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The BIM-based Integrated Design of the SHiP Project Decay Volume

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Abstract. The Search for Hidden Particles (SHiP) experiment is a new general-purpose fixed target facility proposed at the CERN Super Proton Synchrotron accelerator to search for long-lived exotic particles associated with Hidden Sectors and Dark Matter. This paper reports on the BIM integrated design of SHiP's decay volume, a conical steel vessel under vacuum that should host several large particle physics detector systems. The use of BIM characterized the design of the decay volume, both in the modeling and structural design phase, and in the process definition phase for the realization and implementation in the facility of the device. This procedure helps to minimize the risks of incorrect design and construction of the device during the whole process. With the automation of the virtual model and the use of interoperable software, in addition to speeding up the exchange of information, it is possible also to export the detailed information of the structural design directly to the numerical control machines for the prefabrication of the various steel modules. Then, the BIM approach to support the integrated design of the SHiP project decay volume from the conceptual planning to the construction phase is shown in this work.

1. Introduction

The Search for Hidden Particles (SHiP) experiment [1-7] is a new general-purpose fixed target facility proposed at the CERN Super Proton Synchrotron (SPS) accelerator to search for long-lived exotic particles associated with Hidden Sectors and Dark Matter. This paper reports on the BIM integrated design of SHiP's decay volume, a >2000 m3 conical steel vessel under vacuum that should host several large particle physics detector systems. As part of the SHiP experiment, the use of BIM characterized the design of the decay volume, both in the modeling and structural design phase, and in the process definition phase for the realization and implementation in the facility of the device. The design of the decay volume has been characterized by the writing of a visual scripting algorithm in a visual programming environment (Dynamo, 8), which allows the creation of complex geometries. This algorithm allows passing from static to dynamic design, reducing the time for modeling and optimizing the model through a series of comparisons between the different design solutions. The data contained within Revit's [9] adaptive families, used to model the individual elements that make up the decay, have been exported with the use of a specific scripting algorithm for this operation. The structural analysis has been performed with Robot software [10], importing the geometric model of

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Revit [9] into the software, transformed into a structural model using the Analyze nodes contained in Dynamo [8]. The realization of the decay volume, from the production in the workshop of the various panels to the assembly in the experimental area, has been divided into several work phases. During each phase, using the digital prototype, all the individual processes leading to the construction of the device were defined and designed, focusing on possible interferences that can arise during the whole process. To study this process, Navisworks software [11] has been used in order to combine the information from different software. The Navisworks software [11] also identified and corrected the interferences between the various models and those that can occur during the assembly operations of the structural elements of the device. The federated model in Navisworks [11] is used for sharing information and coordinating models with all stakeholders. This procedure helps to minimize the risks of incorrect design and construction of the device during the whole process. With the automation of the virtual model and the use of interoperable software, in addition to speeding up the exchange of information between the various work groups, it is possible also to export the detailed information of the structural design directly to the numerical control machines for the prefabrication of the various modules to the workshop. Then, the BIM approach to support the integrated design of the SHiP project decay volume from the conceptual planning to the construction phase is shown in this work.

2. Overview of the SHiP project

The SHiP research facility is composed of a large infrastructure with a dual detector system (Figure 1). The upstream system is specialised in the direct detection of Dark Matter and in performing measurements on neutrinos. The second detector system is dedicated to searching for decays of so-called Hidden Particles and allows probing a large variety of physics models with light long-lived exotic particles. It is based on a 50 m long decay volume followed by a spectrometer and by detectors for particle identification. A critical component of SHiP is the muon shield. It consists of a chain of magnets that deflect away from the detector the high flux of muons. The deflected flux of muons defines a conical region in which the decay volume and the detector systems may be placed. To suppress the background from neutrinos interacting in the fiducial volume, the decay volume must be maintained at a pressure of <10-3 bar by means of a vacuum vessel.

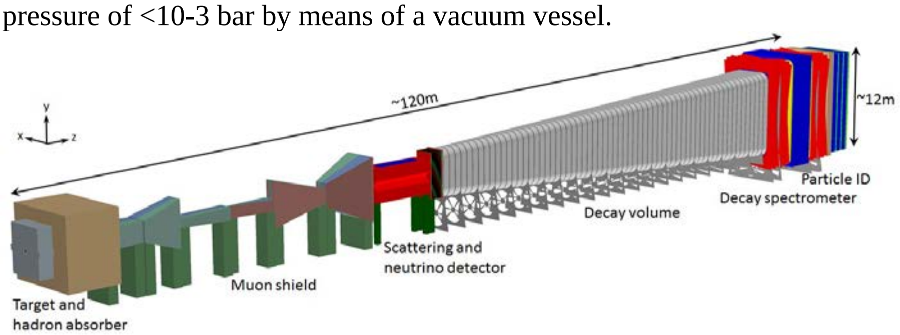


Figure 1: Overview of the SHiP experiment.

SHiP's vacuum vessel has a total volume of ~2040m^3 and logically consists of two parts, the volume in which a decay vertex is accepted, and the spectrometer section. The spectrometer section runs through the spectrometer magnet and lodges four tracker stations, which are symmetrically located with two stations upstream and two downstream of a large spectrometer magnet. An upstream and a downstream end-cap close off the ends of the vacuum vessel. To further ensure that signal candidates are not produced by neutrino or muon interactions in the upstream detector system or the decay volume walls, the decay volume is completely covered by a high-efficiency background tagger system, capable of detecting the charged particles produced in the interactions with the surrounding structure. The current baseline for the background tagger system is based on a "Liquid Scintillator detector" which fills the walls compartments of the decay volume. The dimensions of the experimental area (Figure 2) have been determined starting from the dimensions of the whole SHiP Detector.

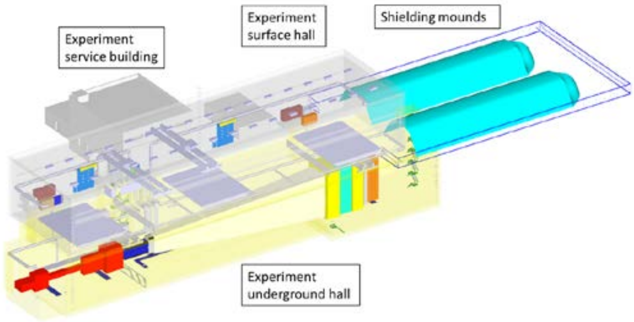


Figure 2: The experimental area.

The total length of the detector is around 120 meters. The assembly of the entire device determines the arrangement of the ground floor, access doors and cranes that will be used for handling loads. The dimensions of the opening on the floor have been chosen in agreement with the maximum dimensions of the individual elements of the device to be lowered. The decay volume will be pre-assembled on site in few big pieces, that will be then lowered in the underground experimental area, where have to be welded among them and connected with the other subcomponents.

3. Methodology

The whole methodology adopted is presented herein. With the use of Dynamo [8] and Revit [9] software, the decay volume has been modeled and imported into Robot [10] to carry out the structural analysis and the safety checks. Once the model has been verified, it has been re-imported into Revit [9] for the export of geometric data through the use of a Dynamo [8] script.

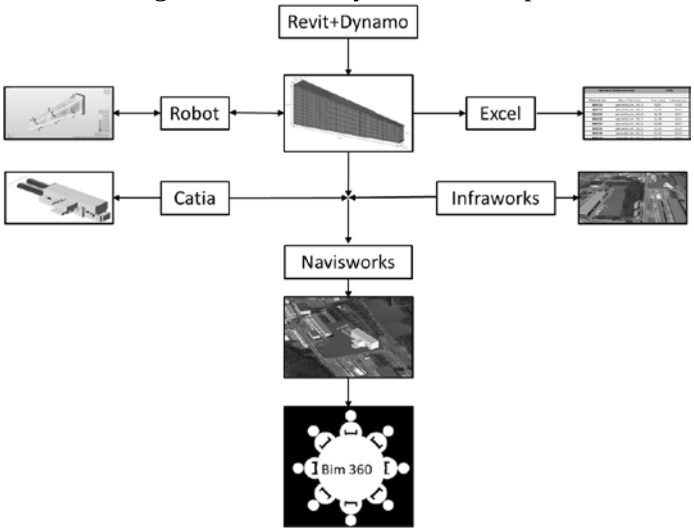


Figure 3: Flowchart of the BIM process.

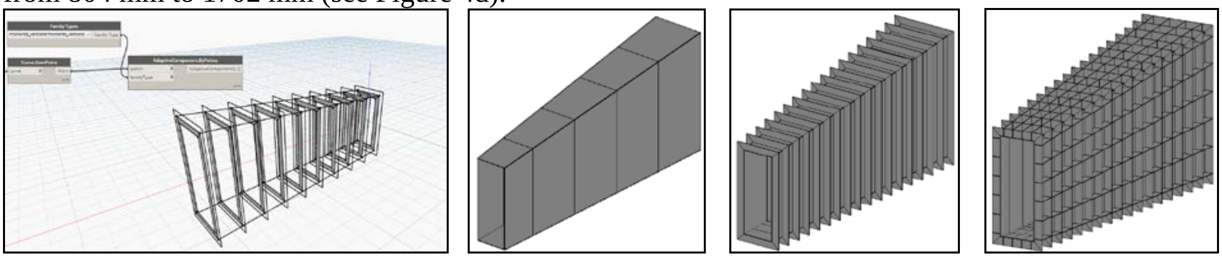
The decay volume model made with Revit [9], the experimental area model made with Catia [12] and the terrain and infrastructure surrounding the experimental area model made in Infraworks [13] were then federated into Navisworks [11]. The complete model has been used to study the assembly phases of the elements that make up the decay volume. The federated model is shared on a BIM 360-type platform, with which the various stakeholders can intervene throughout the device design and construction process. The described procedure is summarized in the flowchart presented in Figure 3.

4. BIM integrated design of the decay volume

4.1. Integrated design development of the decay volume

Considering the goal of minimising the masses and the constraints on the geometry, the steel structure has been chosen. The main conditions to consider in the design process were: a) the necessity to allocate space for the liquid scintillator inside specific compartments inside decay volume; b) the necessity of reducing the thickness of the steel plates as much as possible. Based on these conditions, a box section of S355JO (J2/K2)W Corten steel has been selected. The decay volume has been designed inside a BIM framework, using Revit [9] modeling software and using the open source visual platform, Dynamo [8], integrated directly into Revit [8]. The reason for this choice is that the BIM computational design allows designing highly flexible parametric geometries. The parameters are always editable within the chain of nodes in which they are structured. Any changes to these parameters are directly reflected on the geometry. The Dynamo [8] work environment is structured with nodes and relationships; the nodes manage specific functions and are connected to the other nodes, composing an uninterrupted flow of data (e.g. see Figure 4a). Writing this algorithm avoids the manual insertion of all the elements that form the decay volume, reducing the time for modeling. With this modeling approach, the accuracy of the model increases and the modeling errors are reduced. Finally, by changing the input parameters, it is possible to design structures with different geometries to optimize the structural model. The box section is made up by the following members:

- Inner and outer steel sheets with a thickness of 20 mm (see Figure 4b);
- Transversal stiffening members spaced by 800 mm, with a thickness of 10 mm and a height of about 400 mm (see Figure 4c);
- Longitudinal stiffening elements, with a thickness of 10 mm and with an interspacing varying from 804 mm to 1702 mm (see Figure 4d).



(a) (b) (c) (d)

Figure 4: a) *Adaptive.Component.ByPoint* node for the insertion of adaptive families within the generated surfaces b) Inner steel sheet; c) Transversal and d) Longitudinal stiffening members.

The model generated in Revit [9] through the use of Dynamo [8] software has been imported into Robot [9]. Then, the structural calculations have been performed with Robot [9]. Finally, the data contained within the elements of the model generated in Revit [10] were exported using a Dynamo [8] script. The script allows to export the output data and report them directly on an excel [14] type spreadsheet format. The various elements contained within the Generic Models category have been called up using the All Element of Category node. They have been connected with a series of nodes to know the surface, the volume, the element ID and the name. All this information has been sent to the *Data.ExportExcel* node through the List Creates node. Then, the *Data.ExportExcel* is used to write information in an excel [14] sheet.

4.2. Integrated constructive design of the decay volume

The presented study focuses also on a careful assessment of the assembly phases in the factory and situ. The fundamental principle is to give preference to prefabrication in the factory, a place equipped with multiple equipment, production machines and processing control protocols. This choice is assumed to allow the reduction of the imperfections/errors in the assembly phases on site. Then, the proposed fabrication processes are divided into two phases. The first one concerns the prefabrication in the factory, while the second one is all the on-site assembly processes through manual processing.

Regarding the factory production phase, a basic panel with a width of 2.4 meters with variable height will be produced in the factory workshop, using numerical control machines with thermal break. The welds will be carried out following specific procedures and sequences. During the assembly phase of the individual panels in the workshop, any deformations will be corrected by means of special procedures ("localized heating” and similar procedures) in order to guarantee the most severe execution class (EXC4) foreseen by UNI EN 1090-2 [15]. As a starting point, the various elements that make up the decay volume consist of an internal panel, a series of vertical and horizontal stiffeners and external panels for closing the individual cells for containing the liquid scintillator. The realization of the single components will be carried out through the use of numerical control machines, using the output data that can be obtained from the parametric objects that make up the 3D model of the decay volume, extrapolating the necessary information with the use of a special algorithm created in Dynamo [8]. The assembly phase involves first joining the vertical stiffeners, previously subjected to chamfering, on the internal panel by means of welds with complete penetration with filler material. The next step consists of inserting and welding the horizontal elements, which define the individual cells. The welds will be completely penetrated with filler material on elements subjected to chamfering. Finally, the external panels (Figure 5) are welded.

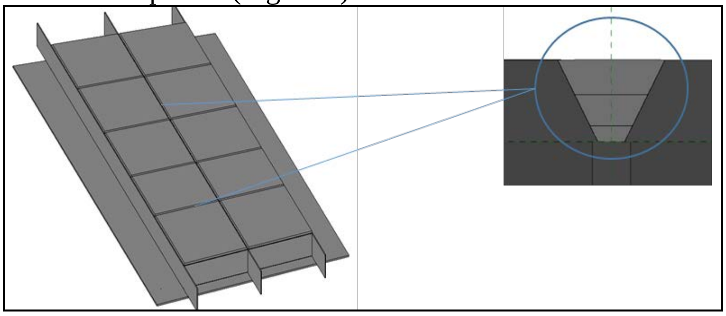
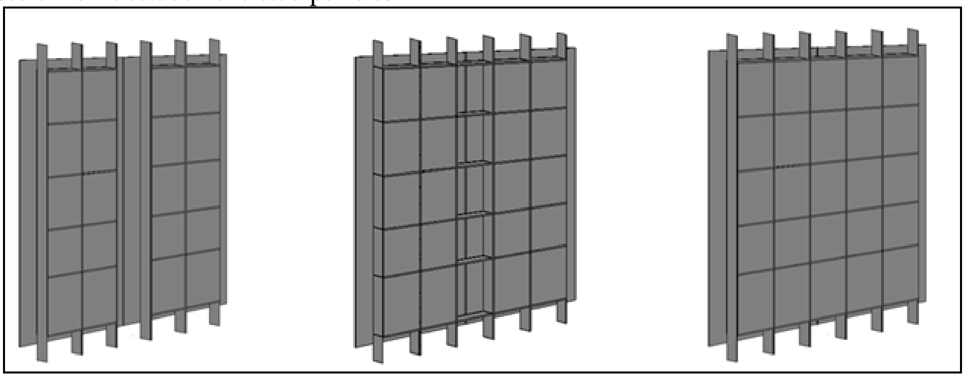


Figure 5: Welding of external panels.

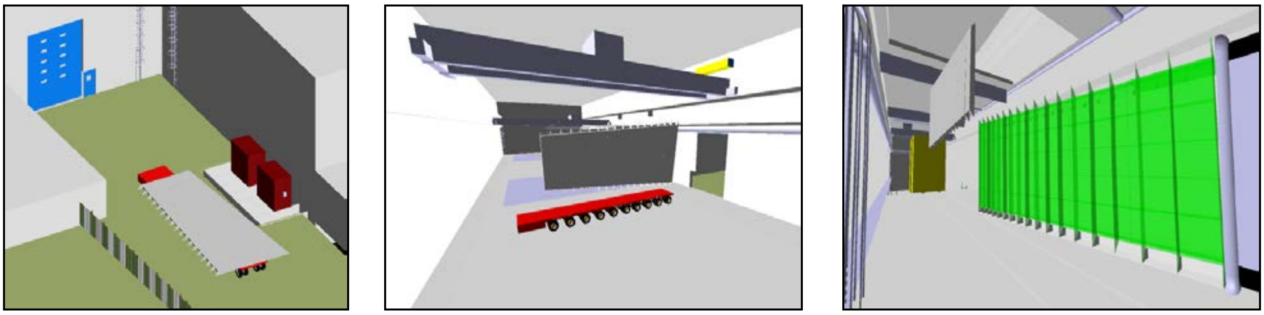
Regarding, the in-situ assembly procedures, once made, the 2.4-meter basic panels will be transported to the construction site to be assembled into a single panel consisting of a maximum of 6 modules. The decay has been divided into 4 blocks to minimize the number of welds to be made within the underground area, where the experiment has to be done. This subdivision into macro blocks allows increasing the flatness between the various panels. Figure 6 shows the main phases that lead to the complete union between the two panels.



(a) (b) (c)

Figure 6: a) Internal welding; b) Horizontal stiffening; c) External panels.

Then, it is crucial to plan the mounting sequence underground. After the transport within the experimental area by mechanical means and the movement with a bridge crane from the first floor to the basement, finally the panel will be positioned at the planned point, using slides. The whole process has been simulated with Navisworks [11] to identify the possible interferences that can occur during the entire construction phase of the device. The panel is transported within the experimental area by means of a mammoth type mechanical device. Arrived in the predetermined position, it is first raised, then moved to the opening that connects the ground floor with the basement and finally is lowered and positioned on special slides to be brought to the final position where it will be mounted. The most important operations are the transport within the experimental area, the handling of loads with the use of the bridge crane and the insulation of the panel on the detective SHIP (Figure 7).



(a) (b) (c)

Figure 7: Assembly of the decay volume in Autodesk Navisworks software [9]: a) panel transport in the experimental area; b) panel lifting by means of a bridge crane; c) panel assembly.

5. Conclusions

The SHiP experiment is a new general-purpose fixed target facility proposed at the CERN to search for particles associated with Hidden Sectors and Dark Matter. This paper reports on the BIM integrated design of SHiP's decay volume. The use of BIM characterized the design of the decay volume, both in the modeling and structural design phase, and in the process definition phase for the realization and implementation in the facility of the device. This procedure helps to minimize the risks of incorrect design and construction of the device. With the automation of the virtual model, it is possible to exchange information and to export the design to the numerical control machines for the prefabrication of the various steel modules. In conclusion, the BIM approach supports the integrated design of the SHiP project decay volume from the conceptual planning to the construction phase.

Acknowledgments

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6. References

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