The Introduction of MSE Wall Elements into the BIM Technology: The S7 Skomielna Biala – Chabowka Project of an MSE Abutment in Poland

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ABSTRACT: *Building Information Modeling (BIM) technology is a well-known methodology within the construction industry. However, it appears as a relatively new concept for geotechnical engineering structures where it has not yet reached a good level of soundness. BIM processes for structural engineering are based on three-dimensional parametric models which centralize geometrical, physical, and project information. Adopting this design methodology, the various users can interact and work together efficiently in every stage of the construction process. The use of BIM as a design tool can help in immediate visualization of the structure, and in noting its obstructions and constraints, if any. Furthermore, BIM could help secure the quality of the construction process, assist in the coordination between the designer and construction crew, and improve the safety on site. For all the aforementioned reasons, BIM methodology could provide excellent results when applied to geotechnical structures, particularly when applied to geometrically complex projects. This paper's goal is to introduce how a Mechanically Stabilized Earth (MSE) system can be modeled in BIM and how the created elements can then be used in the design of the structure. The S7 Skomielna Biala – Chabowka MSE approaching ramp and abutment were designed both with BIM and the traditional tools to compare them in terms of speed, precision, and cost-effectiveness.*

KEYWORDS: BIM technology, BIM modeling, MSE walls, Polymeric strips

SITE LOCATION: Geo-Database

INTRODUCTION

Building Information Modeling (BIM), first introduced as a concept in the 1970s, is a technology which offers integrated platforms that can improve the design and construction by enabling faster delivery of projects. BIM also provides a continuous flow of information which can be exchanged among the stakeholders, and which can be used during all the decision-making processes (Eastman et al., 2008).

The use of BIM software goes beyond the planning and the design phases, and extends to the whole project lifecycle, supporting the construction processes, project management, and the management of facilities and the maintenance of infrastructures. As a matter of fact, the approach used in a BIM design is to define a certain amount of "parametric objects" as parameters that are related to other objects within the project. The parametric objects are mostly geometric and qualitative attributes since they are easy to combine with all the main distinguishing features of the projects; therefore, if a related project is modified, even dependent objects will automatically change (Biancardo et al., 2020).

Even if in the first phase of the design all the operations done to develop a BIM parametric object can lead to a time-consuming process, the time invested in good object modeling will be fully rewarded in the later stages thanks to the simplifications given by the "three-dimensional informative model." The procedure allows an optimization of the control of the construction processes which bring cost savings compared to the traditional process (Garagnani, 2016).

Submitted: 30 June 2021; Published: 1 October 2022
Reference: Trovato, F., Lugli, G., and Intrevado, G. (2022). The Introduction of MSE Wall Elements into the BIM Technology: The S7 Skomielna Biala – Chabowka Project of an MSE Abutment in Poland. International Journal of Geoengineering Case Histories, Volume 7, Issue 2, pp. 1-12, doi: 10.4417/IJGCH-07-02-01

The implementation of Building Information Modeling (BIM) within the architectural, structural, and construction fields is increasing worldwide thanks to the significant benefits that this technology can bring to a project: easier visualization of the structures, reduction of the amount of rework, and increased productivity and coordination between the project stakeholders when compared to traditional design procedures.

In Europe, several millions of euros have been invested by the state governments to support the implementation of new digital technology for the construction industry. However, the approaches to BIM technology are significantly different. Germany, for example, has started with national associations and working groups to implement pilot-projects with a bottom-up approach, while the Italian strategy was to create a national standard (UNI 11337) to enforce the use of BIM for any large-value infrastructure, reducing year after year the total value of the projects that need to use BIM as their construction methodology. Finland has been supporting BIM from the very early stages and has adopted this technology since 1996, while the UK is one of the leading countries in this digital process and has built a growing strategy where BIM is used to improve projects' construction costs and time, export need, and CO_2 emissions (McAuley et al., 2017) (UNI 11337).

Even though BIM tools enable the development of building projects from the early design stages to the most complex construction phases, the development of BIM technology within some of the transportation infrastructures (roads, highways, railway, bridges, etc.) has not yet reached the same level of robustness of the building industry (Biancardo et al., 2020). In addition, a BIM design in the transportation infrastructures field is more complicated than punctual construction in the building sector: the infrastructures are georeferenced and extended for several meters or kilometres and need to be adapted to the surrounding area as compared to the structural building work that are contained in smaller dimensions. This means a slower implementation of the digital models among the engineering firms, but it is also due to the lack of BIM objects implemented by manufacturers of civil engineering products that could be easily used in the design of the most common geotechnical structures.

Understanding the needs of those designers who were willing to adopt the technology even in geotechnical projects, Maccaferri has developed BIM objects that can be used in various geotechnical engineering applications, such as Mechanically Stabilized Earth (MSE) retaining walls and reinforced soil slopes (RSS), basal reinforcement, roads stabilization, etc. This paper focuses on a project where a proprietary MSE wall system with concrete facing panels and geostrips was adopted and examines how all the system elements have been modeled using a BIM-based tool. The paper also includes a comparison between the output of the traditional 2D design and the BIM application, highlighting the benefits and clarifying the issues that might arise during the design. The case study of the S7 Skomielna Biala – Chabowka MSE approaching ramp in Poland is presented.

CASE STUDY

The project consists of a 165 m long bridge approaching ramp on the S7 Expressway Krakow- Rabka-Zdrój supported by MSE wall technology on one side and a 1:2 slope on the other side. The ramp reaches a maximum height in the central portion of the structure and close to the abutment approach of 12.86 m and a minimum height of 7.44 m. The reinforcements range from 0.8H at the bottom to 0.7H after the first few layers (Figure 1 and Figure 2).

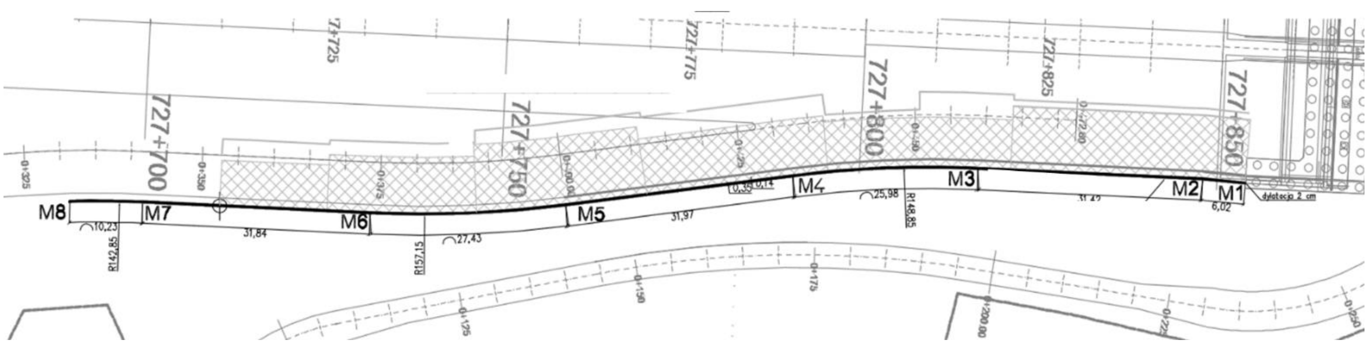

Figure 1. Approaching ramp plan view with reinforcement layout

Figure 2. MSE bridge approaching ramp elevation view during construction.

MSE Wall System Details

The MSE wall selected for this project is commercially known as the MacRes System (Figure 3). The system features segmental precast concrete facing panels and layers of ParaWeb reinforcements, planar geostrips manufactured from high tenacity polyester yarns aligned and co-extruded with linear low-density polyethylene (LLDPE).

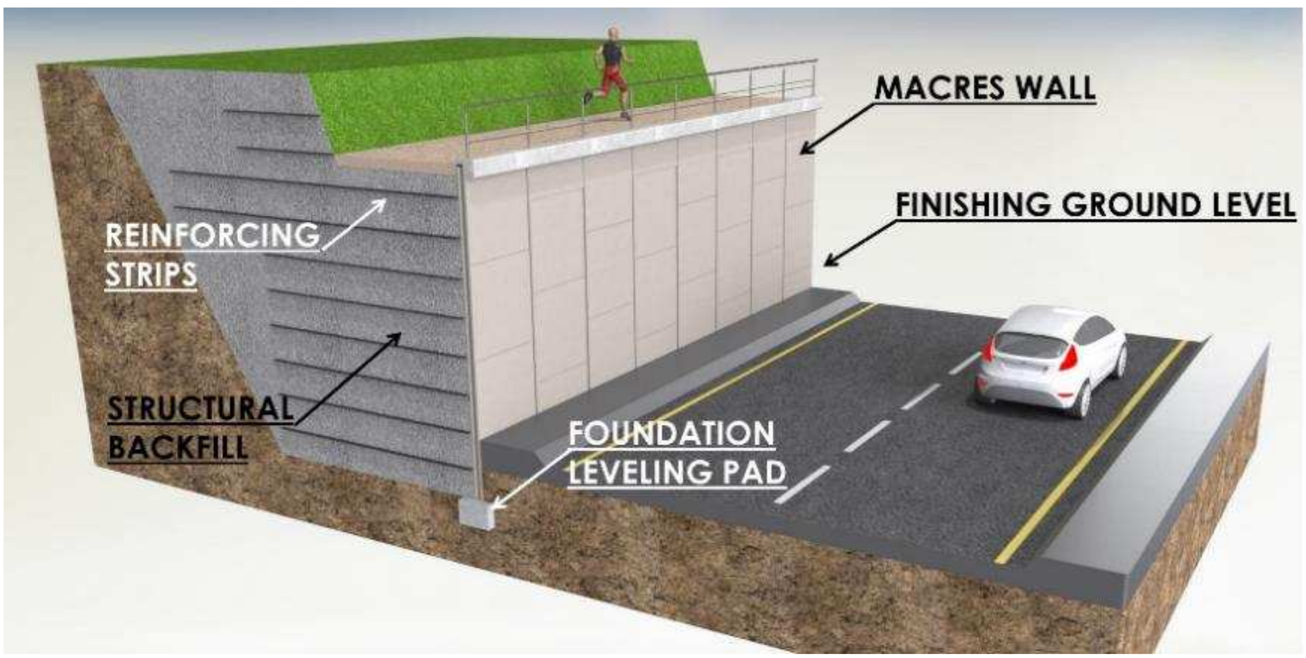

Figure 3. Mechanically stabilized earth wall system.

The panels selected for this project are standard square panels (1.50m by 1.50m), 14 cm thick. The reinforcement is connected to the panels using a polymeric loop made of the same geostrip material and protected by a High-Density Polyethylene (HDPE) saddle to ease the installation of the geostrips (Figure 4). The reinforcing geostrips, the key structural component of the system, are continuously threaded through the connection and looped back to extend in a "V-shape" configuration. The geostrips are available in a wide range of tensile strengths, different thicknesses and widths to accommodate higher loads or pull-out strength requirements. The number of connections, the reinforcements' length, and the strips' grade are defined based upon the result of the stability checks.

Figure 4. Geostrip reinforcements connected to the loop (on the right) and extending from rear of panel.

The MSE wall is built on top of an unreinforced, cast-in-place concrete leveling pad, generally 150 mm thick by 300 mm wide, which serves as a smooth, level surface for placing panels. Properly constructed leveling pads aid wall erection efficiency and aesthetics at both the bottom and upper portions of the wall.

All horizontal joints between panels have elastomeric or polymeric pads to prevent concrete to concrete contact at the horizontal panel joints. To prevent erosion of backfill through the joints, 30 cm wide strips of geotextile filter are placed behind the panel, across panel joints (Figure 5). When a drainage system is required, to allow free drainage of the reinforced fill, the geotextile can be replaced with appropriate drainage geo-composite, always cut in strips and connected to a perforated pvc pipe.

Figure 5. Drainage geo-composite behind concrete facing panels.

The top of top-course panels might remain exposed (i.e., stepped top), but can be capped by a cast-in-place treatment (i.e., barrier or coping) or a precast coping to provide a uniform and aesthetically pleasing geometry along the top of the retaining wall.

Project Design

The characteristics of the backfill material in the project were such to require a soil stabilization with lime to improve the engineering properties of the soil. According to DIN 18123, the soil was classified as fine-grained soil with 50% or more passing the No. 200 (Figure 6).

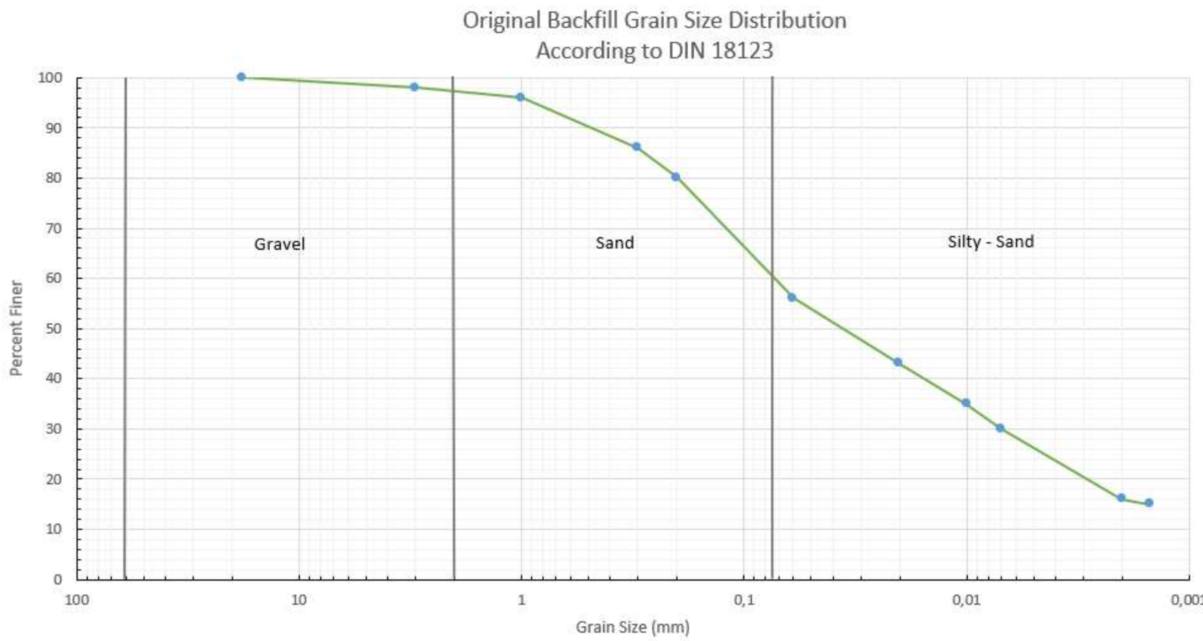

Figure 6. Backfill grain size distribution.

The use of lime can modify almost all fine-grained soils to some extent, but the most dramatic improvement occurs in clay soils of moderate to high plasticity. Soil stabilization using lime is beneficial for improving the quality of the on-site soil, resulting in significant savings of resources and costs. This procedure is covered by standards and specifications and has been used in several MSE wall projects worldwide (Misano, 2006) (Lugli et al., 2016).

The soil stabilization occurs when the proper amount of lime is added to a reactive soil, therefore the on-site material was improved according to the Engineer of Records requirements by adding 1.5% of lime hydrate. The result of soil stabilization typically provides higher resilient modulus values and increase in soil shear strength, even over decades of service (Burgoyne et al., 1993). Even though the soil stabilization improves the properties of the backfill material, this being a fine-grained soil, a pullout test was performed to proceed with the most accurate wall design. The determination of pullout resistance in soil was performed according to DIN EN 13738. The strip tested was a narrow one (49 mm), to test the most conservative scenario. The results obtained are described in the table below and were considered during the design stage.

Table 1. Pullout resistance in soil (according to DIN EN 13738).

Test No.	Normal Stress [kPa]	Max Pullout Resistance [kN/strip]
1	50	4.093
2	75	4.286
3	100	5.402

The soil modification occurs because of the exchange of calcium cations from the hydrated lime, and due to the hydrated lime reacting with the clay in a high-pH environment. Studies and on-field experiences have shown that the highly alkaline environment (pH over 12) typically lasts only 48 hours (Lugli et al., 2016) (Elias et al., 1988).

The geostrips selected for the project were certified by the British Board of Agreement (BBA) for chemical degradation up to a pH of 11 and a design life of 120 years. However, the BBA Certificate n. 12/H191(2019) also mentions that the most aggressive fills are usually of fine particle sizes, which may cause little or no damage to the polyethylene sheath. In such a case, the polyethylene sheath, which acts as a chemical barrier to protect the polyester load bearing fibers (Greenwood et al., 1996), allows the straps to be used in soils with pH levels up to 12, without further increase to the reduction factors (RF_{CH}) given for pH levels 9.6 to 11.0. (refer to Table 2). Professor Jochen Müller-Rochholz (Müller-Rochholz, 2021) mentions that lime-stabilized clay, silt, and fine sands do not damage the LLDPE-sheath; furthermore, with an undamaged PE- sheath, pH values up to 14 are tolerable.

The design of the internal, external, and global stability analysis of the structure has been carried out by taking into consideration the combination DA2 and DA3 of the Eurocode 7. The irregular inclination of the existing ground level (that ranged from a minimum inclination of 3° to a maximum inclination of 18°) required a minimum excavation of 1.20 m below the in-situ soil to ensure a firm and horizontal foundation to the MSE structure. The excavation led to the definition of stepped foundation levels and a variable wall elevation. Five significant sections, which differ in height, were selected along the wall and analyzed for design purposes.

A traffic load surcharge of 25kPa was considered along the ramp and applied as a strip live-load. The site is located in a non-seismic area; therefore, the stability checks have been carried out in static condition only. Loads were amplified according to the Eurocode 7 requirements. The reinforcing strips used in this project are presented in Table 2. Wider geostrips were selected and used in the upper portion of the wall to improve the adherence of the reinforcement to the soil.

Table 2. Mechanical properties of reinforcing geostrip used in the project (according to BBA HAPAS certificate 12/H191).

Ultimate Tensile Strength (UTS) [kN]	Width of the Geostrip [mm]	Creep Reduction Factor (T=20°)	Durability Reduction Factor (9.6<pH<11 @100 Yrs Design Life)	Installation Damage Reduction Factor	Factor of Safety for the Extrapolation of Data
30	83	1.38	1.11	1.05	1.05
27	46	1.38	1.11	1.10	1.05
36	47	1.38	1.11	1.05	1.05
45	48	1.38	1.11	1.05	1.05

The reduction factors for creep, installation damage, and durability were selected for a structure design life of 100 years and a design temperature of 20°, as per project requirements.

The interaction between geostrips and structural soil plays an important role in the stability analysis of the MSE wall. As explained above, the soil parameters and the pullout resistance of the narrow geostrips in the soil were determined through laboratory tests. The external laboratory test results taken into consideration for the internal stability check of the MSE wall are shown in Table 3. The material tested, according to DIN EN ISO 12957-1, was characterized by a friction angle of 27.4 degrees and a cohesion of 46.9 kPa.

Table 3. Laboratory test result of friction characteristics and pullout resistance in soil with 1.5% lime hydrate.

Test	Standard	Unit	Result
Determination of friction characteristics	**DIN EN ISO 12957-1 05.2005**		
angle of friction φ_{sg}		degree	27.4
cohesion c_{sg}		kPa	46.9
Remark: internal sear test of soil with 1.5% lime hydrate			
Determination of pullout resistance in soil	**DIN EN 13735 02.2005**		
Maximum pullout resistance			
Normal stress			
50 kPa		kN/strip	4.09
75 kPa		kN/strip	4.29
100 kPa		kN/strip	5.40

The high adhesion value is a consequence of the soil stabilization process: the lime hydrate reacts with the water in the voids of the soil, and it releases heat. This implies an immediate decrease of the plasticity index and the soil change, becoming harder with high cohesion. This process improved both workability and load-bearing characteristics while increasing stability and impermeability.

Since cohesion highly influences the active soil pressure, reducing the pressure force arm and therefore the destabilizing overturning force and sliding on the MSE wall, its value was conservatively taken equal to zero in the internal, external, and global stability analyses.

The global stability analysis was checked via a proprietary software, which is a 2D design software developed to check the stability of reinforced and unreinforced soil structures. The software is validated by a third-party engineering firm and it is comparable with other commercial software such as Plaxis, GeoSlope, Slope-W, etc. For the stability analysis of the slopes, different calculation methods exist and each gives a final equation that defines the safety factor. The methods implemented in this software are the Bishop Method (1955) and the Janbu Method (1954), or their simplified versions. The stability analysis of these methods is the global limit equilibrium one. This verification is made by analysing a certain number of possible sliding surfaces to find the one that represents the minimum relation between available resistance at break and the effective one; the value of this relation constitutes the safety factor of the slope. For this project, the Eurocode 7 combination selected for the global stability was A2+M2+R3 and the stability was analysed with circular surfaces according to the Bishop Method. The safety factor obtained in this configuration is 1.39. Figure 7 shows the results from the global stability checks of the taller section.

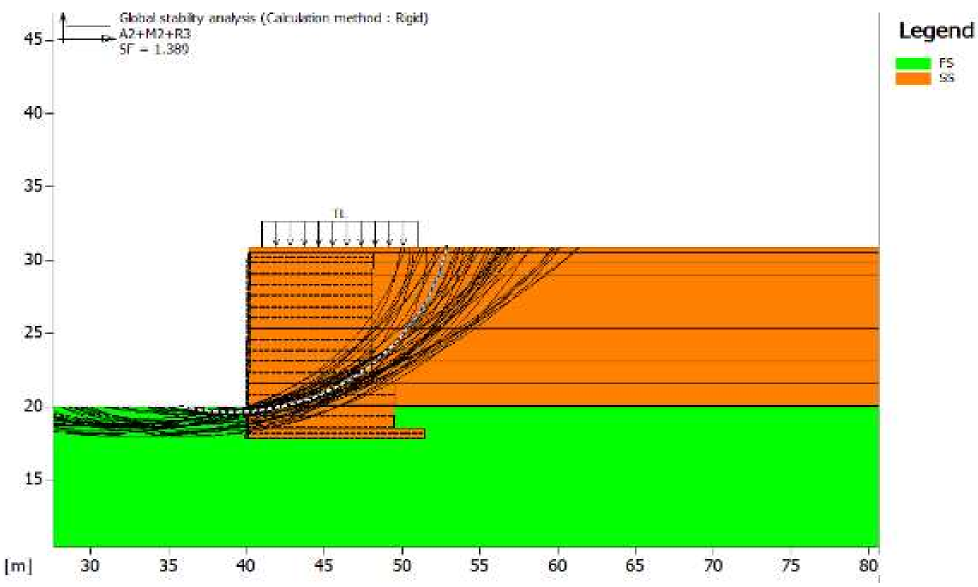

Figure 7. Global stability analysis for the section H=13.27 m.

The internal and external stability analyses were performed with a proprietary software, applying the Eurocode 7 partial factors as per project requirements. The stability checks were carried out for several sections with the use of a dedicated graphic software for the representation of the wall elevation (Figure 8) and cross section.

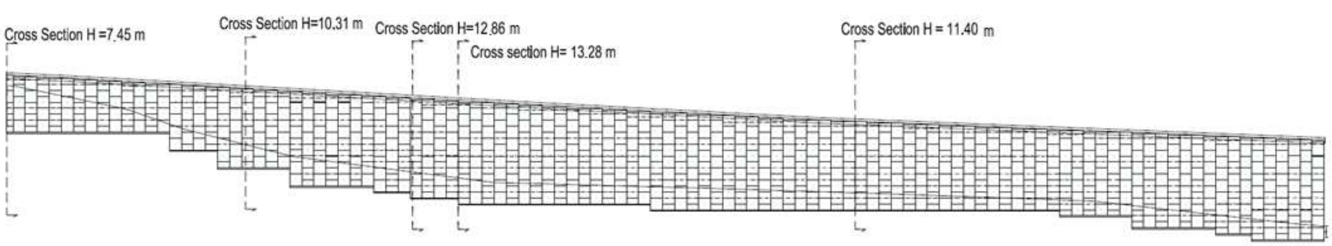

Figure 8. 2D wall elevation from graphic software

Quantities of most relevant materials are shown in Table 4.

Table 4: Quantity of the material of the project

Material	Quantity	Material	Quantity
Precast panels	843 pcs	Geostrip 36kN(*)	11900 m
EPDM pads	1478 pcs	Geostrip 45kN(*)	26700 m
Geostrip 30kN(*)	3600 m	Geotextile	2600 m
Geostrip 27kN(*)	13800 m		

(*) Characteristic short-term tensile strength.

3D MODELING OF THE COMPONENTS OF THE MSE SYSTEM

The goal of this paper is to explain how the design of the wall, initially carried out as a 2D geometry, has been successfully implemented in BIM design. The BIM model was implemented as a "back analysis" approach: based on the realized structure and the actual quantities of material delivered on site, the MSE wall model was created/calibrated to best represent the real in-situ installation of the wall combined to a high level of detail of the single components.

The first step for the translation of the 2D standard design into a BIM design is the creation of the BIM objects that compose the MSE system. For this purpose, Autodesk Revit software was adopted to create the objects.
Many standard and customized panels were prepared to be applicable in different projects. For this reason, a BIM "Curtain Wall" model was used to create all the different shapes and sizes of the concrete panels. The polyester geostrips were modeled as Geostrip-GST Elements, while the MSE wall components (geotextile, polymeric loops and virtual connections, coping beam, and corner element) were modeled as Generic Models (Figure 9).

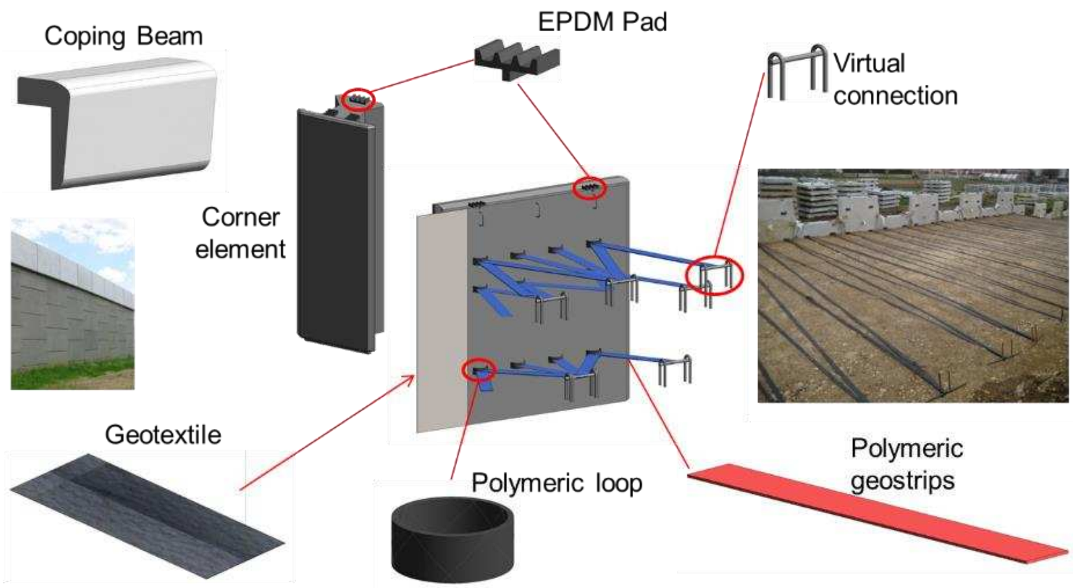

Figure 9. MSE wall system components.

The polymeric strips were modeled to take into account the wide variety of the reinforcements' grades and widths. In fact, every grade of polymeric strips is defined by a material parameter which is color-coded according to the grade of the Ultimate Tensile Strength (UTS) of the strip. The polymeric strip object is also linked to a length parameter. Moreover, a group of parameters was assigned for each extrusion which defines the starting and ending position of each layer of geostrips. Different reference planes were created to which the end of the geostrips extrusions and polymeric loops were linked (Figure 10).

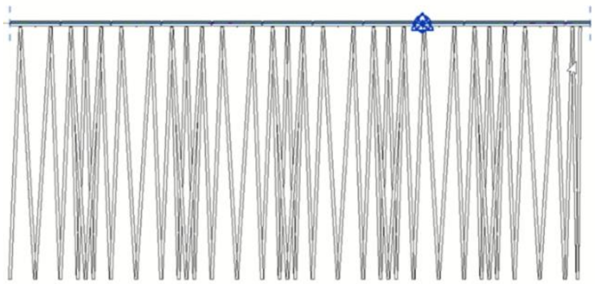

Figure 10. Polymeric strips linked to the reference planes.

The main advantage of working with parametric modeling is that it enables the users to work on pre-established models which can be edited at any time during the design process by inserting new parameters with great potential also in the creation of BIM libraries. Thus, the user does not model each element from scratch; once the first element is modeled, other elements can be immediately extracted, simply assigning the correct input data in the element properties window, within the project.

The BIM objects were made available to the users through external archives (libraries), which can be downloaded from an online BIM platform. The libraries can be uploaded into the project and the designers can select only the most appropriate libraries they intend to use and therefore avoid downloading useless files.

IMPLEMENTATION OF 2D GEOMETRY TO A BIM DESIGN

Once all the families of the BIM library were created, the operating procedures and management of the project information model were defined. By means of a topographic curve, a digital terrain reconstruction was carried out and the infrastructure project was imported by using the georeferenced coordinates. The origin of the Revit Model was set at the toe of the wall. The 2D wall elevation was imported to have the reference line for setting elevations and panel position of the 3D model. The 3D model was created step-by-step according to the construction guidelines of the MSE wall system.

The installation of MSE wall starts with the foundation soil preparation that consists of excavating the existing ground level up to the leveling pad elevation defined in the design. A BIM approach allows users to automatically calculate the excavation volume for the foundation soil preparation through the function “Calculate Cut and Fill Volumes” (Figure 11).

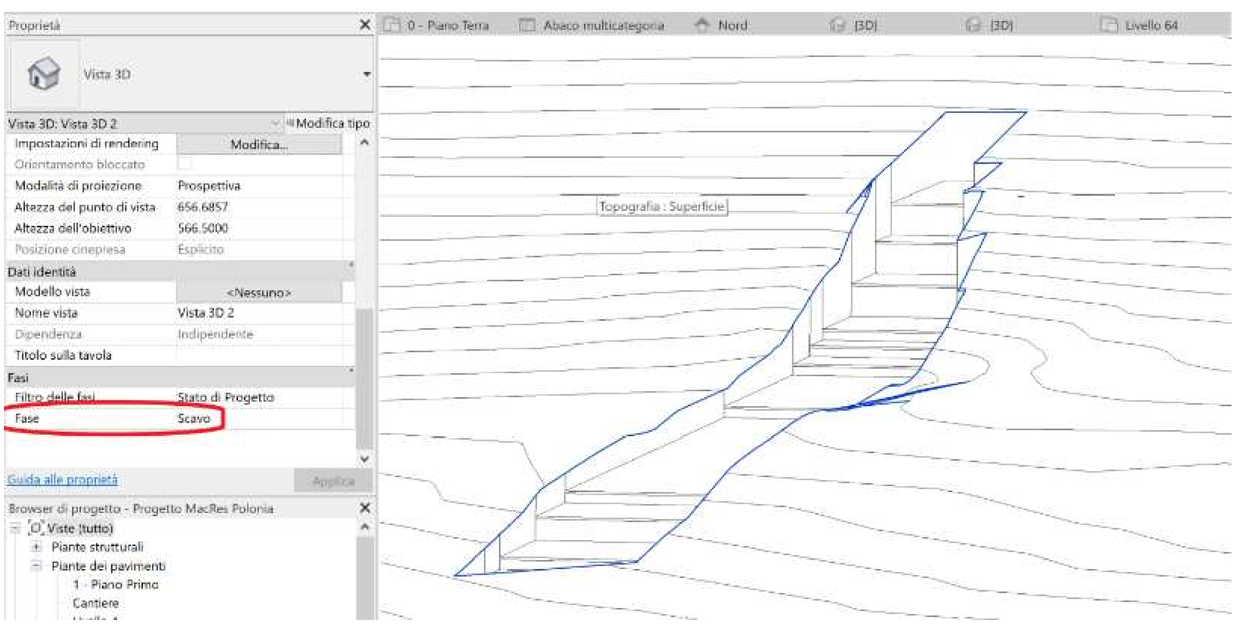

Figure 11. Foundation soil preparation and characterization of the project steps.

The wall was realized by adding the family called "Standard & Cut Panels," which belongs to the MSE panel family in the library. Once the family was uploaded into the project, the wall layout was created by selecting the wall elements and adding to the elements the project design parameters [15]. The elevation view created in BIM is shown in Figure 12.

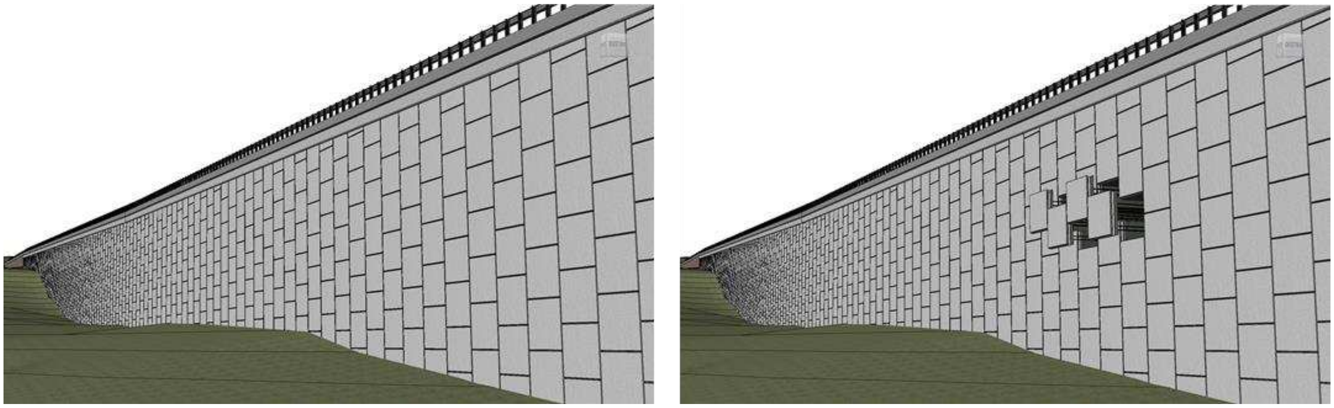

Figure 12. 3D view of the MacRes system digital model showing the Paraweb geostrips and wall elevation.

The 3D model allows users to manage a consistent amount of data that characterizes the geotechnical and infrastructural model within the same software. This information represents an added value to the project in terms of consistency and feasibility. At the end of this process, the material quantities were calculated to carry out an accurate bill of the quantities. The main purpose is to produce an informative 3D model useful for the operation and construction phases. Such an integrated model allows users to build infrastructures where the design phases of the structure will be smoothly linked to the relevant subsequent operational and post-construction management phases. The quantification phase reaches levels of detail directly connected to the Level Of Development (LOD) of the designed structures. The more advanced the LOD is, the more accurate the bill of quantity of materials to be supplied.

The model was able to check the design integrity, eliminating mistakes and bugs using a clash detection. The clash detection also minimizes the need for rework on site and enables a more efficient material management; a precise bill of quantities reduces the costs and minimizes the stock area. Being able to anticipate the precise costs of the earthworks and substructures is one of the interesting and useful features of a BIM-oriented design that allows its users to minimize unforeseen expenses. For this project, a high level of detail was reached thanks to the use of BIM elements that were precisely modeled, including all the attributes related to the project itself.

As an example, the main element of "Standard Panels" can be associated not only with the total amount of concrete [m^3] needed for precasting the panels, but also with additional attributes associated to the panels such as:

- Number of loops;
- Total weight of steel rebars;
- Total length and types of geosynthetic strips per panel;
- Number of EPDM pads;
- Linear meters of coping beams.

A BIM-oriented design can also carry out the bill of the quantities of all the materials not directly connected to the MSE system itself, but which are still needed by the contractor to build the wall, such as the volume of structural soil fill to be used on site in m^3, the virtual connecting anchors for the installation phase. The quantity of the materials extracted from this project BIM model is shown in Table 5.

Table 5. *Quantity of the material of the project coming from the BIM design.*

Material	Quantity		Material	Quantity	
Precast panels	843	pcs	Geotextile	2330	m
EPDM pads	1444	pcs	N. virtual connection	3528	pcs
Geostrip 30kN	3000	m	N. loop	3384	pcs
Geostrip 27kN	15700	m	Linear meter of Coping beam	165	m
Geostrip 36kN	11300	m	Volume of Structural Soil	18874.37	m^3
Geostrip 45kN	25300	m	Total amount of concrete C30/37	251.47	m^3

From a comparison between the quantities extracted from the 2D standard design (see Table 4) and the BIM model results (Table 5), it is possible to see that quantities of the components are comparable, with the exception of 30 kN and 27 kN geostrips where values differ around ±15% compared to the quantities delivered on site and the geotextile where the quantities delivered on site exceed by 10% what was really needed (Table 6).

Table 6. Comparative analysis of the BoQs from the two approaches.

Material	Quantity from 2D Design (Delivered On Site)	Quantity from BIM Model	Differences	Differences %
Precast panels [pcs]	843	843	0	0
EPDM pads [pcs]	1478	1444	34	2.35%
Geostrip 30kN [m]	3600	3000	600	20.00%
Geostrip 27kN [m]	13800	15700	-1900	-12.10%
Geostrip 36kN [m]	11900	11300	600	5.31%
Geostrip 45kN [m]	26700	25300	1400	5.53%
Geotextile [m]	2600	2330	2330	11.59%

A back-analysis was carried out to understand the reasons for the discrepancies. that the discrepancies were due to the quantity in the 2D design being based on the calculated class of heights and not on the real 3D geometry of the wall. In fact, because the MSE wall is an approaching ramp to the bridge, and thus the elevation of the wall varies along the wall chainage, this perhaps led to an error in the evaluation of the bigger quantities of geostrip 30kN (used at the top of the wall) compared to the geostrip 27kN used just below the 30kN layers. Furthermore, to take into consideration the loss of material on site, a certain percentage of wastage was applied in the 2D design, while the 3D design calculated the real quantity of material needed. The excessive quantity of geostrip 2D30 in comparison with the lack of quantity of geostrip ME27 is a clear example that a standard 2D design can lead to inaccuracies when evaluating the total amount of material to be delivered on site, especially if the geometry of the structure is not linear but fluctuates along the wall chainage. This will lead to extra costs due to delays to the construction.

CONCLUSION

Building information modeling is taking a central position in the digital transformation of the construction industry. Thanks to the transparent and seamless flow of information between all the interested parties involved in the project, BIM technology facilitates the collaboration of the stakeholders, reducing the loss of information.

Several benefits can be obtained from modeling a project with BIM tech, thanks to its faster delivery and growing business opportunities, which leads to minimized costs, delays, and wasted resources. Nowadays, the implementation of BIM technology is a well-established methodology in the architectural and construction fields, but it appears a relatively new concept in the transportation industry since it is complicated to model georeferenced infrastructures made of complex substructures (such as bridges, underpasses, overpasses, retaining walls, etc.). This means a slower implementation of the digital models among engineering firms that, very often, are not able to find BIM libraries implemented by the manufacturers of civil engineering products.

The purpose of the paper is to share the results obtained by modeling all the components of a proprietary MSE wall system in a BIM design, highlighting the benefits and the potential that BIM technology can offer. The creation of the BIM library, by using a well-known commercial software, enables the users who want to design a MSE wall in BIM to easily implement the elements into their design. Consequently, users can have an immediate and clear view of the structure and eventually analyze any interference that might occur between the MSE structure and potential obstructions (such as concrete piles, water inlets, or existing structures in the vicinity of the wall), therefore ensuring the consideration these factors in the design stage and avoiding any re-design issues in the construction phase. The use of a BIM approach minimizes the inaccuracies in the bill of quantities of the material delivered on site, granting higher efficiency to the project management while significantly saving money and time.

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