COMPUTATIONAL METHOD FOR FOOTBALL STADIUM RENOVATION

A computational method for the renovation of football stadiums to facilitate designers into making decisions

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REFLECTION

Graduation Topic

My thesis aimed to develop a computational method for football stadium which includes features that can support designers and engineers into making decisions in relation to the topic of renovation in the early design phase. Even though in recent years computational methods have been applied on various building typologies to optimize aspects related to climate design, architectural design and structural design, little literature is available towards the application of computational methods to optimize large-span roofs in relation with the configuration of stadiums, which affects the viewing quality of the spectators of the venues. For this reason, the focus of the thesis is kept on the structural design of the stadium in relation to the roof, which affects both the aesthetic appearance and the overall cost of a stadium design project. The application of a computational method in the design process of a building typology as stadia permits to explore multiple optimal solutions in order to develop more efficient designs. Indeed, stadiums are complex buildings that necessitate the analysis of multiple performances and the compliance with the regulations of both countries and football associations in order to realize an efficient design. When renovating a stadium, the characteristics of the existing elements of the stadia enhances the complexity of the problem, therefore increasing the possibility of developing an inefficient design or, in worst scenarios, the realization of a downgraded stadium compared to the starting one, especially in relation to the viewing quality of the spectators of the venues. As an important aspect of the thesis, the developed computational method aimed to be applicable on different stadiums, rather than focusing on a specific existing stadium. Concerning the master track MSc Building Technology, the development of a computational method falls within the discipline of computational design, which is one of the main subjects of the master track. The disciplines of interest of my graduation projects are reflected in the choice of the mentors, which are members of the Chairs of Design Informatics and Structural Design.

Graduation Process

In the first phase of the graduation, a background research was carried out to understand the relevance of the topic. Indeed, the background research was necessary to understand whether nowadays there is a trend to renovate stadiums, the causes and the objectives of the process. The findings showed that a trend towards the renovation of stadium exists nowadays to improve the safety of the users, to increase the capacity of the stadium and therefore the income of the venues and to improve the user experience of the spectators. In this case, the improvement of the user experience can attract more supporters to the venues, thus enhancing the atmosphere of the venues and, as a consequence, the income. In general, it was found that the renovation a stadium is performed to improve the existing stadium, hence by providing minimal modifications to the present components or by adding new elements, while considering the presence of the existing parts. These aspects are related to the minimization of the costs of the project and to preserve the historical value of the stadium. Hence, a criteria to distinguish the portions of the stadiums worth to be kept from the ones to renovate had to be found. In this case, by taking into considerations the objectives of a renovation, the criteria is individuated in the performances and the requirements of the existing stadium. Therefore, the portions that are bad performing are considered to be renovated.

An extensive literature review was conducted to gain knowledge on the aspects related to the topics of focus of the thesis. Hence, the research was concentrated on the stadium design process and the phases of a computational method PCA, which considers the performances to develop efficient designs in the early design phase. Regarding the stadium design process, the research was conducted to gain knowledge on the components of the stadium necessary to evaluate the viewing quality and the structural performance of the roof. Likewise, the requirements of the components in relation to the performances were researched, as well as the parameters that determines the geometry of the elements and their interpolation. Regarding PCA, the research was conducted to gain knowledge on the phases of the computational method. This phase allowed to envision an initial workflow to generate a stadium, evaluate its performances and optimize the design alternatives in relation to the responses of the new geometries to the performances to be assessed. In addition, the research allowed to envision in which phase of the workflow it was possible to insert the choice upon the components of the stadium to be kept during the renovation.

After the review, the boundaries of the computational method were possible to be defined, taking also in consideration the time-frame available to elaborate the thesis project.

Hence, the computational method was organized in a first phase of generation of the components of the stadium, a second phase to evaluate the viewing quality and the structural performance of the roof and a third phase of set-up of the optimization by selecting the inputs, the constraints and the objective functions to solve the optimization problem. The individuation of the components to be kept constituted a further phase, which was located between the performance assessment and the optimization process. Therefore, it was understood that the conservation of few parts of the stadium based on their performances constitutes the difference between a process of renovation and a process of new design of a stadium. Hence, the developed computational method can also constitute a computational tool to design newly built stadiums by setting-up the initial configuration and produce design alternatives in responses to the objective functions of the optimization problem.

Concerning the form generation phase, since the computational method was envisioned to be applicable on different stadiums and not exclusively on a selected one, different typologies of the components had to be inserted. In this instance, few common layout typologies were implemented, as well as the stand typologies. Considering the roof structure, the structural systems implemented were selected based on their applicability on the selected layout geometries. The phase of form generation determines the design space, hence the number of combinations that can be obtained to generate different design alternatives. In this phase, the complexity of the stadium process emerged. Indeed, the alternatives that can be produced with the developed computational method constitute a small portions of endless combinations that have been realized in practice. Therefore, the number of stadiums that can be implemented in the computational method is limited to the ones that have the same characteristics provided in the form generation. Hence, on the one hand, future research can enlarge the design space and the number of stadiums that can be implemented. However, even including the different typologies of the components excluded in the thesis, it seems unluckily that all the possible combinations will be covered in the near future. Indeed, considering the rate of development of new technologies in stadium design, a general method for the renovation of football stadiums will have to be updated continuously and there is the possibility that all the combinations will not ever be fully covered.

Concerning the performance assessment phase, the viewing quality and the structural performance of the roof were defined and the indicators were selected based on their objectives. The viewing quality of a stadium was defined as the comfort of the spectators into following the activity held in the stadium. In this regard, two main aspects were distinguished. On the one hand, a spectator should not have the view obstructed by any objects and they should be able to follow the activity comfortably from the seats. Considering the roof structure, it has to transfer the external loads to the ground, while providing cover to the spectators from the weather conditions. Hence, the roof structure has to be stable to provide safety to the spectators, *while sheltering them from the weather conditions*. Hence, for the viewing quality, the indicators were selected to evaluate the obstruction of the view provided by the spectators and to evaluate the comfort in following the activity. From all the indicators, the C-value and the capacity were the only indicators related to the different tiers of the stands. Indeed, a simple evaluation on the overall stadium would have prevented the selection of the components to be kept in the renovation to be applicable, therefore compromising the overall thesis. In addition, the C-value and the maximum distance constitutes the only indicators to individuate the portions of the stadium that can be kept during the renovation. Indeed, these two indicators are considered more relevant in practice, as extrapolated from the literature review. Concerning the roof structure, the stability was checked by evaluating the stresses and the displacement in relation to the limit values of the materials and the rule of thumbs of the elements based on their boundary conditions. Considering the influence of the structure on the overall cost of the stadium, the mass and the number of joints and elements are evaluated to have an insight on the overall cost of the material of the roof structure. However, in the optimization, the stresses and the displacement were utilized as constraints. Indeed, whether the structural stability is ensured, the mass of the structure and the number of joints and elements constitute a more relevant factor in relation to the objective of containing the costs of the project. Few indicators were speculated in the initial part of the thesis to evaluate the relation of the structure towards the obstruction of the view of the spectators and the sheltering of the stands. However, during the design phase, it was noticed that, by setting the starting position of the end points of the cantilever in the optimal condition (all stands covered and no obstruction provided). Hence, a roof topology that does not cover the roof and/or obstruct the view can be achieved, but the requirements can be matched during the optimization by controlling the range of values. Hence, the computational time of the method can be reduced. Indeed, the performance assessment affects greatly the computational time of the real-time feedbacks that can be provided by Grasshopper and its plug-ins when the input parameters are altered. In this regards, the device utilized to run the computational method influences have also an impact. Indeed, a more powerful device is able to manage the amount of data produced quicker.

Regarding the renovation process, it was understood during the design phase that the roof structure is the component of the stadium that is affected the most during a refurbishment of a stadium, while the stands composing the bowl geometry can be alter whether they provide a bad quality performance. Indeed, whether the bowl geometry is modified or new elements are added, the configuration of the stadium is altered, therefore modifying the outline of the roof structure. Hence, only the position and the number of the supports was considered to be maintained. It was therefore necessary to implement them in relation to the layout curve of the stadium, which allows to position them and set their number independently from the bowl geometry. Considering the overview, the results are shown and supported with visual maps and color gradients to intuitively individuate the portions of the stadium to be modified and the critical elements of the structure. However, the visualization is displayed on screen and one indicator can be visualized at the time. Considering an application of the method in practice, in future research a solution to export the information in excel sheets or PDF for meetings with the contractors can be found. In addition, the camera setting implemented to simulate the view of the spectators can be researched to provide an application of virtual reality. Indeed, the virtual reality can be utilized to enhance the evaluation of the viewing quality.

Concerning the optimization process, ModeFRONTIER was selected as the computational tool for the process. Indeed, even though its an external tool, it is provided with a variety of algorithms and tools to search design alternatives and to perform the trade-off of the alternatives. Concerning the set-up of the tool, the management of the inputs, the objectives and the constraints of the optimization problem resulted facilitated by the user-interface of ModeFRONTIER. In relation to the optimization process, the objectives and the constraints implemented in the method were individuated on the basis of the objectives of a renovation process. Hence, the minimization of the cost of the project, the improvement of the user experience and the expansion of the stadium. However, it was understood during the validation of the method that the application of the objectives, the constraints and the inputs is dependent on the existing stadium implemented and the objective of the renovation process to be followed. Hence, in practice a designer would have to determine the inputs, the constraints and the objectives based on the needs of the project to be developed. Likewise, the range of values of the inputs and the limit values for the constraints would have to be determined by the designer based on the needs of the project to be developed and in respect to the building regulations of the country where the stadium is located. In general, the optimization process and the design exploration showed potential in the individuation of inefficient designs, which can be discarded. However, the computational time needed to produce the design alternatives is consistent and strictly related to the dimensions of the design space. This aspect can force the designer to stop the optimization beforehand in relation to the time-frame available to explore the design space. Hence, whether this is the case, there is the possibility that better alternatives are left out. Concerning the trade-off of the alternatives, the hierarchical cluster in combination with a manual categorization of the design alternatives resulted to be efficient solution. However, the process of categorization has to be manually set-up. Although, the manual categorization allows the designer to have control over the trade-off of the alternatives and to include non-measurable criteria for the evaluation, such as aesthetic appearance. In this instance, future research can be focused on implementing the categorization in the performance assessment phase to set indicators for both measurable and non-measurable criteria, hence providing an automated categorization while leaving the control of the trade-off to the designer.

Conclusions

The computational method developed and described in the thesis was applied to a validation case to determine whether, starting from an original condition of a stadium, multiple design alternatives which optimize the viewing quality of the bowl and the structural performance of the roof can be achieved.

Hence, following the phases of the computational method, the designer can generate the geometry of the bowl. In detail the designer can set-up the playing area, the layout typology, the number of tiers and the stand typology to apply. Afterwards, the topology of the roof structure can be produced by selecting the structural system, the position and the number of the supports and the cross sections of the structural elements.

Once the stadium have been generated, the performance assessment of the viewing quality of the grandstands and the structural performance of the roof is carried out. Hence, the performances are evaluated on the basis of a set of indicators and limit values. Concerning the viewing quality, the c-value, the field of view, the vertical viewing angle and the maximum distance are evaluated and their results represented in panels. Moreover, the capacity of the stadium is calculated. In this case, the capacity and the c-value are evaluated in relation to the overall stadium and towards the individual tiers of stands. Lastly, the results are visualized with a color gradient to support the decision-making of the designer, which can relate the results to the displayed maps. Concerning the structural performance, the maximum displacement and the maximum stresses for all the groups of structural elements is provided, as well as the values of the mass, the number of elements and joints present within the roof structure. Then, the results are visualized through Karamba 3D and the critical elements are displayed.

Then, the designer is able to individuate the portions of the stadium that are worth to be kept and develop concepts for a renovation. Therefore, multiple design alternatives can be produced through the optimization process. Subsequently, the produced designs can be explored and the trade-off of the alternatives can be realized to choose a suitable solution for further development.

A consideration have to be done in relation to the validation case. Indeed, the little literature available on the parameters of the existing stadiums led to the realization of an arbitrary validation case referenced to the Old Trafford of Manchester. In practice, a lidar scan of the stadium is performed to obtain the information related to the parameters of the components of the stadium. However, this was not possible to be performed. Hence, in this case, the reference stadium was selected on the basis of the layout typology and the structural system, which matched the boundaries of the computational method.

Considering the objective of the thesis and the outcome of its application on the validation case, the proposed computational method can be consider valid. Indeed, starting from an initial situation, multiple design alternatives that improve the initial performances can be produced. Moreover, inefficient designs can be individuated and discarded from further development. It must be stressed that the obtained alternatives can constitute a concept design that will be further developed in the subsequent phases of the design process.

Considering the applicability of the method in practice, few reflections can be drawn. On the one hand, the problematic encountered in the individuation of the validation case due to the lack of literature available on the necessary parameters can be solved by performing a lidar scan of the existing stadium. On the other hand, the developed method focuses on few aspects related to the renovation of football stadium, which are related mainly to the viewing quality, the structural performance of the roof and their related components. Indeed, the number of stadiums that can be implemented in the computational method is limited to the ones that have the same characteristics provided in the form generation. Hence, even though the application on the validation case showed the potential of the computational method, it seems still premature to apply the proposed method in practice. However, future research to refine the typologies of the implemented components can be performed to enhance the computational method for a practical application. In addition, a cost evaluation can be individuated as a crucial feature for future research in order to provide a further valuable criteria to determine the efficiency of the design alternatives.

Lastly, the developed computational method was envisioned to be applicable on multiple stadiums rather than exclusively on a selected one. On the one hand, the followed approach led to the definition of a computational method that has potential in relation to the renovation process of a stadium. However, the combinations that can be achieved are a small portions of the endless combinations that have been realized in practice. In addition, the computational method has the potential to be utilized as a tool to produce multiple different types of newly built stadiums. Indeed, by setting the configuration of the On the other hand, the development of a computational method focused on a selected stadium could have allowed to implement and evaluate more features, but the complexity of the parametric model would have been still restricted to the specific case and/or similar stadiums.