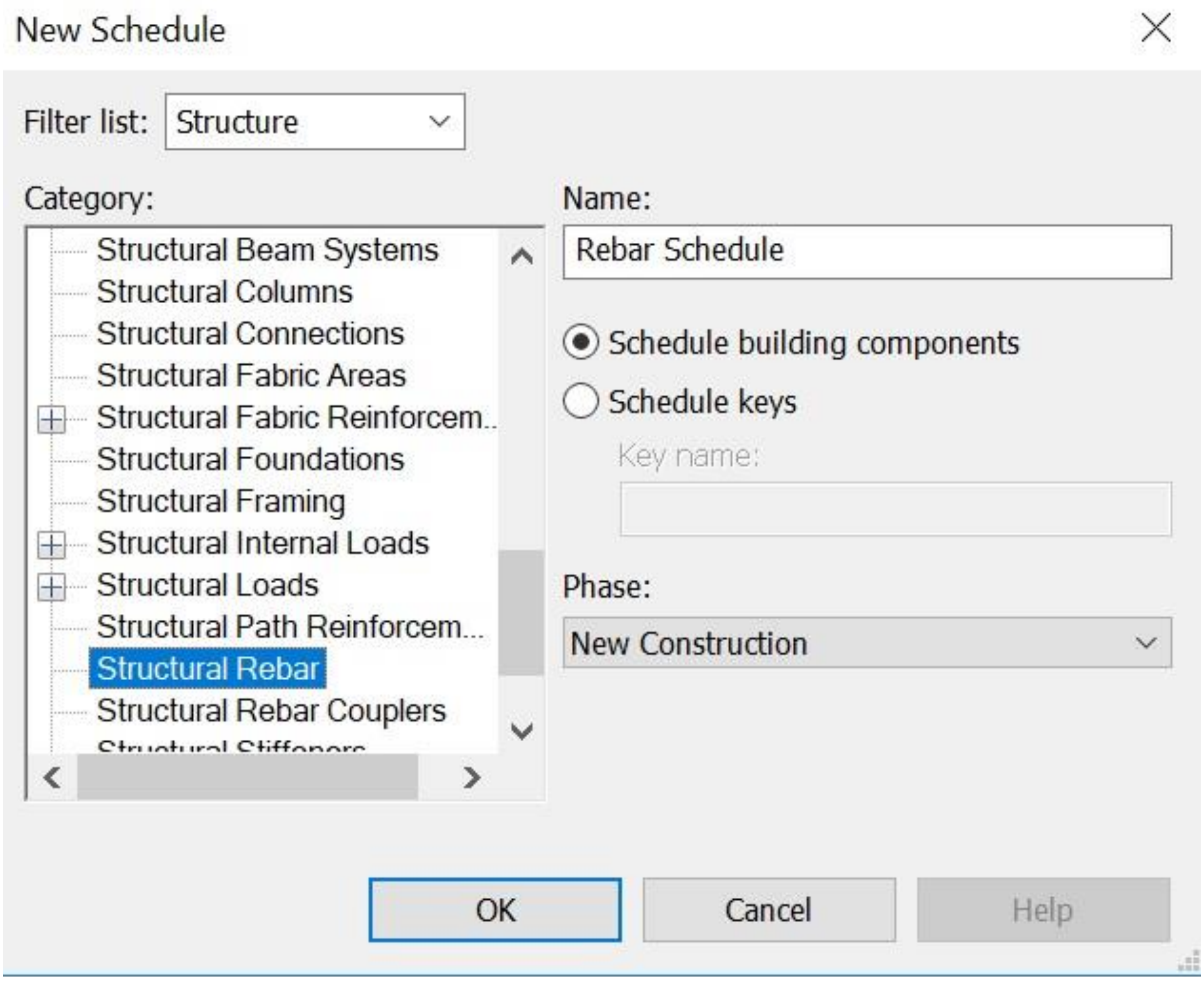

Figure 7.10 Creating of Rebar Schedule (produced by the author)

STATSBYGG

The parameters in the section on Rebar Schedules are all workarounds used in reinforcement production. Figure 7.11 illustrates the way of setting *Scheduled fields* in *Schedule Properties*.

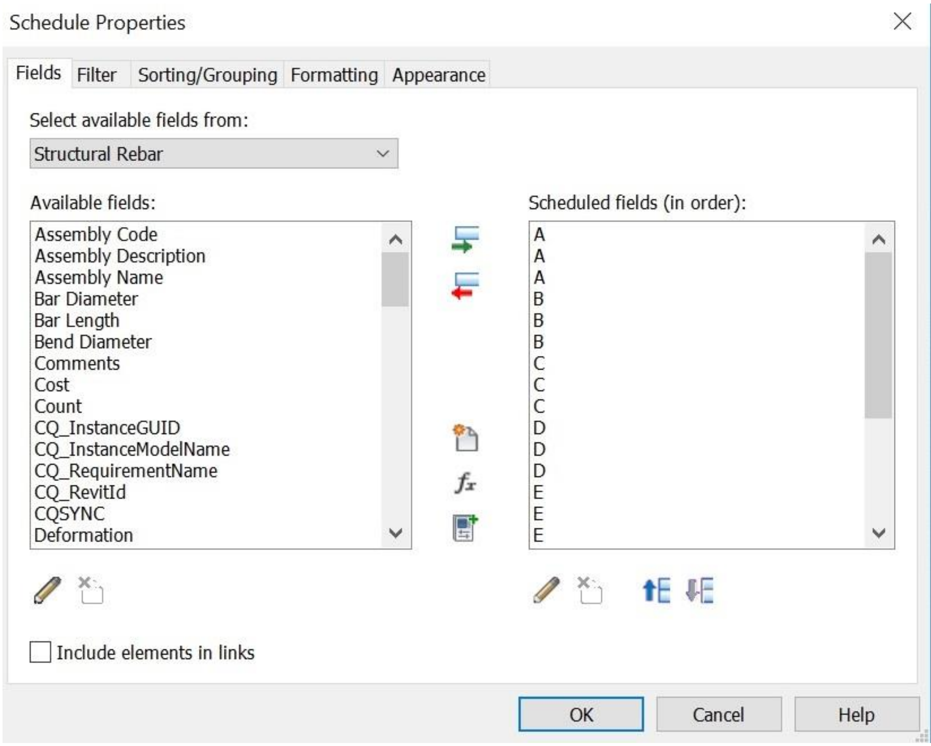

Figure 7.11 Selecting the Available fields of Structural Rebars (produced by the author)

As is shown above, three types of any parameters are given in Available fields. The reason is that rebars were selected from different places and each rebar has own definition for a unique letter. For example, in Figure 7.12, it is seen that three different dimensions were assigned to the same letter a.

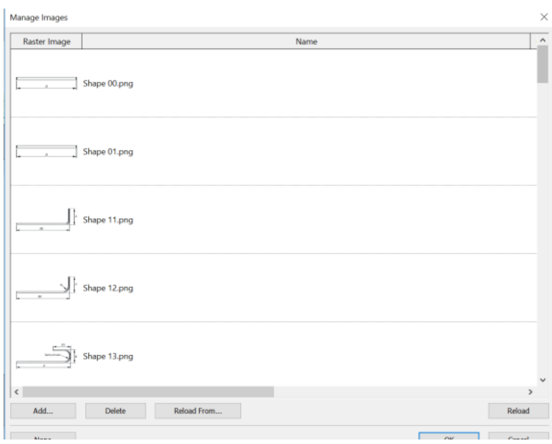

Figure 7.12 Rebar Shapes (produced by the author)

A schedule is a tabular representation of information, extracted from the properties of the project reinforcements. A rebar schedule lists every sample of the type of reinforcements that are scheduling. Below, the Rebar schedule of the foundation is displayed.

<Fundation_Rebar Schedule>

A	B	C	D	E	F	G	H	I	J	K	L	M	N
Partition	Schedule Mark	Type	Quantity	A	A	A	B	B	B	C	C	C	Image
	1	T12	1	2350 mm			0 mm			0 mm			Shape 01.png
F1	1	T12	1			0 mm			3448 mm			2350 mm	
F1	1	T12	1			0 mm			2350 mm			3448 mm	
F1	1	T12	1			0 mm			2350 mm			3448 mm	
F1	1	T12	1			0 mm			3448 mm			2350 mm	
F1	1	T12	1			0 mm			2350 mm			3448 mm	Shape 11.png
F1	1	T12	1			0 mm			2338 mm			3424 mm	Shape 11.png
F1	1	T12	1			0 mm			450 mm			3448 mm	Shape 21.png
F1	1	T12	14			0 mm			449 mm			2349 mm	Shape 21.png
F1	1	T12	1			0 mm			450 mm			3448 mm	Shape 41.png
F1	1	T12	14			0 mm			450 mm			3448 mm	Shape 21.png
F1	1	T12	4	450 mm			450 mm			157 mm			Shape 63.png
F1	1	T12	1			0 mm			2338 mm			3424 mm	Shape 21.png
F1	1	T12	1			0 mm			2338 mm			3424 mm	Shape 21.png
F1	1	T12	1	2350 mm			0 mm			0 mm			Shape 01.png
F1	1	T12	1	2350 mm			0 mm			0 mm			Shape 01.png
F1	1	T12	4		30			225 mm			450 mm		Shape 63.png
F1	1	T12	1	2350 mm			0 mm			0 mm			Shape 01.png
F1	1	T12	1	2350 mm			0 mm			0 mm			Shape 01.png
F2	1	T16	3	1019 mm			426 mm			175 mm			Shape 47.png
F2	1	T16	3	1019 mm			395 mm			175 mm			Shape 47.png

Figure 7.13 Result of Defined Rebar Schedule (produced by the author)

Some complex concrete forms are inefficient to perform in, Revit. The reason is that an individual distribution of rebars cannot get different dimensions and cannot be distributed in another direction and form than linear and perpendicular to the rebar shape plane. These limitations make the workflow difficult, however not impossible[46].

In Figure 7.14 the obtained realistic visual style of modeled foundation in Revit is shown.

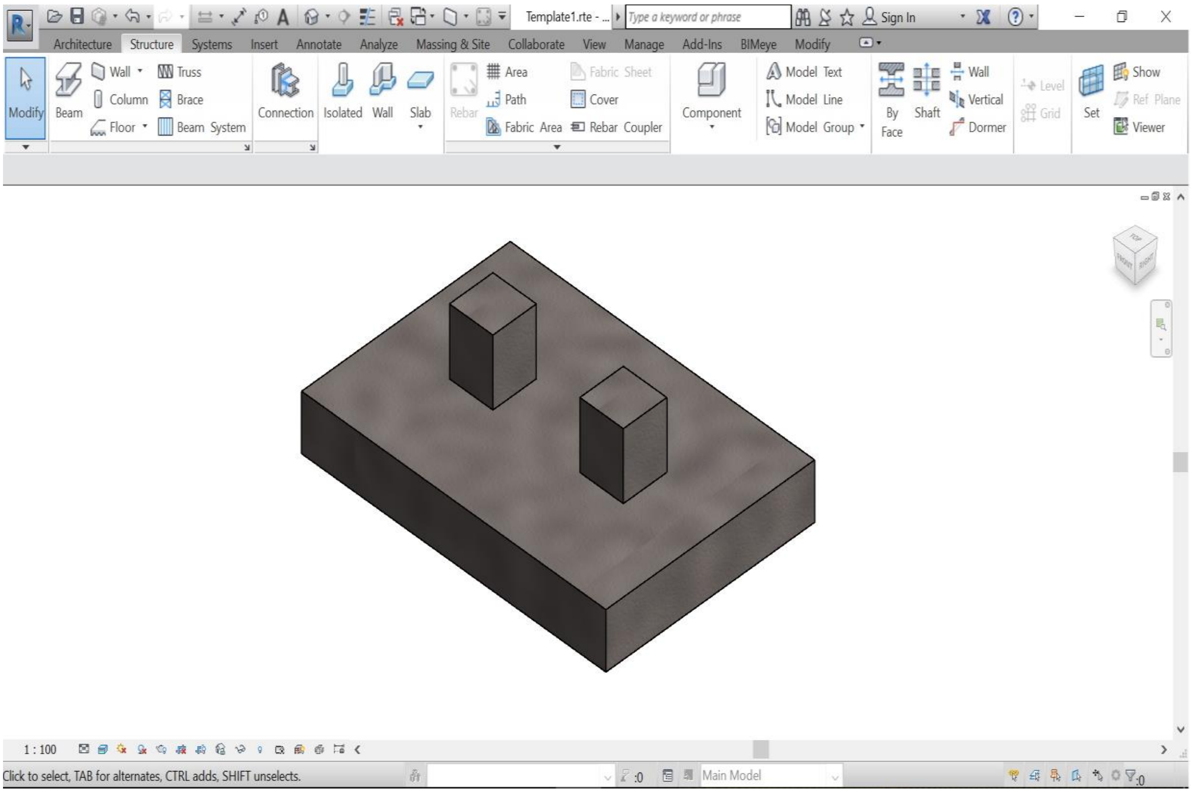

Figure 7.14 Revit Model of Foundation (produced by the author)

7.2. Exporting Data Using Solibri Model Checker Program

According to the earlier explanation, IFC format provides an interoperability solution among other software applications. International standards are applying to import and export of building objects and their specifications in the form of IFC format. It generally reduces the loss of data during transfer from one application to another, with established standards for ordinary objects in the building industry. Solibri improves communication, productivity, delivery time, and quality throughout the life cycle of a building. When a Revit building information model is transferred to IFC format, the information can be applied directly by other building specialists, such as structural and building services engineers [47].

In this report, BIM models generated with Revit was saved to the RVT file format. The model was transferred by using the IFC format to an IFC-certified application, Solibri that does not use the RVT file format. The drawing was opened and worked on in the non-native application. Similarly, in Revit, it is possible to import an IFC file, produce an RVT file, and work on the building model in Revit [47]. To use the IFC file as reference information for an existing model, the Link of IFC tool was used as shown in Figure 7.15:

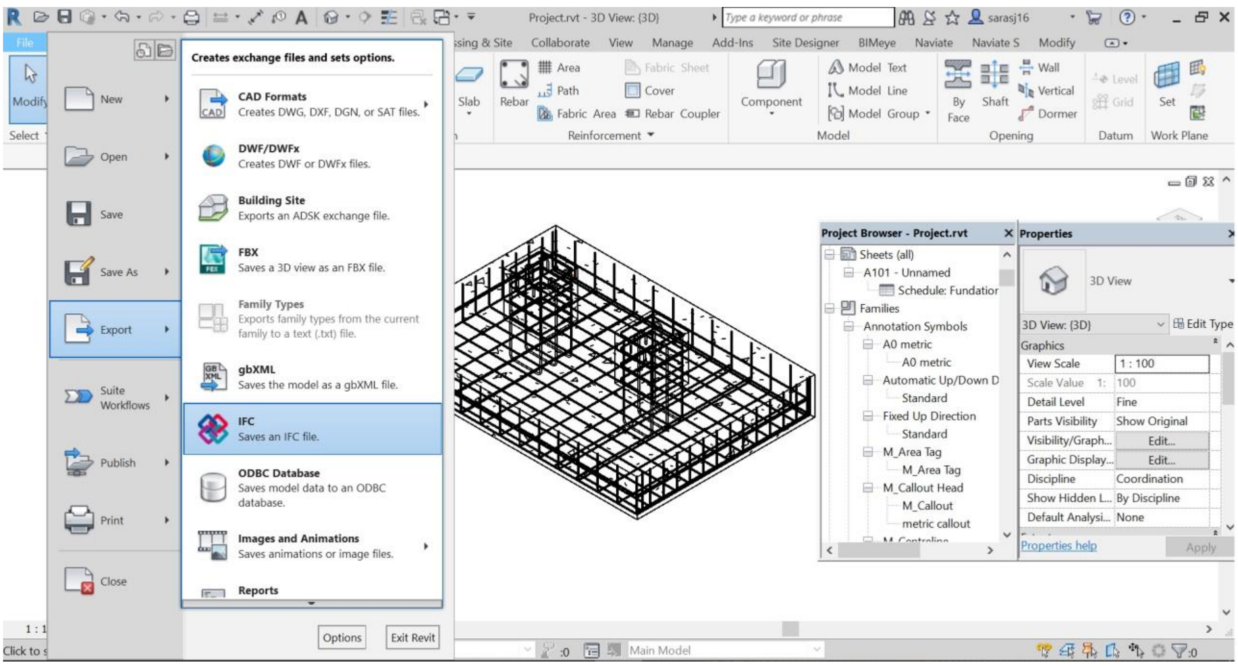

Figure 7.15 Making IFC file from Revit (produced by the author)

After opening the file in Solibri, the location of the object with x and y coordinates are presented in the infobox contains. The connection with other objects, floors, amounts, and features from Revit, are available as following Figure 7.16.

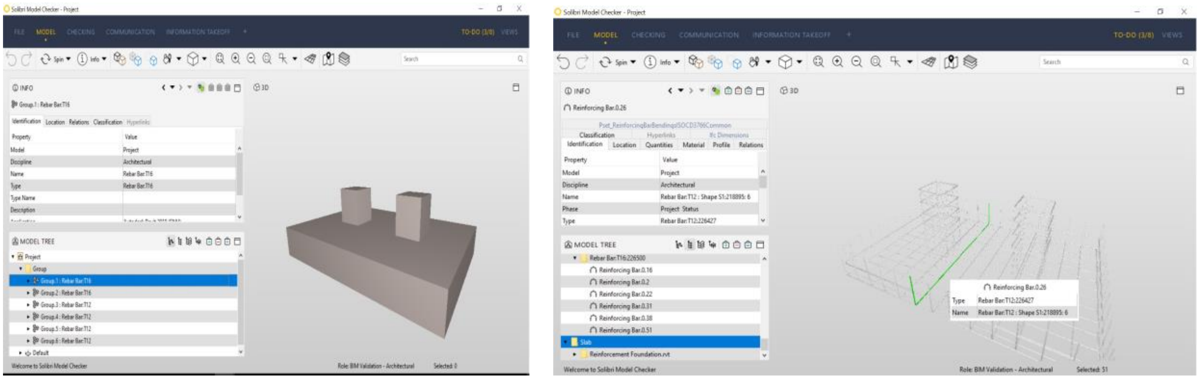

Figure 7.16 Info Box (produced by the author)

In Solibri the files that model should be checked for were chosen. Professional competence sorted the rules. The rule sets were available regardless of the type of project. Once the Ruleset file was loaded, check tab was pressed. At this time the model was verified against this set of rules. Demonstration of results was given in the Results dialog. By pressing on (+) sign, the result was displayed as a section of the model as shown in Figure 7.17. Solibri highlighted the consequence by scrapping the associated object. It was easy to see what the problem was.

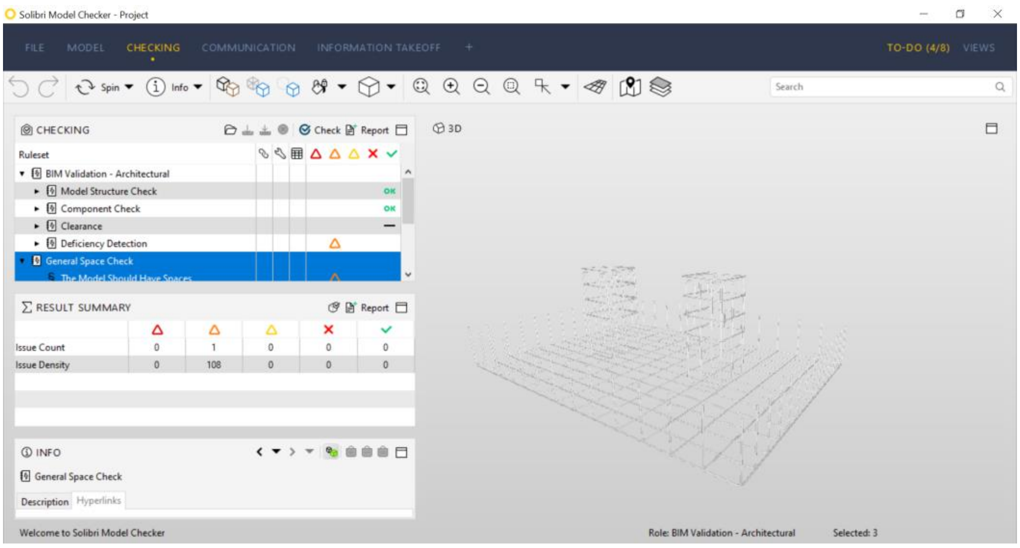

Figure 7.17 Solibri Model Checking (produced by the author)

After the checking the model, it was imported from Solibri into Simplebim, and then data has been got from Simplebim to the Excel application.

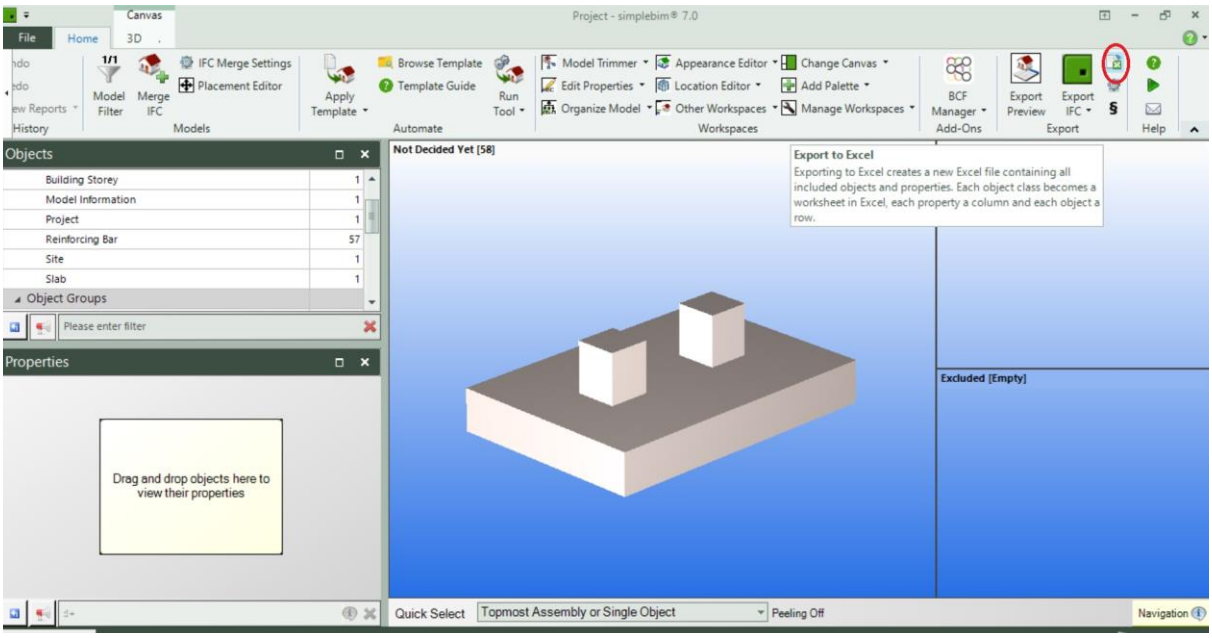

Figure 7.18 Simplebim (produced by the author)

Simplebim transfers all the different types, objects and properties into Excel. Everything that is existed in the model, there will be in Excel as well. Below in Figure 7.19, the picture of excel file is demonstrated.

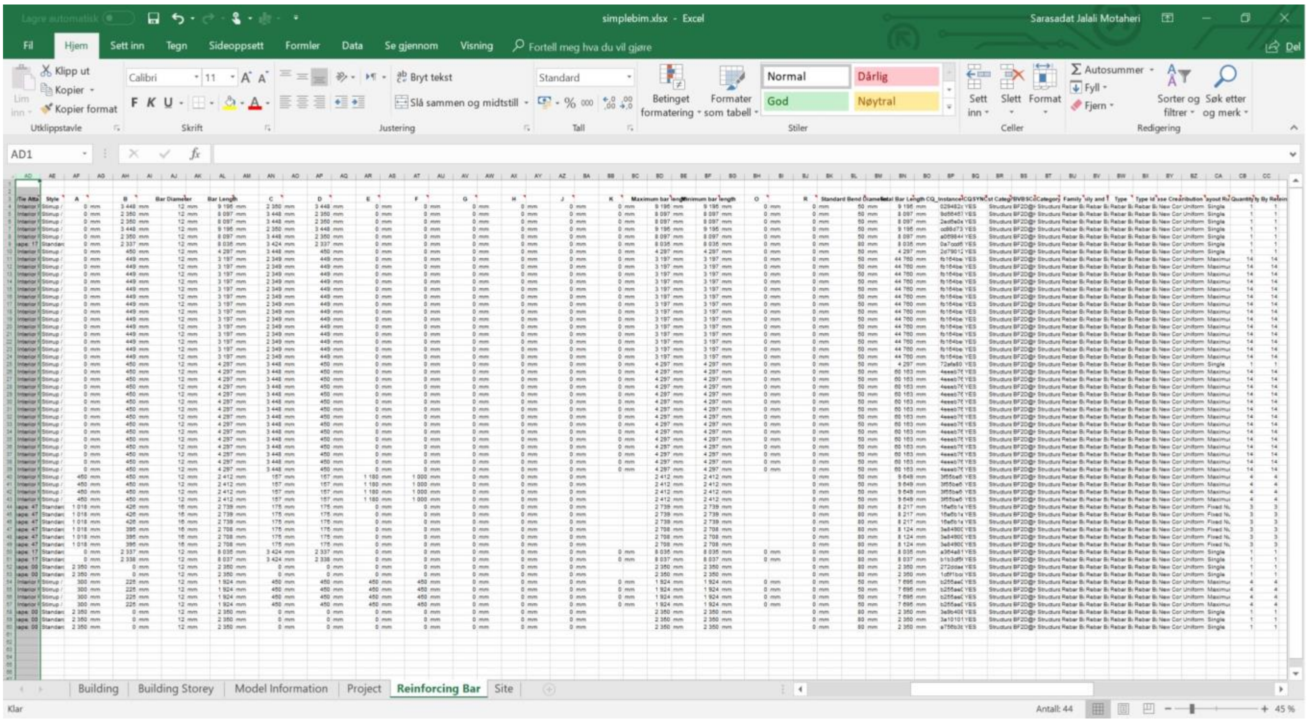

Figure 7.19 Achieved Data of Reinforcements (produced by the author)

7.3. The instruction of exporting data through BIMeye

A supplier on the building site has been given access to see the plan and order the reinforcement, they also return the information to the engineers, and the engineers give cut and bend factory access to a BVBS, *EXMEL that is like a control file. Thus, they do not have to punch all the reinforcement data manually into the machines. The first step was to model up the reinforcements, using partition parameter. All different components of the model have their partitions in Revit that is displayed in Figure 7.20.

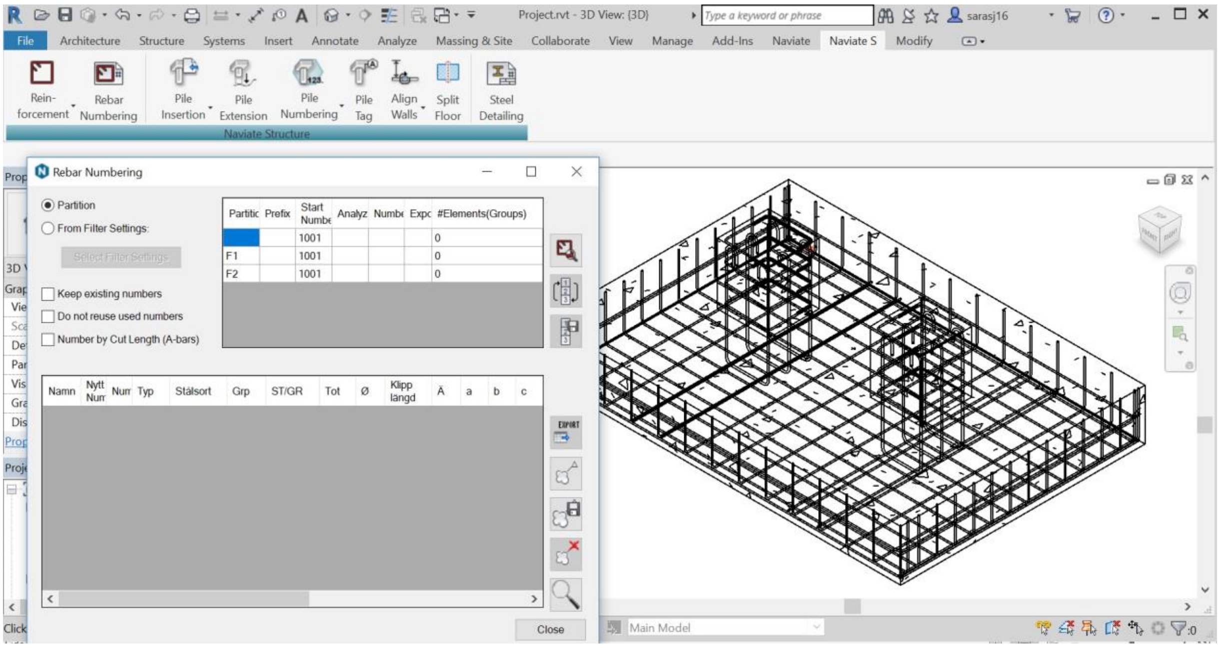

Figure 7.20 Rebar Numbering (produced by the author)

Each element was shown in a unique colure, for example, light blue one is for foundations, and red is for the floors. The simple way of filtering out and ordering the object was needed at a time.
Then rebar numbering function is utilized to get all the rebars, which have position number. Rebar Naviate numbering is also used to have easy control, over partitions or filters, that should be used to get the position of all the rebars. Below the space of Naviate produced by SYMETRI is shown in Figure 7.21.

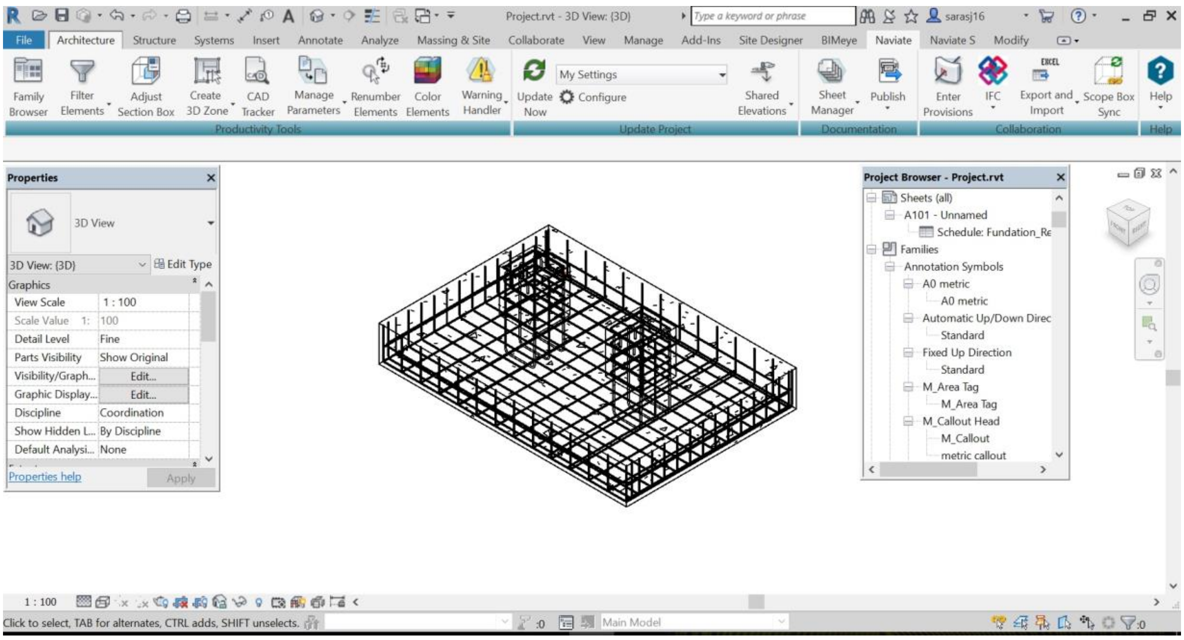

Figure 7.21 Naviate Space (produced by the author)

The last step was to create an export for the BVBS. A parameter that is called BVBS code was needed to be able to make BVBS file by BIMeye as shown in Figure 7.22.

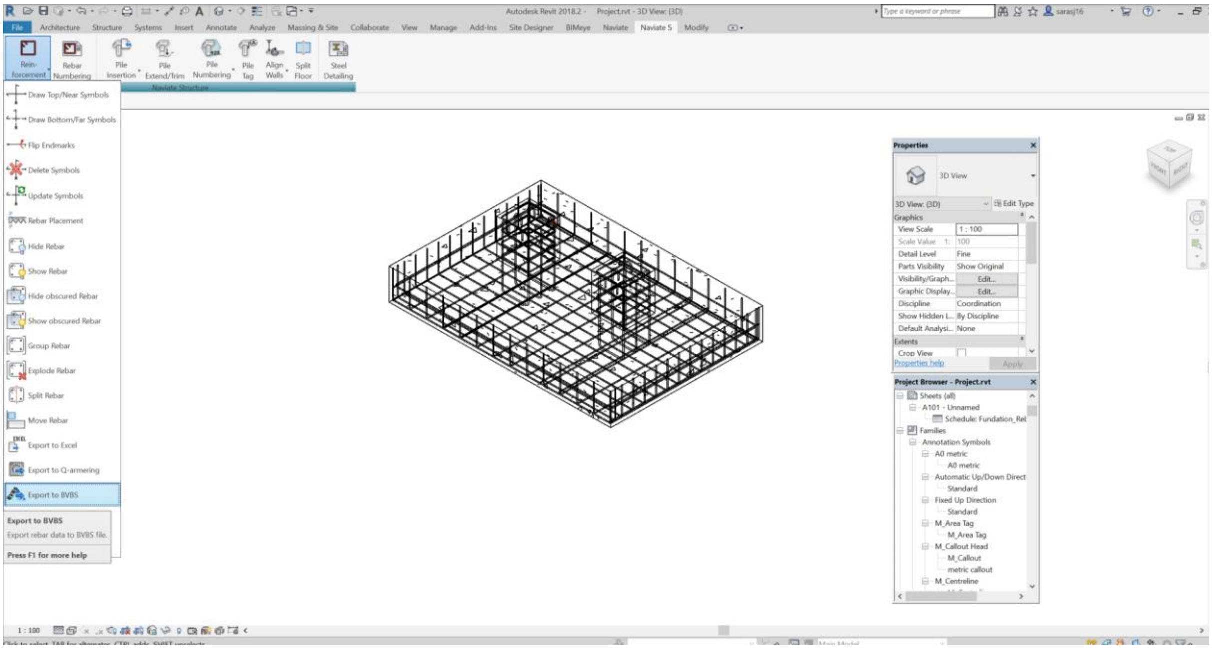

Figure 7.22 Getting BVBS from Naviate S Tab (produced by the author)

BVBS achieved by Naviate S directly from Revit is given in two pictures of Figure 7.23.

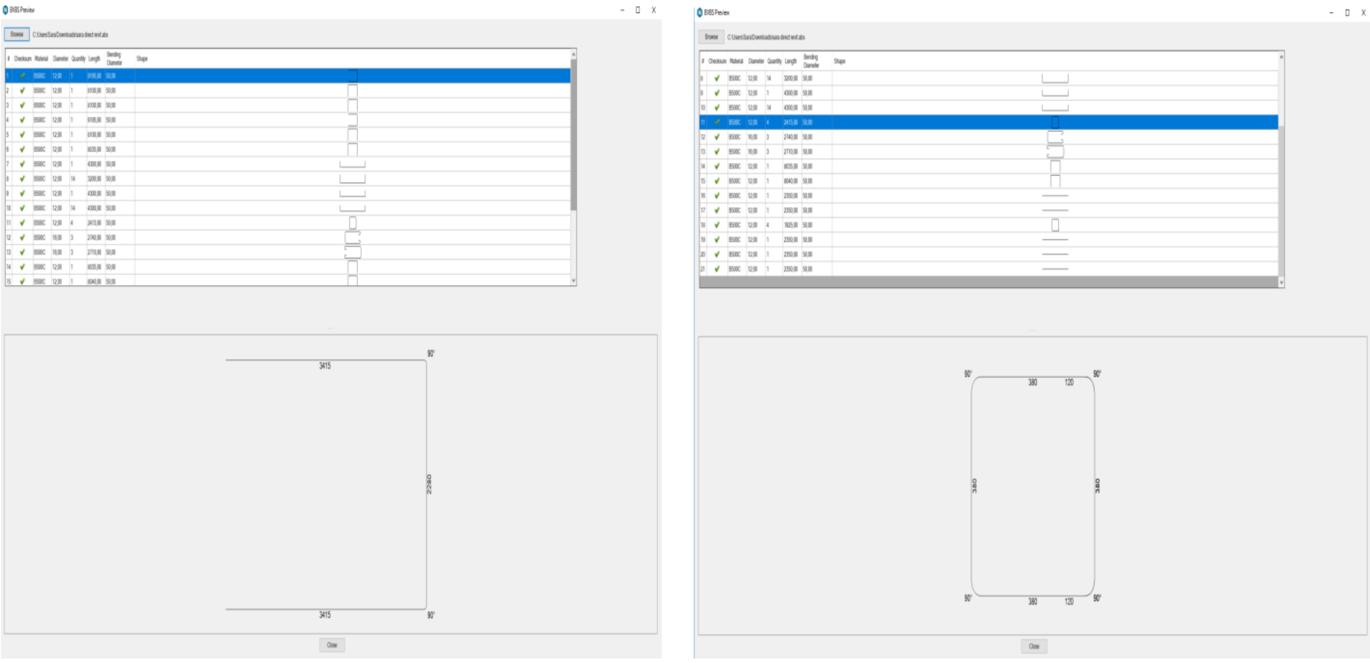

Figure 7.23 BVBS achieved directly from Revit by Naviate S

After getting BVBS, the model was uploaded into the BIMeye. In BIMeye the application was set on the *ASSET Manager* to get the reinforcement, and the 3D model was uploaded as shown in Figure 7.24.

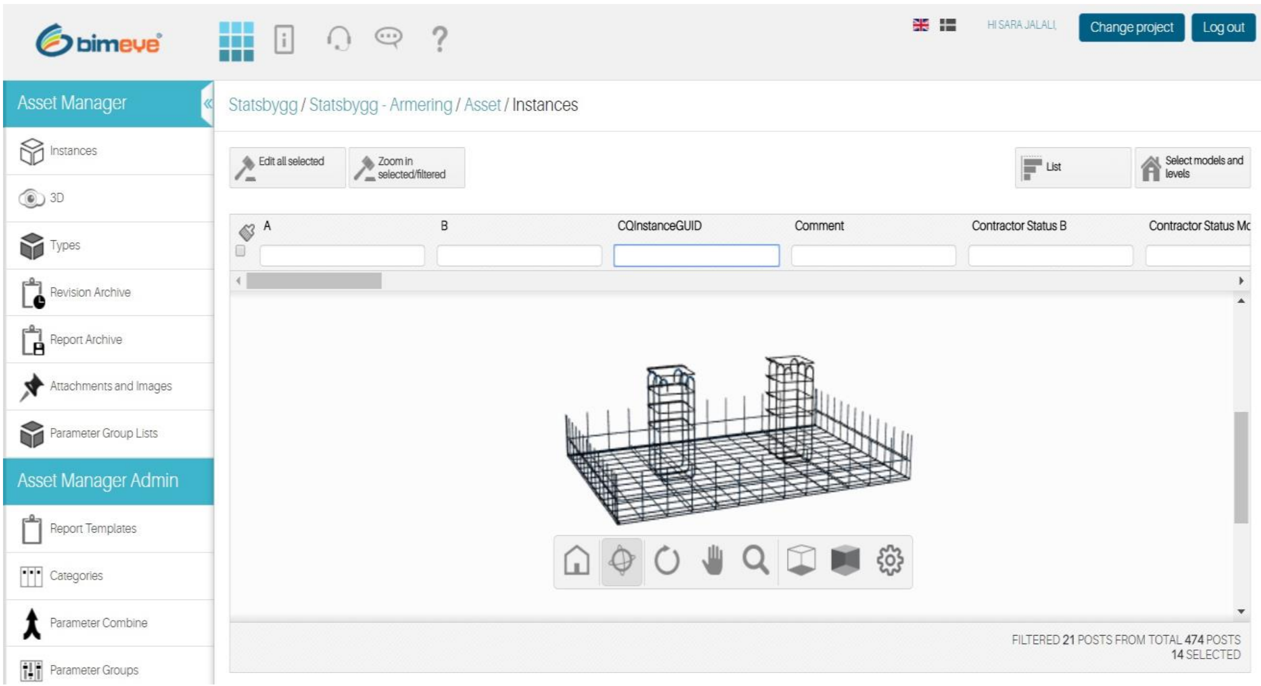

Figure 7.24 BIMeye Asset Manager (produced by the author)

The constructor or the other person who is working on BIMeye can see the 3D model as well. They can also see how engineer decides that rebars be going to locate. Then again *Instance* displays all the partitions, that can be sorted out to every object, that is demanded, as demonstrated in Figure 7.25.

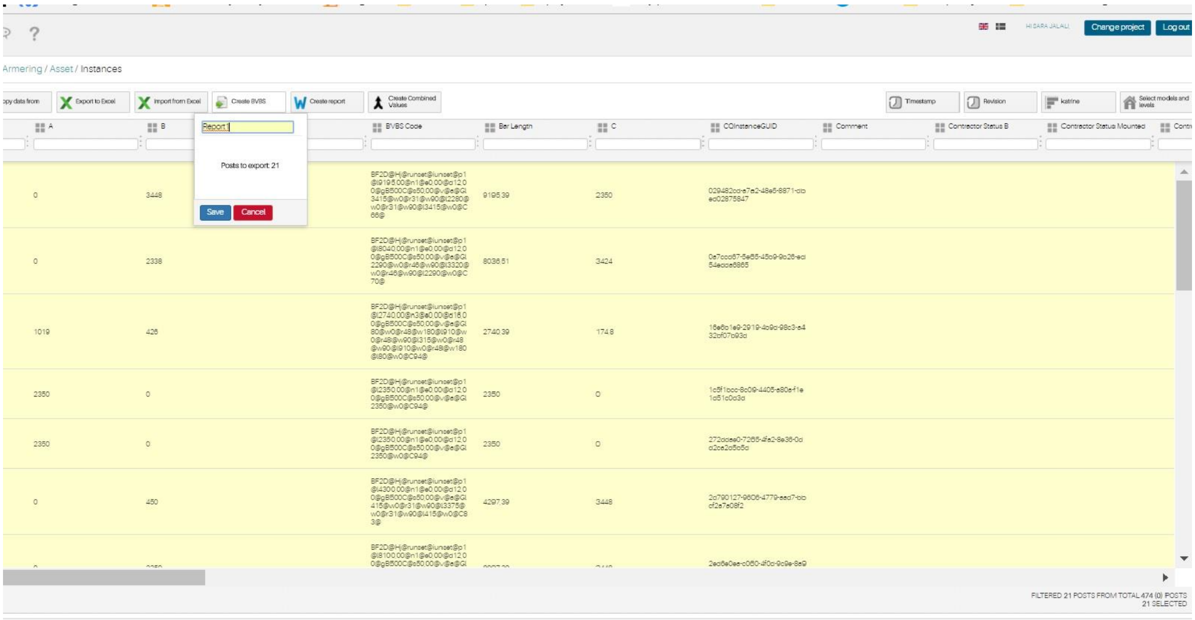

Figure 7.25 BIMeye Instances (produced by the author)

At the time that all the reinforcements located in the foundation are ordered, the corresponding *partitions* are known so that they can be sorted out and be selected. The report name is specified, saved and the *report archive* should be downloaded.

Now is time to create BVBS directly from BIMeye, the obtained BVBS file of this assignment as shown below in Figure 7.26.

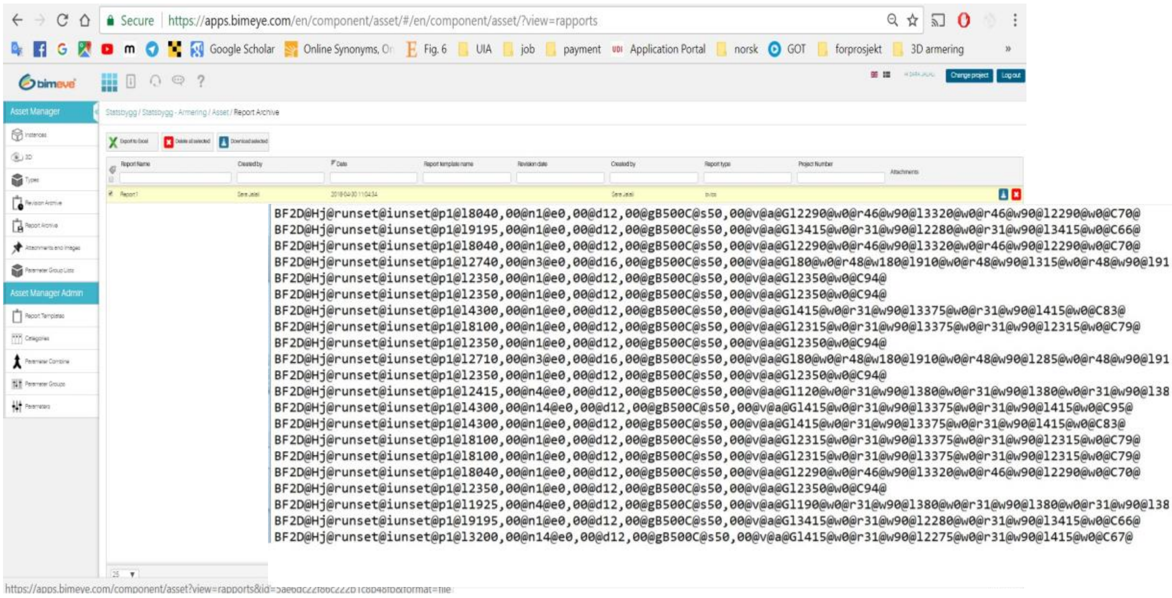

Figure 7.26 Getting BVBS from BIMeye (produced by the author)

Then through *navigate* in Revit, there is a *preview* of the BVBS, all the dimensions of the rebar and the different rebars are demonstrated.
By returning to the BIMeye, and choosing a cut and bend factory, users are enabled to log in to BIMeye directly and to download their required report. It is also possible that the report is sent to constructors. After getting the reports the parameters should be set, that show all these rebars are being ordered. All the selected parameters are changed to the object data. The dates are determined, it is signed, and submitted. From *instance* can be ensured that all the rebars got these parameters. Through the 3D view, the other components can also be selected, the corresponding status can be edited, and finally, the date can be signed and submitted [48].

At this stage, data should be synchronized with Revit model since by selecting rebar, no parameter information is revealed. In BIMeye panel on the top of the Revit menu, the *Asset* is selected, and with BIMeye is synchronized. Now BIMeye allows starting the download. A very time-consuming process for the engineer is that to contact building site through tracking the reinforcements and knowing what has been ordered or built. Sometimes some revisions might be needed to perform. In this case, in Revit model, rebars are selected, the numbers are changed, *rebar numbering function* is revised, and then the *function* should be run. After the revision is done, the new one is named, and it is saved. The new information should be uploaded to BIMeye, and again *asset* should be clicked, data be synced and uploaded from BIMeye. After synchronization with BIMeye is done, data is added to cut and bend factory. By returning to the model, data are uploaded to the web hotel, and the contractor should download the files, open them again, synchronize the model and go back to the BIMeye [48].

Now constructor can sort out the different revisions, create the new BVBS with all the revisions, add revision, select the reinforcements to be ordered, then download data ordering again to the model.

It was attempted to explain how can synchronize the info from model to BIMeye with parameters. Lots of parameters are taken from the model, determined parameters like partition, type, revision moreover, also parameter made in BIMeye and synchronize with the model. It is also possible to have a parameter that has not synchronized with the model over the BIMeye, and there is only much more information that can be written in BIMeye or be mentioned just in the model [48].

8. Disscusion

The enormous scientific theory is the basis of the assignment that has been accomplished. This section has attempted to provide a comprehensive and authentic brief statement of the use of BIM for 3D modeling preparation and automation of drawingless reinforcement production. Additionally, based on the researches have been carried out in recent decades, the reliability of exported files was discussed. For this meaning both theoretical and experimental aspects of the study is considered with offered references.

Revit, Solibri, Simplebim, and BIMeye were used to find the method of data transferring and getting outputs from the model in the formats of IFC or BVBS file. The reason of this attempt was to achieve an automated production of steel reinforcement in a concrete structure. Solibri and Simplebim produced IFC format. The BVBS file extracted once directly from Revit by the help of Naviate S and again by through BIMeye. In this section, the exportation of BVBS- and IFC-data to the production line is evaluated through a sample model that was created in Revit.
To understand the mechanism of IFC-data exporting to the production line the created sample model is used. Each format should be translated and interpreted according to everyday expressions in the construction industry.
In the following, a brief workflow of drawing less reinforcement production will be presented and then the advantages, and disadvantages of each method will be discussed, and the properties of these methods will be compared.

8.1. Design and Modelling

According to the Theory section the workflow of reinforcement production begins from the Design and modelling stage that is conducted based on the analysis and calculations tasks.
In Design and modelling stage the parameter groups are controlled and the work area for production, casting and work packages are defined. The partitions will be specified and MMI, Level of Details (LOD) and Object Status(OS) are determined.
The gained results of Revit test mode file indicated that optimizing the workflow of data extracting was very substantial to have a perfect rebar schedule at the stage of Projecting and Modeling by Revit program. The modeling was implemented according to the analyzed requirements. It was attempted to have a schedule bar contained information corresponding fully to the properties of the project reinforcements is represented. Well defined parameters such as partitioning, position Number, Geometry of the reinforcements, shape codes, object status, Hooks information consisting start and ends of the Hook and materials information, improved the process.

8.2. Qualifications Control

As mentioned in theory section, the goal of the BIM process was to streamline workflow for design and to modify work mappings for fabrication. Thus, a comprehensive quality assurance plan of a BIM model helps to specify dates for deliveries and work tasks. Quality assurance is the other step in to improve the workflow of process structural inspection provided by an involving collaboration between project players involved in both design and construction site, to detect probable conflicts and clashes among different sections. In the sample model of this assignment, there was no significant warning. More of the checking signs turned green. However, it got orange warning related to deficiency detection in part of the required component, and general space check shows the high density of reinforcement, and the model needs spaces, it was modified by simple displacement and space allocation in the Revit file.

8.3. Exporting Modelling Data as IFC File

At this stage of the workflow, model parameters are imported from the Revit file in to the IFC. Before this exchange, in the Revit model, the parameters such as Partitioning, Position number, and Serial Number per Partition are determined. Additionally, the Reinforcements Geometry, shape Code, Object Status, Hook Information and Material are defined in Revit.
In the Revit model, Rebars are sorted based on the Object Status from model to ordering and in addition to all parameters that are defined in the Revit, the shape parameters containing Cuts, Dimensions, Revisions are also transferred in to the IFC file.
Then all the model associated with all these defined parameters are transferred to Solibri in an IFC file.
The same Reinforcement parameters are imported from IFC to an Excel file. This imported file contains Production Stages, Partition, position Number, Shape Code, Material Grade, Bar diameter, Total Amount, Hook end, Hook start, Geometry A G, Bending Radius R Reinforcement Revision, Revision, Total length per position number, Length per Unit, Total Weight, comments.

The obtained IFC result of the test model, which was given in Excel file is a comprehensive data sheet, in which all assigned data in Revit has been transferred. It contains parameters such as the name of rebars, description of object types, tag, steel nominal diameter, cross-section area, and bar length. Parameters like ISOCD3766 shape code, ISOCD3766 shape code parameter a, b, c, e, r, and A, B, C, D, E, F property set dimensions, introduce a specific dimension in any reinforcement, which is not imaged in the Excel file. Bend diameter, geometry, partition rebar number, Schedule mark, and shape property rebar set construction was given as well. Moreover, bar diameter, bar length, attachment of property set construction, style property, length of each bar was provided by Excel. Excel file also gave the parameters such as ISOCD3766 Bending start hook, ISOCD3766Bending end hook, Hook at the start, hook at the end, and material attribute name is given based on previous Revit definitions.

Besides all, an unpredictable issue was that the parameters presented by Excel file were BVBS format, which could have made the processes much more comfortable if the author knew that it is contained in the IFC and subsequently in the Excel at the beginning. Accurate checking showed that there is an exact match between the obtained BVBS codes covered in the Excel file, the BVBS got directly from Revit, and the one got from BIMeye. Excel file can sort data arbitrary according to the desire, for instance, data can be set up based on the reinforcement's length, shape, position, diameter and so on. IFC does not satisfy all the expectations for bright time saving parametric stuff, and it is mainly limited on the geometry and data. On the other sight, IFC records contain too many details and specialized info, that can make the fabricators confused.

Another problem is that the excel file is not sent straight to the fabrication machine and it does not demonstrate the real shape of reinforcement. Therefore, there is an urgent need to prepare digital drawings to the production line. Illustration of the reinforcement along with the dimensions shown on it gives a better understanding to the fabricators.

Below, the most critical parameters of this excel file are illustrated in following Tables.

A comparison of the bar lengths in Excel with the bar lengths in BVBS data sheets shows the bars have more accurate lengths in Excel file rather than the lengths given by BVBS. For instance, the bar lengths such as 8097 mm, 9195 mm, 8035 mm, 4297 mm, 3197 mm,2412 mm,2739 mm,2708mm, 2350mm, 1924mm, in BVBS are rounded to some approximate lengths such as; 80100 mm,9195 mm, 8040 mm,4300 mm,3200 mm,2415 mm,2740 mm,2710 mm, 2350 mm,1925mm.

Even though it was not found any particular loss of information during the exchange procedure of the test model, IFC is not ordinarily successful in transferring big files through the various software. In many cases exchanging of IFC, that has a small modification, and the users do not have the freedom to control the exchange file.

The standard bend and standard hook diameter are 80mm, Stirrup/Tie Bend Diameter is 50mm, Maximum Bend Radius18mm. Standard bend diameter is considered 80mm for the following rebar lengths 8035mm, 2739mm,2708 mm, 8037mm, 2350mm length.

The first privilege provided by the IFC format is its ability to make collaboration between the various technical roles involved in the construction process. IFC ‘s capacity enables the user to exchange information through a standard format. This results in higher quality, causes the reduction of costs and time consuming, with consistent data and information flowing from the design phase to the fabrication. Eventually, IFC is successful in transferring semantic information.
The advantages of IFC format can be titled as follows:

- Clear understanding of project material and execution,
- Higher quality that leads to fewer misunderstandings,
- And better control of amounts,
- Opportunity to take arbitrary view cut and separate views of model,
- Easier to take control of the construction site of projected reinforcement,
- Possibility to manage the list of bending lists against ordering and picking up reinforcement,
- Especially useful for narrow construction sites,
- Possibility to state the status of objects / rev: ordered - delivered – mounted,
- Makes it possible to create visual progression model by model
- Acceptable transferring of semantic data

- Providing the possibility of collaboration between different disciplines
- Cost reduction and time-saving procedure of data flow

Looking through the experiences of BIM experts, there also seems to be much dissatisfaction with IFC. IFC is typically utilized for a static as-built record Information, however, even in this usage, the validation of the data is critical. IFC has the high probability of losing information or dropping data during exporting from its native format. The most critical barrier in this assignment was that regardless how excellent IFC becomes, it will never have the functionality as the native Revit it was generated in. IFC does not seem to satisfy all the functionality of BIM software like Revit. It includes sizes and dimensions, however, doesn't determine which geometric component is governed by these dimensions. Therefore, IFC cannot export working parametric objects. Also, static objects that, are generated by IFC are no longer editable. This behavior continues challenges that BIM is supposed to overcome. The problem is that If size parameters are edited, the geometry does not change with those edits, there is potential for situations where the scheduled size of reinforcement does not match its geometric size. For this reason, clash detection is not entirely reliable. This study does not contain any significant data losing after exporting data from Revit to Solibri and from Solibri to Simplebim. However, it lost many critical data during a testing exchange from Solibri to Revit.
Some disadvantages of the IFC format can be briefly classified as following:

- FME “Feature Manipulation Engine” struggles to translate destroyed IFC geometry
- Invalid geometry export
- Conversion process damages information
- Level information lost

8.4. Exporting Modelling Data as BVBS File

The workflow of drawingless reinforcement production can follow another path by use of BVBS file, which digital bending list can be sent directly to the bending machine.
In this section first, the BVBS data string obtained in Result of the test model will be translated and analyzed.
The BVBS data that was achieved through three ways: Excel, BIMeye, and Naviate S installed on Revit, will be compared together. The adjustment between all the obtained data strings will be checked. Each data string is translated based on BVBS Guideline Exchanging Reinforcement data. Naviate S installed on Revit besides the BVBS file, presented the whole rebar shapes that are illustrated after each BVBS data string.
BF2D@Hj@runset@iunset@p1@l8040,00@n1@e7,13@d12,00@gB500C@s50,00@v@a@Gl2290 @w0@r46@w90@l3320@w0@r46@w90@l2290@w0@C70@
Analyze:
BF2D: two-dimensional re-bar
Hj: name of the project given in Revit
r46: assembly position
p1: position number
l8040: cutting length calculated by Revit
i: index of respective drawing
n1: number of re-bars
e7.13: weight of the bar [kg]
d12: bar diameter [mm]
gB500NC: steel grade
s50 – bending diameter [mm]
a: layer
This item has 8040 mm Total Length with two 90 °hooks with a bending diameter of 50 mm, and the Length at each end is 2290 mm. This item has the same form code as the one achieved by Revit Naviate S. item's shape is displayed in Figure 8.1.

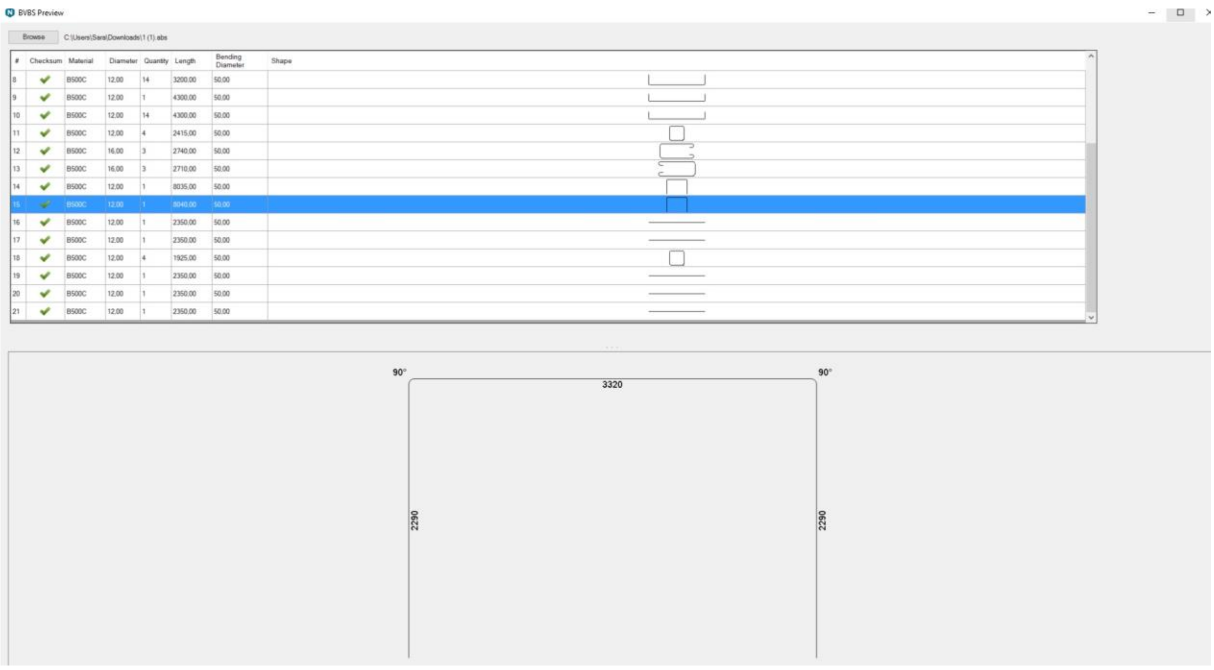

Figure 8.1 Total Length 8040 mm, through Naviate S (by the author)

BF2D@Hj@runset@iunset@p1@l9195,00@n1@e8,16@d12,00@gB500C@s50,00@v@a@Gl3415@w0@r31@w90@l2280@w0@r31@w90@l3415@w0@C66@

Analyze:

BF2D: two-dimensional re-bar

Hj: name of the project given in Revit

r31: assembly position

p1: position number

l9195 – cutting length calculated by Revit

i: index of respective drawing

n1: number of re-bars

e8.16: weight of the bar [kg]

d12: bar diameter [mm]

gB500NC – steel grade

s50: bending diameter [mm]

a – layer

This item has 9195 mm Total Length, including 2280mm with two 90 °hooks, the Length at each end is 3415 mm with a bending diameter of 50 mm. This Item is exactly accordance with the one got from Revit Naviate S and illustrated in Figure 8.2.

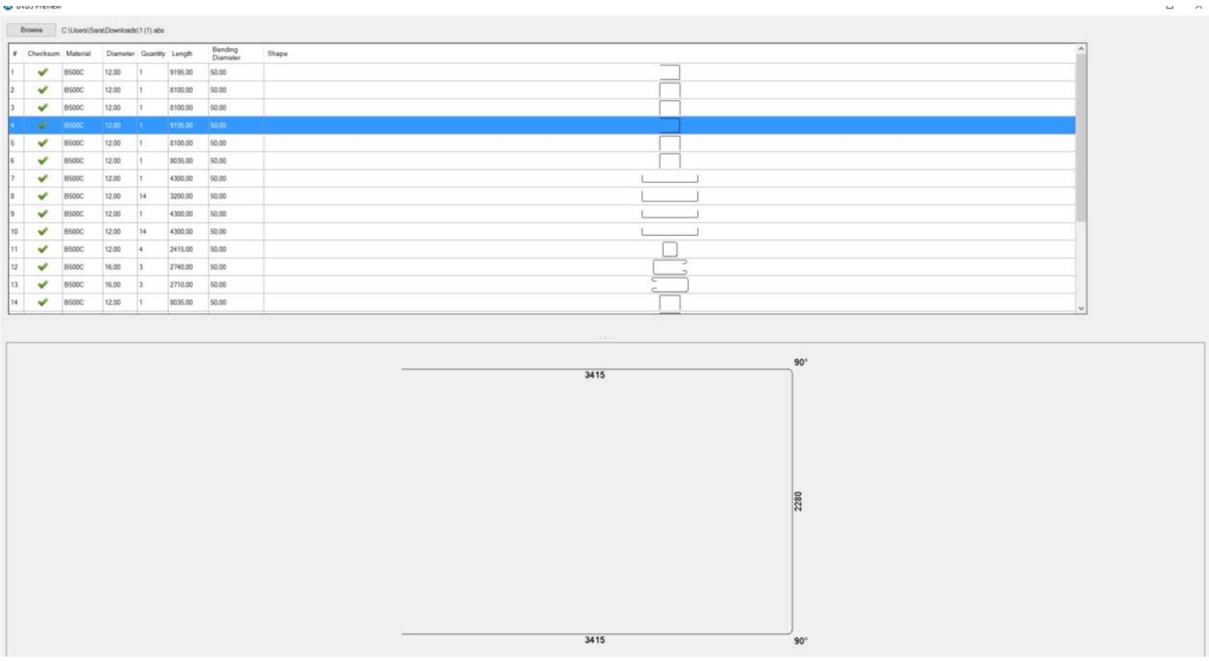

Figure 8.2 Total Length 9195 mm, through Naviate S (by the author)

BF2D@Hj@runset@iunset@p1@l8040,00@n1@e7,13@d12,00@gB500C@s50,00@v@a@Gl2290@w0@r46@w90@l3320@w0@r46@w90@l2290@w0@C70@

Analyze:

BF2D: two-dimensional re-bar

Hj: name of the project given in Revit

r46: assembly position

p1: position number

l8040: cutting length calculated by Revit

i: index of respective drawing

n1: number of re-bars

e7.13: weight of the bar [kg]

d12: bar diameter [mm]

gB500NC: steel grade

s50,00: bending diameter [mm]

a: layer

This item has 8040 mm Total Length, including 3320 mm length, two 90 °hooks with 2290 mm length at the ends it is exactly same as detailed belonging to Figure 8.1.

BF2D@Hj@runset@iunset@p1@l2740,00@n3@e4,32@d16,00@gB500C@s50,00@v@a@Gl80@w0@r48@w180@l910@w0@r48@w90@l315@w0@r48@w90@l910@w0@r48@w180@l80@w0@C94@

Analyze:

BF2D: two-dimensional re-bar

Hj: name of the project given in Revit

r48: assembly position

p1: position number

l2740: cutting length calculated by Revit

i: index of respective drawing

n3: number of re-bars

e4.32: weight of the bar [kg]

d12: bar diameter [mm]

gB500NC: steel grade

s50: bending diameter [mm]

a: layer

This item is accordance with Revit Naviate S result as demonstrated in Figure8.3. It has 2740 mm Total Length

, including 315 mm Length, two 90 °hooks with 910 mm Length, two 180° hooks on both ends with a bending diameter of 50 mm, and length at each end is 80 mm.

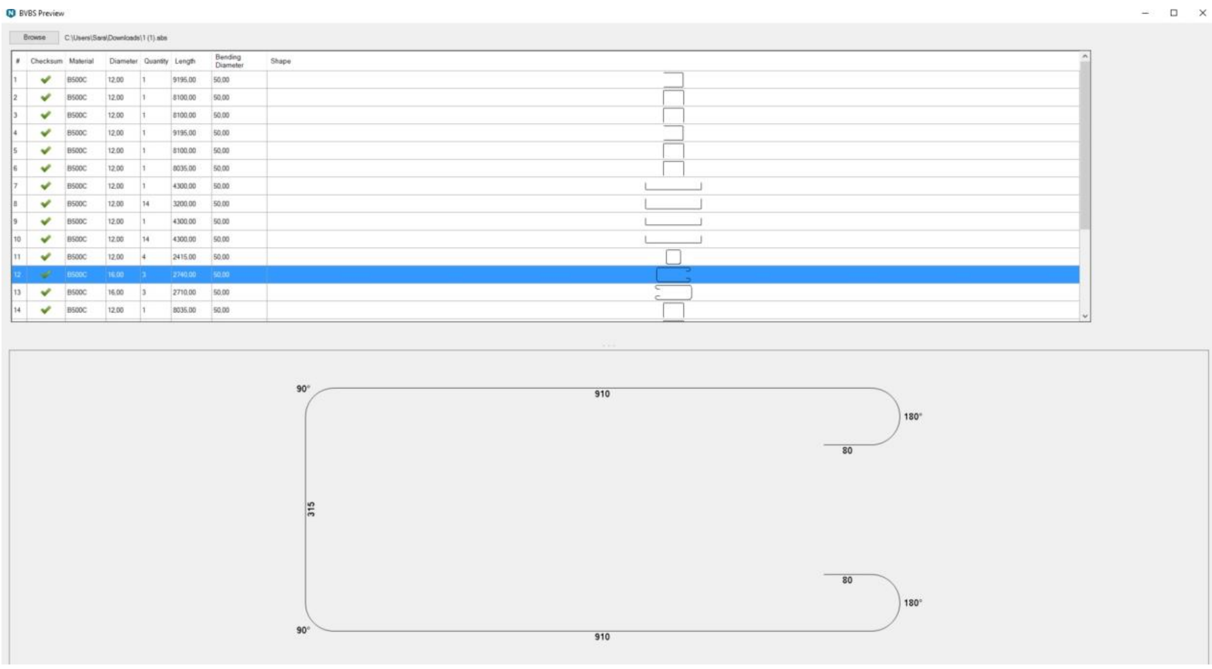

Figure 8.3 Total Length 2740 mm through Naviate S (by the author)

BF2D@Hj@runset@iunset@p1@l2350,00@n1@e2,09@d12,00@gB500C@s50,00@v@a@Gl2350 @w0@C94@

Analyze:

BF2D: two-dimensional re-bar

Hj: name of the project given in Revit

p1: position number

l2350: cutting length calculated by Revit

i: index of respective drawing

n1 – number of re-bars

e2.09 – weight of the bar [kg]

d12: bar diameter [mm]

gB500NC – steel grade

s50: bending diameter [mm]

a: layer

This item has 2350mm total Length, and no hook. This item has the same form code as the one achieved by Revit Naviate S is shown in Figure 8.4.

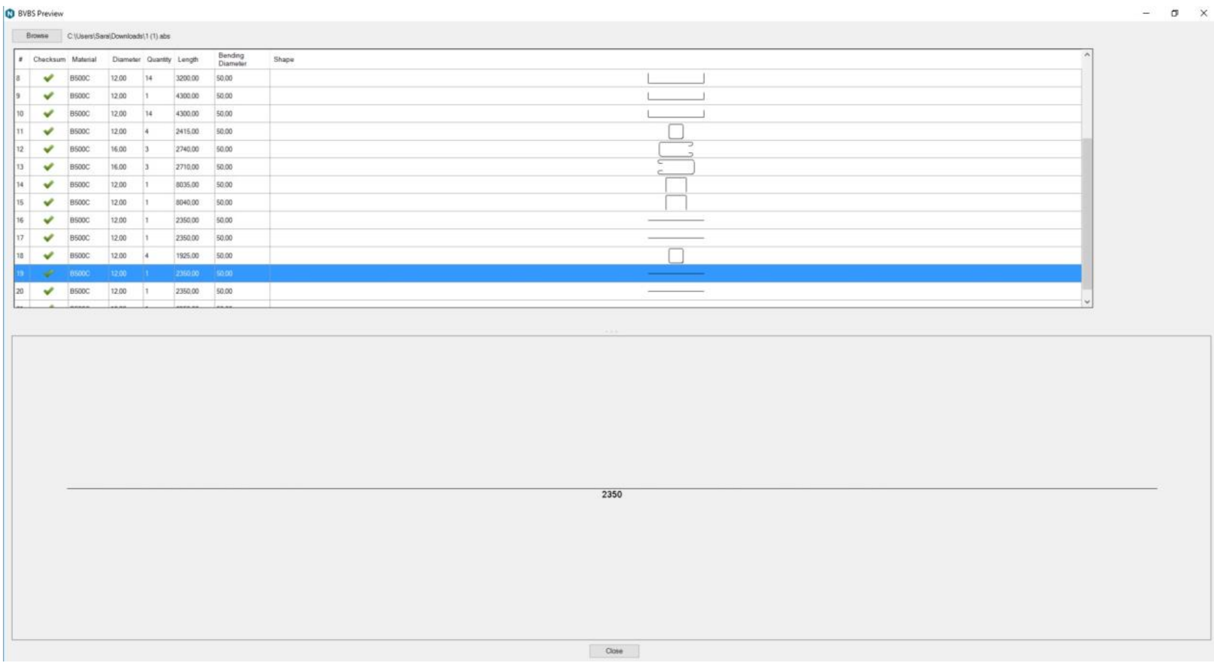

Figure 8.4 total Length 2350mm, through Naviate S (by the author)

BF2D@Hj@runset@iunset@p1@l2350,00@n1@e2,09@d12,00@gB500C@s50,00@v@a@Gl2350 @w0@C94@

Analyze:

BF2D: two-dimensional re-bar

Hj: name of the project given in Revit
p1: position number
l2350: cutting length calculated by Revit
i: index of respective drawing
n1: number of re-bars
e2.09: weight of the bar [kg]
d12: bar diameter [mm]
gB500NC: steel grade
s32: bending diameter [mm] This item has 2350mm total Length, and no hook
a0: layer
This item has 2350mm total Length, and no hook. It has the same form code as the one achieved by Revit Naviate S that is illustrated in Figure 8.4.

BF2D@Hj@runset@iunset@p1@l4300,00@n1@e3,82@d12,00@gB500C@s50,00@v@a@Gl415@w0@r31@w90@l3375@w0@r31@w90@l415@w0@C83@

Analyze:
BF2D: two-dimensional re-bar
Hj: name of the project given in Revit
r31: assembly position
p1: position number
l4300: cutting length calculated by Revit
i: index of respective drawing
n1: number of re-bars
e3.82: weight of the bar [kg]
d12: bar diameter [mm]
gB500NC: steel grade
s32: bending diameter [mm]
a0: layer
This item has 4300mm Total Length, including 3375 mm Length two 90 °hooks with 2315 mm Length. It has the same form code as the one achieved by Revit Naviate S and shape was obtained from Revit Naviate S as well as shown in Figure 8.5.

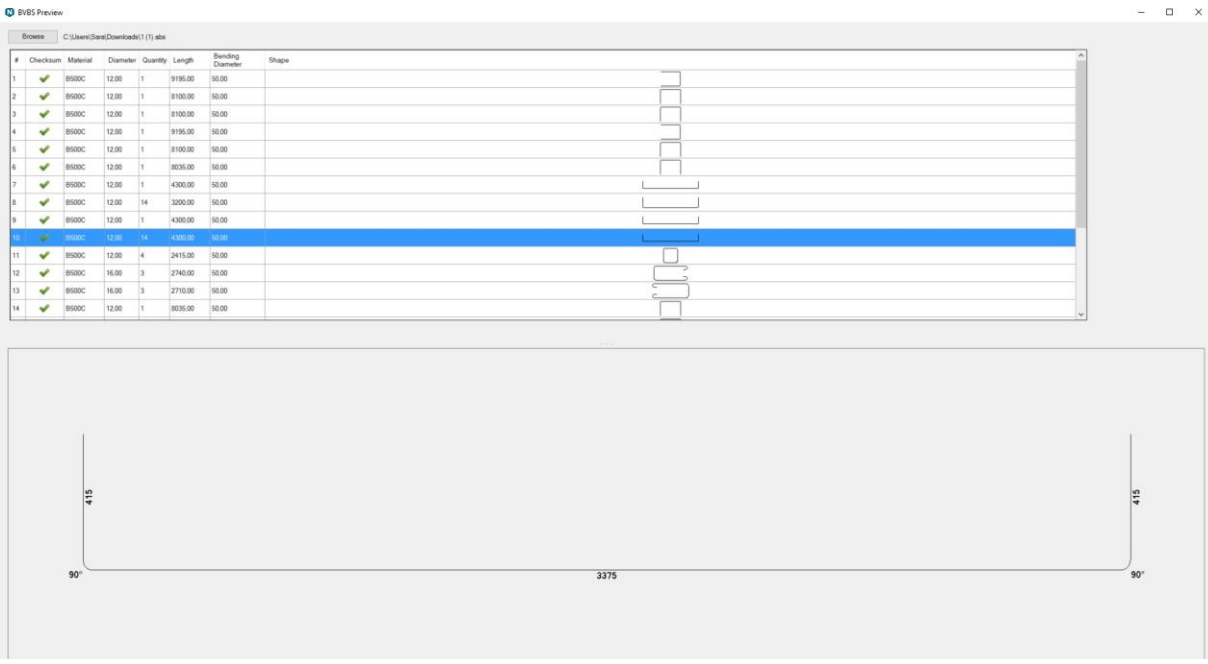

Figure 8.5 Total Length 4300mm through Naviate S (by the author)

BF2D@Hj@runset@iunset@p1@l8100,00@n1@e7,19@d12,00@gB500C@s50,00@v@a@Gl2315@w0@r31@w90@l3375@w0@r31@w90@l2315@w0@C79@

Analyze:

BF2D: two-dimensional re-bar
Hj: name of the project given in Revit
r31: assembly position
p1: position number
l8100: cutting length calculated by Revit
i: index of respective drawing
n1: number of re-bars
e7.19: weight of the bar [kg]
d12: bar diameter [mm]
gB500NC: steel grade
s50: bending diameter [mm]
a: layer

This item has 8100mm total Length, including 3375 mm length two 90 °hooks with 2315 mm length. . It has the same form code as the one achieved by Revit Naviate S and shape was obtained from Revit Naviate S as well as is displayed in Figure 8.6.

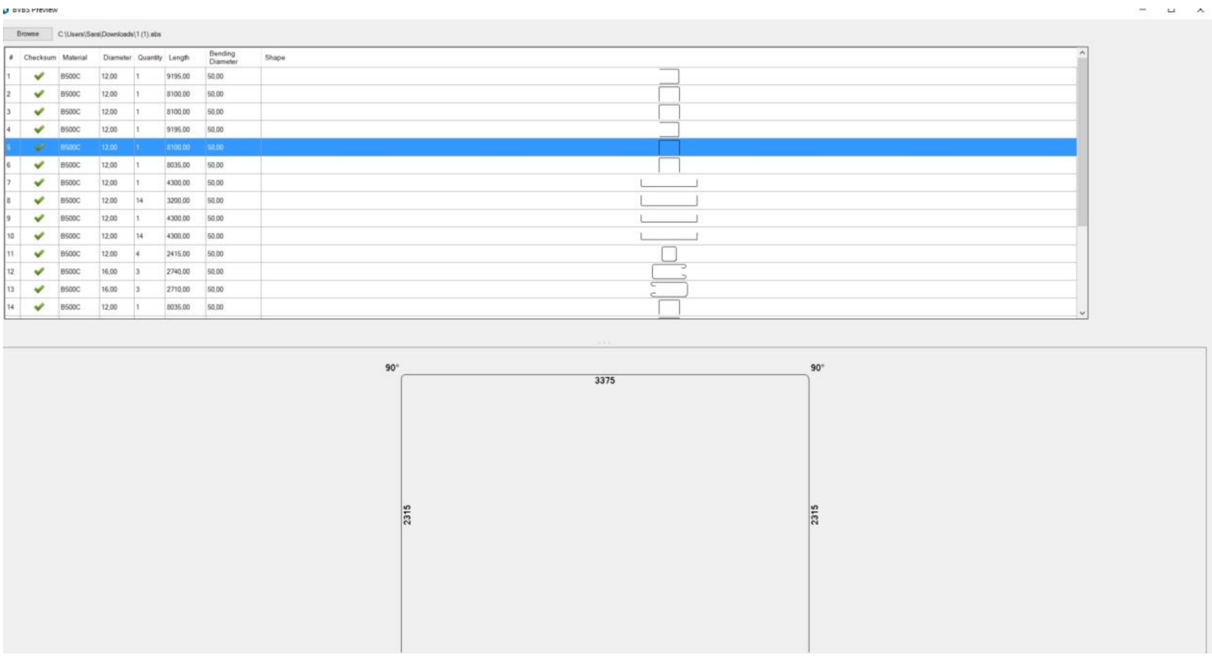

Figure 8.6 Total Length 8100mm through Naviate S (by the author)

BF2D@Hj@runset@iunset@p1@l2350,00@n1@e2,09@d12,00@gB500C@s50,00@v@a@Gl2350@w0@C94@

Analyze:

BF2D: two-dimensional re-bar

Hj: name of the project given in Revit

p1: position number

l2350: cutting length calculated by Revit

i: index of respective drawing

n1: number of re-bars

e2.09: weight of the bar [kg]

d12: bar diameter [mm]

gB500NC: steel grade

s50: bending diameter [mm]

a: layer

This item is same as Revit result, and has 2350 mm total Length, no hook. It has the same form code as the one achieved by Revit Naviate S and shape was obtained from Revit Naviate S as well and it is shown in Figure 8.4.

BF2D@Hj@runset@iunset@p1@l2710,00@n3@e4,27@d16,00@gB500C@s50,00@v@a@Gl80@w0@r48@w180@l910@w0@r48@w90@l285@w0@r48@w90@l910@w0@r48@w180@l80@w0@C91@

Analyze:

BF2D: two-dimensional re-bar

Hj: name of the project given in Revit

r48: assembly position
p1: position number
l2710: cutting length calculated by Revit
i: index of respective drawing
n3: number of re-bars
e4.27: weight of the bar [kg]
d12: bar diameter [mm]
gB500NC: steel grade
s50: bending diameter [mm]
a: layer
This item has a BVBS form code as same as what was given by Revit, it has 2710 mm Total Length, including 285 mm Length with two 90°hooks, two rebars with 910mm Lenghts,180 °hooks and 80mm additional Length at two ends. It has the same form code as the one achieved by Revit Naviate S and the shape given in Figure 8.7, was obtained from Revit Naviate S as well.

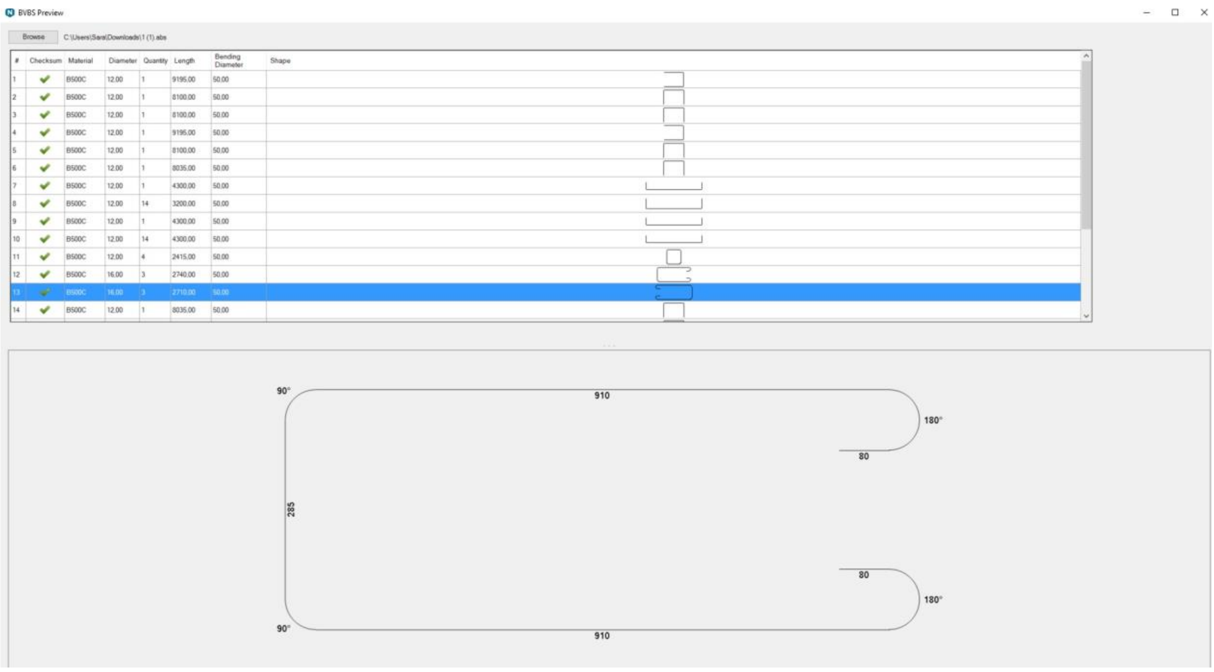

Figure 8.7 Total Length 2710 mm through Naviate S (by the author)

BF2D@Hj@runset@iunset@p1@l2350,00@n1@e2,09@d12,00@gB500C@s50,00@v@a@Gl2350 @w0@C94@
Analyze:
BF2D: two-dimensional re-bar
Hj: name of the project given in Revit
p1: position number
l2350: cutting length calculated by Revit
i: index of respective drawing

n1: number of re-bars
e2.09: weight of the bar [kg]
d12: bar diameter [mm]
gB500NC: steel grade
s50: bending diameter [mm]
a: layer
This item has 2350mm total Length and no hooks. It has the same form code as the one achieved by Revit Naviate S and is presented in Figure 8.4.

BF2D@Hj@runset@iunset@p1@l2415,00@n4@e2,14@d12,00@gB500C@s50,00@v@a@Gl120@w0@r31@w90@l380@w0@r31@w90@l380@w0@r31@w90@l380@w0@r31@w90@l380@w0@r31@w90@l380@w0@r31@w90@l120@w0@C96@
Analyze:
BF2D: two-dimensional re-bar
Hj: name of the project given in Revit
r31: assembly position
p1: position number
l2415: cutting length calculated by Revit
i: index of respective drawing
n4: number of re-bars
e2.14: weight of the bar [kg]
d12: bar diameter [mm]
gB500NC: steel grade
s50: bending diameter [mm]
a: layer
This item has 2415 mm Total Length, in the form of square, including 308 mm each square side Length with four 90 °hooks, and 120mm additional Length at two ends. It has the same form code as the one achieved by Revit Naviate S. Figure 8.8 shows the rebar shape along with the mentioned details.

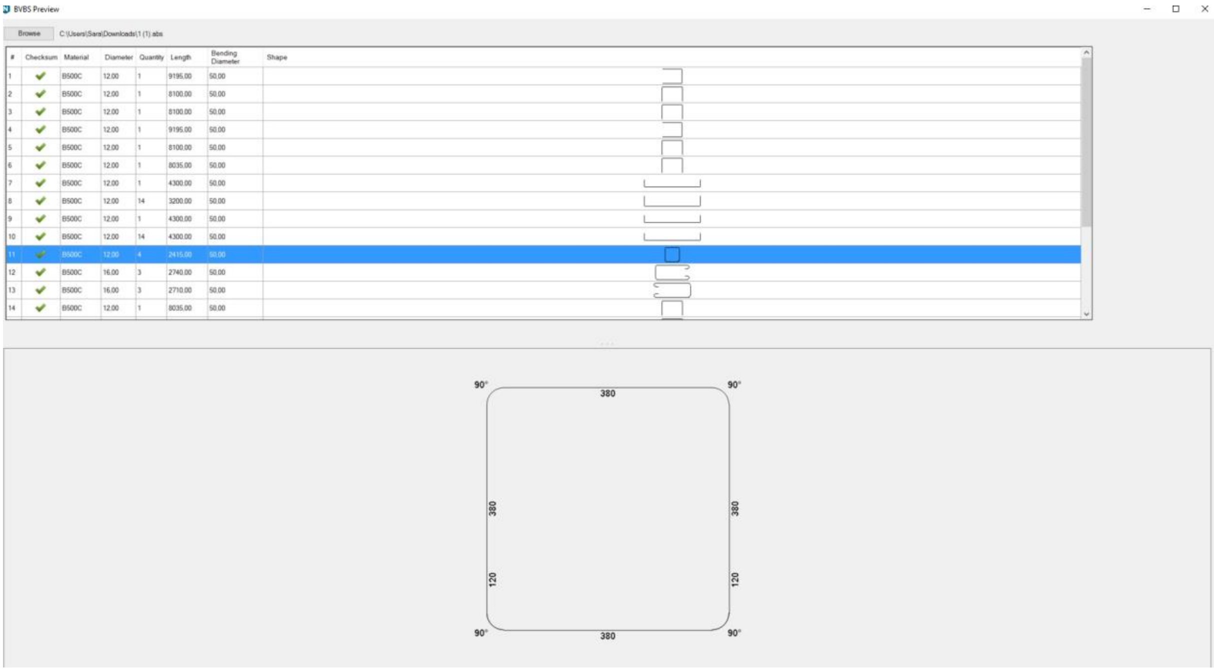

Figure 8.8 Total Length 2415 mm through Naviate S (by the author)

BF2D@Hj@runset@iunset@p1@l4300,00@n14@e3,82@d12,00@gB500C@s50,00@v@a@Gl415@w0@r31@w90@l3375@w0@r31@w90@l415@w0@C95@

Analyze:

BF2D: two-dimensional re-bar

Hj: name of the project given in Revit

r31: assembly position

p1: position number

l4300: cutting length calculated by Revit

i: index of respective drawing

n14: number of re-bars

e3.82: weight of the bar [kg]

d12: bar diameter [mm]

gB500NC: steel grade

s50: bending diameter [mm]

a: layer

This item has 4300mm Total Length, including 3375mm Length two 90 °hooks with 415mm Length at the ends. It has the same form code as the one achieved by Revit Naviate S as shown in Figure 8.5.

BF2D@Hj@runset@iunset@p1@l4300,00@n1@e3,82@d12,00@gB500C@s50,00@v@a@Gl415@w0@r31@w90@l3375@w0@r31@w90@l415@w0@C83@

Analyze:

BF2D: two-dimensional re-bar

Hj: name of the project given in Revit

r 31: assembly position

p1: position number
l4300: cutting length calculated by Revit
i: index of respective drawing
n1: number of re-bars
e3.82: weight of the bar [kg]
d12: bar diameter [mm]
gB500NC: steel grade
s50: bending diameter [mm]
a: layer
This item has 4300mm total Length, including 3375mm length two 90 °hooks with 415mm length at the ends. It has the same form code as the one achieved by Revit Naviate S as mentioned and imaged above in Figure 8.5.

BF2D@Hj@runset@iunset@p1@l8100,00@n1@e7,19@d12,00@gB500C@s50,00@v@a@Gl2315 @w0@r31@w90@l3375@w0@r31@w90@l2315@w0@C79@
Analyze:
BF2D: two-dimensional re-bar
Hj: name of the project given in Revit
r31: assembly position
p1: position number
l8100: cutting length calculated by Revit
i: index of respective drawing
n1: number of re-bars
e7.19: weight of the bar [kg]
d12: bar diameter [mm]
gB500NC: steel grade
s50: bending diameter [mm]
a: layer
This item has 8100mm total Length, including 3375mm length two 90 °hooks with 2315 mm length. It has the same form code as the one achieved by Revit Naviate S exactly as illustrated in Figure 8.6.

BF2D@Hj@runset@iunset@p1@l8100,00@n1@e7,19@d12,00@gB500C@s50,00@v@a@Gl2315 @w0@r31@w90@l3375@w0@r31@w90@l2315@w0@C79@
Analyze:
BF2D: two-dimensional re-bar
Hj: name of the project given in Revit
r31: assembly position
p1: position number
l8100: cutting length calculated by Revit
i: index of respective drawing
n1: number of re-bars
e7.19: weight of the bar [kg]
d12: bar diameter [mm]
gB500NC: steel grade
s50: bending diameter [mm]

a: layer
This item has 8100mm total Length, containing 3375 Length with two 90 °hooks and 2315 mm length at the ends. It has the same form code as the one achieved by Revit Naviate S as mentioned and illustrated above in Figure 8.6.

BF2D@Hj@runset@iunset@p1@l8040,00@n1@e7,13@d12,00@gB500C@s50,00@v@a@Gl2290@w0@r46@w90@l3320@w0@r46@w90@l2290@w0@C70@

Analyze:
BF2D: two-dimensional re-bar
Hj: name of the project given in Revit
r46: assembly position
p1: position number
l8040: cutting length calculated by Revit
i: index of respective drawing
n1: number of re-bars
e7.13: weight of the bar [kg]
d12: bar diameter [mm]
gB500NC: steel grade
s50: bending diameter [mm]
a: layer
This item has 8040mm total Length, containing 3320mm length, two 90 °hooks with 2290 mm length at the ends. It has the same form code as the one achieved by Revit and Naviate S as shown in Figure 8.1.

BF2D@Hj@runset@iunset@p1@l2350,00@n1@e2,09@d12,00@gB500C@s50,00@v@a@Gl2350@w0@C94@

Analyze:
BF2D: two-dimensional re-bar
Hj: name of the project given in Revit
p1: position number
l2350: cutting length calculated by Revit
i: index of respective drawing
n1: number of re-bars
e2.09: weight of the bar [kg]
d12: bar diameter [mm]
gB500NC: steel grade
s50: bending diameter [mm]
a: layer
This item has 2350 mm Total Length, no hook. It has the same form code as the one achieved by Revit and Naviate S, as shown in Figure 8.4.

BF2D@Hj@runset@iunset@p1@l1925,00@n4@e1,71@d12,00@gB500C@s50,00@v@a@Gl190@w0@r31@w90@l380@w0@r31@w90@l380@w0@r31@w90@l380@w0@r31@w90@l415@w0@C85@

Analyze:

BF2D: two-dimensional re-bar
Hj: name of the project given in Revit
R31: assembly position
p1: position number
l1925: cutting length calculated by Revit
i: index of respective drawing
n4: number of re-bars
e1.71: weight of the bar [kg]
d12: bar diameter [mm]
gB500NC: steel grade
s50: bending diameter [mm]
a: layer
This item has 1925mm Total Length, in the form of square, including 380 mm each square side length with four 90 °hooks, and 35mm additional length at the end. The result is same as the one got from Revit and Naviate S as illustrated in Figure 8.9.

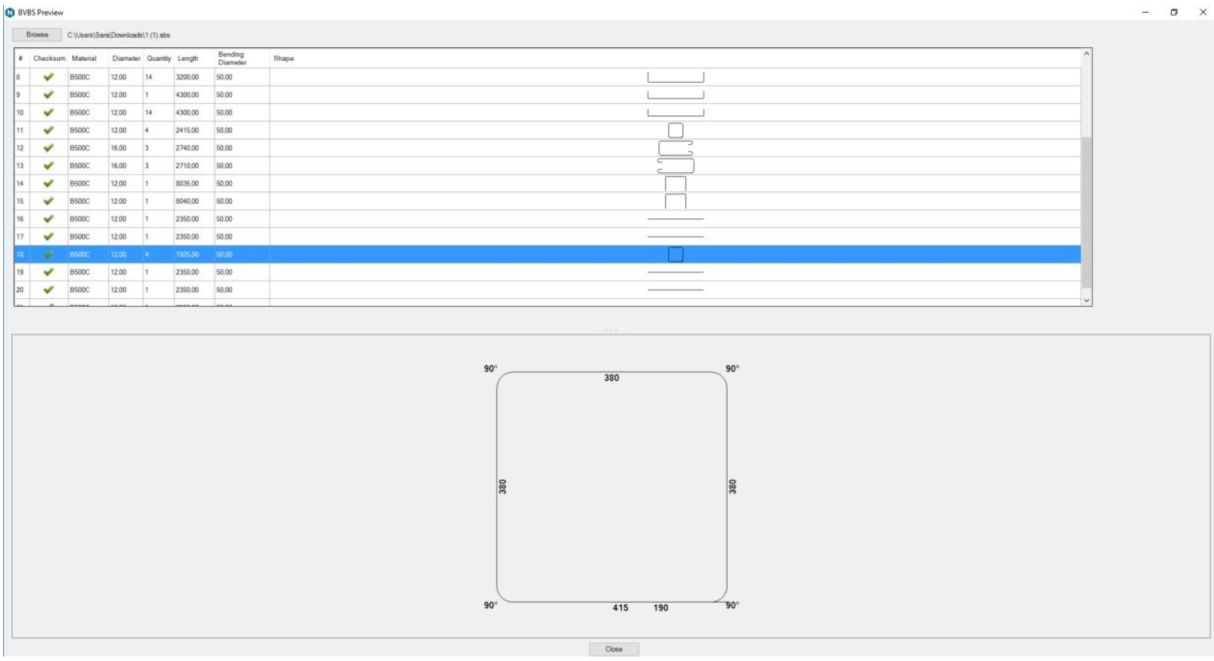

Figure 8.9 Total Length 1925mm through Naviate S (by the author)

BF2D@Hj@runset@iunset@p1@l9195,00@n1@e8,16@d12,00@gB500C@s50,00@v@a@Gl3415@w0@r31@w90@l2280@w0@r31@w90@l3415@w0@C66@
Analyze:
BF2D: two-dimensional re-bar
Hj: name of the project given in Revit
r31: assembly position
p1: position number
l9195: cutting length calculated by Revit

i: index of respective drawing
n1: number of re-bars
e8.16: weight of the bar [kg]
d12: bar diameter [mm]
gB500NC: steel grade
s50: bending diameter [mm]
a: layer
This item has 9195 mm total Length, including 2280 mm length with two 90 °hooks, and 3415 lengths at the ends. It has the same form code as the one achieved by Revit Naviate S as shown in Figure 8.10.

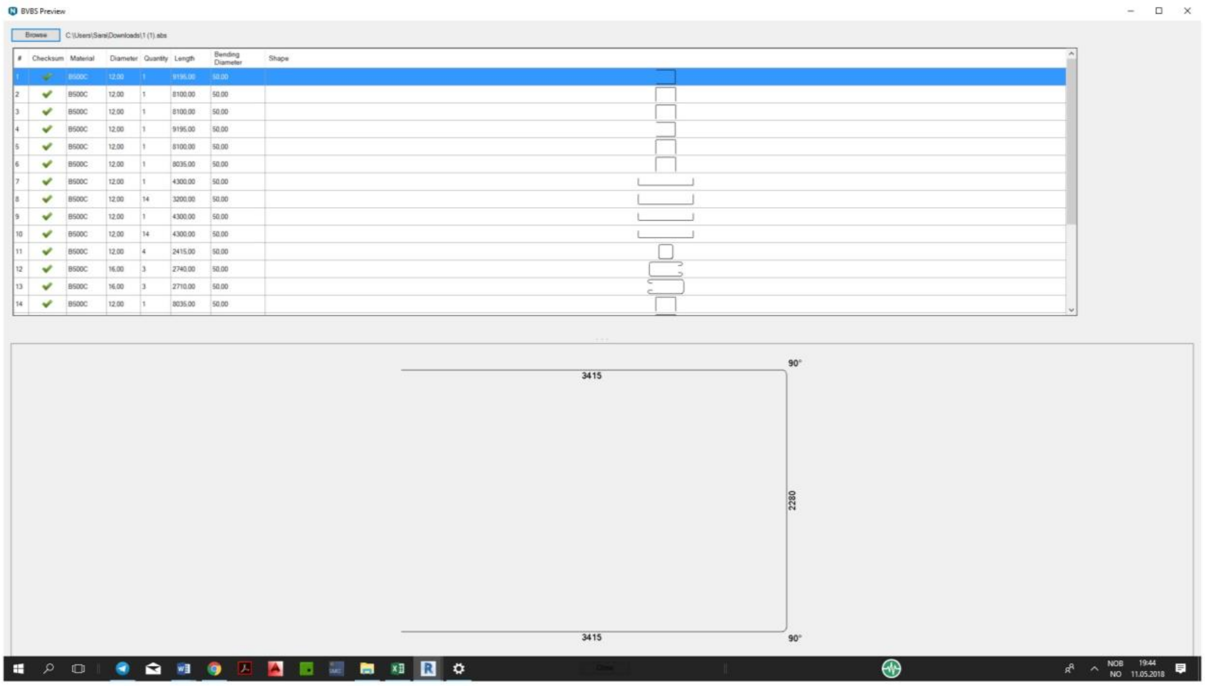

Figure 8.10 Total Length 9195mm through Naviate S (by the author)

BF2D@Hj@runset@iunset@p1@l3200,00@n14@e2,84@d12,00@gB500C@s50,00@v@a@Gl415 @w0@r31@w90@l2275@w0@r31@w90@l415@w0@C67@
Analyze:
BF2D: two-dimensional re-bar
Hj: name of the project given in Revit
r31: assembly position
p1: position number
l3200: cutting length calculated by Revit
i: index of respective drawing
n14: number of re-bars
e2.84: weight of the bar [kg]
d12: bar diameter [mm]
gB500NC: steel grade
s50: bending diameter [mm]

a: layer

This item has 3200 mm Total Length, including 2315 mm Length with two 90 °hooks, and 415 Length at the ends. It has the same form code as the one achieved by Revit Naviate S Figure 8.11.

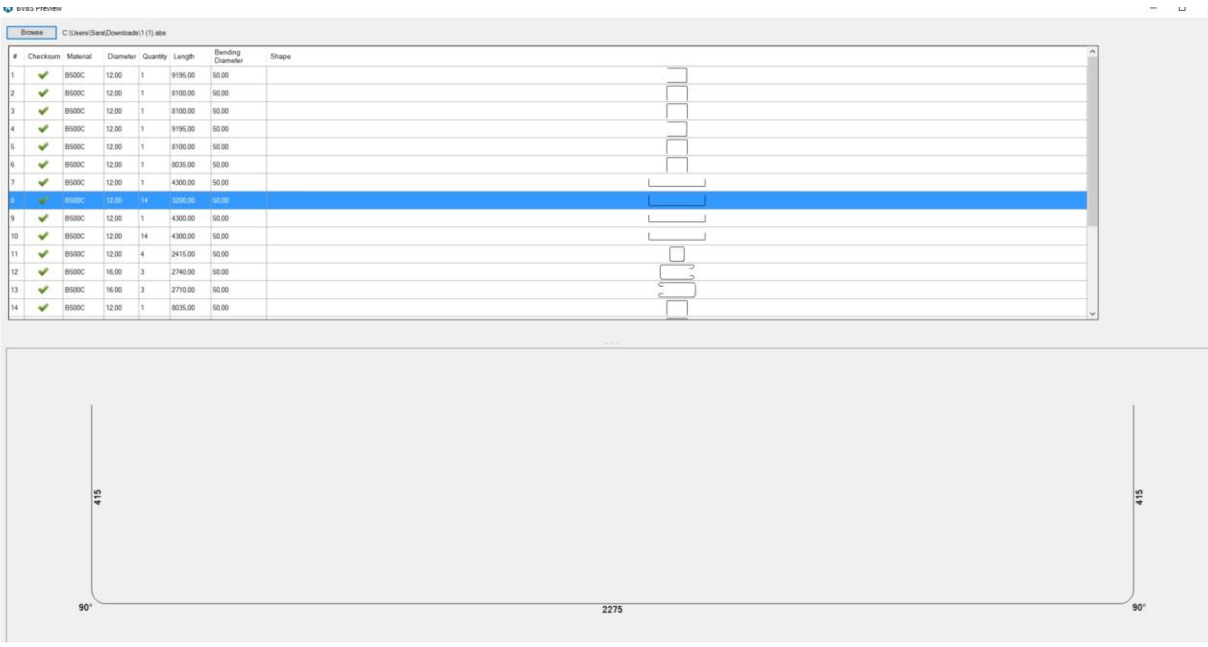

Figure 8.11 Total Length 3200mm through Naviate S (by the author)

After analyzing the given BVBS data string is time to discuss the BVBS files properties. In this assignment, there was a full adjustment between data strings got from different programs. Despite the substantial achievements of BIM authoring tools in the parametric modeling of reinforced concrete, some essential technical deficiencies remain, that hinder applicable and error-free transportation of created models during design, detailing, production and project management processes.

One of the defects is that usually there is not a full adjustment between the result got from two different programs. Although using the same form codes, actors will have full control over quality assurance; still, in complex rebar shapes, there is a possibility of the mismatch in the BVBS data strings. Fortunately, in this assignment, simple bar shape was utilized that resulted in no considerable mismatch between the formats.

The ASCII format achieved by BVBS is an open standard that describes the formats, lengths, and angles of the reinforcement that will be manufactured by machines. Advantages of BVBS if it had been possible to generate is mentioned as following:

- Freedom in design
- There is no need to concern about the form codes which are available with the suppliers
- No need to create sketches for complicated hoops
- A full digital process from modeling to production software and directly on to the fabrication machine
- However, some disadvantages are also found in BVBs extracted data:
- Conversion to form code is impossible because the whole point is gone
- Recognition is an uncertainty process where the bending may fall into the wrong form code

- The file must be delivered from consultant engineer, and it cannot be generated in Solibri. Today entrepreneur does not have flexibility to interfere the modeling process. Although, it is possible to export BVBS string in (property sets) so that it comes along with IFC file, however then it must be exported to a .txt file, and the format must be changed to BVBS afterward.
- It has a lousy overview in the case of being compared to the digital Bending list.
- It does not provide any solution for different types of reinforcement's connections such as Lenton, end plates, and so on.

8.5. Excel vs BVBS

A comparison between two methods of extracting data and delivering them to the fabrication system shows that IFC provides a solution for collaboration and quality control during generating the Excel file. IFC cannot guarantee the high quality of perceiving information, during exchanges among different software. It creates a network that improves the design and projecting through the BIM tools, while BVBS producing programs do not provide any space for quality control discussion and interaction.
BVBS has full digital process from modelling to production, while Excel file normally needs drawings at the production stage.
Excel file is sortable freely according to the desire parameters. For instance, data can be set up based on the reinforcement's length, shape, position, diameter and so on.
BVBS losses the original points which hinder it to convert to form code again.
BVBS not only applies to the geometry but also it refers to a given form code. However, it has a flexibility to create more various form codes than those given by the supplier. It should be connected to a form code located in the system. No production software reads any form codes, which may be standardized and common to all. Therefore, in the case of disability of reading, it will be stopped in production machine software [37].

Imported BVBS file from the visualizing software such as Solibri or BIMeye to Production Software may also vary if fabricator wants to export all rebars or desires to export rebars based on production custom applications. When BVBS is exported to production Software, machine recognizes all rebars that have known form codes in it. It functions well for all known form codes; however, the variations in 99 form codes given by Norwegian Standard will be challenging. BVBS also struggle with couplings and anchoring plates. Generally, it is not beneficial to use BVBS were this is exhausted to handle complicated rebars.
Excel can provide compressive details for sketching the connections. While, BVBS does not have any solution for different types of reinforcement's connections such as Lenton, end plates, and so on.
Contrary to the Excel file that cannot be transferred directly to the reinforcement fabrication machine, BVBS is transferred directly to steel machine and allows it to understand the BIM model manufactured by Revit. For this reason, BVBS does not need to create digital sketches for complicated hoops, while IFC needs to represent digital 3D sketches in a detail level.

9. Conclusion

In this Master thesis was attempted, moreover a convenient internal modeling, an optimum value from 3D parametric reinforcement model be obtained. For this purpose, 3D reinforcement of a small foundation section of Gol project as a test model is simulated, and the outputs were exported in both IFC and BVBS formats. Using Modelling and visualizing BIM software, facilitated data flow in the test model creation and gaining outputs. In this process, the possibility of losing information during the exchange procedure and the ability to restore data were considered.

In a bigger picture, the process of data transmission between various disciplines and across project stages was studied. This study shows How strong interaction built up between different actors can improve the reliability of data exchange. The role of software interoperability to achieve a cost-effective communication and data exchange among various BIM tools were evaluated as well.

The parameters, which must be included in the model, numbering and naming methods were discussed. Standard views and regulations that contained the data exchange regulations and the rules regarding the production/assembly at the construction site were studied.

Several workflows of 3D reinforcement production were suggested to show how important is to decide to have the outputs of test model in the forms of IFC either BVBS. The best format of extracting data that can streamline and accelerate the process of reinforcement production under different purposes was discussed. Also, it was evaluated that, how the workflow of a process can be standardized by using Excel and BVBS file formats.

Revit test model was generated, then data once extracted in IFC form through Solibri and SimpleBIM. After internal control and quality assurance, IFC data should be prepared on paperless digital drawings and be delivered to the building site. The challenges with quality assurance and the way of setting status on objects were extensively considered. This time, Revit data was extracted from the test model in BVBS format, which can frequently be transferred directly into the cut and bending machine.

Then, consequently the differences between these two exported formats were mentioned practically, and their advantages and disadvantages were determined.

10. Suggestions

10.1. Further Studies

In this study, it is attempted to evaluate two methods of extracting outputs from the model in the forms of IFC either BVBS for the meaning of standardizing and automating the reinforcement production. However, during this process, less attention has been paid to the importance of features regarding economic and quality aspects. These topics have the high capacity to be compared within with traditional methods and be studied in future.
This study does not offer any solutions for transferring data regarding reinforcements special connection. It would be a creative idea to evaluate different connections and find a solution to extracted data in BVBS probably by creating a private data block which is available in design programs such as Tekla.
This assignment does not provide the actual methods of batch allocation into the different types of rebar fabrication machines. Each type of machine has a specific batch allocation regarding the rebar information such as shape, diameter, length and so on. Therefore, the manufacturing of reinforcement-bar from the design by a focus on the production optimizing might also be beneficial research. Comprehensive research is demanded, in which the capabilities of the different cut and bending machines are evaluated.
It would be a fascinating idea to evaluate unique production plan of each machine type and establish machine language files subsequently according to the production plan, that is generated and downloaded to the different machine s by the NC interface.

10.2. Recommendations to Principals

Although the author had full access to the BIM material associated with the Gol project, the communication and cooperation among the players following the IFC and BVBS generation are not visualized well in this assignment. This lack also reflects the current situation in the construction industry as well. Collaboration is the force that drives for implementing BIM in the process. It is essential to implement BIM by cooperation, where players utilize BIM for the project, not just for their benefit.
It is recommended that research be conducted with a focus on cooperation and communication in the 3D reinforcements' drawings and production.
Cooperation and communication would be beneficial to create a system, in which high-quality workflow in the project is provided. After participating in several meetings with Statsbygg actors, where several pilot projects were under process, it was realized that there is sufficient experience with the use of BIM on design, projecting construction and on construction site. Now it is time to make use of the knowledge that has been acquired and start with the process that accelerates assigning status and creating a network among the consultants at the offices and the fabricators on the sites required. This collaboration may be a requirement for using BIM in reinforcement production as a supplement at the start, and further out.

BIM and the construction process must be the central part of the education for construction engineering students. Throughout the study, the author got little training in these topics and learned to use some programs. Graduate engineers are those who can take this responsibility in the future with a clearer picture of the industry.

Attachements

BVBS Data Strings and the Excel File

BF2D@Hj@runset@iunset@p1@l8040,00@n1@e0,00@d12,00@gB500C@s50,00@v@a@Gl2290@w0@r46@w90@l3320@w0@r46@w90@l2290@w0@C70@
BF2D@Hj@runset@iunset@p1@l9195,00@n1@e0,00@d12,00@gB500C@s50,00@v@a@Gl3415@w0@r31@w90@l2280@w0@r31@w90@l3415@w0@C66@
BF2D@Hj@runset@iunset@p1@l8040,00@n1@e0,00@d12,00@gB500C@s50,00@v@a@Gl2290@w0@r46@w90@l3320@w0@r46@w90@l2290@w0@C70@
BF2D@Hj@runset@iunset@p1@l2740,00@n3@e0,00@d16,00@gB500C@s50,00@v@a@Gl80@w0@r48@w180@l910@w0@r48@w90@l315@w0@r48@w90@l910@w0@r48@w180@l80@w0@C94@
BF2D@Hj@runset@iunset@p1@l2350,00@n1@e0,00@d12,00@gB500C@s50,00@v@a@Gl2350@w0@C94@
BF2D@Hj@runset@iunset@p1@l2350,00@n1@e0,00@d12,00@gB500C@s50,00@v@a@Gl2350@w0@C94@
BF2D@Hj@runset@iunset@p1@l4300,00@n1@e0,00@d12,00@gB500C@s50,00@v@a@Gl415@w0@r31@w90@l3375@w0@r31@w90@l415@w0@C83@
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BF2D@Hj@runset@iunset@p1@l2350,00@n1@e0,00@d12,00@gB500C@s50,00@v@a@Gl2350@w0@C94@
BF2D@Hj@runset@iunset@p1@l2710,00@n3@e0,00@d16,00@gB500C@s50,00@v@a@Gl80@w0@r48@w180@l910@w0@r48@w90@l285@w0@r48@w90@l910@w0@r48@w180@l80@w0@C91@
BF2D@Hj@runset@iunset@p1@l2350,00@n1@e0,00@d12,00@gB500C@s50,00@v@a@Gl2350@w0@C94@
BF2D@Hj@runset@iunset@p1@l2415,00@n4@e0,00@d12,00@gB500C@s50,00@v@a@Gl120@w0@r31@w90@l380@w0@r31@w90@l380@w0@r31@w90@l380@w0@r31@w90@l380@w0@r31@w90@l380@w0@r31@w90@l120@w0@C96@
BF2D@Hj@runset@iunset@p1@l4300,00@n14@e0,00@d12,00@gB500C@s50,00@v@a@Gl415@w0@r31@w90@l3375@w0@r31@w90@l415@w0@C95@
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BF2D@Hj@runset@iunset@p1@l8100,00@n1@e0,00@d12,00@gB500C@s50,00@v@a@Gl2315@w0@r31@w90@l3375@w0@r31@w90@l2315@w0@C79@
BF2D@Hj@runset@iunset@p1@l8100,00@n1@e0,00@d12,00@gB500C@s50,00@v@a@Gl2315@w0@r31@w90@l3375@w0@r31@w90@l2315@w0@C79@
BF2D@Hj@runset@iunset@p1@l8040,00@n1@e0,00@d12,00@gB500C@s50,00@v@a@Gl2290@w0@r46@w90@l3320@w0@r46@w90@l2290@w0@C70@
BF2D@Hj@runset@iunset@p1@l2350,00@n1@e0,00@d12,00@gB500C@s50,00@v@a@Gl2350@w0@C94@
BF2D@Hj@runset@iunset@p1@l1925,00@n4@e0,00@d12,00@gB500C@s50,00@v@a@Gl190@w0@r31@w90@l380@w0@r31@w90@l380@w0@r31@w90@l380@w0@r31@w90@l415@w0@C85@
BF2D@Hj@runset@iunset@p1@l9195,00@n1@e0,00@d12,00@gB500C@s50,00@v@a@Gl3415@w0@r31@w90@l2280@w0@r31@w90@l3415@w0@C66@
BF2D@Hj@runset@iunset@p1@l3200,00@n14@e0,00@d12,00@gB500C@s50,00@v@a@Gl415@w0@r31@w90@l2275@w0@r31@w90@l415@w0@C67@

Description Object type	Steel Nominal diameter	Bar Length (mm)	ISO CD3766 Shape code	ISO CD3766 Shape parameter_b (mm)	ISO CD3766 Shape parameter_c (mm)	IO CD3766 Shape parameter _R (mm)	Bend Diameter (mm)	A	B	Standard Bend Diameter
Rebar Bar: T12: 226427	12	9 195	S3	3 448	2 350	25	50	0	3448	50
Rebar Bar: T12: 226427	**12**	**8 097**	**S3**	**2 350**	**3 448**	**25**	**50**	**0**	**2350**	**50**
Rebar Bar: T12: 226427	**12**	**8 097**	**S2**	**2 350**	**3 448**	**25**	**50**	**0**	**2350**	**50**
Rebar Bar: T12:226427	**12**	**9 195**	**S5**	**3 448**	**2 350**	**25**	**50**	**0**	**3448**	**50**
Rebar Bar: T12: 226427	**12**	**8 097**	**S6**	**2 350**	**3 448**	**25**	**50**	**0**	**2350**	**50**
Rebar Bar:T12:226427	**12**	**8 035**	**17**	**2 337**	**3 424**	**40**	**80**	**0**	**2 337**	**80**
Rebar Bar:T12:226427	**12**	**4 297**	**S1**	**450**	**3 448**	**25**	**50**	**0**	**450**	**50**
Rebar Bar:T12:226427	**12**	**3 197**	**S1**	**449**	**2 349**	**25**	**50**	**0**	**449**	**50**
Rebar Bar:T12:226427	**12**	**3 197**	**S1**	**449**	**2 349**	**25**	**50**	**0**	**449**	**50**
Rebar Bar:T12:226427	**12**	**3 197**	**S1**	**449**	**2 349**	**25**	**50**	**0**	**449**	**50**
Rebar Bar:T12:226427	**12**	**3 197**	**S1**	**449**	**2 349**	**25**	**50**	**0**	**449**	**50**
Rebar Bar:T12:226427	**12**	**3 197**	**S1**	**449**	**2 349**	**25**	**50**	**0**	**449**	**50**

Description Object type	Steel Nominal diameter	Bar Length (mm)	ISO CD3766 Shape code	ISO CD3766 Shape parameter_b	ISO CD3766 Shape parameter_c (mm)	IO CD3766 Shape parameter _R (mm)	Bend Diameter (mm)	A	B	Standard Bend Diameter
Rebar Bar: T12: 226427	**12**	**3 197**	**S1**	**449**	**2 349**	**25**	**50**	**0**	**449**	**50**
Rebar Bar: T12: 226427	**12**	**3 197**	**S1**	**449**	**2 349**	**25**	**50**	**0**	**449**	**50**
Rebar Bar:T12 :226427	**12**	**3 197**	**S1**	**449**	**2 349**	**25**	**50**	**0**	**449**	**50**
Rebar Bar:T12 :226427	**12**	**3 197**	**S1**	**449**	**2 349**	**25**	**50**	**0**	**449**	**50**
Rebar Bar:T12 :226427	**12**	**3 197**	**S1**	**449**	**2 349**	**25**	**50**	**0**	**449**	**50**
Rebar Bar:T12 :226427	**12**	**3 197**	**S1**	**449**	**2 349**	**25**	**50**	**0**	**449**	**50**
Rebar Bar: T12: 226427	**12**	**3 197**	**S1**	**449**	**2 349**	**25**	**50**	**0**	**449**	**50**
Rebar Bar: T12: 226427	**12**	**3 197**	**S1**	**449**	**2 349**	**25**	**50**	**0**	**449**	**50**
Rebar Bar: T12: 226427	**12**	**3 197**	**S1**	**449**	**2 349**	**25**	**50**	**0**	**449**	**50**
Rebar Bar: T12: 226427	**12**	**4 297**	**S1**	**450**	**3 448**	**25**	**50**	**0**	**450**	**50**
Rebar Bar: T12: 226427	**12**	**4 297**	**S1**	**450**	**3 448**	**25**	**50**	**0**	**450**	**50**

Description Object type	Steel Nominal diameter	Bar Length (mm)	ISO CD3766 Shape code	ISO CD3766 Shape parameter_b	ISO CD3766 Shape parameter_c (mm)	IO CD3766 Shape parameter _R (mm)	Bend Diameter (mm)	A	B	Standard Bend Diameter
Rebar Bar: T12: 226427	**12**	**4 297**	**S1**	**450**	**3 448**	**25**	**50**	**0**	**450**	**50**
Rebar Bar: T12: 226427	**12**	**4 297**	**S1**	**450**	**3 448**	**25**	**50**	**0**	**450**	**50**
Rebar Bar: T12: 226427	**12**	**4 297**	**S1**	**450**	**3 448**	**25**	**50**	**0**	**450**	**50**
Rebar Bar: T12 :226427	**12**	**4 297**	**S1**	**450**	**3 448**	**25**	**50**	**0**	**450**	**50**
Rebar Bar: T12: 226427	**12**	**4 297**	**S1**	**450**	**3 448**	**25**	**50**	**0**	**450**	**50**
Rebar Bar: T12: 226427	**12**	**4 297**	**S1**	**450**	**3 448**	**25**	**50**	**0**	**450**	**50**
Rebar Bar: T12: 226427	**12**	**4 297**	**S1**	**450**	**3 448**	**25**	**50**	**0**	**450**	**50**
Rebar Bar: T12: 226427	**12**	**4 297**	**S1**	**450**	**3 448**	**25**	**50**	**0**	**450**	**50**
Rebar Bar: T12: 226427	**12**	**4 297**	**S1**	**450**	**3 448**	**25**	**50**	**0**	**450**	**50**
Rebar Bar: T12: 226427	**12**	**4 297**	**S1**	**450**	**3 448**	**25**	**50**	**0**	**450**	**50**
Rebar Bar: T12: 226427	**12**	**4 297**	**S1**	**450**	**3 448**	**25**	**50**	**0**	**450**	**50**

Description Object type	Steel Nominal diameter	Bar Length (mm)	ISO CD3766 Shape code	ISO CD3766 Shape parameter_b	ISO CD3766 Shape parameter_c (mm)	IO CD3766 Shape parameter _R	Bend Diameter (mm)	A	B	Standard Bend Diameter
Rebar Bar: T12: 226427	**12**	**4 297**	**S1**	**450**	**3 448**	**25**	**50**	**0**	**450**	**50**
Rebar Bar: T12: 226427	**12**	**4 297**	**S1**	**450**	**3 448**	**25**	**50**	**0**	**450**	**50**
Rebar Bar: T12:22 6427	**12**	**2 412**	**63**	**450**	**157**	**25**	**50**	**450**	**450**	**50**
Rebar Bar: T12: 226427	**12**	**2 412**	**63**	**450**	**157**	**25**	**50**	**450**	**450**	**50**
Rebar Bar: T12: 226427	**12**	**2 412**	**63**	**450**	**157**	**25**	**50**	**450**	**450**	**50**
Rebar Bar: T12:22 6427	**12**	**2 412**	**63**	**450**	**157**	**25**	**50**	**450**	**450**	**50**
Rebar Bar: T16: 226500	**16**	**2 739**	**47**	**426**	**175**	**40**	**80**	**1018**	**426**	**80**
Rebar Bar: T16: 226500	**16**	**2 739**	**47**	**426**	**175**	**40**	**80**	**1018**	**426**	**80**
Rebar Bar: T16:22 6500	**16**	**2 739**	**47**	**426**	**175**	**40**	**80**	**1018**	**426**	**80**
Rebar Bar: T16: 226500	**16**	**2 708**	**47**	**395**	**175**	**40**	**80**	**1018**	**395**	**80**
Rebar Bar: T16: 226500	**16**	**2 708**	**47**	**395**	**175**	**40**	**80**	**1018**	**395**	**80**

Description Object type	Steel Nominal diameter	Bar Length (mm)	ISO CD3766 Shape code	ISO CD3766 Shape parameter_b	ISO CD3766 Shape parameter_c (mm)	IO CD3766 Shape parameter _R	Bend Diameter (mm)		B	Standard Bend Diameter
Rebar Bar: T16:22 6500	16	2 708	47	395	175	40	80	1018	395	80
Rebar Bar: T12: 226427	12	8 035	17	2 337	3 424	40	80	0	2337	80
Rebar Bar: T12:22 6427	12	8 037	17	2 338	3 424	40	80	0	2338	80
Rebar Bar: T12:22 6427	12	2 350	00			40	80	2350	0	80
Rebar Bar: T12:22 6427	12	2 350	00			40	80	2350	0	80
Rebar Bar: T12:22 6427	12	1 924	42	225	450	25	50	300	225	50
Rebar Bar: T12:22 6427	12	1 924	42	225	450	25	50	300	225	50
Rebar Bar: T12:22 6427	12	1 924	42	225	450	25	50	300	225	50
Rebar Bar: T12:22 6427	12	1 924	42	225	450	25	50	300	225	50
Rebar Bar: T12:22 6427	12	2 350	00			40	80	2350	0	80
Rebar Bar: T12:22 6427	12	2 350	00			40	80	2350	0	80
Rebar Bar: T12:22 6427	12	2 350	00			40	80	2350	0	80

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UNIVERSITETET I AGDER

STATSBYGG

BYG508 Master thesis

Title:

Use of BIM Technology and 3D-Modeling to Automate the Paperless Reinforcement Production

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Abstract

This assessment demonstrates development trends in the BIM software industry according to concrete 3D-reinforcement. It is attempted to simulate a small section of Gol project to get a better understanding of the workflow.

In this assignment the focus would have be on the workflow and improvement or optimization of this purposes.

- Consider how we can standardize the workflow using file formats (excel / BVBS). Pros / Cons of these.
- What are the challenges with quality assurance? How to set status on objects?
- What parameters must be included in the model?
- Which standard views must be included in the production / assembly at the construction site

Introduction

BIM has generally lower adoption to contractors and reinforcement manufacturers compared to other specialists like architects and engineers.

Statsbygg in construction project (Norway's first Digital Construction: Gol conservation station and day-care center), attempts to obtain a full digital drawings and documentation. The digital solutions will be measured and evaluated to take further experiences to future Digital Construction.

In this project, Statsbygg tries to provide the following possibilities regarding 3D reinforcements.

1. To automate the production of reinforcement. Production by direct export from model. Avoid manual work in the form of official bending lists and minimize incorrect production / deliveries.

2. Reinforcement of cast-iron structures by model. Avoid traditional reinforcement drawings on building sites.

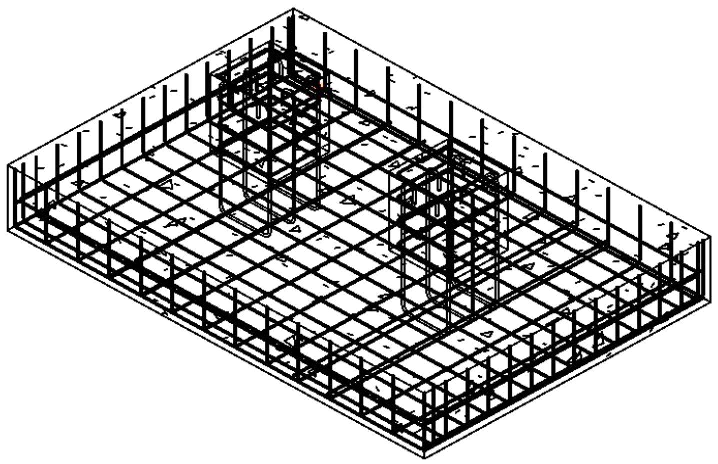
Method

The methodology of this assignment can be considered as a combination of Literature Study and Case Study. This study reviews the available knowledge about the 3D reinforcement supply chain. The Case study contains the information flow process, and the preparation of a section of Gol project as a test model. Then export/import tests were conducted by utilizing the model.

The research includes the process of creating and modifying concrete reinforcement model, abilities to exchange models through other disciplines' programs, and finally specifications to apply the created models in fabrication activities.

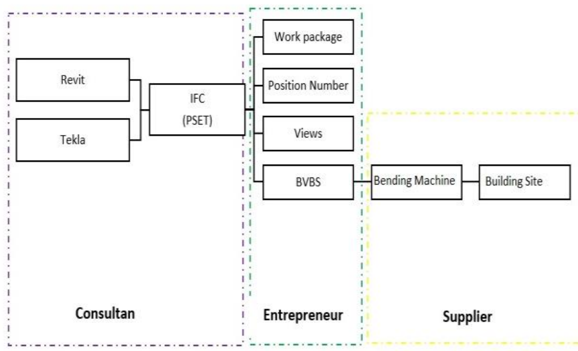
Results

- BIM models generated with Revit was saved to the RVT file format. Then data was exchanged to IFC format by using Solibri. Solibri highlighted the result by scrapping the associated object.



- After checking the model, the model was imported from Solibri into Simplebim and then data has been extracted from Simplebim in an Excel file. Simplebim transfers all the different types, objects and properties into Excel file.
- All different components of the model had their own partitions. Rebar Navigate numbering is used to have easily control, over partitions or filters, that should be used to get the position of all the rebars.
- An export for the BVBS was created by BIMeye. After getting BVBS, the model was uploaded into the BIM eye.
- To keep tracking of project deliveries, the rebars can be labeled as "ordered", "partly ordered". "delivered" or "installed."

Conclusion



In this Master thesis was attempted to introduce an applicable workflow that can streamline and accelerate the process of the paperless reinforcement production For this aim a 3D reinforcements of a small foundation section of Gol project was modelled as a test model. The outputs were exported in both IFC and BVBS formats. Using Modelling and visualizing BIM software, facilitated dataflow in the test model creation and getting the outputs.

the possibility of losing information during the exchange procedure and the ability of restoring data were considered. The challenges with quality assurance and the way of setting status on objects were extensively explained. The parameters, which must be included in the model, numbering and naming methods were discussed. Standard views and regulations that contained the data exchange regulations and the rules regarding the production / assembly at the construction site were studied. The best existing workflows were introduced. Then, consequently the differences between these two exported formats were mentioned practically and their advantages and disadvantages were determined.