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Earned Value Management with the Use of Building Information Modelling

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Abstract

Building Information Modelling (BIM) is rapidly becoming the prevailing approach for the delivery of construction projects. While, cost monitoring and control is among the main processes supported by BIM, the widely applied Earned Value Management (EVM) method has not yet been adequately introduced in the BIM context. This paper provides a simple walkthrough on how to easily apply a BIM-based EVM. The presented approach is based on the integration of BIM technology and EVM method in a single software platform (AUTODESK's Revit), thus minimizing manual handling and consecutive errors and more importantly facilitating a fast and accurate decision-making process on cost and time control issues. The integration is validated through a case study of a building project that explicitly demonstrates the various implementation steps of the presented three-stages process and provides an example for construction project control practitioners of BIM-based EVM in construction projects.

Keywords

Building Information Modeling, Earned Value Management, Earned Value Analysis, Project Monitoring, Project Control.

1. Introduction

Building Information Modeling (BIM) offers a broad spectrum of services and perspectives to the construction industry covering all life cycle phases from the design of a feasibility study to the monitoring/maintenance during operation. The visualization through a BIM model of a construction project that includes a high volume of multifaceted information provides the interface for timely and fully informed communications between stakeholders that enhance collaboration and efficiency in the project's development and management. One of the most critical support BIM models provide is with regard to cost monitoring and control.

Hakanen (2017) mentions that while an accurate budget is the starting point of a successful project, cost monitoring and control during the project's development is essential for compliance with cost baselines. This process must be holistic, i.e., examine all project's cost items concurrently (Kerzner, 2013) and should be realized by a cost monitoring and control system that (Bennet, 2003; Potts and Ankrah, 2008):

- Enables comparison between actual and planned costs to track deviations in the budget's execution
- Considers time and quality impacts on incurred costs
- Supports a database for productivity assessment at present and future projects
- Documents claims regarding cost overruns and budget deviations, and
- Assists in decision-making on cost related issues

Earned Value Management (EVM) is an established and well-known framework for monitoring and controlling costs that is widely used in the construction industry. EVM is a systematic approach that exploits the evolution in time of the value of the produced work, thus integrating time, quality and cost aspects in a performance baseline, which constitutes an important tool for project management (PMBOK, 2017). Therefore, EVM is a robust framework that fully satisfies the demands of a cost monitoring and control system and could be appropriately modelled as such.

Wang et al. (2014) have reviewed the attempts of incorporating BIM to a cost monitoring and control system for construction projects and have found a limited number of related efforts; moreover, this efforts presented shortages

either due to a partial consideration of the project's cost items or due to the orientation to small- and medium-sized projects. Furthermore, the few attempts to combine EVM and BIM were limited to the use of the latter for a more accurate and efficient data management in EVM application, rather than integrating the methodological and technological approaches towards the creation of a single BIM-based tool for the application of EVM.

This paper presents an attempt to integrate BIM and EVM in a single BIM model that facilitates and speeds up cost monitoring and control by using a single software platform instead of a combination of more than one of them. In the next sections, first EVM is briefly summarized and previous attempts to combine EVM and BIM are briefly reviewed to present the context and background of this research. Then a case study of a real project is presented where cost monitoring and control during the construction phase are performed with an integrated BIM-based platform that applies EVM. The proposed model is discussed in terms of the benefits and limitations it presents. Overall, this work aims at providing to the stakeholders in the construction industry a simple, replicable, easy to use and manage BIM-based application of EVM for cost monitoring and control.

2. BIM-based Applications of the Earned Value Management

EVM introduces a set of measures and indicators, which when used in combination allow the cost's monitoring of any project. The basic measures as listed in the Standard for Earned Value Management (PMI, 2019) are: (a) the Budget at Completion (BAC), i.e., the total budget of the project, (b) the Planned Value (PV), i.e., the budgeted cost for the amount of scheduled work up to a given time, (c) the Actual Cost (AC), i.e., the real costs incurred and accounted for the work performed until the time of control, and (d) the Earned Value (EV), i.e. the value of the work performed until the time of control. These basic measures with simple mathematical operations produce several indicators such as the Schedule Variance (SV), the Cost Variance (CV), the Schedule Performance Index (SPI), the Cost Performance Index (CPI), the Estimate at Completion (EAC), etc. The measures and indicators constitute a toolbox for cost monitoring and control, while the estimates are predictors based on the assumption that previous experience may indicate future performance.

Kenley and Hartfield (2015) have recorded EVM and BIM as the main approaches for construction projects control when applied both separately and in combination. Kim et al. (2010) have designed and applied a 5D BIM-based model, where the outputs after running the model were a 3D plan of the structure, a Gantt chart and an EVM graph. Turkan et al. (2013) have used laser scanning to collect data from a structure and compare them to the respective BIM model to evaluate the project's progress. Other researchers have also focused on the use of automated data collection tools and equipment (e.g. GPS, RFID, UWB) to support EVM (Boschè et al. 2013). Foremny, Kluczuk, and Nical (2014) have developed the Mobile Earned Value Management System (MEVMS), an operable system in mobile phones and tablets that uses as an interface the MS Excel and allows for the exchange of EVM assessments and project plans, thus facilitating communication on cost monitoring. Marzouk and Hisham (2014) have attempted to apply EVM on bridges through an application that extracted work volume data from a Bridge Information Modelling (BrIM) tool to MS Excel that was, consequently, used for cost assessments. Elghaish et al. (2019) have integrated EVM and BIM with Activity Based Costing (ABC) to support Integrated Project Delivery (IPD) in terms of enhanced cost structure and risks/rewards allocation.

In all these cases with the exception of the work by Elghaish et al. (2019), which, however, is focused on a broader topic, there is no actual integration of EVM and BIM but rather a combined application of them, which is achieved through the data exchange between different software tools. This process, though, is time consuming due to the manual processing of input data, while it retains the limitations met in platforms of cooperating software tools (e.g. compatibility), thus resulting to an approach which lacks cost efficiency. The presented work in this paper integrates EVM in a BIM software tool, thus allowing more efficient cost monitoring and control.

3. Integration of EVM and BIM: Design and Application

3. 1 Design
The implementation of EVM through a BIM model is designed as a three-stage process:
1. Create the structure's 3D model and the EVM calculation sheets that draw input from the 3D model's plans. The direct connection to the model's plans ensures the dynamic update of the calculations every time there is a change in the model.
2. Select the cost assessment approach between the two main alternatives, which are: (a) assess costs on the basis of structural elements or (b) assess costs on the basis of used material. The first alternative requires a

very accurate and analytic model as the volumes of the structural elements must be precise to assess costs per element based on unit costs. The structural elements may be further grouped based on spatial or other criteria. The second alternative takes into consideration the used volumes of the various materials employed in the project, ignoring, though, the structural element where these materials have been were used for. This option may seem simpler; however, it lacks a direct connection to the model, thus rendering it useless for scenario planning.

3. Insert budget and cost data for the various structural elements and calculate the basic EVM measures and indicators. This step will be repeated periodically based on the model's update with actual costs or at any time during the construction phase when the project's management team tests various risk and performance scenarios.

The described process was applied on a test case that is presented in detail in the following section.

3.2 Application

The described approach was applied to the four-story residential building presented in Fig. 1. The building was constructed in 2010 and its selection was based on the availability from the construction company of sufficient data for the design and implementation of the project in terms of scheduling, budgeting, and materials use. At each floor a 100m^2 apartment was built, while the building had an open parking area (pilotis), and a basement.
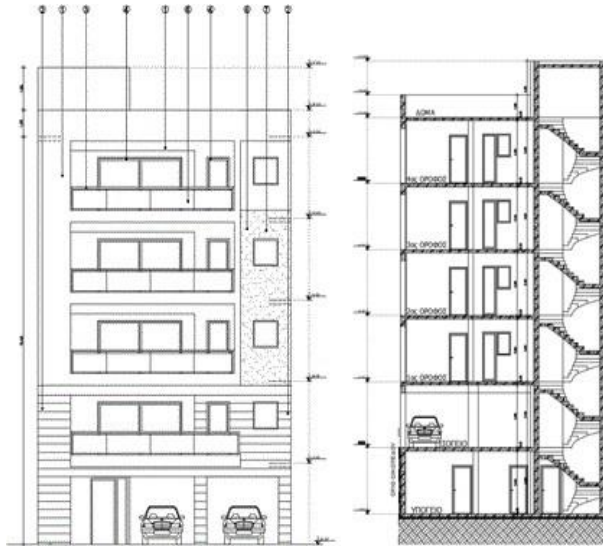
Fig. 37. View and Section of the modelled building figure

The contractor apart from the plans, also, provided the total costs of the used materials, namely steel, concrete, masonry, frames, insulation panels, and floors (marble, wood, and tiles). Based on these data, the building was modeled in AUTODESK's Revit and the result is shown in Fig. 2.

AUTODESK's Revit provides reports in tabular form (called Schedules) that allow customized calculations with the help of parameters selected by the user. The default parameters, while relevant in some cases (e.g., element's cost, element's volume, etc.) are not directly associated to EVM; therefore, the software's option to build new customized parameters oriented to the desired analysis has to be activated. Following a simple line of commands, the parameter's type and properties are set and, consequently, the PV, EV, AC tables are formed. The three tables have a similar form, which is illustrated in Fig. 3. A final table is created to collectively present all the information of the earned value analysis, including all EVM measures and indicators (SV, CV, SPI, CPI). This table is depicted in Fig. 4.

Apart from tables, EVM is mainly presented through the graphical illustration of the evolution in time of the cumulative values of the basic measures. The production of these graphs from any BIM software is impossible; therefore, another solution is required for the full application of EVM. In the context of this work, the pyRevit rapid-prototyping environment was applied. pyRevit is a fully open source software tool that introduces a Python script library in Revit, which allows the programming of several tabs in Revit user interface to facilitate processing of BIM

models. In this case, pyRevit was installed and used to program a command that allows the extraction of EVM tables to MS Excel where the creation of the graphs is feasible. The transition from Revit to MS Excel (depicted in Fig. 5) is mandatory since Revit cannot produce EVM graphs; however, the programmed command with the use of pyRevit allows both an easy, automated transition between the two software tools and the update of the graphs after each modification in the BIM model. In this way, a unified software platform is, practically, created that saves the construction manager from manual input of the cost data and, instead, translates any studied or performed changes during construction to EVM indicators, thus allowing the automated BIM-based application of EVM.

Fig. 38. BIM model of the studied building

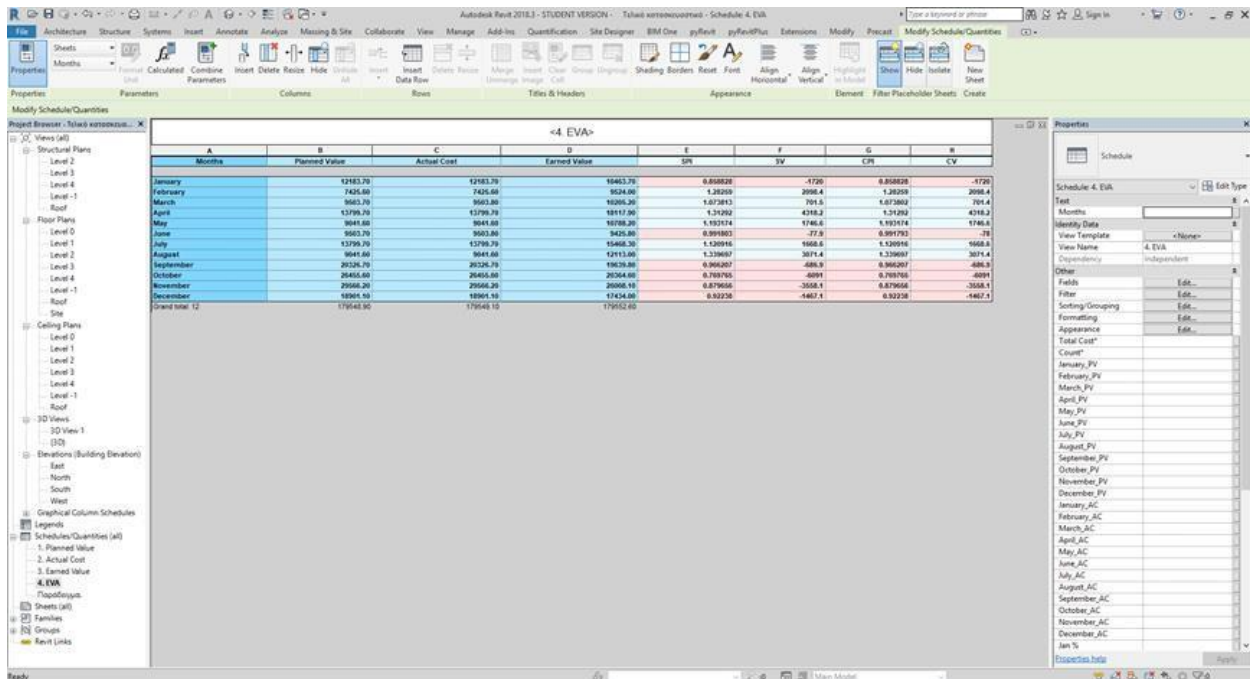**Fig. 39.** Basic measures (PV, EV, AC) table form

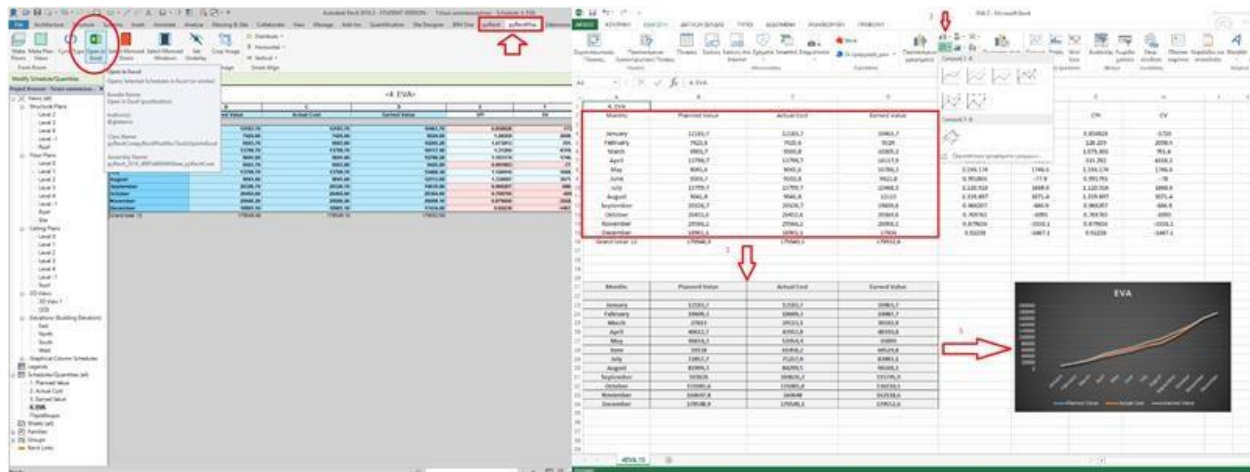**Fig. 40.** Earned Value Analysis integrated in BIM software

Fig. 41. Transition from AUTODESK's Revit to MS Excel for the creation of Earned Value Analysis graphs

The next stage involves the determination of the cost assessment approach. In this case, it was selected to assess costs based on the structural elements that had to be constructed at different building levels. The reasons for adapting this fragmented cost assessment approach were several. First, the construction company that provided the data had not recorded costs based on the exact composition in terms of material, thus preventing from applying the analysis at the material level. Second, the common professional practice is that contractors assess the costs based on the activities they have to perform, which is usually denoted by the name of the structural elements; therefore, the cost records, in this case also, were directly associated to the work performed for specific structural elements.

Another common practice is that several works related to various structural elements are assigned to different sub-contractors (e.g., there is one sub-contractor for concrete elements, another one for masonry, etc.), thus resulting to cost records associated to sub-contractors and indirectly to their part of the total work that has to be performed. The choice to consider the costs for the structural elements per different level was dictated from the need to better align the model with the construction process and facilitate the recording of the project's actual progress in terms of performance. First, the horizontal structural elements (i.e., beams and slabs) are progressing in iterative steps that are

repeated for each different building's level. The same stands also for frames and masonry that according to the plans are following the same pattern in terms of placement per floor. Therefore, it is reasonable for these elements to model them at the floor level and monitor the performance and costs of the related work accordingly. The vertical structural elements (i.e., the columns) could be modeled uniformly for the total building's height; however, this approach would hinder the automatic assessment of the work progress as there would be difficulty to determine the percentage of work performed at intermediate levels between start and finish of their construction. This obstacle would also affect the correct application of EVM; therefore, the appropriate way of modeling the structural elements for the needs of EVM would be to discretize them per floor.

Based on the above-mentioned analysis, the structural elements were grouped at the floor level as slabs, beams, columns, masonry and frames. Each structural element was considered as built only after the conclusion of all construction activities required for rendering it operable in the building. This means, for example, that a slab was considered as concluded work only after the construction of the floor on top of it and, similarly, a wall was considered as concluded work only after its painting, etc.

The final stage of the process involves the model's periodical update with progress data that the construction manager inserts during the project's development. The designation to the model of concluded structural elements either to depict real progress or to test future performance scenarios is a standard iterative process of cost monitoring and control.

For validation reasons, the building model presented so far was tested under a hypothetical scenario of an alleged delay of about two weeks due to unexpected weather conditions that hindered concrete activities at the third floor. Following, according to the scenario, an already poor progress in the project's development that was depicted through low values of EVM indicators (i.e., the scenario considered SPI=CPI=0.6), the new delay would have an adverse effect on schedule and would derail substantially the project with an impact on keeping the budget.

Facing such a scenario in the traditional way would involve several calculations based on alternatives of future performance that could be only verbally described among the project's stakeholders and, finally, involve changes to several plans and reports with the directions for future actions. Having the BIM model, though, the construction manager could investigate rigorously and fast, several future alternatives for increasing future performance by changing the sequence of activities or shortening their duration based on resources re-allocation. The most important is that the examined multiple scenarios (e.g., prioritizing the construction of structural elements as shown in Fig. 6) were immediately reflecting the changes to EVM measures (see Fig. 7) and the overall performance based on EVM indicators (see Fig. 8), thus allowing a clear presentation of the impact of each investigated scenario. This presentation according to the contractors of the construction company that provided all data would definitely reduce the response time to potential risks by facilitating understanding and coordination among the stakeholders and allowing fast and well-informed decision-making.
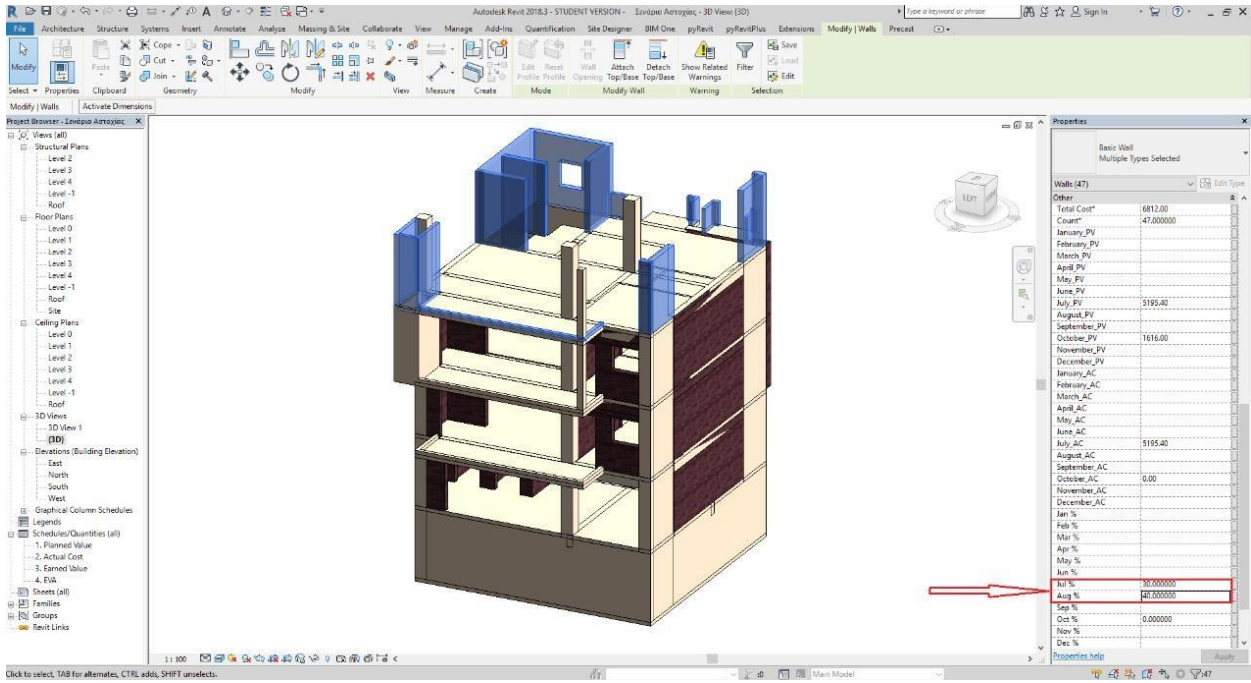
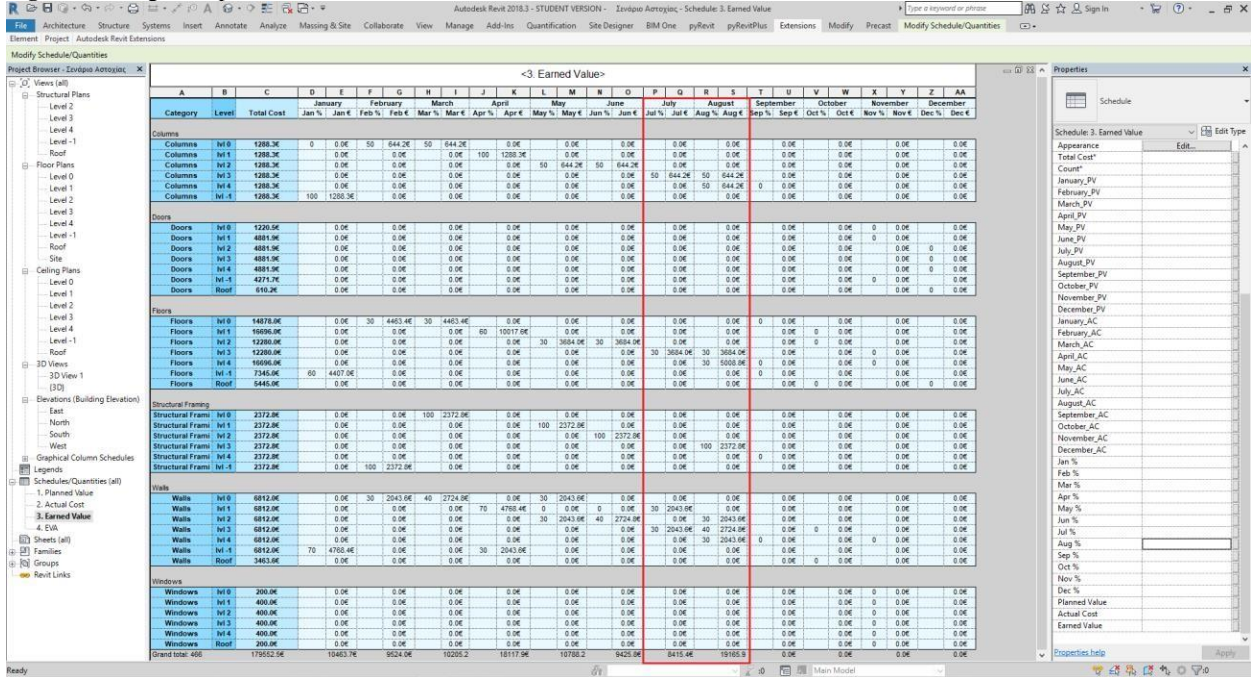**Fig. 42.** Testing of response alternatives to scenario threats

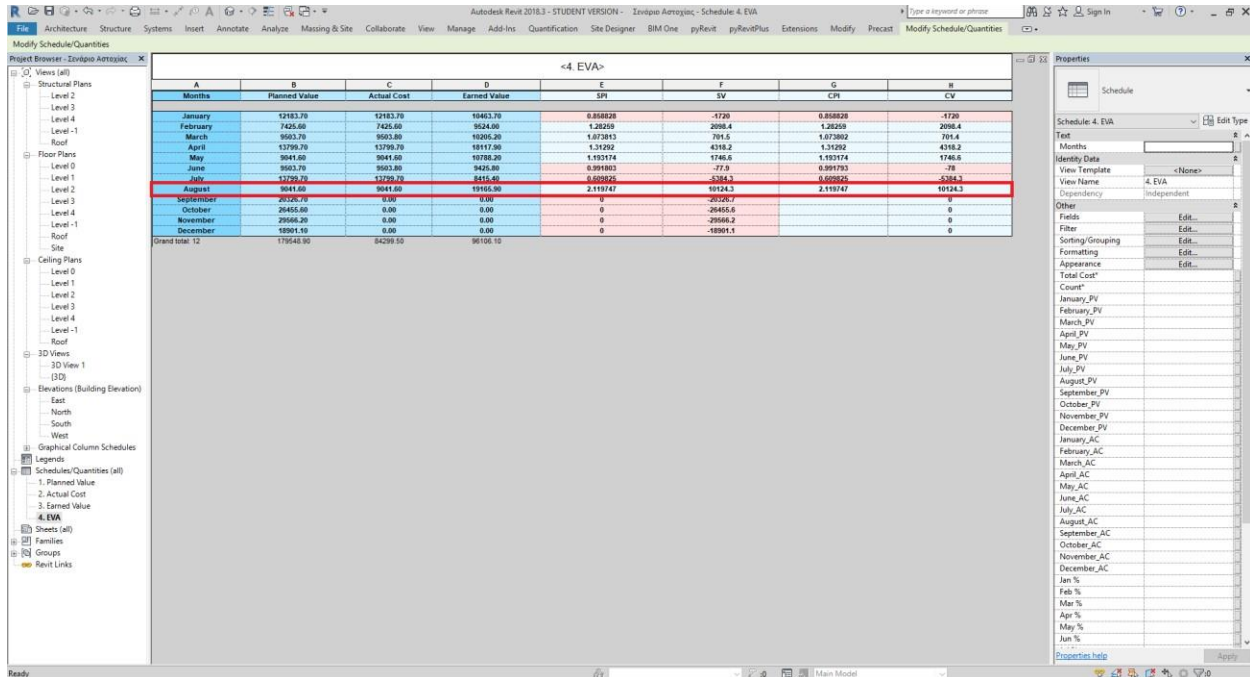**Fig. 43.** Reflection of changes to EVM measures

Fig. 44. Reflection of changes to EVM indicators and estimates

4. Discussion and Conclusions

This paper presents a practical and easy way to integrate Building Information Modelling with Earned Value Management for construction projects cost monitoring and control. Despite, the obvious potential and benefits of such integration, there have been only few previous similar efforts, which, moreover, presented limitations with the more important one being the lack of direct and automated connection between software tools used for this reason. The work presented in this paper manages with the help of pyRevit to put together AUTODESK's Revit and MS Excel to perform EVM without the need for manual import of data and with the significantly greater part of the analysis conducted in the BIM software, while MS Excel is used only for producing the graphical outputs of EVM.

Beyond the obvious yet critical benefits of performing an automated BIM-based EVM, such as the accurate and fast decision making regarding responsive actions against potential risks and threats or controlling schedule and cost variances during a project's development, a few more fundamental effects of this integration can be observed.

The first is that the requirements of the cost control and monitoring approach dictate the modelling process of the structure. This tradeoff is essential as the design phase is functionally linked to the execution phase of the project's life cycle, thus enhancing the overall project's constructability. Furthermore, it brings forward at an early design stage, the managerial aspects that govern the project's development, something, which is generally undermined at this phase due to the emphasis given on engineering issues.

The second effect is that the provided transparency to the cost monitoring and control process, substantially enhances the project's stakeholders shared understanding regarding cost issues. Consensus in dealing with the several risks is built thanks to these shared views, but more importantly requests of changes are documented and unnecessary claims, which often raise when the project's deviate from planned performance goals are reduced.

The third, and last noted, effect is that the proposed approach enhances the managerial perspective during the project's development through the creation of a holistic viewpoint that also allows the obtaining of a more complete and more accurate project's knowledge.

All the above-mentioned positive impact fosters the practical and easy integration of BIM and EVM as confirmed in the context of the presented work.

References
Bennet, F. (2003) The management of construction. A project life cycle approach. Oxford: Butterworth-Heinemann.

Boschè F, Guillemet A, Turkan Y, Haas C, Haas R. Tracking the Built Status of MEP Works: Assessing the Value of a Scan-vs.-BIM System. Journal of Computing in Civil Engineering. 2013;28(4).

Elghaish, F., Abrishami, S., Reza Hosseini, M., Abu-Samra, S., & Gaterell, M. (2019) Integrated project delivery with BIM: An automated EVM-based approach. Automation in Construction, 106, https://doi.org/10.1016/j.autcon.2019.102907.

Foremny, A., Kluczuk, P., & Nical, A. (2014) Design and implementation of automated, mobile construction projects monitoring system (MEVMS) based on Earned Value Management as an element of BIM in the execution stage. In: Creative Construction Conference 2014, Prague, CzechRepublic, CCC.

Hakanen, L. (2017) Classification of cost data and its use in 5D Building Information Modelling. MSc.
Tampere University of Technology.

Kenley, R., & Harfield, T. (2015) Construction project control methodologies and productivity improvement: EVM, BIM, LBM. In: International Conference on Engineering, Project, andProduction Management (EPPM 2015). Gold Coast, Queensland, Australia, EPPM.

Kerzner, H. (2013) Project management: A systems approach to planning, scheduling and controlling. 11thed. Somerset: John Wiley & Sons.

Kim, H., Benghi. C., Dawood, N., Jung, D., Kim, J. & Baek, Y. (2010) Developing 5D system connectingcost, schedule and 3D model. In: IABSE Symposium Report 2010. Venice, Italy, IABSE.

Marzouk, M. & Hisham, M. (2014) Implementing Earned Value Management using bridge informationmodeling. KSCE Journal of Civil Engineering, 18, p.p. 1302-1313.

Potts, K. & Ankrah, N. (2008) Construction cost management. Learning from case studies. London: Routledge.

Project Management Institute (2017) A guide to the Project Management of Knowledge (PMBOK Guide).
6th ed. Newtown Square, PA: Project Management Institute.

Project Management Institute (2019) The standard for Earned Value Management. Newtown Square, PA:Project Management Institute.

Turkan, Y., Bosché, F., Haas, C. & Haas, R. (2013) Toward automated earned value tracking using 3Dimaging tools. Journal of Construction Engineering and Management. 139, p.p. 423-433.

Wang, X., Yung, P., Luo, H., & Truijens, M. (2014) An innovative method for project control in LNGproject through 5D CAD: A case study. Automation in Construction. 45, p.p. 126-135.