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A proposal for a tool for automatic correction of geometrical errors in acoustical simulation

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ABSTRACT

Acoustical simulation is an important issue in room acoustics since algorithms and computers allow developing acoustic numerical models. Through this process, it is possible to obtain acoustical parameters from any environment, whether it is already built or in its design phase. From these parameters, the acoustical characteristics of a room can be improved and it is possible to test the effect of any change. In our work, we are focused on the simulation of geometrically complex rooms. When doing acoustical simulation, we have to build properly the geometrical model, but if there is any error –made by the modeller or in any conversion–, it must be corrected in order to achieve an accurate model. Having a good geometrical model of the room is essential, but in some cases this is not possible. Moreover, when using simulation software, the geometrical model is imported, in most cases, from other modelling software (CAD modelling), and this process can lead to some conversion errors. Up to now, these errors were corrected by hand, but it might be a tedious process when working with highly complex buildings. We propose a tool to automatically reduce the geometrical errors derived from such complex models. We start from a debug file which includes a list of geometrical errors detected by the acoustical simulation software and these are corrected in an iterative process between our tool and the simulation software.

INTRODUCTION

In room acoustics, acoustical simulation and auralization is an important issue and it is widely performed. There are many computer programs that are used to study room acoustics (CATT [1], Odeon [2], Ease [3], …) and with them, we can work through the whole process, starting by creating the geometrical model of the room and in the end obtaining an auralized sound file in that room. However, the process of modelling becomes more difficult than if it was made with specialized modelling software as AutoCAD. For this reason, it is common to use them to model the room and afterwards import it to the room acoustical software [4]. Still, there is a drawback: some acoustical simulation software has its own geometry file format and consequently the model has to be imported with the software's importer.

The geometry of the room has to be built accurately. Nonetheless, it is possible to find errors when doing the acoustical simulation and these have to be corrected in order to process the simulation. Up to now, such errors were corrected by hand only with the help of the graphic viewers provided with the acoustical software. But this could be a great problem when the geometry becomes too complex, as sometimes it is difficult to see where the error is.

Experience is essential in order to correct efficiently the geometry. The main drawback when facing the correction of geometric models is that there is no clear methodology for new and inexperienced users to follow.

With this work we propose a tool that will help the users of acoustical simulation software to correct the geometry of room models. The tool has been developed to use jointly with CATT's software.

This work has been developed within the scope of a project approved and financed by the Ministry of Science and Innovation of Spain "*Study of objective and subjective parameters assessors of perceived sound quality, in rooms, halls and buildings of historical and artistic heritage. Validation of an acoustic quality protocol*", which started in 2009, ref. BIA2008-05485 [5].

ERRORS

CATT software provides a debug file which can be used as a guide for solving geometrical modelling errors. The tool we have developed employs this debug file for the correction of different kinds of errors. We have studied these errors and solved them in an efficient way. The errors we expose here are the ones that can be a consequence of importing an AutoCAD model (dxf model).

These conversion errors must be corrected in order to assure an accurate simulation of the room impulse responses.

Unstable planes

This kind of error blocks the prediction algorithm of the acoustics simulation software; therefore, it needs to be corrected. A plane is detected as not stable when any of his angles are close to 0º or to 180º. In this case, the simulation software recommends dividing the plane in two parts.

Planes modelled twice

When a plane can be reached by a ray from both sides it has to be modelled as two different planes with opposite normal vectors. When the software detects a plane modelled twice the solution in most cases is to change the normal in one of the planes.

Duplicate corners

This error warns about the proximity of two different corners. This error can be caused by precision issues and can be avoided using the snap tool when modelling. Nevertheless, when facing this error, the easiest solution is to keep one of the corners and use it for all planes where the rejected one was used.

Single-connected corners

Single-connected corners and cutting or touching edges are the most common errors and both are related. Such errors arise when a plane is drawn and one or more of its corners are not used to build other planes. Even if, visually, a plane intersects with other planes and we seem to perceive a closed space, the acoustics simulation software does not recognize it as a closed space, as it does not compute any intersection. For this reason, all intersections must be defined in the geometry file.

This problem can be prevented by defining these intersections in the modelling phase; however, it can be solved in case the modeller had not taken this into account. The tool finds any intersection between the troublesome plane and the nearest ones, creating any necessary corners and redefining the involved planes.

Besides, this kind of error may be caused by oversight if both sides of the plane are reachable by sound. In this case, no intersection will be found and the tool will create the opposite plane.

Inaccurate plane corners

This error indicates that the corners of a plane are not in the same plane, therefore generating a warp in the plane, which is not supported by the acoustics simulation software because the reflexions could not be accurately calculated. To avoid such issues, the geometry should be created with triangles, but this would increase considerably the complexity of the model. The proposed solution is to triangulate only the detected planes.

Coinciding planes

A plane cannot overlap another plane surface because the acoustic simulation software will detect an open space. This case is similar to the one described in single-connected corners error. To create a closed space, all the intersections must be created by adding new corners and edges and the involved planes have to be redefined.

Edges cutting or touching

As explained before, when two planes intersect or touch and the intersection is not defined, the acoustics simulation software interprets it as if there were no intersection, therefore causing a not-closed space. In this case, the junctions have to be computed and the plans involved have to be redefined.

Reversed planes

The acoustic simulation software obtains a list of possibly reversed planes, but this does not imply that all planes in the list are reversed. Some planes may appear in this list because of other errors. Due to this reason, the tool will detect which planes have incorrect normal vectors and it will redefine their corners in the appropriate way.

APPLICATION

The developed tool has a simple interface (Figure 1) which asks the user for a geometry source file and the corresponding debug file provided by the acoustics simulation software. The tool shows the user the number of errors listed in the debug file and the user can choose which error to correct. After running the tool, a new geometry file is created.

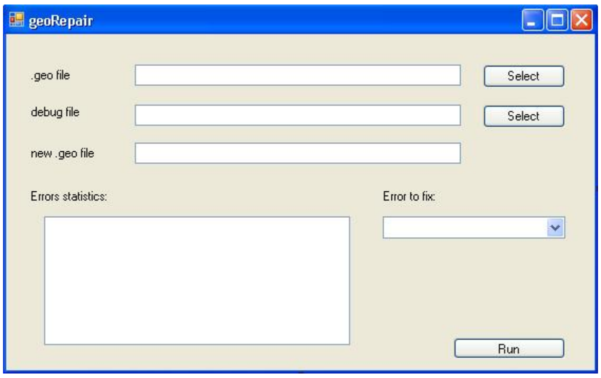

Figure 1. Graphical User Interface of the developed tool

The correction tool is used iteratively with the acoustics simulation software. The new geometry file created by the tool is checked again in order to get the new debug file, which will have less number of errors. Some errors are related, hence, by fixing one kind of error, others can be reduced. These relations are reviewed in the results section.

MODELS

The aim of the project within which this tool is being developed is to study the acoustical parameters of emblematic buildings of the Valencian Community (Spain), as well as creating a protocol to validate the acoustical quality of rooms.

When modelling auditoriums, the geometry usually has straight walls and the errors obtained by the acoustical simulation software can be managed easily. However, the project involves not only auditoriums but also more geometrically complicated buildings such as chapels, basilicas and cathedrals. Specifically, we are studying some auditoriums (Music's Palace of Valencia, Reina Sofia Palace of the Arts), some theatres (the Principal Theatre of Valencia), some emblematic buildings (like the Lonja (the Silk Exchange building)), the Cathedral of Valencia and its Holy Chalice Chapel, among other buildings.

With buildings as complex as these, it is very difficult to create a geometrical model without any error. Moreover, it is necessary that those responsible for creating the models have experience with the acoustical simulation software. This is because the creation of the model should follow some rules that are dependent on the simulation software.

The tool we propose has been tested on two different models: the Auditorium and Conference Centre of Castelló and the Holy Chalice Chapel.

The Auditorium and Conference Centre of Castelló was built in 2004. It is characterized by the asymmetrical design of the volumes, and it hosts both corporative and cultural events (conferences and concerts). The auditorium can hold up to 1200 people and it has 14850 m^3.

The Holy Chalice Chapel is part of the Cathedral of Valencia and it dates from the middle of the 14th century. It is important because legend has it that it houses the true Holy Chalice. In the beginnings it was used as a chapter house and as a theology studies room. Nowadays, it is used to celebrate special mass, funeral mass and for organ concerts. The Chapel's volume is 3205 m^3, and it has capacity for, approximately, 150 people.

The information about the modelled geometry of the Auditorium and the Chapel is summarized in Table 1.

Table 1. Geometry characterization

	Number of planes	*Number of corners*	*Volume (m3)*	*Capacity (people)*
Auditorium of Castelló	1894	3999	14850	1200
Holy Chalice Chapel	4565	5045	3205	150

In Figure 2 and Figure 3 the geometrical models of the studied buildings are shown. Besides, in Figure 4 the model of the Cathedral of Valencia is shown. In this, the location of the Chapel is marked.

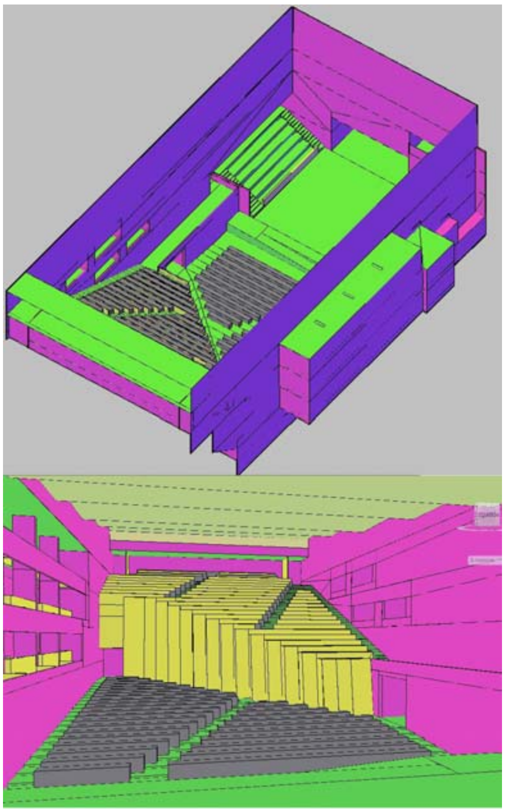

Figure 2. Geometrical model of the Auditorium of Castelló

The Chapel model uses a large number of plans. This number could be reduced by using fewer surfaces to approximate the dome, as it is where the complexity resides. However, when doing a less accurate approximation the simulation will be less exact because the rays will not reflex in the same way as in the original room. Therefore, there has to be always a compromise between the complexity of the geometry and the performance of the acoustics simulation software. Nevertheless, in this study, we are not concerned about the performance but the exactitude. That is the reason for using so many planes.

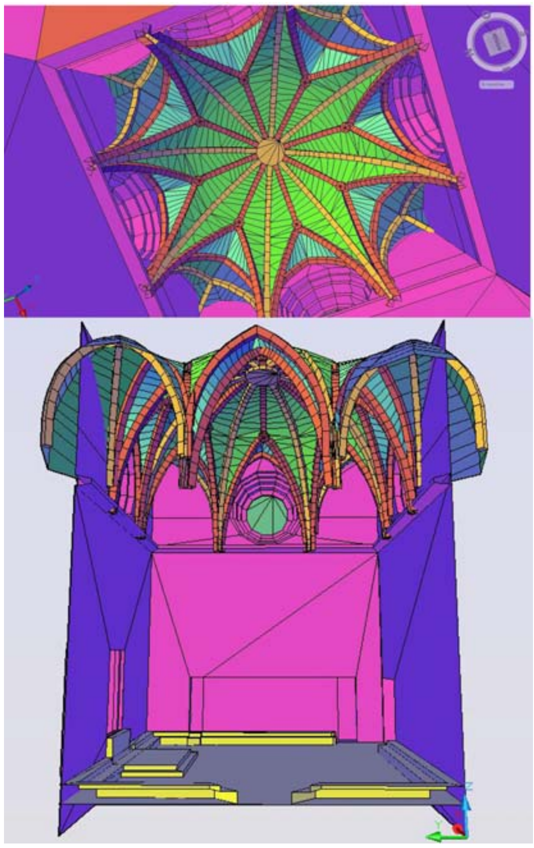

Figure 3. Geometrical model of the Holy Chalice Chapel

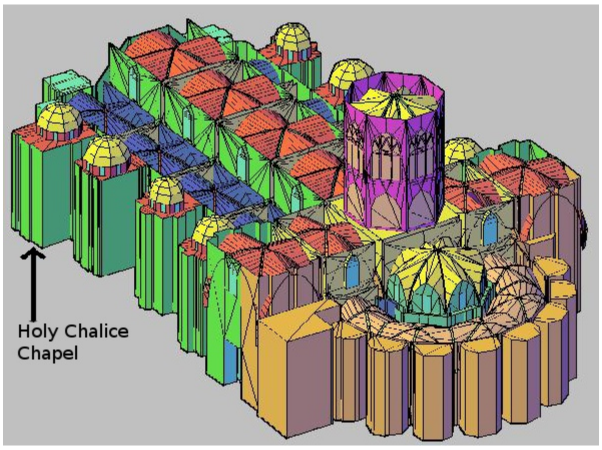

Figure 4. Geometrical model of Cathedral

RESULTS

In the process of testing the tool, the rooms presented in the previous section were used. They were processed by the CATT Acoustics software and we obtained the corresponding debug file for each model. From the debug file we used the tool for correcting each kind of error, and every time an error was fixed we created another debug file, which contained the updated errors. Iteratively, all errors can be corrected.

Table 2 and Table 3 show the evolution of the number of errors for each type of error. Table 2 corresponds to the geometry of the Auditorium of Castelló and Table 3 to the geometry of the Holy Chalice Chapel.

Each row of the table represents a different type of error and shows the number of errors of this type that the model has. The last row represents the total number of errors. Each column represents which type of error is fixed in each iteration. The first column stands for the number of errors found in the original model (without any fixed error).

This tool is a work in progress, thus, some functionalities are not yet in working order. Due to that reason, the tables only show the results of applying some of the corrections.

Table 2. Auditorium of Castelló. Evolution of the number of errors for each type of error

	Original model	*Unstable planes*	*Duplicate corners*	*Inaccurate plane corners*
Duplicate corners	909	909	0	0
Single-connected corners	1561	1546	429	382
Inaccurate plane corners	163	163	219	0
Coinciding planes	56	60	58	63
Edges cutting or touching	3623	3714	2867	3288
Possibly reversed planes	949	952	945	1067
Total	**7261**	**7344**	**4518**	**4800**

Table 3. Holy Chalice Chapel. Evolution of the number of errors for each type of error

	Original model	*Unstable planes*	*Duplicate corners*	*Inaccurate plane corners*
Duplicate corners	73	73	0	0
Single-connected corners	172	169	112	111
Inaccurate plane corners	910	940	950	0
Coinciding planes	8	5	2	2
Edges cutting or touching	2418	2515	2328	2856
Possibly reversed planes	1796	1786	1783	2014
Total	**5377**	**5488**	**5175**	**4983**

From the tables, it can be seen that when applying a correction, the number of errors does not only descend for this type of correction but also, other types of error descend.

In Table 2, the biggest decrease is found when correcting duplicated corners: the number of single-connected corners has been reduced by 72.3%, the number of edges cutting or touching has been reduced by 22.8% and finally, the total number of errors has been reduced by 38.5%; by only correcting one type of error. By applying the three corrections included in the table, the total number of errors has been reduced by 33.8% with regard to the original model. It can be seen that by fixing the inaccurate plane corners, the total amount of errors increases. This happens because the troublesome planes have been divided, hence, increasing the number of planes and, as a consequence, increasing the number of edges cutting or touching.

In Table 3, the maximum decrease is found when applying the correction for duplicated corners, thus, coinciding with the results in Table 2. In this case, the number of single-connected corners has been reduced by 33.7%, the number of edges cutting or touching has been reduced by 7.4% and the total number has decreased by 5.7% when fixing duplicated corners. From the original model, the total amount of errors has been reduced by 7.3%. In this case, it can be seen that the reduction of inaccurate plane corners involves an increase in the number of edges cutting or touching as happens in Table 2. However, the number of errors that have been corrected is higher than the increase in the number of errors. Therefore, the total number of errors has not increased.

When correcting duplicated corners, the number of corners decreases, which induces a reduction in the number of corner-related errors. However, the number of inaccurate plane corners increases in both cases. This is due to possible minimal deformations in planes, which cause the angles to go near 0º or 180º, thus triggering the error.

In both tables we can see that the most repeated error is edges cutting or touching and it is related with single-connected corners. Therefore, when correcting any of them, the total amount of errors will be reduced significantly.

Furthermore, although the number of possibly reversed planes is considerably high, we do not consider it meaningful because not all planes listed there are necessarily reversed.

Finally, after correcting each kind of error, the simulation will be done guaranteeing accuracy.

CONCLUSIONS

In this paper we have proposed a prototype of a tool for automatic correction of geometrical errors detected by the CATT acoustic software.

We have made a study of the different errors that can be found when creating a geometrical representation of a building in CAD software and later importing it in the acoustic simulation software.

We have tested the tool in two different models: the Auditorium of Castelló and the Holy Chalice Chapel, both with very different geometry. In both cases, we have showed that the number of errors has been reduced.

The tool is not fully developed yet so we have presented a partial study of efficiency where we show how the errors are correlated. When finished, this tool will be very important as it will allow any acoustics simulation software user to work out easily any geometrical problem.

In the near future, the research will be oriented to obtain a mesh transformation system. This system will be used to transform the model into a mesh. In the mesh, all planes will be connected and the algorithm will find any intersection, creating any necessary extra corners and planes [6][7].

Furthermore, we want to research the relation between simplification of the geometry [8] and the number of errors obtained by the acoustics simulation software.

Finally, this tool will be implemented to work with other acoustics simulation software as they have similar problems to the ones presented here.

ACKNOWLEDGMENTS

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