Application of 6D Building Information Model (6D BIM) for Business-storage Building in Slovenia

Zoran Pučko 1, Dražen Vincek 2, Andrej Štrukelj 1, Nataša Šuman 1

1 Faculty of Civil Engineering, Transportation Engineering and Architecture, University of Maribor, Maribor, Slovenia

2 Gebr. Schmölzl GmbH&Co.KG, Wappachweg 27, 83457 Bayerisch Gmain, Germany

natasa.suman@um.si

Abstract. The aim of this paper is to present an application of 6D building information modelling (6D BIM) on a real business-storage building in Slovenia. First, features of building maintenance in general are described according to the current Slovenian legislation, and also a general principle of BIM is given. After that, step-by-step activities for modelling 6D BIM are exposed, namely from Element list for maintenance, determination of their lifetime and service measures, cost analysing and time analysing to 6D BIM modelling. The presented 6D BIM model is designed in a unique way in which cost analysis is performed as 5D BIM model with linked data to use BIM Construction Project Management Software (Vico Office), integrated with 3D BIM model, whereas time analysis as 4D BIM model is carried out as non-linked data with the help of Excel (without connection to 3D BIM model). The paper is intended to serve as a guide to the building owners to prepare 6D BIM and to provide an insight into the relevant dynamic information about intervals and costs for execution of maintenance works in the whole building lifecycle.

1. Introduction

The life of buildings goes through many phases. The project starts after the recognition of needs for buildings. Upon initiation of the project, which includes feasibility analysis, the project is developed as drawings and specifications or nowadays as a BIM model with additional information. Afterwards, a building is built. By the end of construction works, it is turned over to the owner. A finished building is occupied, maintained, repaired and renewed in its lifecycle. This is the operation time in which the owner is responsible for ensuring the functioning and durability of the building. Since this period involves neither the architect nor the construction professional all the design and technical documentation should be handed over to the owner. In addition, the process to start-up building’s active technical systems should be done together with owner's representatives [1].

Undoubtedly, operation and maintenance phase is the longest period in the whole building lifecycle, lasting for many years before a general renovation is needed. Therefore, life time of the building is highly dependent on regular and timely maintenance. Regular maintenance services are important building management functions and the part of the integrated Facility Management (FM). Obviously, the aim of building management is to maintain or even increase the value of the building and is responsible for maintenance functions, comprising the technical management, operation, maintenance, repair, and emergency management [2].
On the other hand, regular implementation of the maintenance services is related to the applicable legislation. From the technical aspect, Construction Act [3] defines the term building maintenance, representing execution of works whereby the object is maintained in good condition, and enables its use. Next, it defines the term regular maintenance, representing investment maintenance works, repairs, construction, installation and finishing works and improvements following the progress of technology. These works should not interfere in the structure of the building or change its intended use. The Article 6 [3] does not require obtaining a building permit for this works. From business perspective, Housing Act [4] provides conditions for building maintenance whereas Rules on management of multiple dwellings [5] specify functions of building management and powers of building manager. Further, in Rules on standards for the maintenance of apartment buildings and apartments [6], the Annex 1 provides maintenance standards for 323 building elements with its and maintenance mode. In Slovenia, maintenance services are regulated only for multi-residential buildings, whereas legislative acts are applied mutatis mutandis for non-residential buildings. Other countries have standards such as ISO 16739:2013 (covering industry foundation classes (IFCs)); PAS 1192:1-5, (covering data format specification) and ISO 29481-1:2016 (covering BIM information manual), where the BIM and FM were developed. Thus, the Construction Operations Building Information Exchange (COBie) standard was elaborated (published in 2007 in the US and later adopted as British Standard in 2014) [7], while Uniclass or Uniclass2 classification was developed within National Building Specification for the UK. In Slovenia, such a standard has not been implemented; therefore, the abovementioned legislative acts are applied.

Nowadays, possibilities for more efficient building management can be addressed from the perspective of modern approach to building modelling and named building information modelling (BIM) [8]. BIM approach is a comprehensive approach to design, construction and maintenance of building. The basic concept is the chain connection of all participants who contribute to the integrated information in the whole building lifecycle within single phases [9]. BIM approach deals with the various dimensions from 3D to 6D or to even more [10], [11]. The introduction of BIM approach for design phase is expanding rapidly today (3D, 4D and 5D models). On the other hand, more and more users emphasize the importance of introducing BIM approach for a period of building operation by recommending 6D BIM [12], [13], [14]. Actually, clear guidelines and instructions for 6D BIM creation were not detected so far. However, Pärn et al. [7] give an extended review of published literature on the latest research and standards development about BIM and its application in FM.

6D BIM is modelled in handing over procedure and intended as a guide with all the necessary information which is given dynamically. It serves for organizing smooth functioning of the building and planning measures for maintenance work and renovations over the entire lifetime of the building. One of the most important benefits of 6D BIM is an easy access to the building element databases from which information about producer, type and model of equipment, service intervals, and technical specifications can be accessed at any time. In this way, the building manager manages information and supplements easily, while receiving information material in the traditional FM, such as the as-built drawings, instructions for operation and maintenance, certificates of completion is of static importance.

For that purpose, this paper provides an application of 6D BIM on a real business-storage building in Slovenia. Section 2 gives general description of the business-storage building. Detailed description of step-by-step procedure for modelling 6D BIM is presented in Section 3. Initially, a 3D BIM model was designed to allow the preparation of an Element list for all elements that should be operated and maintained. Service intervals and lifetime are determined for each element, followed by cost and time analysis. Based on the relevant data, 6D BIM model was developed in unique way where 5D BIM model is created as linked data to 3D BIM model in Vico Office (VO) [15] and 4D BIM model as non-linked data by support of Excel.
2. Description of business-storage building

2.1. Location and functional design
The business-storage building is located in Hoče, Bohova 73, 2311 Hoče, Slovenia and is owned by the company Halder d.o.o. The building is functionally divided into the store with warehouse and the office space. The form of the building is an elongated rectangle with a roof above the entrance and above delivery space. The external dimensions are 36.5 m by 16.5 m, the total gross area is 801.2 m² and net surface is 715.3 m². The business section (the store and the offices) has two floors, while the warehouse has a single storey and is double height. An outdoor space for cooling and heating devices is located on the south side of the building [16]. Figure 1 presents view on west and east façade of the building [17].

![Figure 1. Western façade with the main entrance and east façade of the building [17]](image)

2.2. Technical characteristics

2.2.1. Constructional design. The foundation of a business section is made with a reinforced concrete foundation plate. The load-bearing structure is a brick wall in thickness of 30 cm. The foundation of a warehouse includes footings jointed by reinforced concrete beams. Load-bearing structure consists of reinforced concrete prefabricated elements, which are longitudinally connected with steel sections/profiles. Reinforced concrete slab is used for mezzanine structure. The slope of the flat roof is 3°, implemented by trapezoidal metal sheet and system of hydro and thermal insulation according to DIN 18234. Façade panels with intermediate glazing cover the façade. Façade panels are fixed on the mounting steel substructure.

2.2.2. Carpentry. Aluminium windows with external blinds (\(U_f = 1,3\) W/Km², \(U_g = 1,0\) W/Km²) are mounted on the façade. Interior doors are made of metal doorframes and door panels are from solid wood or glazed. The main entrance and exit into exhibition area has double sliding glass doors monitored by sensor. The warehouse is equipped by an industrial sectional roll-up door whereas in the northern part of the building is a high delivery door.

2.2.3. Internal surface treatment. The final treatment of the ground in the warehouse includes surface-hardened reinforced concrete plate. Final coverings in business section were carried out by means of large format tiles and carpeting in offices. Ceramics is laid on the floor of toilets; walls and ceilings of the business section are lined with plasterboard panels. Sensors for fire protection, lighting and ventilation equipment are built-in in the raster suspended ceilings.

2.2.4. Electrical installations and electrical equipment. Connection nominal power of the object is \(P_n = 32,9\) kW, \(I_n = 50\) A. The size of the fuse is 1 x 3 x 50 A. Horizontal distribution pipes for electrical installations are carried on cable shelves, and a vertical pipe is placed in a protective tube in
the walls. General and safety lighting is installed in the building. Telecommunication links are routed into the building through the telecommunications closet which is located in the room for the server.

2.2.5. Active technical systems, waterworks and sewerage. Heating of business section is provided by the heat pump air/water and the floor heating system. Heating of the warehouse is supplied by the heat pump air/air, which serves for office cooling in the summer. The external units of heat pumps and air conditioning are installed in the outdoor space on the south side of the building. Forced ventilation of business section includes two heat recovery units, an integrated filter and an air inlet and outlet fan. The transfer of outside (fresh) air and exhaust air is conducted through channels. Toilets have an intake ventilation valves and discharge pipe ventilators. The building is connected to the existing water supply network. It has an indoor fire hydrants and distribution pipes for hot water. Domestic hot water is supplied centrally by a combination water heater (V = 100 l; heated with a heat pump or electricity). The building is connected to the existing sewer system. A horizontal distribution pipe is made with polypropylene tube.

3. Practical example of 6D BIM model for business-storage building

The following is a description of a step-by-step procedure for modelling 6D BIM in unique way. The procedure begins with the collection of information about all buildings elements and preparation of Element List for maintenance. After that, lifetime and service measures for each element are determined. Afterwards, the cost and time analysis is performed, where the cost analysis includes maintenance cost estimation and development of 5D BIM model by applying VO (with linked data to 3D BIM model elements). The result of the time analysis is a schedule for maintenance work, displayed in MS Excel (without connection to 3D BIM model elements). The final step incorporates display/view of created 6D BIM model in tabular form.

3.1. Element list for maintenance

The first step to the creation of 6D BIM is to prepare an inventory of all structural and non-structural elements requiring maintenance and their quantities. In addition, inventory of all installed equipment and installation must be prepared. The present building input data are obtained from the final design and technical documentation, which contains as-built drawings, instructions for operation and maintenance, certificates of completion, Evidence on Reliability of the performed works, etc. By collecting necessary information, the so-called Element list for maintenance was prepared. To achieve the systematic approach of the 6D model, the list was prepared in tabular form. The table was divided in groups of works, namely construction and finishing works, installations, and external layout.

3.2. Determination of the lifetime and service measures for maintenance elements

The next step towards development of 6D BIM is determining lifetime and service measures for each maintenance element. We predicted lifetime of 60 years for business-storage building. Relevant information for the individual elements is mostly taken from Rules on standards for the maintenance of apartment buildings and apartments [6]. The rule in Annex 1 provides maintenance standards for 323 building elements and in Annex 2 standards for 70 elements for equipment and maintenance of building lot. Maintenance standards for each element include code in relation to group of works, description of an element, normal lifetime, factor of theoretical replacement after 60 years, factor for small repairs according to a new value and mode of maintenance works. The service measures for elements from the Rule [6] are recorded in the maintenance mode and covering a variety of activities such as: regular cleaning, regular servicing, regular review, repair of element, control of parts of the element, replacement of worn or damaged parts, painting, etc. Data about estimated lifetime and modes of maintenance for elements not included in the Rule [6] base on interviews with manufacturers or service providers or on data from COBie/Uniclass classification. The prices for servicing and implementation of regular maintenance work were acquired on the market.
The maintenance mode for heat pump air/water is described more specifically because this element is not defined in the Rule [6]. Therefore, we obtained data on the market by considering the latest state of technology and with the review of COBie/Uniclass classification [18]. We have summarized the 25-year lifetime span. Modes of maintaining were determined as a) regular maintenance and cleaning once a year and b) implementation of investment maintenance works two times in the intended lifetime. Regular maintenance is provided by a qualified service technician with servicing equipment and includes: visual inspection, cleaning heat exchanger of the outdoor unit, inspection and flushing condensate drain, oversight and control of electrical components, control of the pressures in the system, control of water filters, expansion tank, hot water storage tank, supervision of the plumbing work installation, a functional check and test of device, as well as control of software settings. Investment maintenance works are related to 60 years’ period during which we anticipate 2 times replacement of equipment, because only the implementation of the repair can ensure appropriate functioning of the pump. Thus, we anticipate that the heat pump is replaced by a new one once in the 25th and 50th year. We also determined the percentage of the value of small repairs in the amount of 10% from the initial value.

3.3. Cost analysis

The basis for estimating the maintenance costs are maintenance mode for all building elements, which must be maintained in the building lifetime. Cost estimation was performed by using VO. Data exchange from 3D Modelling Software, in our case ArchiCAD, to VO was carried out through the options “Publish to Vico” (Add-on in ArchiCAD). For each maintenance element we provided the unit price and multiplied it by the number of servicing intervals, replacements etc. throughout the entire lifetime of the building. In this way we estimated the annual costs and the total maintenance cost of the 3D BIM model elements.

Estimation of the maintenance costs was discussed in three parts i) replacement of individual elements in the building lifetime, ii) maintenance of individual elements in the building lifetime and iii) servicing of installations and equipment. Parts i) and ii) are characterized for the elements of construction and finishing works, part iii) shows significant costs of regular servicing. For elements with lifetime 60 years or more only the costs for maintaining are included in the calculation. In addition, the replacement costs are included for other elements, and the servicing costs are taken into account for the installation and equipment.

To estimate the total maintenance costs of the building, we considered two approaches: a) cost estimation for the construction of building elements (representing input data for the calculation of the 1st and the 2nd part) and b) cost estimation for servicing elements.

3.3.1. Cost estimation for the construction of building elements. Input for estimation of maintenance and replacement costs for individual building element (e.g. concrete, masonry, ceramic works) are the amount of its construction costs. Construction costs were calculated by using the norms [19], [20]. and the market prices of materials and labour. Cost estimation was performed by VO, representing a Project Management Software designed for the BIM approach and joining 3D, 4D and 5D BIM. VO was chosen because it can easily and very accurately determine the quantities required for cost analysis.

First we designed a detailed 3D BIM model of the business-storage building. The model was created in the ArchiCAD program (Revit, Allplan, or other Modeling Software), and afterwards imported into the VO. 5D BIM model for all structural and non-structural elements was subsequently developed in module Cost Planner. In this module we determined the individual building elements and divided them into the construction and finishing works, installations and external layout. An Element list created in VO is shown in Figure 2.
This was followed by the implementation of cost estimation: first, quantities (Source quantity) and norms (Consumption) of each resource are given; next, the final quantity (Quantity or Qty) with the appropriate unit of measure (UOM) and price per unit (Unit Cost) is determined; and finally, the total cost of each element is calculated in the Base Cost column. These costs were the basis for estimated costs for replacing and maintaining elements. Thus, costs of replacing are calculated according to the factor of theoretical replacement after 60 years while maintenance costs regard the factor for small repairs according to a new value.

Two examples of estimating the maintenance costs are presented here: for structural element i.e. reinforced concrete foundation, and for active technical systems i.e. heat pump air/water. The same lifetime as for a building is assumed for foundation, that is 60 years. The cost estimation in VO provided the initial value for their construction in amount of € 5500. Costs for small repairs are set out according to the regulations: 1 % from the initial value, i.e. a total of € 55. Costs are distributed evenly through the years of the building lifetime. The lifetime for heat pump air/water is estimated on 25 years. The price of new heat pumps with an installation was obtained on the market and calculated to € 7610. As stated in chapter 3.2, two replacements are planned (in 25th and 50th year) which amounts to € 15220. Costs for small repairs makes 10 % from the initial value, where the new value includes the replacement of pump, i.e. a total of € 1522. Costs are distributed evenly through the years of the building lifetime.

3.3.2. Cost estimation for servicing elements. We considered regular servicing costs for built-in installations and equipment for estimation of these costs. Regular servicing intervals are mostly prescribed by legislation, e.g. for fire protection equipment with Fire Protection Act [21]. We acquired prices for the services in the market by authorized service.

As an example we present the costs of servicing the heat pump air/water. We anticipated annual regular servicing costs, amounting to € 100. In the era of 60 years servicing each year is taken into account except the 1st, 25th and 50th year which equals 57 times.

3.4. Time analysis
The time analysis is created manually; bases on designed 3D BIM model represent the preliminary estimates of the costs and consider service intervals and lifetime of equipment. In VO so-called 4D BIM model is created in the module Schedule Planner. It represents a model with a time component and is created after the following steps: record of activities in order of priority; the connection of activities with the costs which have previously been defined in the module Cost Planner; provision of
the Schedule Planner module itself with the support of BIM converted working hours and duration of the activity in days for one work unit; setting the working calendar and determination of the links between the activities and the leading manpower and machinery. The results displayed in VO are Flow line View and Gantt View. Unfortunately, for the operating phase, which is 60 years in our case, such a display is not transparent. So we decided to perform the display of schedule for execution of maintenance work with the help of MS Excel (without connection to the elements in 3D BIM model).

4. Results and discussions

Based on the data obtained in the cost and time analysis, 6D BIM model was modelled to specify all costs for regular and investment maintenance in the intended lifetime of the building. The model was made in a unique way by using the VO (with connection to 3D BIM model) and the Microsoft Office Excel (without connection to 3D BIM model). We decided to display model in Excel because of more explicit visual overview of planned maintenance and since this work includes a large number of elements and is set for 60 years.

6D BIM model is made systematically in tabular form. It is a graphical representation of the schedule for execution of maintenance work in a way that the vertical axis represents the elements of the building and the horizontal axis time in years. The rows for individual elements are marked with different colours according to different activities of maintenance works, such as: regular cleaning, regular servicing, regular review, regular maintenance, replacement of damaged parts, element restoration, and paintings. We added a symbol in the field for the execution of maintenance work that indicates the performed type of maintenance, for example: regular servicing once a year, regular servicing several times a year, review and assessment of the situation, replacement, maintenance several times a year (lawn mowing), painting and impregnation etc. Therefore, the resulting table of the 6D BIM model gives the timetable for implementation of maintenance work. The table serves to the owner as a source of information and guidance about the expected maintenance mode for each year. Figure 3 represents section of the schedule for execution of maintenance work in the first 25 years for the heating and cooling system for the business-storage building.

| Item/element number and description | TIME AFTER CONSTRUCTION IN YEARS |
|------------------------------------|----------------------------------|
| 50 Heat pump air / water           | ![Table Rows]                   |
| 51 Heat pump air / air             | ![Table Rows]                   |
| 52 Air conditioning system         | ![Table Rows]                   |
| 53 Pipelines of steel              | ![Table Rows]                   |
| 54 Pipelines of copper             | ![Table Rows]                   |
| 55 Gate valves on the pipeline     | ![Table Rows]                   |
| 56 Floor heating                   | ![Table Rows]                   |
| 57 Electric heater                 | ![Table Rows]                   |
| 58 Pump for hot water              | ![Table Rows]                   |

- □ regular servicing 1x per year replacement
- ● regular servicing, maintenance and a review by the expert
- ● regular cleaning and maintenance
- ● regular maintenance according to the manufacturer

Figure 3. The schedule section for maintenance work execution for the business-storage building, [17]

The review and analysis of the results from the timetable and cost maintenance plan provides the owner with a simple overview of the building maintenance, classified on an annual basis and by individual groups of works. The adequate planning of relevant activities enables the owner to avoid unforeseen situations and problems regarding the functioning of the building, which could arise as a
result of improper maintenance. Also, the owner can avoid a situation where some elements are damaged due to their wear.

5. Conclusions
This paper presented an application of 6D building information model (BIM) of the real business-storage building in Slovenia by providing information for maintaining building details of costs and time intervals for the user of the building, i.e. Halder company, in a unique and transparent manner. Initially, features of building maintenance in general and according to the current Slovenian legislation and general principle of BIM were addressed in Introduction. Thereupon, basic description of business-storage building was given in Section 2. Step-by-step procedure for modelling 6D BIM model was introduced in Section 3. In addition, cost and time analysis was developed for the need of modelling 6D BIM. Cost estimation was performed by using VO software and time analysis was created, for better clarity, with the help of MS Excel (without connection to the elements in 3D BIM model).

The proposed 6D BIM model was modelled in a unique way, because of the lack of a uniform methodology to link the scope of FM and BIM approach. Also, the compatibility of software for FM and BIM is at a low level. The accessible literature has not yet detected a large number of studies and practical examples for this area which directs us to further research.

References
[1] F. Gould, J. and Joyce, “Construction Project Management,” 3rd ed., Prentice Hall, New Jersey, 2008.
[2] K. O. Roper, R. P. Payant, “The Facility Management Handbook,” 4th ed., Amacom, New York, 2014.
[3] Construction Act. Official Gazette of the Republic of Slovenia, No. 102/04, 126/07, 108/09, 20/11-Decis. CCS, 57/12, 110/13, 19/15.
[4] Housing Act. Official Gazette of the Republic of Slovenia, No. 69/2003, 57/2008, 56/2011-Decis. CCS, 87/2011.
[5] Rules on management of multiple dwellings. Official Gazette of the Republic of Slovenia, No. 60/2009, 87/2011, 85/2013.
[6] Rules on standards for the maintenance of apartment buildings and apartments. Official Gazette of the Republic of Slovenia, No. 20/2004, 18/2011.
[7] E.A. Pärn, D.J. Edwards, and M.C.P. Sing, “The building information modelling trajectory in facilities management: A review,” “Automation in Construction, vol. 75, pp. 45–55, 2017.
[8] C. Eastman, P. Teicholz, R. Sacks, and K. Liston, “BIM Handbook: A Guide to Building Information Modeling for Owners, Managers, Designers, Engineers and Contractors,” “2nd ed., John Wiley & Sons, New Jersey, 2011.
[9] Z. Pučko, N. Šuman, U. Klanšek, “Building information modeling based time and cost planning in construction projects,” Organization, technology & management in construction: An International Journal, vol. 6, pp. 958-971, 2014.
[10] Designing BuildingsWiki. BIM and facilities management. Available at: http://www.designingbuildings.co.uk/wiki/BIM_and_facilities_management [Accessed 7 Dec. 2016].
[11] L. Ding, Y. Zhou, and B. Akinci, "Building Information Modeling (BIM) application framework: The process of expanding from 3D to computable nD," Automation in Construction, Vol. 46, pp. 82–93, 2014.
[12] B. Becerik-Gerber, F. Jazizadeh, N. Li, and G. Calis, "Application Areas and Data Requirements for BIM-Enabled Facilities Management," Journal of construction engineering and management, Vol. 138, pp. 431-442, (2012).
[13] J.J. McArthur, “A building information management (BIM) framework and supporting case study for existing building operations, maintenance and sustainability,” Procedia
Engineering, Vol. 118, pp. 1104 – 1111, 2015.

[14] A.K. Nicał, and W.Wodyński, "Enhancing Facility Management through BIM 6D, ” Procedia Engineering, Vol. 164, pp. 299 – 306, 2016.

[15] Trimble Navigation, Ltd. Vico Office R5.2. Available at: http://support.vicosoftware.com/FlareFiles/Content/SupportLink/Downloads.htm [Accessed 9 Oct. 2016].

[16] Arhilab d. o. o. Business-storage building in Hoče, Final project, Maribor, Slovenia, 2015.

[17] D. Vincek, ”6D building information model of Halder d. o. o. enterprise in Hoče, ” Master thesis, Faculty of Civil Engineering, Transportation Engineering and Architecture, University of Maribor, Maribor, 2015.

[18] BIMobject® Corporation, Nimbus-Compact, Ariston, Available at: https://bimobject.com/en/ariston/product/nimbus-compact [Accessed 9 Apr. 2017].

[19] The norms and standards of work in the construction industry, Građevinska knjiga, Beograd, 2004.

[20] The norms for concrete and reinforced concrete work, Chamber of Craft and Small Business of Slovenia, Construction Section, Ljubljana, 2005.

[21] Fire Protection Act. Official Gazette of the Republic of Slovenia, No 3/2007, 9/2011, 83/2012.