BIM-Based Quantity Takeoff

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ABSTRACT

Building Information Modelling (BIM) has been widely used to manage building information throughout the project life-cycle more effectively and efficiently. Particularly in quantity take-off (QTO) and estimation, BIM-based process is getting more and more attention. While BIM-based quantity takeoff is one of the potentially most important and profitable applications for BIM, it is still generally under-explored. This article is designed to explore how the information in a BIM model like the Work Breakdown Structure (WBS) and the Assembly Code for the different elements can be used to set the model effectively for extracting the quantities of elements and materials during and after the design stage by showing a case study of a residential complex in St. Petersburg city, and exploring how quantities can be extracted using the Quantification tool in Autodesk Navisworks Manage and the Schedule/Quantities tool in Autodesk Revit in association with the PivotTable tool in Microsoft Excel.

Content

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1. Introduction

Quantity takeoff is applied throughout the construction process. In the early stages it provides the base for a preliminary cost estimate for the project; in the tendering stage it is used to assist in the estimation of the project's cost and duration of the construction activities; before the construction stage it is used to forecast and plan the construction activities; and during the construction stage it is used for the economic control of the project. An accurate quantity takeoff is decisive for the economic balance of the contractor's finances as it is the only way of achieving a thorough analysis of the productivity and of the different types of costs in a particular project [1, 2].

Traditionally, quantity takeoff is a manual process that involves measuring the different design elements, namely, floor plans, elevations, cross sections and other similar documents. Since it is based on human interpretation this approach is very error prone. Furthermore, 2D-based documents, whether they are designed by hand or with the help of CAD tools, are also error prone. 2D documents are designed based on other 2D documents developed by a manual process; wrong inputs and interpretations are therefore very common since it is very hard to process complex situations, in particular, connections between various building elements (e.g. a cross section of the connection of a beam, a column, a wall and a slab) in a 2D frame. A further complication is the coordination of different project specialties while avoiding clashes between different elements, all of which makes the manual production of 2D documentation even harder. When quantity takeoff is performed manually, based on 2D documents that are also manually designed, a cascade of errors is likely to occur [3, 4].

Building Information Modelling (BIM), the process of generating and managing building data during its life cycle, has been gaining increasing awareness in the Architecture, Engineering and Construction (AEC) industry [5, 6].

One of the most useful tasks that can be automated through BIM use is quantity takeoff (QTO). A BIM-based model is an assembly of objects defined by specific properties, some of which are the element's geometric attributes. Most BIM tools contain routines to perform calculations using the element's geometric properties and provide spatial quantities like area and volume in text form. BIM-based QTO is reported to provide simpler and yet more detailed and accurate cost estimates of the project, reducing time and expenses [7, 8], though it is also a tricky feature and it tends to be used only by experts [9].

In a BIM environment, quantity take-offs are performed several times during the project. Fig. 1 illustrates the process flow of quantity take-off during the design and construction phases of the life cycle of a project. A rough cost estimate called a parametric estimate is made at the inception or early design phase of a project when the needs and objectives are barely available. A space plan and a requirements model are created early in the project with information like spaces and activities. After a rough cost estimate is obtained that sets the target price, a building construction information model is developed and quantity take-off is performed a second time for a detailed cost estimate. This cost estimate is used by the contractor to develop the offer made to the construction owner. The third time where the quantity take-off process is performed is on site, during actual construction [10, 11].
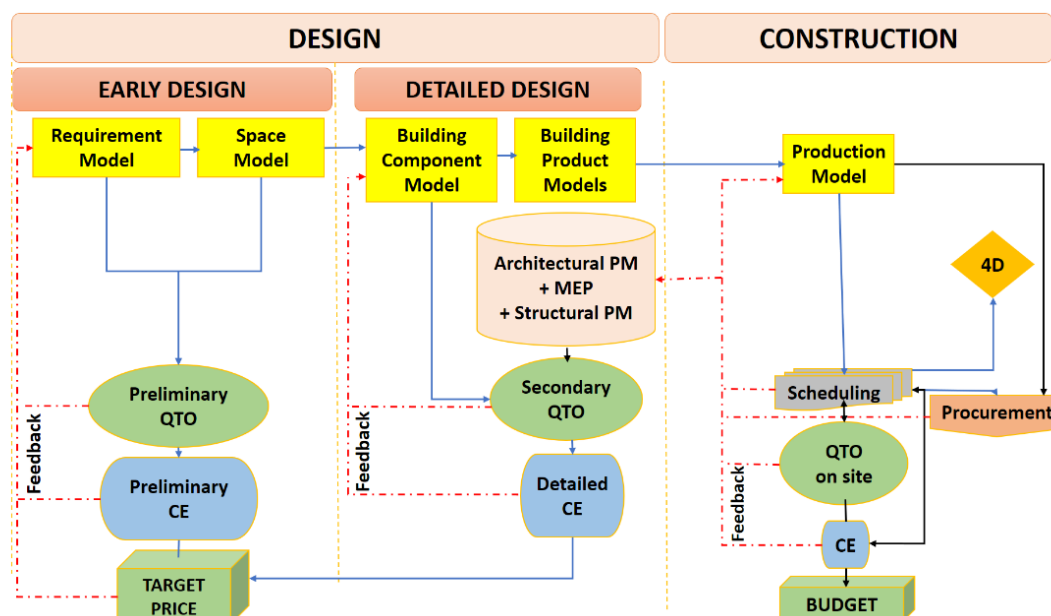

Fig. 1. Process flow of quantity take-offs during life cycle of a project [10].

Classification systems constitute the backbone of effective model-based quantity take-off [12]. Classification systems differ greatly from country to country, such as MasterFormat in the U.S. [13], OmniClass [14], Uniformat and Uniformat II [15], UniClass [16] and Building 2000 used by architects and Building 80 used by builders in Finland. Building 2000 is generally favoured because it supports BIM.

One of the first requirements for an automatic QTO process is to have a system that follows a desired structure in the organization of information. This type of organization is called a Work Breakdown Structure (WBS) [17]. Given the wide range of an AEC project life-cycle, the chosen WBS should be used by all the agents involved in the project, to avoid conflicts, errors and omissions. The WBS is usually built on a series of increasingly detailed levels and different domains. Each element of the WBS is identifiable by a specific code. The fastest way to apply this type of organization to a BIM model is to enter the codes in ID form. The different systems and different documentations in the AEC life-cycle must use the same organization to guarantee the consistency of the data flows [10].

In the studied residential complex to represent the work break down structure (WBS), a private classification system was used. The classification system was revised and modified many times throughout the different stages of the project. The parties involved in studying and executing the project use Autodesk Revit 2016 for architectural, structural and MEP modelling [18]. Autodesk Revit 2016 uses by default Uniformat classification system which is the system used to in USA and Canada to provide a common structure linking the building program, specifications, and estimates through its classification for building elements and related site work [19].

In Autodesk Revit 2016, the Assembly Code Settings dialog is used to specify the assembly code file to use for assigning a Uniformat code to the Assembly Code type property of model elements. The assembly code file is assigned to the project, and the file name and location are saved with the project settings [20, 21].

2. Description of the Studied Residential Complex

The complex is located in the North of St. Petersburg and it involves the construction of four residential blocks with 1221 apartment units, underground parking lots, shops and a landscaped public area. Complex occupies the plot of 12.8 ha.

The first block of the complex occupies plot of 3.6 ha and it consists of 8 residential units with 346 apartments and it was completed in July 2014. During the design and execution of this block the QTO was calculated manually using the 2D and 3D drawings. After the completion of the first block, BIM-based documentation and modelling was fully adopted. The second block of the complex was finished in August 2015. This block occupies the area of 3.2 ha and consists of 8 residential units with 291 apartment. The QTO was conducted using the BIM model during the construction stage and with continuous modifications to the used classification system since little consideration was given to the BIM model as a tool for QTO during the design phase. During the execution of this block the adopted classification system and its WBS were developed to give more accurate QTO. The third block is now under construction and it occupies the plot of 3.1 ha and consists of 9 residential units with 301 apartments. During its design and modelling many drawbacks were avoided by taking the BIM-based QTO into account for faster and easier extraction of the project's quantities according to the developed work breakdown structure. The design of the fourth block is meant to start after the finish of the third one. The fourth block occupies the plot of 3 ha and consists of 6 residential units with 283 apartments. The different blocks of the complex with the method applied to extract the QTO are summarized in Table 1.

Table 1. The different blocks of the project and the methods applied for QTO.

| Block	QTO Method	
	Design	**Construction**
Block 1	Manually using 2D and 3D drawings	Manually using 2D and 3D drawings
Block 2	Using the BIM model with little consideration to the model as a tool for QTO	Using the BIM model and developing the WBS for better QTO
Block 3	Using the BIM model with taking into account the model as a tool for QTO	Using the BIM model efficiently and accurately with less need for revision
Block 4	Using the BIM model efficiently	Using the BIM model efficiently

3. Methodology

In order to better understand the requirements of the QTO, the structure of the complex should be analysed. Each residential block consists of a number of residential units and each unit has a different number of floors. Each unit consists of a basement floor, first floor, second floor, number of typical floors, the last floor and the roof. Since the construction elements usually differ depending on the type of the floor, it's important to pay

attention to that in the design period in order to give the suitable properties to the elements e.g. the base/top constraints of the walls, the right assemble code according to the adopted classification system.

3.1 Using the Quantification Tool in Autodesk Navisworks Manage

As shown in Table 1. during the execution of the second block the QTO was extracted Using the BIM model. Fig 2. shows the model of this block.
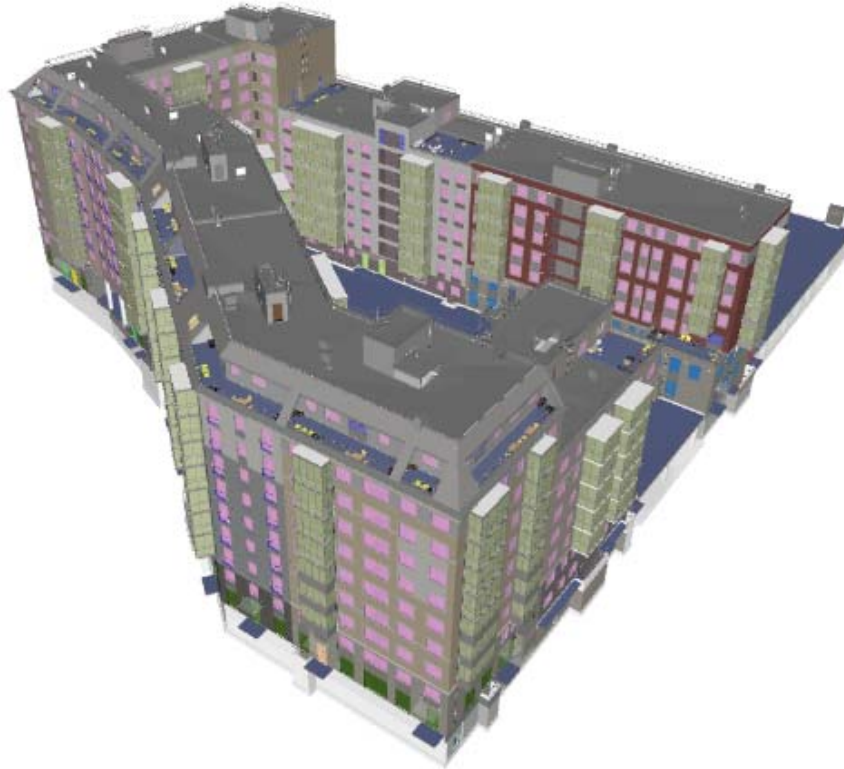

Fig. 1. BIM model of the second block of the complex.

During the construction period the QTO is required for the detailed cost estimation. To demonstrate how the BIM model was used for QTO purpose, a simple example of extracting the quantities of the doors will be studied. The contractor was interested in modifying the WBS so that the doors will be extracted according to their location and function exterior/interior/balcony doors and to their fire resistance properties: fire/non-fire doors. Also it was required to distribute the quantities of the doors according to the type of the floor they are located in: basement/first floor/second floor/typical floor/last floor/roof. The QTO for this block was extracted using the Quantification tool in Navisworks Manage [22].

To extract the QTO using Navisworks Manage 2016, firstly the model should be exported from Revit 2016. In order to do that, the Navisworks Addon Exporter should be installed. The different parts of the model can be then exported using the Add-In tab in Revit, External Tools panel and then clicking the Navisworks 2016 from the dropdown list. In the Export Scene As window and by clicking the Navisworks Settings button the export settings can be adjusted in the Navisworks Options Editor - Revit window. It is important to make sure that all the parameters and properties of the elements will be exported. All the parts of the model should be exported to Navisworks and saved as NWC files. In Navisworks Manage 2016 the different parts of the model can be assembled together using Append button in Home tab, Project panel and the model can be then saved as a NWD file.

As demonstrated in Fig. 2, to extract the QTO in Navisworks, the Quantification tool is used in Home tab, Tools panel. The Quantification Workbook window then appears. We start by clicking Project Setup and selecting the Takeoff Catalog. By default, Navisworks Manage offers to choose between three catalogs: CSI-16, CSI-48 and Uniformat. These catalogs are associated with the MasterFormat and Uniformat classification systems. Since the WBS is required to be described in accordance with another classification system, a file containing the work breakdown structure of this system should be created in XML format. It is also possible to choose None in Select Catalog step and then build the Quantification Workbook manually by using the Item Catalog.
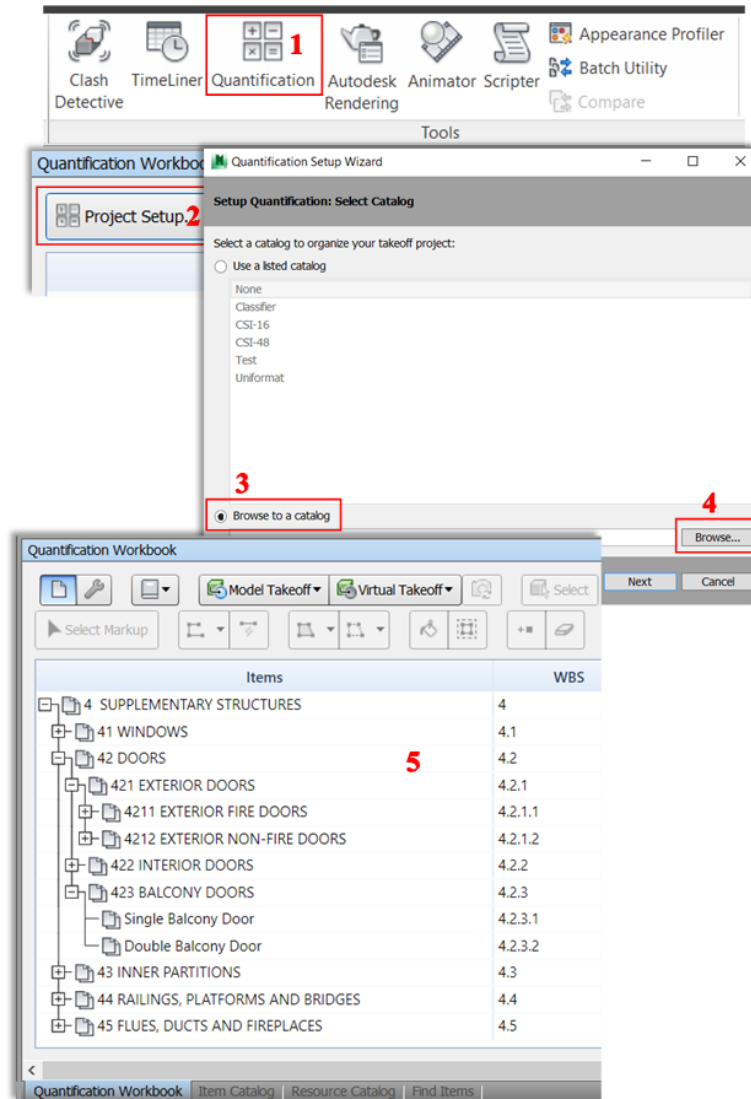
Fig. 2. QTO extraction in Autodesk Navisworks Manage.

Since the used classification system was not associated with the building elements during the design phase of this block and it was still under revision and modification, a need for solutions to extract the quantities according to the WBS has appeared. In order to extract the QTO much effort and time were consumed to analyse the model and understand the combination of the different units and of the elements in each unit. To extract the doors in the model, inquiries about the location and function of the door, about the fire properties and about the floor on which the door is located were created using the Find Items tool in Home tab, Select & Search Panel and saved in the Sets browser using the Save Search button. Too much time was consumed to study the different properties of the elements and the method by which they were modelled in order to define the research criteria: Category, Property, Condition and Value.

The inquiries were run successively to extract the quantity corresponding to the item in the Quantification Workbook. For an example to find the number of interior fire doors located on the basement, first the Interior Doors inquiry is run to select all the interior doors in the model, then the unselected elements are hided. Next the Fire Doors inquiry is run to select only the fire interior doors and the unselected doors are hided. Finally, the Basement inquiry is run to select the interior fire doors in the basement. Having the interior fire doors of the basement appearing on the screen, the Select None button in the Search & Select Panel is clicked to relinquish the previous selections and then the Select Box to select the doors appearing on the screen. By clicking Save Selection in the Sets browser a set is created and it can be given a name convenient with the corresponding item. Having the set ready to take off the doors saved under it, the set can be dragged to the corresponding item in the Quantification Workbook tree. As a substitute, by running the selection set to have the elements selected, and then right clicking the corresponding item in the Quantification Workbook and choosing Take Off Selected Model Items the selected doors are added to their item. And so on for all the items in the catalog. Fig. 3 shows the inquiries required to extract the quantities of the doors and an example of setting the search criteria for the fire doors.
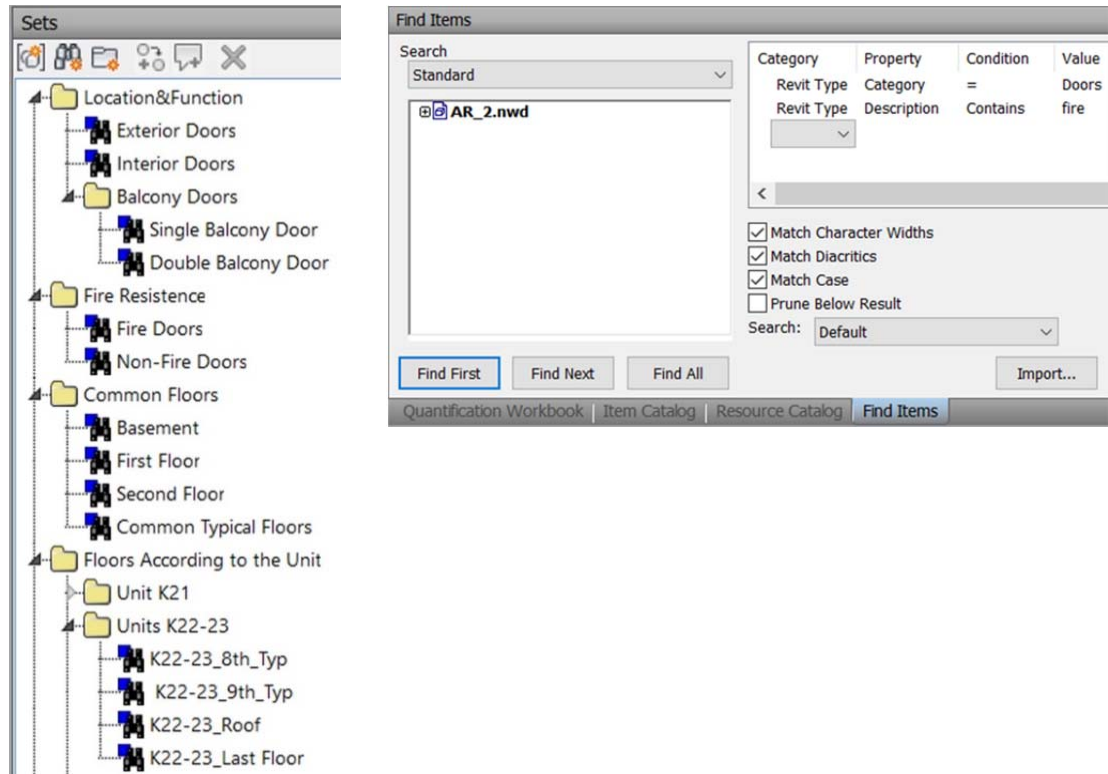
**Fig. 3. Doors inquiries and search criteria for fire doors.**

3.2 Using the Schedule/Quantification tool in Revit with PivotTable in Microsoft Excel

Fig. 4 shows the model of the third block of the complex. During the design phase of this block many drawbacks were avoided by taking much attention to the BIM model as a tool for extracting the QTO. During the modelling of the elements the properties were assigned more precisely. One of the most important properties to consider during the design stage is the Assembly Code. In Revit, all model elements have Assembly Code and Assembly Description type properties based on the hierarchical list of Uniformat codes assigned by R.S. Means [13]. Since in the studied complex a private classification system different from Uniformat was used, a Delimited Text file containing the classification system is created and the default assembly code file in Revit is changed using Additional Settings tool under Manage tab in Settings panel, then choosing Assembly Code from the dropdown list and browsing to locate the file.


Fig. 4. BIM model of the third block of the complex.

Taking into consideration the studied example of the doors, the corresponding assembly codes were assigned to the properties for each door type to easily identify the type during the QTO process. According to the assigned assembly code, it was possible to set the needed inquiries easily as demonstrated in Fig. 5.
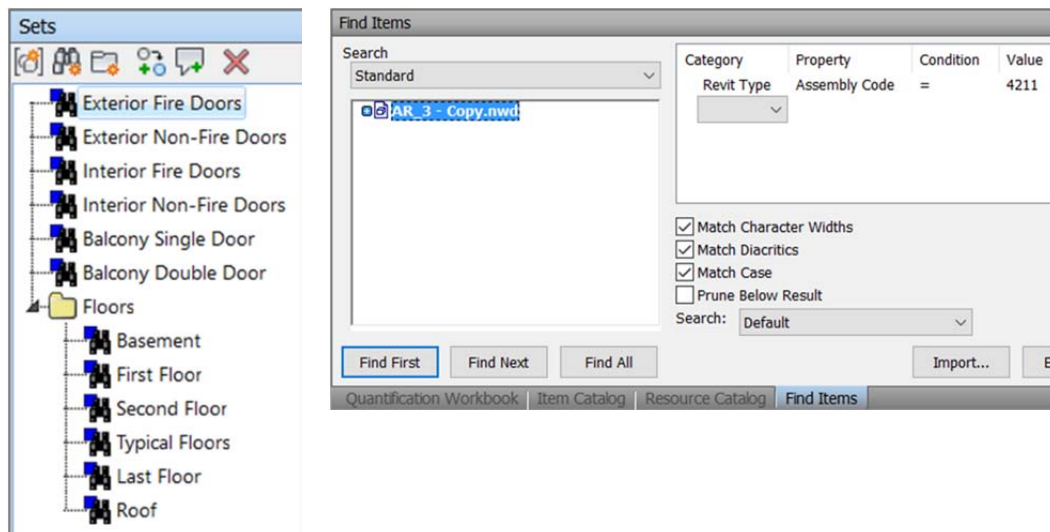
Fig. 5. Inquiries according to the assembly code.

Having the properties of the elements set correctly and precisely, it is also possible and more feasible to use the Schedule/Quantities tool in Revit under View tab in Create panel, Schedule dropdown list. The category of the Doors should be chosen and the required fields are added to the schedule as shown in Fig. 6.
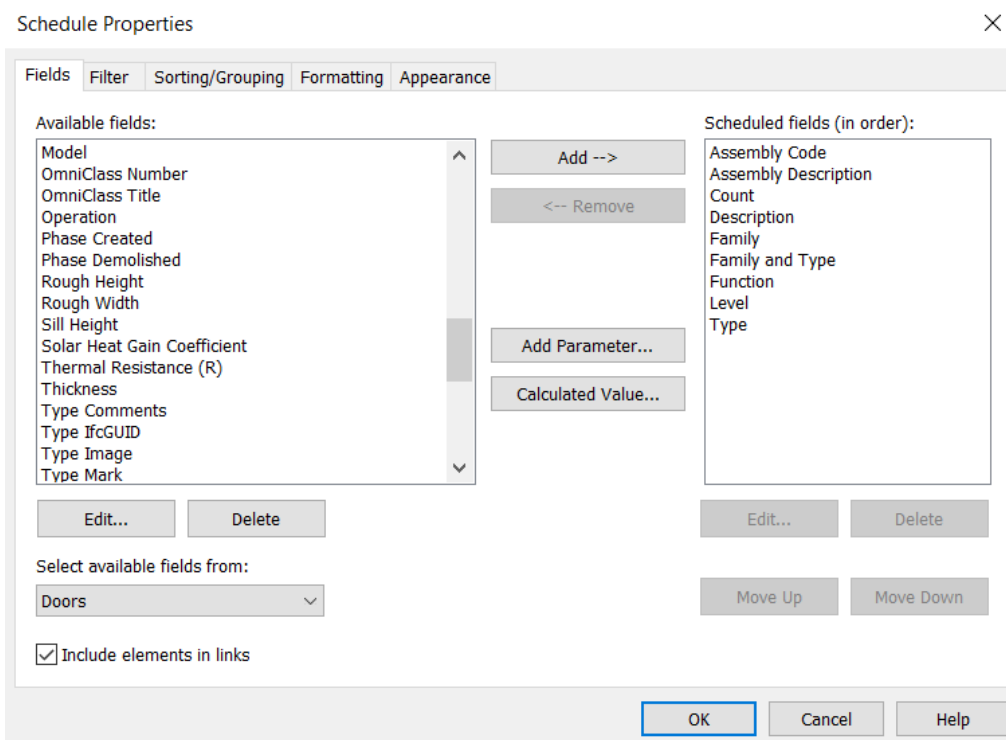
Fig. 6. Doors schedule in Revit.

After creating the schedule, it can be then exported as a Delimited text file using the Export Reports tool in the program icon dropdown list. The file then can be opened in Microsoft Excel and by accepting the defaults in the Text Import Wizard, the file can be then saved as an Excel file. To have more flexibility in processing the data of the schedule, it can be converted to a PivotTable under Insert tab in Tables panel. The fields necessary to extract the quantities can be added using the areas of the PivotTable, and for an example the Doors PivotTable for the first floor of one unit of the third block will look as shown in Fig. 7.

Fig. 7. PivotTable of the doors for one unit of the third block.

As it can be seen throughout the study, the QTO process gets faster and more accurate when the model is designed having in mind the different input/output dynamics for quantity takeoff.

4. Conclusions

Through the utilization of building information models (BIM) it is possible to make quantity take-off considerably more effective, and to increase the utilization of quantity data in different decision-making situations. Measuring quantities manually from drawings is replaced by computer-assisted measurement from a BIM. Quantities can be measured from architectural, structural and building services technology data models and their integrations. It is possible for building owners and clients, designers, contractors and product fabricators to utilize quantity take-off in completely new ways and from new perspectives.

BIM-based operations change the work of the quantity surveyor significantly – the amount of routine tasks decreases while professional skill requirements increase. The quantity surveyor is noticeably becoming a quantity specialist. However, a BIM does not resolve quantity take-off related issues "exhaustively" and not all quantities needed during a project can be taken off from a BIM. The professional skill of a quantity specialist is still needed for assessing the validity of the source data and source materials, ensuring the coverage of the take-off, proposing alternative solutions and analysing the results.

When the BIM-based documentation method is adopted and in light of what has been covered in this case study, difficulties arise in situations where the design solution is not modelled according to requirements, and in addition, the modelling was done differently in different parts of the same model, thereby, from the perspective of quantity take-off, the most important attribute of a model is consistency: all building and building services elements should be modelled according to BIM requirements and the modelling method used is documented in the BIM specification.

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Предварительный расчёт объемов работ на основе информационного моделирования зданий

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АННОТАЦИЯ

Информационное моделирование зданий (BIM) широко используется для более эффективного управления информацией строительства на протяжении всего жизненного цикла проекта. В частности, предварительный расчет объемов работ (QTO) и оценка, основанные на BIM, привлекают все более пристальное внимание. В то время как предварительный расчет объемов работ на основе информационного моделирования зданий является одним из потенциально наиболее важных и прибыльных приложений для BIM, он по-прежнему недостаточно изучен. Эта статья предназначена для изучения возможного использования информации в модели BIM, такой как перечень видов работ и код сборки для разных элементов, для эффективного извлечения количества элементов и материалов во время и после проектирования. Исследование проведено на жилом комплексе в Санкт-Петербурге. В ходе статьи изучено то, как объемы могут быть извлечены с помощью инструмента количественной оценки в Autodesk Navisworks Manage и инструмента Schedule / Quantity в Autodesk Revit в сочетании с инструментом сводной таблицы в Microsoft Excel.

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