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DESIGNER'S DILEMMA

The precision of numerical simulations in design systems

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Abstract. Performance based design systems are characterised through the use of performance related evaluation methods or by providing design environments which are restricting the design space according to performance criteria. The performance of a design can be evaluated by numerical simulations. With the use of numerical simulations a fundamental dilemma appears: the precision implied in numerical simulations and the imprecision of the design process itself are systematic contradictions. User control or user interaction in open systems places the user into charge of the imprecision required by the design process. In closed systems, as the below described evolutionary system, methods of imprecision have to be integrated i.e. into the precise simulation based evaluation procedure. Through tolerant selection methods and the gradual evaluation of individuals the rigid and precise system can be guided towards a design system rather than an optimisation system. Due to technical requirements which are related both to the fact of using computer systems but also to the systematic conditions implied to simulations the use of the tolerant selection methods is limited.

Keywords. Simulation based design; generative design; creativity, acoustics.

1. Introduction

With the recent spread of computer based design in the architectural domain the idea of integrating building performance as design driver into the design processes arises. The performance of a building is reflected by various criteria including but not limited to structure, function, climate or acoustics. The performance of a building can be modelled by numerical simulation. These simulations can be integrated into the design process in order to relate the design outcome to the desired performance criteria. Mainly two different ways of integration can be identified. Some approaches use simulations as an integrated and interactive solver

(Attar et al., 2009; Rippmann and Block, 2011; Ahlquist and Menges, 2011) which provides a design environment based on a set of boundary conditions in which the design evolves according to these conditions. Others use simulations as performance based evaluation tool within a generative design algorithm (Lehmkühler, 2009; Spaeth and Menges, 2011). Both approaches aim to integrate complex performance criteria early into the design process in order to implement these criteria substantially into the design outcome. Both the simulated environment in which the design process takes place and the evaluation of the design through the use of simulation takes the matter of the simulation as a major design driver into account. But the integration of a more or less scientific simulation guides the designer to a dilemma. The dilemma is based in the fundamental clash of numerical simulations and creative design processes. Numerical simulation, since they are algorithms, are characterised as to be fully determined, computable, finitely and terminated (Cormen et al., 2007). Design as a process in contrast is considered as a "wicked problem" (Rittel and Webber 1973, p. 160) or an open system. The major characteristics of this open system are the absence of a definite formulation of the problem and the lack of determination in general. (Rittel and Webber, 1973, pp. 161–167) These two premises are the poles of the dilemma of a simulation based design process. Between this span of determinism and precision on the one side and a non-determined, open-end design process on the other side a simulation based design system is located. The challenge is to integrate the precision of the expert simulation system with the generative power of the imprecise design process.

2. Integration of Performance Criteria

Within a generative design system the design goals are reflected by the definition of the evaluation criteria which are driving the selection procedure. Thus only criteria which are defined as a part of the evaluation algorithm have the capacity to contribute to and be reflected in the design outcome. Hence the evaluation procedure as a closed system doesn't provide control from outside during the process itself. This is a crucial and systematic difference to a simulation based design environment where an interactive solver is providing boundaries to the design and the evaluation is continuously carried out by an actively controlling user. Consequently in such an open system the design goals and outcomes are directly and intuitively constraint by the acting user. Thus only the performance based boundaries which the design is going to take place in have to be defined. These boundaries are limiting the opportunities of action for the user to constrain the design result to the desired performance criteria. Whereas within the closed generative system both the boundary conditions as well as the design information are to be defined beforehand. Since the design goals are under the continuous control of the interacting user within the design environment the closed system doesn't provide any input from outside during the generative process.

Certainly the set of evaluation criteria is crucial for the success of any design system. Within the evaluation criteria both the design aspect as well as the performance aspect has to be reflected. In the discussed approach the performance aspect is represented through a numerical room acoustic simulation and the design goals which also can be considered as performance criteria are represented through morphological and functional criteria. Since all three aspects are computed by algorithmic procedures all results are rigour and precise within the given boundaries.

3. Technical Boundaries and Side Conditions

In an ideal world a design system would be an entirely open system where any imaginable criterion can be considered and any imaginable design solution could be created. Unfortunately since the design system is represented by algorithms it needs to be technically determined and limited (Cormen et al., 2007) just to make it computable.

Thus there are technical side conditions required for the design system. In the case study the creation of the geometry within the evolutionary design system is based on points in a three dimensional space. Although the position of the points is theoretically random it is necessary to limit the available domain for the points, because computers are not able to compute genuine random figures based on infinity but they need to draw the lot within specified boundaries. In consequence this means that the available space for design solution is limited by this definition. Aside the non-existence of infinity also the computable precision has to be restricted. Assuming an infinite precision would cause an infinite use of memory capacities which are practically not available. These technical restrictions apply also to the simulated environment approach where a user is interacting with the system. These computational restrictions apply to all algorithmic based design approaches but their impact to the design outcome can be reduced by providing sufficient computer power.

Aside the basic universal computational limitations also some method specific side-conditions have to be taken into account. These limitations are specific to the chosen methods within the design system and do not necessarily apply to other design systems.

The described design system is a genetic based evolutionary system. The genetic code of the individuals can be noted either as binary code or as floating point numbers. The genetic information as a binary code is demanding for a rigid definition within the structure of the genetic code. The advantage of a more easily analysable binary code is in trade for the disadvantage of having a prescriptive domain where the solutions are located in. Within a binary description of coordinates of points i.e. the decimal has to be defined and limited in order to represent it within the binary description. This assumes that the range and precision of points is known beforehand. In many cases this is exactly what the designers don't know at the beginning of a design process. Thus this would be quite a significant restriction to the solution space where the evolutionary algorithm is searching for solutions in. The description of the individuals can also been realised by storing floating point digits in the genetic code which then limits the solution space to the capacity limitations of the computer systems only.

Within the simulation algorithm the described design system is using a combined method of a so called mirror sound source method along with a ray tracing method to analyse the acoustical quality of the enclosure. Due to the arbitrary distribution of the acoustics energy rays within the ray tracing method, the examined volume is required to be geometrically enclosed. Additionally the enclosure hull must not intersect itself. The calculation method for the acoustic quality relies also on the visibility between the sound source and the sound receiver. As soon as the sightline between the source and receiver element is blocked the acoustics calculation is incorrect. Additionally the receiver and the source must be represented as a spherical volume. As a result of these requirements all sources and all receivers not only must be included in the hull but also must have a certain distance from the surfaces.

Consequently individuals that do not include all receivers and all sound sources, or that are self-intersecting or that are not totally enclosed must be sorted out before the evaluation process is applied, because these individuals are not computable correctly by the acoustical simulation.

4. Tolerant Selection Procedures and Technical Side Conditions

The major mechanism within an evolutionary system is the selection process. In general the selection process applies not only according to the performance criteria but also according to the fulfilment of the boundary and side conditions. Individuals in the current population that don't match to the respective criteria are not selected to proceed to the next generation. Basically the threshold is a sharp borderline, where either the individual is fulfilling the requirements or not. But the strict use of the sharp borderline causes the problem of early convergence (Petzold, 1998, p. 123). The convergence problem could be solved by a tolerant selection method. The tolerant selection method enables the survival of individuals even if they do not fulfil the requirements completely. These surviving individuals can be either flagged as extraordinary survivors or they are punished with a reduction of

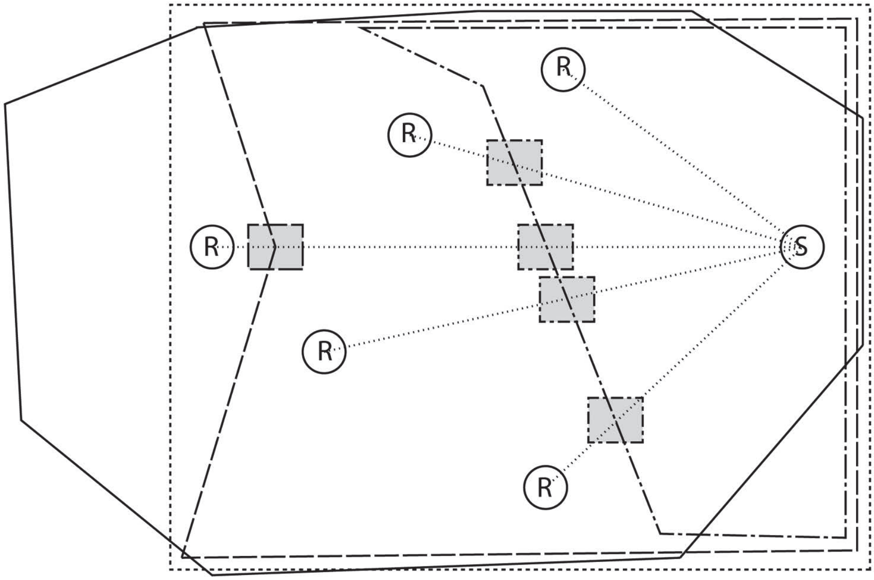

Figure 1. Diagram of the sight line prevention condition.

evaluation ratio. In Figure 1 the application and impact of a tolerant selection method is diagrammed according to the sightline prevention criteria.

In the diagram (Figure 1) the sound source is represented by a sphere (S) and the receivers are represented by another sphere (R). The dotted lines between the source and receiver are representing the sight line. With the grey hatched rectangles the violation of the side condition is marked. Given that the optimum volume is the area outlined with the dot line and three different individuals are represented through other different line types, the dashed volume is the closest to the optimum. But due to its violation of the side condition (sight line prevention) it is eliminated from the population whereas the volume represented by the continuous black line survives. If the tolerant selection method could now select not only the volume represented through the continuous line but also the volume with the dashed line into the new population the algorithm would be more efficient in finding appropriate solutions. By comparing the grade of violation through adding the distances of the violation point to the receiver a selection of minor violation could be realised.

But this method fails if the integrity of the criterion is required for the ability to compute the evaluative simulation. The basic response to this problem by avoiding computing the simulation is either the addition of a punishing value within the evaluation process or to apply a reparation function before the evaluation process to enforce the individual to be computed. But this requires a precise knowledge of the solution domain. In order to assign a reasonable punishing value the range of evaluation values with in the population must be known. But as long as the optimum is not known, which is systematic for design processes this method doesn't apply. The reparation function might work in general but considering the special situation with the genetic description of the geometry through the notation of points and also considering the condition of non-self-intersection the establishment of a reasonable reparation function is not achievable in this context.

5. Gradual Evaluation

The acoustical simulation is delivering precise results of the sound energy based physicality in the hull. The physics based results do not represent the perceptive quality of the enclosure, but they are describing the physical reality only. Qualitative thresholds are gained through different ratios of sound energy in relation to distinguished timeframes. These thresholds are not precise values, but they are defined as more or less large ranges within specific acoustic qualities that are recognised by a majority of listeners. Asides the acoustic thresholds the rooms are also evaluated in terms of functional and morphological qualities. Through the analysis of surface distances, sizes, angles and other morphological criteria of the enclosure quality measures related to function and morphology can be gained. These quality values are also not precise digits because the functional quality of a space as a comfortable area to stay within a certain physical reality may be evaluated equally. According the tolerant selection method the quality evaluation is processed through a gradual transcription algorithm which transforms the physical simulated reality gradually into a quality measure (Figure 2).

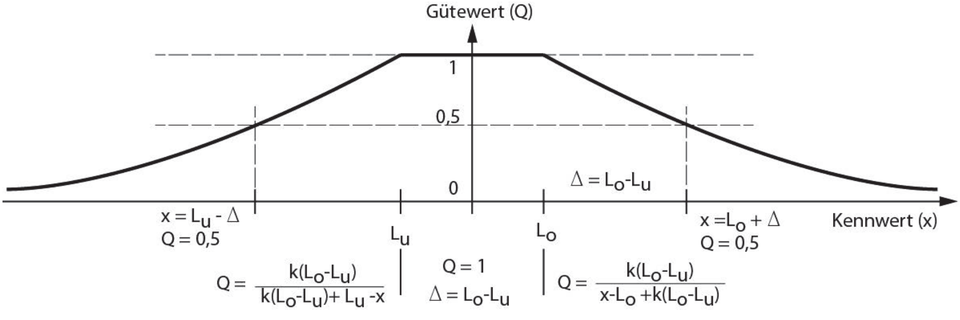

Figure 2. Transcription algorithm of physical properties into quality values.

The graph in Figure 2 shows that the gradient of the quality is in relation to the optimum area for the regarded criterion. The larger the range of this optimum area the bigger the slope of the graph is. The slope is defined through the 0.5 threshold which has the same distance on the abscissa to the lower or upper boundary value as the distance of the optimum range. Through this transformation algorithm the different ranges of optimum amongst the different criteria is balanced and related to their inherit precision.

6. Implementation of the Imprecision into the Design System

Since the proposed design system is a closed system which doesn't provide user interaction from outside the imprecision required by the nature of the design process has to be implemented into the evaluation procedure. The above exploration shows that not all of the side conditions such as sightline prevention, self-intersection or inclusion of all sources and receivers can be handled tolerantly. Regarding these strict conditions the population is created homogeneously computable by sorting out the not matching individuals and replacing them by newly created ones which are computable by the room acoustical simulation. The room acoustical simulation is carried out with the entire precision possible by the computational power. But the results of the simulation are transferred into quality measures according to the above mentioned gradual evaluation algorithm. The acoustic quality is evaluated not only by one single acoustical criterion but by various perceptive acoustic criteria and also on multiple positions in the enclosure. Alongside with this transformation other criteria such as morphological and functional criteria are integrated into the evaluation measure. The evolutionary algorithm which is searching for the design result is formulated as a maximisation algorithm which searches for the best solution using the described three main evaluation criteria, acoustics, morphology and function. Respectively the algorithm is not eliminating individuals that are failing criteria but is looking for the maximization of the quality measurement. Thus not only the gradual evaluation procedure but also the general selection method which is tolerant provides the necessary imprecision for the design system.

7. Conclusion

Although the selection of evaluation criteria is crucial for the success of the design system and although the criteria are representing design goals still they are not responding to the requirements of solving “wicked” problems. The imprecision which is required by any design process can be incorporated into a design system either by enabling user control or by integrating tolerant selection methods and gradual evaluation procedures. Through user control the system as such can remain very precise and strict because the user is in charge to provide the imprecision for the design process. Through the gradual evaluation and tolerant selection methods the imprecision is integrated into the system itself. The extent of integrating these methods is limited by technical restrictions that are i.e. related to the applied simulation method. Thus not every criterion which is desirably treated tolerantly can be handled accordingly. And even substitutive methods like punish function or reparation function are not applicable in every case.

This exploration was done with in the development of a form finding algorithm for acoustic rooms. In the applied acoustic simulation a tolerant selection method for the sight line prevention criterion is not applicable due to the technical necessity of the receivers to be viewed directly by the source and the lack of knowing the bench marks. But for other geometric criteria, which are not included in the simulation process, like number of hull faces, or the distance of the receiver to the hull the selection of the individuals could be handled tolerantly and or gradually. Due to the lack of knowing the solution landscape punishment functions could not be applied to the evaluation procedure. But the gradual evaluation method is applied to any of the evaluation criteria.

Nevertheless the application of tolerant selection and gradual evaluation opens the closed system of evolution based generative system on the basis of an acoustic simulation towards a system that reflects the notion of imprecision in the design process and makes it act more as a design system than an optimisation system. The combination of design oriented evaluation criteria with a tolerant selection strategy keeps the potential of surprising or unforeseen results which are typical for design systems.

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