Design optioneering for the definition of technological solution of envelope using BIM

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Abstract

The research conducted has developed a simulation tool meant to help the designer in the selection of the most appropriate technological solution for building's envelope. The goal was reached combining the parametric nature of Building Information Modeling and computational design techniques. By writing a code in visual programming language (VPL), a design optioneering algorithm has been set up to define and compare several alternative technological solutions and perform technological choices. The method was applied to a horizontal partition towards an unheated space and to an external wall. The optimization, focused on sustainability, constructability and economic issues, led to the implementation of a wood-fibres insulation layer for the slab and a rock-wool one for the façade wall both on the internal and external side.

Key Innovations

- VPL script was designed and written entirely autonomously and therefore no previous and specific reference can be found.
- The tool proposed can be applied in the preliminary design stage. Filtering the generated solutions, different and often conflicting aspects can be evaluated in order to satisfy different needs.
- While most of the studies in literature focus on the overall analysis of the buildings, the research proposes a specific methodology for the technological components.
- The tool created could even be used by designers not-expert in computer technology.

Practical Implications

In the definition of the variability ranges for design parameters in the VPL script, the designer must always comply with the legislative minimums for each considered topic. The comparison with further disciplinary aspects (buildability, cost-effectiveness, environmental sustainability) can instead be indicative for the definition of boundary values that cannot be exceeded.

Introduction

The choice of materials and components used in newly designed buildings is relevant to meet requirements about the following issues: i) energy, ii) mechanical, iii) acoustics, iv) environmental, v) economic, vi) specific of construction sector (buildability, maintainability, etc.). The preliminary research phase of a project is crucial to identify the right technological solutions able to ensure the fulfilment of the requirements mentioned before and, in addition, the ones connected with overall sustainability. Decisions made in the early stages of the design process can have a great impact on the final quality of the project and the designer, dealing with the research of the best compromise solution, must necessarily consider multidisciplinary aspects. The decision-making process is constituted in this sense as a multifactorial optimization problem and therefore modern digital tools can support designers in the analysis of alternative solutions. Given this framework, the research intended to suggest a methodological workflow for the definition of the envelope stratigraphy recurring to optioneering procedures.

Background

Concurrently with the development of new energy and environmental performance requirements, the construction sector is facing a digital revolution. New design management techniques and simulation tools are nowadays emerging trends. This is the case of Building Information Modelling (BIM), which is introducing working methodologies based on the definition of procedures and technologies that can ensure digital and multidisciplinary management (Eastman et al., 2011) (Succar, 2008). The parametric nature of BIM modeling opens-up new possibilities in architectural design, considering the new developments referred to computational design and optimization procedures as well. Combining the potential of these tools, professionals can experiment new solutions capable of assisting them in the decision-making processes. This is the case of the new multi-criteria optimization methods based on the use of generative design (Tan et al., 2021). This approach leads to the automatic generation of several different solutions complying requirements directly defined by the designer at the beginning of the design process. Therefore, generative design is particularly suitable for optioneering design applications. This method allows the exploration of the various design options obtainable from a given set of parameters. By this way, the designer can easily identify the most relevant variables in the project under consideration and the solutions to be preferred (Pavan et al., 2017). Decisions can be taken more quickly and consciously by exploring a wide set of possibilities, generated taking advantage of computers' computing potential and otherwise not evaluable recurring to

https://doi.org/10.26868/25222708.2021.30352

traditional means. For instance, the Autodesk group (Walmsley, 2017) applied a generative design algorithm in the project of work spaces, in order to combine subjective factors (operational and proximity needs) with objective parameters (contribution of sunlight, noise levels, minimum size of spaces). Other authors suggest the use of Mc Neal's Grasshopper in morphological design selection: enabling the use of a wide variety of plug-ins this software can be used for cross-reference analysis (Holzer, 2016). Unlike the aforementioned examples of multifactorial optimization, most studies focus on energy performance of buildings and their environmental impact (Evins, 2013). Some of them concern the search for the design solution able to maximize the LEED score of the construction (Marzouk et al., 2018) with particular regard to variables such as the shape and orientation of the building, the thermophysical properties and thickness of the envelope, the size of windows and their shading (Touloupaki and Theodosiou, 2017) Recently similar applications have been tested in Italy as well (Vanossi and Imperadori, 2015) (Tagliabue et al., 2018). Nowadays genetic algorithms that simulate natural selection processes (i.e. evolution of the species) are also used in optimization problems. These algorithms converge to an optimized solution by proposing improvements of starting configurations through subsequent iterations of their combinations and the introduction of random changes of variables. Some studies (Tuhus-Dubrow and Krarti, 2010) concern building envelope and the design of glazed elements performing lighting and energy simulations (Hemsath and Bandhosseini, 2015) (Fesanghary et al., 2012) (Wang et al., 2005). However, other researchers (Landim, 2017) highlight the lack of direct control by the designer over operations and parameters, since optimization proceeds until convergence in an autonomous way. Despite this, some authors (Rahmani Asl et al., 2015) still use genetic algorithms in the creation of optimization software based on simulations carried out from BIM models, but performed recurring to external platforms. There is also the possibility to act directly within BIM authoring software (i.e. Revit) that integrates visual programming tools for editing and processing the parameters set in the model (Kensek, 2015).

Aim of the research

The research proposes a methodology that can considerably simplify the decision-making process related to the definition of building envelope components implementing generative design techniques. The multi-objective optimization method discussed in the paper was tested in the selection of technological solutions for the realization of a horizontal partition and an external wall. In the case study, the thermal, acoustic and mechanical performances of building components, their buildability and their environmental and economic impacts were taken into account in an integrated way. The proposed method is based on the generation of several alternative technological solutions and their subsequent analysis referring to different factors of interest. The aim is to develop a tool that can facilitate the designer in identifying the technological stratigraphy that best meets the specific needs of the project, according to construction, economic, energy and environmental requirements. As the algorithm was drafted in a totally autonomous way, it is emphasized that the result obtained is completely innovative and there is not similar one in literature.

Method

The method combines the use of Revit (Autodesk, 2020), Dynamo (Autodesk, 2020) and Project Refinery (Autodesk, 2020). Produced by Autodesk and perfectly interoperable, these software allowed to integrate design optioneering into a totally BIM-based project management. Dynamo was used to write the algorithmic simulation code in visual programming language. Project Refinery ensured the iteration of the operations set in the VPL script and allowed an effective classification of the results obtained.

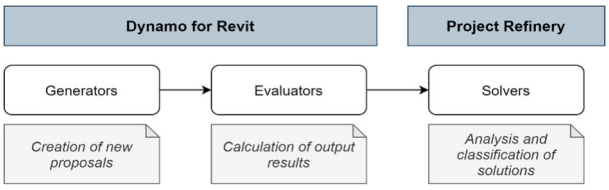


Figure 1 Dynamo and Project Refinery interaction.

The methodology proposed in this paper has been applied to a case study that deals with the project of a new cultural facility in the centre of Florence. The project concurred in a competition of ideas. The workflow followed is made up by a series of subsequent phases described in the diagram in Figure 2. The operational steps will be specifically detailed in the next sections.

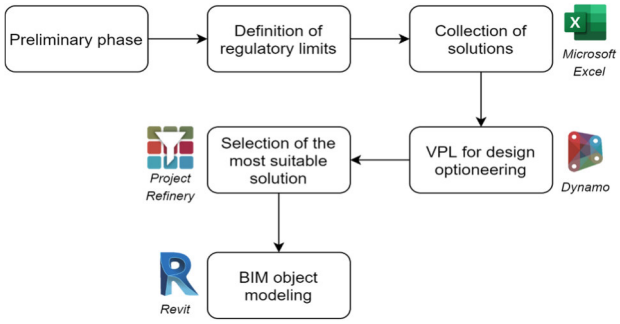


Figure 2 Research workflow.

1. Preliminary Phase

The building component was initially studied to identify its functions and the performance expected. As a result, reference parameters to be considered in the design optioneering process were defined.

2. Definition of regulatory limits

The minimum performance requirements prescribed by the reference regulations for each subject of interest were quantified. This procedure limited the range of input parameters' variability and avoided the generation of ineligible configurations. In the present case, the parameters related to the energy and environmental performances of the package were chosen as the reference values. On the other hand, the acoustic requirements were satisfied by the introduction of a specific insulation layer,

https://doi.org/10.26868/25222708.2021.30352

which was therefore always adopted in the various stratigraphies analyzed. In addition to the requirements in the legislation, an assessment of the economic feasibility and actual buildability of the component had to be performed. To meet these two requirements, the maximum values of expenditure, the number of layers of the components and the size limits of the elements in relation to their installation have been respectively estimated.

3. Creation of solutions

Various technological solutions currently available on the market were investigated. An analysis of the possible stratigraphies was conducted and the technical data for the associated materials have been collected into an Excel file. Both for the external wall and the interfloor slab, the structural layer and the external coating solution have been assumed as design invariable. Commercial reference products have been associated to each material. Thermoigrometric characteristics, density, cost and global warming potential (GWP) have been deduced from product sheets and technical data. GWP was chosen as index for the estimation of environmental impact. When not provided by the manufacturer, this value was desumed by the Baubook (Vorarlberg Energy Institute, 2018) platform database with reference to "*total GWP*", which includes both the contribution of greenhouse gas emissions to global warming and the amount of carbon dioxide stored in biomass over a 100-year lifespan. The variables of interest for each material and, consequently, for each functional layer are:

- Thicknesses available on the market [m]
- Thermal conductivity [W/mK]
- Steam permeability [kg/msPa]
- Density [kg/m^3]
- Cost [€/m^3]
- GWP100 total [kg CO_2/kg]

Performance, economic and environmental factors were subsequently chosen as output parameters to be used in the definition of the technological package of interest. These indicators are:

- Thickness of the technology package [m]
- Surface mass [kg/m^2]
- Thermal transmittance [W/m^{2}K]
- Cost of the solution [€]
- Global Warming Potential [kg CO_2]

The mechanical resistance of both the packages has not been included among the output of interest. In this regard, only insulating materials compatible with the distributed loads of the operating conditions were chosen for the slab's solution. Once the solution of interest had been identified, further considerations were taken with specific relation to the concentrated loads. For the external wall, on the other hand, mechanical resistance requirements were implicitly met recurring to an adequate substructure for the advanced façade with stone cladding, assumed as invariant in the optioneering process.

4. VPL for design optioneering

Such as in the majority of visual programming languages, also in Dynamo codes are assembled with a series of graphical elements: the algorithm is formalized in "nodes" containing pre-assembled code's strings, and "arrows" that connect them expressing relations and sequences between the instructions. Once the script was created, it was processed by the Project Refinery solver. The calculation procedures and sequences to be performed in an automated way by the computer were defined in this initial stage. The problem was divided into subsequent operations that were translated into computer language and recombined sequentially within the algorithm of Figure 3. The numbering in the following paragraph refers to it. To begin [1], the values organized in the excel file were extracted and imported so that they could be used in subsequent calculations. In Dynamo, an identifying color has been assigned to each material to ensure an immediate visual feedback in the stratigraphies created [2]. Going on, the geometry of the various functional layers [3] was created and represented with solids of unitary surface and variable height according to the desired thickness. The minimum thickness of each insulating layer has been obtained according to the regulatory limit for the transmittance of the whole stratigraphy to ensure compliance with the requirements for each design solution developed. Each functional layer, in addition to the geometric characteristics, has been assigned the material and the corresponding mechanical and thermophysical properties. The calculation of global outputs of interest [4] has been set up to ensure automatic update with the changes in materials and their thicknesses in each alternative technological configuration. If necessary, the calculations combine the geometric data of layers and the physical-mechanical properties of materials.

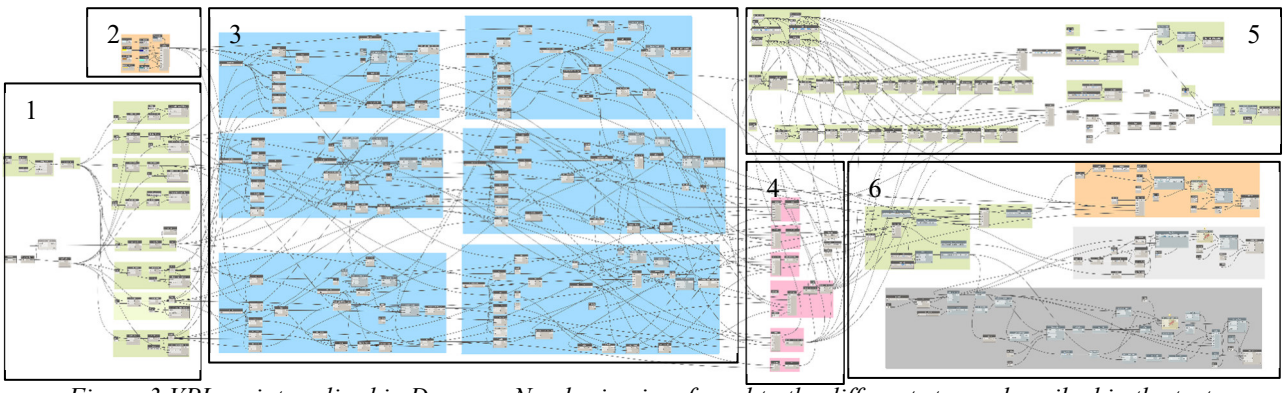


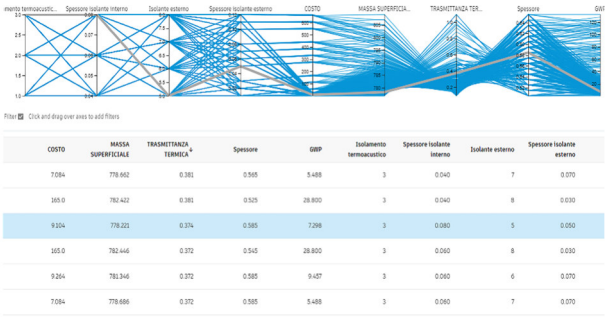
Figure 3 VPL script realized in Dynamo. Numbering is referred to the different stages described in the text.

https://doi.org/10.26868/25222708.2021.30352

An automatic calculation of the steam and saturation pressures trend to assess interstitial condensation formation and the tracking of the relevant graphs has been set up within the script [5]. Through a rapid visual control, it was therefore possible to have an immediate feedback on the validity of the solution from the thermo-hygrometric point of view. A rapid and effective graphical return of results, in addition to the textual listing of components and properties of the package, was moreover provided through a radar diagram. The project outputs (cost, thickness, thermal trasmittance, surface mass, GWP) are here expressed in a normalized form. The procedure adopted presented a twofold computational advantage. The use of computing platforms external to the BIM software was avoided and the compilation of information data concerning the properties of materials in the Revit model was automated, thanks to a direct interface.

5. Selection of the most suitable solution

The following step revolved around the analysis of the design alternatives using Project Refinery, able to return all the possible solutions produced by the various combinations of the incoming variables. Depending on the type of study, Refinery offers the user four different operating modes. Two are oriented towards optimization logics using the NGSA-II genetic algorithm, while the others are related with the optioneering field. Choosing this second strategy, it was possible to operate on the variables in a direct and manual way, ensuring a more effective control over both data combinations and their results. While optimization problems need an objective function to be set before the analysis, this approach has no pre-defined outputs to be either maximized or minimized and thus promotes greater flexibility in exploring design options. Once the generation of the design alternatives was completed, it was possible to apply filters looking for the solution of interest and narrowing the range of variability of the parameters described above. Figure 4 shows a software dialogue screen: the parallel coordinate display, combined with the one in table form, ensured quick control over the performance provided by the selected technological stratigraphy.



COSTO	MASSA SUPERFICIALE	TRASMITTANZA TERMICA	Spessore	GWP	Isolamento termoacustico	Spessore isolante interno	Isolante esterno	Spessore isolante esterno
7.084	778.662	0.381	0.565	5.488	3	0.040	7	0.070
165.0	782.422	0.381	0.525	28.800	3	0.040	8	0.030
9.104	778.221	0.374	0.585	7.298	3	0.080	5	0.050
165.0	782.446	0.372	0.545	28.800	3	0.060	8	0.030
9.264	781.346	0.372	0.585	9.457	3	0.060	6	0.070
7.084	778.686	0.372	0.585	5.488	3	0.060	7	0.070

Figure 4 Results visualisation in Project Refinery.

6. BIM object modelling

After the definition of the stratigraphy for the technological unit, the BIM element was recreated within the architectural model. The inter-floor slab was generated using the system family already included in Revit by modifying layers' material and thickness to obtain the configuration chosen during the selection phase. On the other hand, for the restitution of the external wall, two juxtaposed system families were used to model respectively:

- the advanced screen façade, adopted as external coating solution
- the structural core, the internal finishing layer and the related insulation layers.

Analysis setup

The optimization procedure involved a horizontal partition and a façade wall. Although the two studies were conducted with the same methodology described above, it is necessary to make some distinctions.

Inter-floor slab

The horizontal partition studied separates heated rooms from outdoor environment and therefore the adoption of an appropriate thermal insulation layer was needed. The limit thermal transmittance assumed coincides with the one established by Ministerial Decree 26 June 2015 (Decreto Interministeriale 26 Giugno 2015). The value, for the climatic zone D, where Florence is located, is equal to 0.29 W/m^{2}K. As for the structural aspect, the Italian technical standards for constructions of 2018 (Decreto Ministero Delle Infrastrutture e dei Trasporti 17 Gennaio 2018) were followed. Recurring to these legislative references, it was possible to point out findings referring respectively to energy performance and technical standards for constructions. A distributed load of 5.00 kN/m^2 was considered, following the prescription for museum spaces. Since all insulating agents chosen for the analysis were generally able to withstand such load conditions, this aspect was considered less significant for the choice of the optimal stratigraphy. Therefore the mechanical resistance was considered at the end of the optimization process, specifically referring to the response offered to concentrated loads, usually more critical for insulating materials. For sure, these sollecitations are responsible of differential subsidences in the insulation layer and, consequntly, in the flooring one. The reference stratigraphy included a lightened slab in reinforced concrete (0.30 m), an acoustic insulation layer, a double layer of thermal insulation, a screed (0.08 m) and a stoneware finish with adhesive for laying (0.02 m). The creation of the insulating layer using two distinct overlapping layers has been functional to buildability and allowed a better quality in simulation, as it permitted to explore multiple solutions. It is precisely the definition of the insulating layer that has been the primary aim in this case. The alternatives analyzed were the following ones:

- Insulating panels in EPS
- Insulation panels in XPS
- Insulating panels in rock wool
- Insulating panels in wood fibres

Table 1 shows the values of the parameters used in the analysis and set as input variables to the algorithm. The following values are reported for each material: i) thermal conductivity values λ [W/mK]; ii) steam permeability p

https://doi.org/10.26868/25222708.2021.30352

[kg/msPa]; iii) steam resistance coefficient μ; iv) density ρ [kg/m^3]; v) cost [€/m^3]; vi) GWP [kg CO_2 eq. /kg].

Table 1 Insulation layer – Interfloor slab

Material	EPS	XPS	Rock wool	Wood fibres
λ [W/mK]	0.022	0.035	0.039	0.048
p [kg/msPa]	1.4 x 10^{-12}	1.3 x 10^{-12}	200 x 10^{-12}	40 x 10^{-12}
μ [-]	148	150	1	5
ρ [kg/m^3]	36	38.5	180	250
Cost [€/m^3]	182.08	114.33	132.34	516
GWP [kg CO_2 eq. /kg]	4.17	4.2	1.93	-0.804

The price of the different products is currently expressed in [€/m^2] and depends on insulating panels thickness. To get a simplified assessment of the technological packages' costs, mean values were extracted from the 2019 price list of "Chamber of commerce, crafts and industry of Florence" and converted in [€/m^3]. The calculation script was programmed through Dynamo to admit 4 variations for the type of insulation and 5 for the thickness (0.04-0.06-0.08-0.10-0.12 m). The increment of 0.02 m was meant to reproduce the geometry of panels generally found in the market. The variation of parameters has been designed to ensure, for each solution, the minimum limit of thermal transmittance imposed by legislation. For the calculation of thermoigrometric verification, 20 °C temperature and 60% relative humidity for indoor air and 5° C and 80% humidity for outdoor air were assumed as boundary conditions.

External wall

For the construction of the external wall, reference was made to a technological stratigraphy (inside-outside) made of a dry counter wall with double gypsum fibre boards (each 0.0125 m thick) and thermoacoustic insulation directly applied on a structural wall in reinforced concrete (0.30 m), an insulating layer and an advanced screen façade with an air cavity (0.10 m, assumed weakly ventilated) and stone outer coating (0.04 m). In this case, the design optioneering procedure was applied for the definition of the insulation solution on both the inner and outer sides of the wall. As for the first element, the algorithm has been set up for the evaluation of two alternatives consisting of the adoption or not of a thermoacoustic insulation layer in the cavity of the internal counter wall. The script also included the selection of the material and the thickness to be used in case the insulation layer was used. The optimization examined the alternative use of rock wool and fiberglass, with a thickness of the layer varying between 0.04 m and 0.06 m. To ensure adequate acoustic performance, the choice of materials was limited only to the two materials mentioned above, while the thickness of the insulating layer necessarily followed the width of the air cavity in the gypsum-fibre counter wall. Regarding the external side, the considered design alternatives for the insulation layer were the ones listed below:

- Insulating panels in rock wool
- Insulation panels in fiberglass
- Insulating panels in EPS
- Insulating stratum in Aerogel

For each material, a thickness ranging from 0.01 m to 0.12 m with a unit increase was considered. Although insulating material panels are generally on the market with thicknesses with increases of 0.02 m, the adoption of such a design hypothesis would not have reflected current practice in the case of aerogel. Table 2 and Table 3 show the materials considered in the study of the building component, together with the related thermoigrometric, physical, economic and environmental data already mentioned. Values referred to the layers assumed as invariants were omitted. Indeed, their specifics would have not affected the choice between the design alternatives elaborated in the simulation of generative design.

Table 2 Insulation layer – Façade wall, Inner side

Material	Rock wool	Fiberglass
λ [W/mK]	0.035	0.035
p [kg/msPa]	200 x 10^{-12}	200 x 10^{-12}
μ [-]	1	1
ρ [kg/m^3]	110	21
Cost [€/m^3]	132.34	101.2
GWP [kg CO_2 eq. /kg]	1.93	2.45

Table 3 Insulation layer – Façade wall, Outer side

Material	EPS	Rock wool	Fiberglass	Aerogel
λ [W/mK]	0.022	0.035	0.039	0.015
p [kg/msPa]	1.4 x 10^{-12}	200 x 10^{-12}	200 x 10^{-12}	40 x 10^{-12}
μ [-]	56	1	1	5
ρ [kg/m^3]	36	38.5	180	250
Cost [€/m^3]	182.08	132.34	101.20	5500
GWP [kg CO_2 eq. /kg]	4.17	1.93	2.45	4.8

Results and discussions

Inter-floor slab

Once developed in Project Refinery, Dynamo's script led to the generation of 400 workarounds, produced by the several combinations achievable for the variables introduced. The configurations generated so far were analyzed using a display of outputs in both table and graphical form as shown in Figures 6 and 7. The variables of the optimization problem, thus materials and thickness

https://doi.org/10.26868/25222708.2021.30352

of the insulating layers, are listed in the four columns on the left. The remaining columns in the diagrams express the design outputs (cost, surface mass, transmittance, thickness, GWP). By filtering the properties of the stratigraphy, it was possible to determine which combination of the design variables would achieve the desired results Findings were further analyzed to estimate interesting correlations between the factors under consideration. For instance, the comparison between Figures 6 and 7 shows that the cost and GWP values are inversely proportional. In the case of Figure 6, assuming only high GWP values (shown in the last column) the corresponding solutions are characterized by low costs. On the other hand, the adoption of sustainable materials capable of reducing environmental impact (Figure 7) leads to an increase in the global cost of the stratigraphy. The GWP value was assumed, together with the overall thickness of the stratigraphy, as a discriminating value for the selection of the suitable configuration. Aiming at pursuing environmental sustainability objectives, a very strict filter has been applied on the amount of CO_2 produced by the solution. A second limitation was imposed on the output related to the thickness of the stratigraphy, to exclude all those overly bulky configurations, difficult to build and related to unjustifiably reduced thermal transmittance values. The stratigraphy identified through these considerations required the adoption of a double insulation layer in wood fibres for a total thickness of 0.14 m. Figure 7 shows the selection process for the configuration mentioned before. Some additional reflections upon the mechanical resistance of the insulating layers selected had to be made to ensure a final validation of the choice. To avoid brittle breakage in case of high concentrated loads, the opportunity to use an additional cement bonded particle board was considered. This layer (0.04 m thick) was introduced to increase resistance and ensure a more effective redistribution of stresses. This further step is an example of the inevitable need for a critical analysis by the designer. Indeed, simulation tools must always assume only an aid and support role in the design process.

External wall

Project Refinery provided the choice between 360 automatically generated configurations for the external wall. The application of restrictions on the scope of investigation was particularly helpful in this case. Alternatives which did not meet the regulatory limits of thermal transmittance had to be excluded as shown in Figure 8. The presence of very low thickness values of the external insulation, admitted in the case of aerogel, led to a high number of non-compliant solutions. Thanks to its extremely reduced thermal conductivity, aerogel is used recurring to very limited thicknesses compared to traditional solutions. However, it has much higher costs than the latter. The introduction of very low insulating thicknesses into the algorithm precluded the possibility to generate only technological stratigraphies that meet regulatory limits (0.29 W/m^{2}K). The final choice led to the adoption of a 0.06 m rock wool panel for both the insulation layers in the stratigraphy. This solution (Figure 9) was preferred due to the limited environmental impact (GWP) and the low overall cost. The presence of one insulating layer on both sides also results in a reduction in the overall thickness of the external wall. The values of interest were also expressed in immediate form thanks to the graphic form set up in Dynamo (Figure 5).

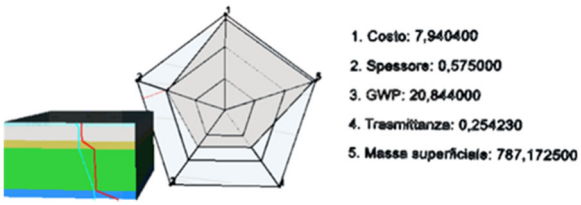


Figure 5 Technological solution chosen for the façade wall: proprieties and Glaser verification.

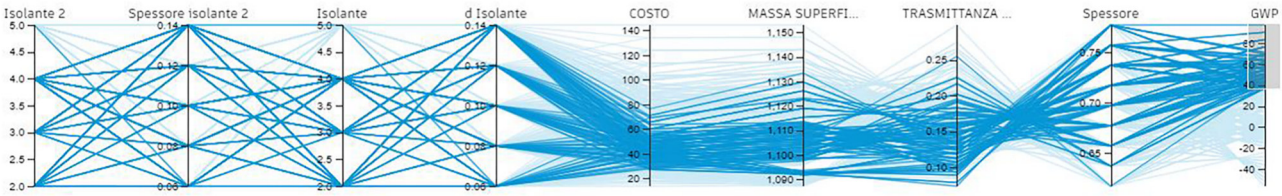
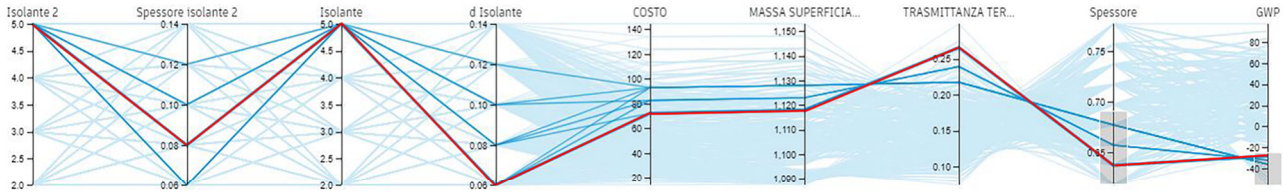


Figure 6 Project Refinery: High environmental impact solutions



COSTO	MASSA SUPERFICIALE	TRASMITTANZA TERMICA	Spessore	GWP	Isolante 2	Spessore isolante 2	Isolante	d Isolante
72.240	1118.0	0.266	0.637	-28.140	5	0.060	5	0.080
72.240	1118.0	0.266	0.637	-28.140	5	0.080	5	0.060

Figure 7 Project Refinery: Selection of the most suitable solution.

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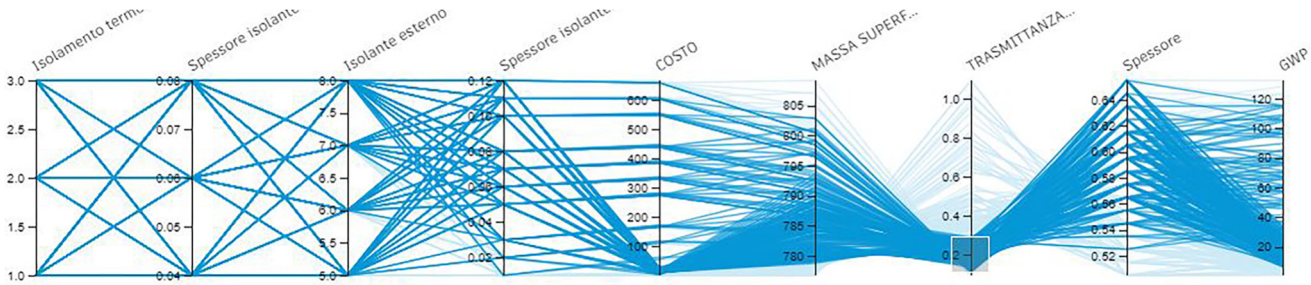

Figure 8 Project Refinery: exclusion of solutions with thermal transmittance above regulatory limits

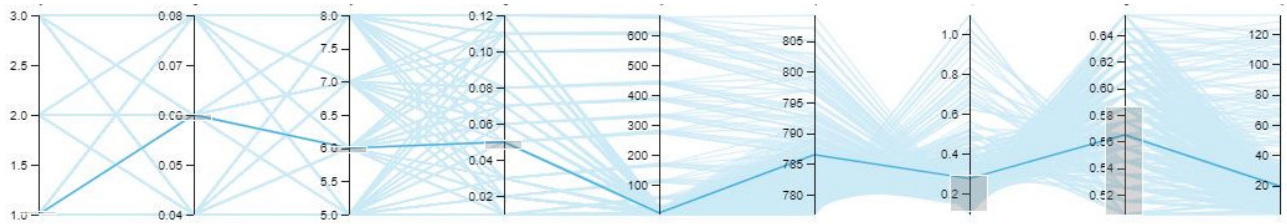

Figure 9 Project Refinery: Identification of the design technological configuration for the façade wall

Conclusion

The method applied in the research made possible to examine several design alternatives, otherwise unimaginable, and to validate the choices made. Thanks to the many variables introduced, it was possible to carry out multi-objective analysis. Many technological solutions have been evaluated in relation to energy performance, environmental sustainability, economic feasibility and buildability. As it concerns the thermal insulation of the interfloor slab, the results of the simulations carried out led to the adoption of a double wood fibres layer for a total thickness of 0.14 m. In addition to the functional layers initially provided in the calculation, it was decided to introduce a further cement bonded particle board. This 0.04 m thick additional layer was meant to ensure a higher mechanical resistance and a more effective redistribution of loads. For the façade wall, a rock wool insulating layer of 0.06 m thick was chosen for both the external and the inner sides, filling the gap formed by the gypsum-fibre counter wall and otherwise meant to host systems. In this case the material chosen allowed a good thermal and acoustic insulation as well. The implementation of computational design tools for design optioneering purposes is set to radically transform the design approach in the next years. If properly integrated into decision-making logic, the new digital tools, can offer fundamental support for the success of the project. The methodology applied involved the realization of a visual programming script easy to use even for professional figures not trained in the computer field. The need of an appropriate knowledge of the specific syntax required by linear programming languages is easily overcome by the intuitive and user-friendly nature of VPL that is emerging as a more effective and flexible resource. Generative design tools and VPL programming are integrated in the latest versions of BIM software and they can be useful to overcome interoperability issues, enabling to perform simulations in the same environment, preventing possible data losses during the exportation of the model. Otherwise, scripts can be created to interact directly with the data contained in the models: they can be exported in several formats and then processed, analyzed or organized for several further applications. Similarly, the automated management of the calculation operations and the reading of results, that can be filtered or sorted according to the objectives, allow rapid and intuitive multidisciplinary analysis. In the case dealt with in the research, it was decided to limit the use of design optioneering techniques to the definition phase of technological solutions. Starting from an easier task, the authors intended to test the tools available to verify their reliability and effectiveness. Once the methodology has been validated, its application can be experimented to perform comprehensive assessment on a building scale. A detailed BIM model of the building should be preliminarily created to collect all the necessary data. At the same time, the VPL script should be conveniently modified including specific codes or plug-in meant for the scope of the research performed. For instance, analysis could be performed to estimate the influence of opaque envelope technological solutions or glazed surfaces on energy consumptions. Moreover, with similar procedures, general architectural decisions can be evaluated. At this regard, optimization could be implemented in the definition of the most convenient shape and orientation for a building, preventing cold wind expositions or bad lighting conditions. However, the methodology proposed is affected by limitations related to the specific tools used and the technology itself. Firstly, the research described availed Autodesk suite software that ensured a perfect interoperability among them. This may not be true for designers using different BIM authoring software. In this case they could apply the same methodology but recurring to different instruments (i.e. Grasshoppers for Rhino). Moreover, in case of complex tasks or extremely specific problems VPL and generative design may not be the best solution. In fact, these cases may force the designer to write autonomously the solving code, since its main parts could be probably not available among the predefined

https://doi.org/10.26868/25222708.2021.30352

ones. Even if the generative design procedure allows the comparison between several alternatives, it is always necessary to clearly define variables and their limitations to avoid time consuming calculations and undesired results. The results obtained at the end of the design optioneering process must be always carefully examined by the designer, that provides final validation after further considerations based on current practice and his professional experience.

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