Grandstand Grammar and its Computer Implementation

A computational approach to facilitate decision making and encourage efficiency in the design of sports facilities

Yimin Sun[1], Lu Xiong[2], Ping Su[3]
State Key Laboratory of Subtropical Building Science, South China University of Technology
[1]arymsun@scut.edu.cn, [2]bbxlarc@gmail.com, [3]suping@scut.edu.cn

Abstract. *In sports facilities, a grandstand is the structure which provides good sight quality and safety evacuation conditions for the spectators. Grandstand plays important functional and formative roles in sports facilities, and especially in large scale stadia. This paper argues the notion of shape grammar and its computer implementation will solve the difficulties in grandstand design. The authors identify the specific difficulties of grandstand design, then set the aims of the grammatical computer tool. Afterwards the shape grammar of grandstand design is formulated, and a computer tool is developed based on the grammar. At last, the paper discusses the application and usage of the grammar and the computer tool both in early design phase and design development phase with a design practice case study of a large scale stadium.*
Keywords. *Grandstand design; shape grammar; parametric modelling.*

INTRODUCTION

In sports facilities, a grandstand is the structure which provides good sight quality and safety evacuation conditions for the spectators. Grandstand plays important functional and formative roles in sports facilities, and especially in large scale stadia. Apart from the function and form of the grandstand, the designs of other parts of stadium such as the facade surface and the roof are closely related to the grandstand, and most of the interior rooms are placed under the grandstand. In the very early design phase of a large scale stadium, the design of the grandstand must be considered to accommodate the spectators and the other basic need of the building. Traditionally, the process of a grandstand design trends to be complicated and tedious. Therefore the in the early phase of the design practice, architects are likely to use existing grandstand design with similar condition rather than design a new grandstand for the project. In the design development phase, modification of grandstand design will result in the large amount of remaking of documentation. Furthermore, the modification process of the other parts of the building would be delayed by the grandstand. Three problems are identified in the traditional grand stand approach. How to provide a highly customized grandstand model in early design phase? How to provide rapid response to the modifications in the design developments phase? How to rapidly negotiate the relationship between grandstand and the other parts of the building?

This paper argues the notion of shape grammar and its computer implementation will give a solution to the above three problems. Similar studies show the parametric design approaches to facilitate the grandstand design (Hudson, 2010; Miller, 2009). However, the studies trend to focus on the grandstand as an isolated part. The relationship between the grandstand and the other parts of the stadium is not explored. The design rules of grandstand is are not presented in formal ways. Grandstand design follows strict and complicated function rules and patterns. The shape grammar approach provides a computational and logic device for recording design rules and patterns. Computer tools can be made base on a shape grammar to solve specific design problems.

In the following part, the authors identify the specific difficulties of grandstand design, then set the aims of the grammatical computer tool. Afterwards the shape grammar of grandstand design is formulated, and a computer tool is developed based on the grammar. At last, the paper discusses the application and usage of the grammar and the computer tool both in early design phase and design development phase with a design practice case study of a large scale stadium.

THE DIFFICULTIES IN GRANDSTAND DESIGN AND THE AIMS OF THE GRAMMATICAL COMPUTER TOOL

The difficulties in grandstand design

The design of grandstand requires complicated professional knowledge. The difficulties in grandstand design can be identified in the following aspects:

1. Section design. The raise of each row should be precisely calculated to guarantee the sight quality of the spectators. The amount of raise will be affected by the type of game, the first row profile, the elevation of the first row, C value and the row distance. The calculation could be time consuming and tedious if was done manually.
2. Plan drawing. After the configuration of the first row profile, the plan drawing is a tedious process. The designer spend most of the time drafting the offset row profiles. If the first row profile is modified, the whole drawing will have to be remade.
3. The capacity calculation in the early design phase. The capacity is related to multiple factors such as the area of the grandstand, the number of aisles, the number of vomitories, row distance and the seat width. The precise capacity can only be obtained at the very late phase of grandstand design. If the row profiles is a curve, the distribution of seats will be a lot more difficult than the linear row profile.
4. The generation of the 3D profile of the grandstand boundary. For the case that the boundary is not parallel with the row profile, the profile of the boundary will be a 3D curve and define the skyline of the grandstand. It plays an important role in the façade of the building and acts as a key reference of the roof. The curve can only be generated in the late phase of grandstand design.

The aims of the grammatical grandstand design tool

The digital model should be served a reusable tools to assist the designs of varied grandstands for different projects. After the identification of the difficulties in grandstand design, the tool should achieve the following aims:

1. Ease for use. In this case the ease for use contains two aspects: the easy acquisition of design knowledge and the friendly user interface. The designers who are not familiar with grandstand design could quickly gain the according knowledge in a systematic way. The user-friendly interface could promote the designers to use the tool and focus on the grandstand design regardless of their knowledge of computer programming and 3D modeling.
2. Real-time visual feedback. The 3D model can be updated synchronously with the design conditions and parameters.

3. Real-time performance feedback. The performance indicators such as capacity, elevation of each level and the sight quality of each seat can be updated with the 3D model.
4. Enhance design efficiency. Majority of the manual works can be overtaken by the computer tool.
5. Enhance design quality. More energy could be put in the generation of alternatives, exploring of design space, refinement of design decision making. The 3D model would help reduce design mistakes that are difficult to be reflected in 2D drawings.

THE FORMULATION OF THE GRANDSTAND GRAMMAR

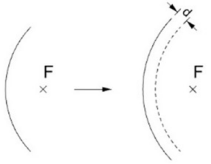
Subdivision of tasks

Considering the complicity of the grandstand design, the design task is divided into the following sub tasks:

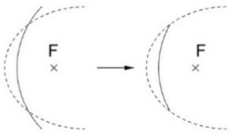
1. Generation of the plans of rows. The task contains the generation of the plan profile of each row, the position of the vomitory, seat distribution guide line and the estimated capacity of the grandstand. The input shapes are the first row profile, boundary of the grandstand, focus point and the aisle axis. The input parameters are row distance, number of rows, aisle width, evacuation method, vomitory width, vomitory start level, vomitory end level, seat width and seat offset. The outputs are the plan shapes of rows, seat guide lines and estimated capacity.
2. Aisle generation. The input shapes are the first row profile and the focus point. Input parameters are seat width, maxim seat number in a row, row distance, number of rows and aisle width. The outputs are the aisle axis and aisle region curve. The generation could be controlled automatically or manually. In the automatic generation, the distance between the aisles is determined by the maxim number of seats and the seat width. Since the position of aisle is influenced by other factors such as the space beneath the grandstand and the position of columns and beams, the user can also manually input the aisle axis. The position of vomitory will change according to the aisle axis.
3. Raise calculation. The raise of each row away from its low row is calculated in the task. The input shape are the first row profile and the focus point. The input parameters are number of rows, row distance and C value. Calculation is made according to equation (1). In the equation, Y is the elevation from the focus point to eye point, K is the number of rows, C is C value (John and Sheard, 2000). The output are the elevation of each row and the sightlines.

$$Yn = [(Yn\text{-}1 + (Kn\text{-}1) \times C] \times Xn / (Xn\text{-}1) \quad (1)$$

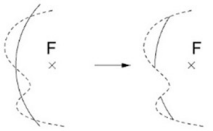
4. Generation of the grandstand 3D model. The task elevates the shapes on the construction plane to their designed height. Then the solid model are generated from the shapes. For the consideration of quick feedback and the time saving from the solid computation, the user can choose only to elevate the curves rather than generate the solid models. The input shapes are all the row profiles and seat guide lines. The input parameters are the elevations of the shapes. The output are the elevated shapes and solids.
5. Seat distribution. The task inserts seats on the seat guide lines and calculate the precise capacity of the grandstand. The input shapes are the seat guide lines, seat rectangle and the 3D seat model. The input parameters are the dimensions of the seat. The output are the inserted seat shapes and the precise capacity.
6. Sight quality analysis. The task analyses the sight quality of each seat. The inputs are the seats model, 3D model of possible obstructive, seated people model and eye level height. The outputs are the sight quality indicators such as view angle and view distance. Collision test between the sight line and the possible obstructive will be operated to show the blocked sight lines. First person perspective render can also be obtained to simulate the view of spectators.



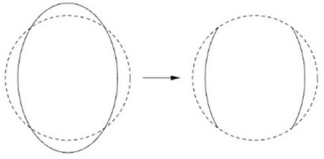
R1: offset a curve away from the direction point F and offset distance d to get another curve.



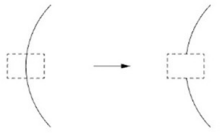
R2: trim a curve according to another curve and the direction point F to get a new curve.



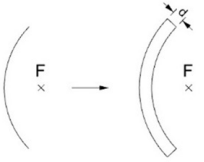
R3: trim a curve according to another curve and the direction point F to get several new curves.



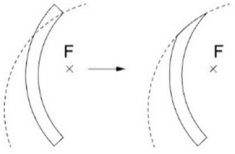
R4: trim a curve according to an closed curve and keep the segments in it.



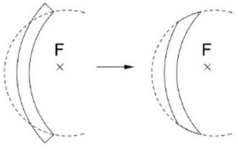
R5: trim a curve according to an closed curve and keep the segments out of it.



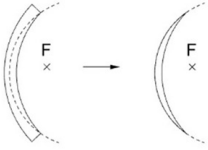
R6: offset a curve away from the direction point F and offset distance d to get a closed curve.



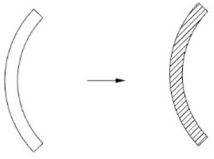
R7: trim a closed curve according to a curve and a direction point F to get another closed curve.



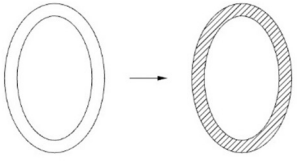
R8: trim a closed curve according to a curve and a direction point F to get another closed curve.



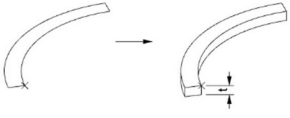
R9: trim a closed curve according to a curve and a direction point F to get another closed curve.



R10: get a planar surface from a closed curve.



R11: get a planar surface from 2 closed curves.



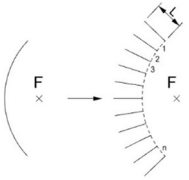
R12: extrude a closed curve by thickness t to get a solid.

Figure 1
R1 to R12 are the rules of row and seat guide curve generation.

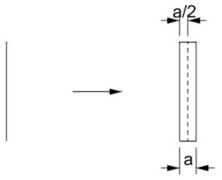
The contents of Grandstand Grammar

After the identification of the design tasks, the rules can be translated to a shape grammar called Grandstand Grammar (GG). Rules in GG are organized into 4 groups: rules of row and seat guide curve generation (Figure 1); rules of aisle generation (Figure 2); rules of seat distribution (Figure 3); rules of elevation calculation and elements translation (Figure 4). Figures 5 to 7 show the process of using GG to generate a single tier grandstand.

Figure 2
R13 and R14 are the rules of aisle generation.

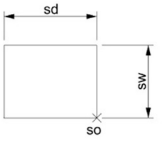


R13 get the lines which lengths are l and perpendicular to a curve with equal distances.

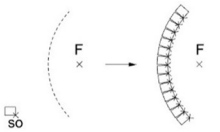


R14: offset a line by both sides to get a closed rectangle with width a.

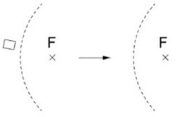
Figure 3
R15 to R19 are the rules of seat distribution.



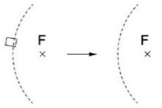
R15: add a rectangle.



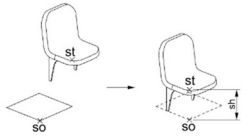
R16: insert the rectangles to division points of a curve.



R17: delete the rectangle which is not on the "F" side of the curve.



R18: delete the rectangle which intersects with the curve.



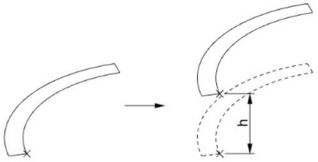
R19: insert a 3d model according to a rectangle and the height sh.

Figure 4
R20 and R21 are the rules of elevation calculation and elements translation.

$$Yn = [(Yn\text{-}1 + (Kn\text{-}1) \times C] \times Xn / (Xn\text{-}1)$$

Where Y is the elevation from the focus point to eye point, K is the number of rows, C is C value.

R21 elevation calculation equation



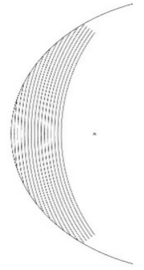
R21 raise the shapes vertically by h from the plan

THE COMPUTER IMPLEMENTATION OF GG

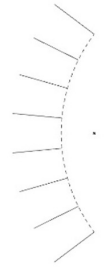
The goal of the computer implementation of GG is to develop a reusable tool for grandstand design. The stability and ease for use should be considered. The user could design with the tool without refering to the detail rules. Therefore the rules should be sealed in the tool and not to be exposed to the users in order to avoid the miss-operation and the confusion of the user. The input and output of the tool should reflect the simple need of the grandstand design. Grasshopper in Rhino3D is chosen as the parametric modeling platform. Scince the seat distritution task is strongly relied on the plan drawing task, the 2 tasks are incoporated into 1 component. The components of aisle axis generation, elevation calculation and 3D model generation are also developed (Figure 8). İnitial sets of parameters are introdued to the components to guarentee the ease of use. The user can use and connect the components to solve design problems of the grandstand.

1. The initial shapes are the first row curve and the focus point.

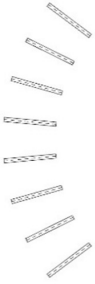
2. Use R1 to offset the first row curve to get several row curves.



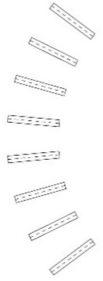
3. Introduce the boundary curve and use R2 to trim the row curves.



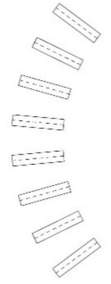
4. Use R13 to generate the axis of the aisles.



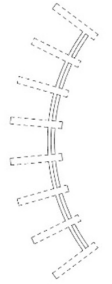
5. Use R14 to generate the regions for aisles.



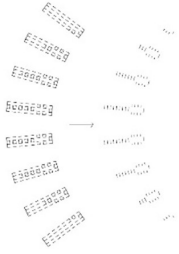
6. Use R14 to generate the regions for vomitories.



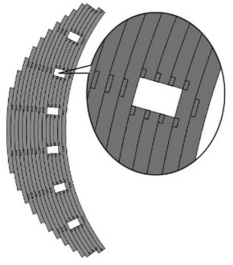
7. Use R14 to generate the regions for aisles adjacent to vomitories.



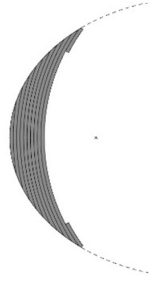
8. Use R5 to trim the row curves with the vomitory regions.



9. Use R5 to trim the row curves with the aisles the get the aisle step curves.



10. Use R6 to get the closed curves for each row and aisle step.

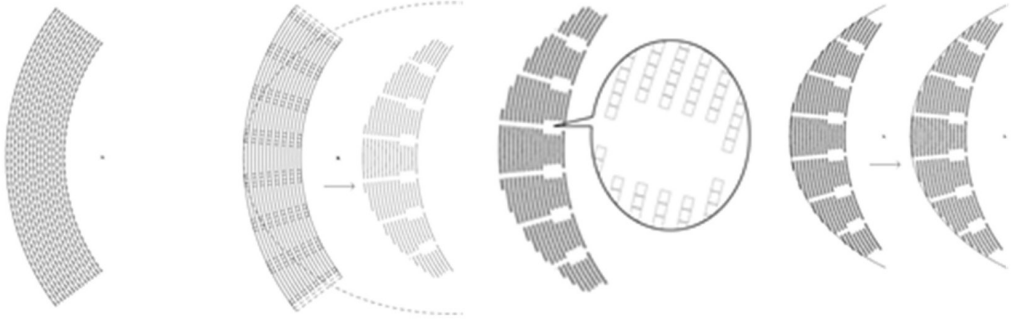


11. Use R7 to R9 to trim the closed curves in step 10 with the boundary.

12. Until now the plan curves for rows and aisle steps are generated.

Figure 5
Step 1 to 9 show the generation of the plan curves for rows and aisle steps.

Figure 6
Step 13 to 16 show the population of seats.



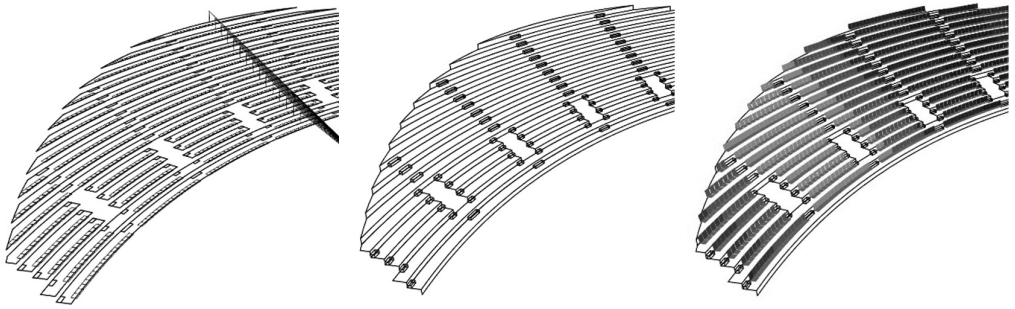
13. Use R1 to offset the row curves to get the seat guide curves.

14. Use R5 to trim the seat curves with grandstand boundary, aisles and vomitories.

15. Use R15 and R16 to insert seat plans on the seat guide curves.

16. Use R17 and R18 to delete the seats out of the grandstand boundary.

Figure 7
Step 17 to 19 show the generation of the whole grandstand 3d model.



17. Use R20 and R21 to calculate the elevations and translate the elements.

18. Use R12 to extrude the row and step curves into solids.

19. Use R19 to locate the seat models.

Figure 8
Main components of the grandstand design tool.

Component for plan generation

Component for aisle axis generation

Components for elevation calculation and 3d model generation

THE APPLICATION OF GG AND ITS COMPUTER TOOL

GG and its computer tool is applied to the design practice of a stadium with 25000 seats. In the preparation phase of the project, new designers were trained to learn the knowledge of grandstand design and the use of the parametric model. Their abilities to build the 3D grandstand model varied greatly in terms of the understanding of the grandstand rules and the 3D modeling software. However, the learning curves were benefited from the systematically formulated shape grammar, friendly user interface and the detailed initial set of parameters. All of the designers could basically operate the tool in the 4 hours session of training. After the training they could use the tool to generate simple grandstand 3D models. As we should point out, the tool did not turn them into experts of grandstand design in the very short time span. Also the digital tool should not be seen as a guarantee of good grandstand design. In the design process, the model should always be reviewed and evaluated by the experts to avoid design mistakes.

In the design competition phase, the tool was used to guide the design decision making. A main issue of the project is the configuration of seat number on the tiers of the two sides. The change of configuration has an important impact on the height of the grandstand: symmetry configuration results in the same height of both sides; uneven configuration results in different height of sides. Multiple designs were generated to reflect the relationship between the height and the seat configuration.

In Grasshopper, model of the grandstand and the other parts are inter-related to each other. The first row profile and the boundary of the grandstand are the key shapes for both grandstand design and roof design. Therefore different design tasks could share some key parameters. The design of the 2 parts can be carried out simultaneously and separately because of the parametric feature of the model. Designers could parametrically model the roof according to its relationship with the grandstand. Therefore the roof model can be updated in the grandstand process. The designer could also adjust the grandstand design according to the evaluation of the roof. The relationship between the grandstand and the whole building was reflected in real-time to enhance the design communication and facilitate the making of design decision (Figure 9).

İn the design develpment phase, the parametric model was used to tackle the intense design modifications. During the process, several modifications were carried out. Curvature and elevatioin of the first row profile, row distance, seat width, number of rows, elevation of the upper tier, distance between aisles, position of vomitories and the boudary of the upper east tier are changed compare to the grandstand in the design competion phase. Thanks to the rapid response and the flexibility of the parametric model, the grandstand designs were quickly updated to facilitate the modifications of the other parts of the building (Figure 10).

During the design practice, the aims of GG and its computer implementation were verified. The combination of shape grammar and parametric modeling enhance the learning experience of the grandstand design knowledge. Real-time 3D visual feedback, performance feedback and the integration of the whole building enables the architect to widely explore the design space in the early design phase. İn the design develpment phase, the parmetric model could cope with the multiple design modifications and promote the efficiency of the whole building.

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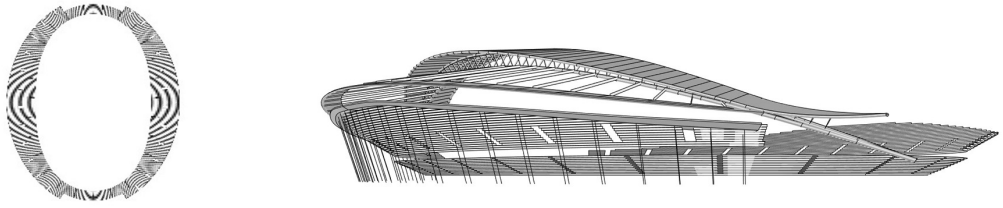
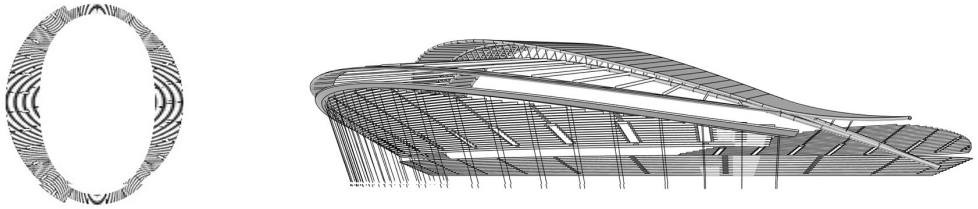
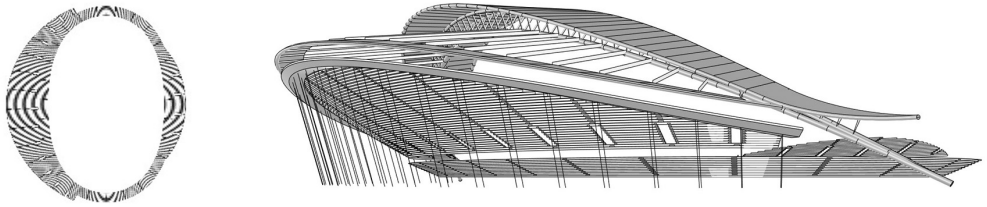
Figure 9
3 grandstand designs with approximate 25000 seats. Different seat population of the west and east tiers result in different heights and form of the grandstands and the associated roof structures.



Seat count: West tier = 6754, East tier = 6754, lower tier = 12049, total = 25557

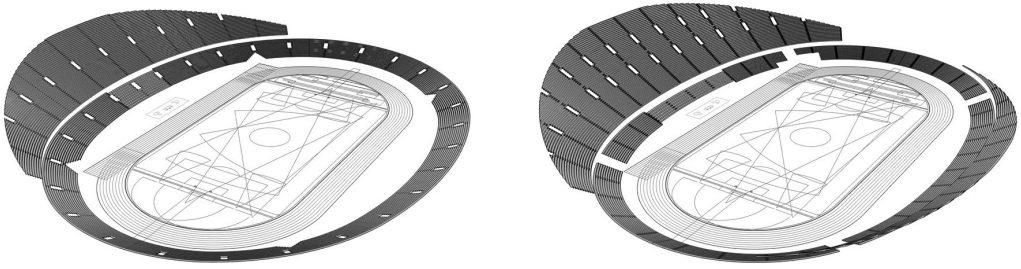


Seat count: West tier = 8486, East tier = 4775, lower tier = 12049, total = 25310



Seat count: West tier = 11350, East tier = 2204, lower tier = 12049, total = 25603

Figure 10
grandstand design of the schematic design phase (left) and the design development phase (right). Many parameters were changed during the design process. The model can be updated quickly according to the adjustment of the parameters.



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