Abstract. Although in recent years presentation using CAAD animation has played an important role in architectural design, it is still weak in terms of acoustic environment simulation. Current acoustic simulation software are mainly for accurately calculating various acoustic indices and the calculation is normally not real-time. This research is therefore to explore the possibilities of adding instant acoustic responses to presentations using CAAD animation.

1. Introduction

Presentations made using CAAD animations have played an important role in the architectural design process in recent years. Increasing numbers of designers are using the animation presentation to support the design process and communication with clients.

Since the introduction of this technique considerable progress has been made in simulating visual details including space modelling, materials and lighting environment (Szalapaj, 2001). However, one area where CAAD animations are still weak is in presentation of the acoustic environment. Currently presentations only give a very rough impression of sound by adding background music rather than providing an instant response relating to the space.

A number of acoustic simulation software packages exist, but these are limited to calculation of various indices and calculation is not carried out in real-time. As a result, they are unsuitable to be integrated directly into CAAD. This research aims to explore the scope for adding instant acoustic
responses to CAAD with a long-term aim of developing a simple and effective acoustic tool that can be integrated directly into CAAD software.

This paper gives an overview of this on-going research project including:

- A review of CAAD and acoustic software;
- Interviews and questionnaire survey on requirements;
- Space generalisation for simplified acoustic simulation;
- Establishment of sound field database;
- Development of a prototype; and
- Further development of the prototype.

2. Review of CAAD and Acoustic Software

Initially the feasibility of adding acoustic responses to CAAD depends to a large degree on the availability and flexibility of currently available software. The two most commonly used CAAD programs, AutoCAD (Autodesk, 2003) and 3D Studio (Creative-3D.net, 2003), have been studied. Auto CAD features tools for precise 2D drafting and 3D modeling while 3D Studio focuses more on the further editing process including material editing and assigning, environment configuration of lighting and camera movement, and the making of animations.

Both packages can produce precise animations with 3D Studio in particular capable of importing more material databases to aid rendering realism. However, both programs concentrate simply on visual environment, and lack the ability to add source sound samples as rendering elements. Neither package allows sound source or receiver movement to be described.

There are many acoustics-related software packages (Cope, 1991; Dodge and Jerse, 1985). For acoustic simulation there are two main types (Kang, 2002). The first type focuses on room acoustic simulation: Raynoise (LMS, 1997), Odeon (Lynge, 2000), and CATT (Dalenbäck, 2003). The second type examines outdoor noise-mapping: Cadna (DataKustik, 2003) and SoundPlan (Braunstein+Berndt, 2003), for example. These applications focus on accurately calculating various acoustic indices and the calculation is normally time-consuming and not in real-time.

While most of these applications do not have any animation functions, Cadna provides a simple tool for this purpose which can produce a simulation of a vehicle moving along a route with a sequence of different sound effects corresponding to its movement. This simulation is a good attempt of adding instant sound responses to an animation although it lacks graphical finesse compared with full CAAD packages.

It is clear that existing programs in both relevant acoustic areas work in isolation and lack the ability to combine acoustics with CAAD and that this function needs to be explored and improved.
3. Interviews and Questionnaire Survey on Requirements

When developing a new tool the scope and outputs need to be clearly defined. Interviews and a questionnaire survey are being carried out to determine the accuracy requirements in simulating acoustic environment for design process and CAAD animation. Acoustic environments using several levels of simulation technique are played back to interviewees and subjective evaluations are being carried out, in order to determine suitable simulation and auralization techniques (Kleiner et al, 1993). The responses from the interviewees have been analysed and some preliminary results are discussed below.

Many architectural designers seem not to be paying much attention to acoustics, while some of those do believe that it is simply a matter of providing sound insulation. Some interviewees assessed acoustic design only when required by building regulations and a few interviewees didn’t think at all about acoustics and had no opinions about it.

Many of those interviewees who pay attention to acoustics simply require a tool for communication with clients. For instance, a designer mentioned they would like a presentation tool with acoustic environments that is able to show clients the aural differences between before and after an interior space is decorated - a function which is lacking in current applications.

Some alternative opinions have also been expressed. Some interviewees think it is essential to have accurate acoustic environment in CAAD animation. What they require is a precise demonstration rather than a rough adjustable presentation with real-time sound responses. One respondent commented that he expected the acoustic design element to become as important as lighting is currently.

The general consensus amongst interviewees is that adding acoustic responses to CAAD tools would be very useful, and it would need to work in real-time. This suggests that accuracy might need to be reduced to lower the calculation times.

4. Space Generalisation for Simplified Acoustic Simulation

As noted any new tool for including acoustic responses to CAAD animation would need to focus on shortening calculation time. To achieve real-time calculation, simplified algorithms will be essential (Rindel, 1995). To create simplified but acceptably accurate algorithms it is important to understand the basic characteristics of architectural spaces in terms of acoustics.

Three building types have been examined: houses, museums and offices, which have been taken to represent private, public and busy working spaces respectively. For simplicity, this study has focused on single storey space and ignores variation in cross-sections. Twenty-two houses, seventeen museums,
and twenty-three offices have been looked at and every space of each building type has been examined and classified into a number of simple space types.

It has been demonstrated that spaces of these three building types can be simplified into a few common types, which are useful for establishing the sound field database as discussed below. Figure 1, 2 and 3 show some examples of these simplified space types for houses, museums and offices, respectively.

After analysing each building type, an overall characterisation of all the results from the three building types has been carried out. This refines them into some basic space types, which are suitable for acoustic simulation (Tcher et al, 1994). Figure 4 lists the generalised space types.

![Diagram of simplified space configurations]

**Figure 1.** Simplified space configurations based on the analysis of 22 typical house designs.
Figure 2. Simplified space configurations based on the analysis of 17 museum designs.

Figure 3. Simplified space configurations based on the analysis of 23 office designs.
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<tr>
<th>No.</th>
<th>Description</th>
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<tbody>
<tr>
<td>a</td>
<td>Normal rectangular space</td>
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<tr>
<td>b</td>
<td>Long space closed on both ends</td>
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<td>c</td>
<td>Long space closed on one end and linked to another space on the other end</td>
<td>![Diagram]</td>
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<td>d</td>
<td>Long space linked to other spaces on both ends</td>
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<td>e</td>
<td>Joint rectangular spaces</td>
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<td>f</td>
<td>Coupled space</td>
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<td>g</td>
<td>Connected long spaces</td>
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<td>h</td>
<td>Large space with a block inside</td>
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<td>i</td>
<td>Large space with small spaces around</td>
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<td>j</td>
<td>Large space linked with several long spaces</td>
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*Figure 4.* Simplified space configurations based on the analysis of typical designs of houses, museums and offices, in order to develop a sound field database.
5. Establishment of Sound Field Database

The sound field of each simplified space type has been studied according to the results of space type characterisation. Acoustic software Raynoise was available and has been used to establish a sound field database. A number of sound samples have been compiled for each room type using pre-recorded dry signals. This sound sample database can be adopted to support the new acoustic simulation tool to be integrated into the CAAD animation simulation.

Before establishing the database of each sound field, it is essential to determine suitable parameters used in Raynoise. This includes, for example, ray numbers and reflection orders. Various boundary conditions have also been considered. Calculations with various absorption coefficients have been carried out to obtain a set of sound fields (LMS, 1997).

Simulation of each sound field has been undertaken at three typical frequencies, 125, 1k and 4kHz. Sound pressure level (SPL), early decay time (EDT) and reverberation time (RT30) have been considered. SPL colour maps have been produced, as well as RT30 and EDT curves, to show the details of sound fields (Kuttruff, 1973). Figure 5 shows the working environment of Raynoise and the SPL colour map of a sound field at 1kHz.

Figure 5. SPL colour map of a sound field produced using Raynoise.
The SPL colour map of a coupled space is shown in Figure 6. The map is created in Excel based on calculation data imported from Raynoise. Correspondingly, Figure 7 shows an EDT curve at three different frequencies. It can be seen that between the two spaces there is a significant difference, but within each room the EDT is rather even.

![Figure 6. SPL colour map of a coupled space made in Excel, data imported from Raynoise.](image1)

![Figure 7. EDT curve of a coupled space. Line, 125Hz; dashed line, 1kHz; dotted line, 4kHz.](image2)

Sound samples with corresponding room acoustic effects have also been produced after simulation and have been organised to establish a sound sample database. Both the sound field database and the sound samples can be adopted in CAAD program for animations, producing acoustic responses corresponding to the source and receiver movement. This process can be
very fast, which suggests that adding instant acoustic responses to CAAD animation is feasible.

6. Prototype

To demonstrate the feasibility of adding instant acoustic responses to CAAD animation, a simple attempt has been made using programs including AutoCAD, 3D Studio and Premiere (Adobe Systems, 2003). Although in this prototype only fixed sound sources and receivers are used when calculating the impulse response using acoustic software Raynoise, and the acoustic effects of movement are edited by audio editing software, this process however provides a useful demonstration - showing features of an animation with instant acoustic responses corresponding to the movement.

The prototype used AutoCAD to establish a model of a building with seven rooms. The route of movement was also determined in AutoCAD. Materials, lighting and animation environment set-up were undertaken in 3D Studio. A dry signal and several pre-recorded sound samples were used for this animation – the former was a speech through a PA system, and the latter were noise sources. The space model was first imported into Raynoise to simulate the acoustic responses of the dry signal. Sound samples with acoustic effects were then inserted into the animation by Premiere. Detailed editing of animation was undertaken in Premiere.

Figure 8 shows the working environment of AutoCAD and the model for this demonstration, while Figure 9 shows the working environment of 3D Studio and the animation configuration environment, and Figure 10 shows the working environment of Premiere and the animation editing process.
Figure 8. Modelling process in AutoCAD for establishing the prototype of a CAAD animation with instant acoustic responses.

Figure 9. Animation set-up process and configuration environment in 3D Studio.
After the establishment and editing process described above, an animation of a person moving among this seven-room building was made, with instant acoustic effects corresponding to the movement. For example, the volume of a sound source increases while the person moving closer to it and the volume of street noise decreases immediately when a window is closed. This prototype has given a good example of CAAD animation with instant acoustic responses.

The acoustic effects of the prototype will be demonstrated during the conference presentation.

7. Further Development of the Prototype

Since the prototype was only created as a demonstration, development work on an actual tool is ongoing, using C++. The integrated tool will be in the form of a graphical interface program, which will accept basic information about a room model and original dry sound samples. It will then calculate relevant data about the room, including area, volume etc, and produce a new sound file which takes into account room effects. This will be done in one of two ways depending on the user’s needs in terms of calculation time and accuracy:
• Obtain sound samples directly from pre-input sound database established during the process of sound field study.
• Use simplified algorithms in this tool to generate new sound samples considering the room effects.

The tool mainly focuses on adjustability and aims to be easy for users to input related data and then get the acoustic effects instantly. The next step is to integrate the acoustic tool into CAAD, which can be done in several possible ways:

• The sound sample database can be integrated into an existing CAAD program, with a similar function to the CAAD material database. An alternative way, which can provide relatively more accurate acoustic environment relating precisely to the actual space dimensions and surface conditions, is to adopt above-mentioned simplified algorithms in CAAD rendering process. Both methods can produce an animation with instant acoustic responses, and the acoustic environment can be easily adjustable according to design.
• Extract basic animation functions from CAAD software and combine them with the acoustic tool currently being developed to form a new program. The new program should focus on producing basic, acceptable and easily adjustable animation with instant acoustic responses rather than presenting a sophisticated animation in visual environment.

8. Conclusions

This research has shown the feasibility of adding instant acoustic responses to CAAD animations. From the prototype and currently developed tool an acoustic effect corresponding to source and receiver movement can be obtained in real-time. Further work is ongoing to combine the model with current CAAD animation programs.

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References

Creative-3D.net: 2003, 3D Studio Max, http://www.creative-3d.net/max5.cfm