The first step toward understanding the relationship between auditory and visual spatial impression is to investigate the terms that describe the impressions. This chapter is essentially a review of the texts in auditory and visual perceptions and it aims to draw some understanding of auditory and visual spatial impression as represented in auditorium acoustics and architectural design, respectively. This textual analysis is restricted to the sensational experience in concert auditoria. This section would serve as a theoretical basis for the subjective experiments and analysis of the results.

2.1. INTRODUCTION: WHAT IS SPATIAL IMPRESSION?

In auditorium acoustics, 'spaciousness', 'envelopment', 'intimacy', 'warmth', 'clarity', and 'loudness' are among the terms used to describe the subjective aural impression of an auditorium. These terms have been related to measurable acoustic parameters, which can be derived from impulse response measurements. Terms such as 'spaciousness', 'envelopment' and 'intimacy' have connotations beyond the auditory, and are used in architectural design to describe visual perceptions. This section considers factors that contribute to spatial impression in both the room acoustical and architectural design disciplines. As the overall spatial impression is likely to be formed from both visual and auditory cues, there is some prospect for the two modes of design to work together in rendering the spatial experience of an auditorium.

How a listener perceives and experiences an auditorium depends largely on the acoustical quality of the room. Spatial impression is explored widely in the auditorium acoustic literature, and many explanations have been offered. By way of definition Marshall writes, “The sensation of spatial impression corresponds to the difference between feeling ‘inside’ the music and looking ‘at’ it, as through a window” (Marshall, 1967). ‘Spaciousness’, ’envelopment’ and ‘intimacy’ are distinct aspects of spatial impression, which have been related to measurable acoustic parameters. Such parameters include the strength of the sound, measures of interaural cross correlation, direct-to-reverberant ratios, low frequency strength and late lateral sound level (Bradley, & Soulodre, 1995a; Beranek, 1996, pp23, 36-38; Griesinger, 1997). These parameters are affected by physical features, such as the auditorium size and shape, distance between listener and stage, and surface irregularities, as well as many others.

Hence, the physical character of auditoria plays a major role in shaping the sounds produced and eventually, the room may be evaluated acoustically on its ‘spaciousness’, ‘envelopment’ and ‘intimacy’. It is also probable that the perception may be shaped not only by the auditory factors but by visual factors as well. Whilst acousticians may believe that the room acoustical impression is strongly shaped by the visual (e.g. Griesinger, 1997), their concentration on the auditory aspect generally excludes discussion of the visual impression and its interrelationship with the aural.
Beyond the field of auditorium acoustics, the everyday experiences of space are primarily influenced by its physical characteristics, namely volume, surface texture, colours, and light. In discussing the visual perception, this concept will be divided into two components - form and surface. ‘Form’ refers to aspects such as an auditorium’s shape, volume; and ‘surface’ refers to texture, light, and shadow. These physical parameters of ‘physical space’ are related to the perception of ‘visual space’, which refers to aspects such as visual angle, perceived distance, shape, size, and texture gradient of the physical space. For the purpose of this section, the visual world has a spatial and visual component, ‘spatial’ relating to form, and ‘visual’ relating to ‘surface.’ This section will discuss these in relation to the physical attributes of auditoria.

A person experiences a space through observing, moving about, sensing the space, often through ‘body knowledge’ (Hall, 1967, p49; Pallasmaa in Holl et al, 1994, p28-36). Architects and designers of auditoria have been using accepted practices, non-architectural concepts, and have primarily been driven by clients’ directives. Empirically, there has been little exploration of how an auditorium’s design affects visual spatial perception within it.

This section will discuss the experience of sound and space through stationary observation, where the observers are not moving about an auditorium (or space), but where it is assumed that head movement is possible. This section presents the three types of spatial impression in terms of the acoustical and architectural disciplines. In terms of acoustics, spatial impression is discussed through the subjective impression, the objective measurements, and the physical attributes that influence the objective measurements. In terms of architecture design and visual perception, spatial impression is discussed as a phenomenon, the apparent cause of the phenomenon, and physical attribute of the apparent cause. The section will conclude on a note for further discussion on the interrelationship between the visual and aural impression in auditoria, and of a possible affinity between the desired acoustics, and the architectural form and surface properties of auditoria. For clarity, the terms ‘auditory’ and ‘visual’ are added to ‘spatial impression’ to distinguish the two senses of spatial impression.

2.2. SPATIAL IMPRESSIONS
2.2.1. Spaciousness

‘Spaciousness’ is the first of three subjective spatial impressions in auditorium acoustics. Beranek has developed a consensus on the definition of ‘spaciousness’ and other subjective auditorium acoustical attributes. According to Beranek, “a concert hall is said to have one of the attributes of ‘spaciousness’ if the music performed in it appears to the listener to emanate from a source wider than the visual width of the actual source” (Beranek, 1996, p23). This attribute is also called the ‘apparent source width’ (ASW). However, in his latest edition (2004, p29), ASW is not mentioned but rather “spaciousness” is discussed.

The several objective acoustical measurements that relate to this spatial impression are early interaural cross-correlation coefficient (IACC_E), early lateral fraction, and sound pressure levels – especially at lower frequencies.

IACC_E is a measure of the fine similarity between the first 80 milliseconds of impulse responses (or echo patterns) at the two ears of the head and torso simulator (HATS) or a dummy head (see figure 2.1 & 2.2). It was originally developed by Schroeder (Schroeder et al, 1974) to identify the strength of early lateral reflections existing in real concert halls. Beranek (1996, p466) finds, at least for mid frequencies, IACC_E to be the most powerful predictor of ASW. Theoretical values range from 0 (great binaural dissimilarity) to 1 (a perfect match between the two ears). The desirability of spaciousness is indicated by the best auditoria having IACC_E values less than 0.4, and ‘fair’ auditoria having values in the vicinity of 0.6 (Beranek, 1996, p467).

The relative strength of early lateral reflections, known as lateral energy fraction (LF_E), is another predictor of ASW.
It is measured using an omnidirectional and figure-of-eight pattern microphone, where the latter is oriented to either side of the auditorium. The ratio of the lateral to omnidirectional energy in the first 80 ms of the impulse response is determined. Using simulated sound fields, Barron and Marshall (1981) find that increasing LF$_E$ yields an increase in the breadth, body and fullness of music samples.

The overall loudness of sound affects its apparent size. Auditorium acoustical studies find a 1.5° increase in ASW per decibel increase in sound pressure level (Williamson, 1989). Although this was a finding of Barron’s (1974) influential doctoral study, this factor has received much less attention than the more subtle IACCE or LF$_E$ in predicting ASW. The degree to which an auditorium can be described as ‘loud’ is represented by its ‘strength factor’ (G), which compares the sound pressure level of an omnidirectional source at 10 m distance in an anechoic environment with its level in the auditorium.

Several studies point to the importance of low frequencies in expanding the auditory image in auditoria (Barron & Marshall, 1981; Marshall, 1986; Morimoto & Maekawa, 1988; Williamson, 1989; Hidaka et al, 1995; Marshall & Barron, 2001). Morimoto and Maekawa find effects on ‘horizontal spaciousness’ for frequencies below 510 Hz, with stronger effects at lower frequencies (Morimoto & Maekawa, 1988). Hidaka et al (1995) find level increases below 355 Hz have a greater effect on ASW than level changes above 355 Hz. The effects of sound pressure and low frequency on auditory image size have also been explored outside the auditorium context, in the psychophysical area of auditory volume (Cabrera, 2003).

The values of these acoustical predictors of spaciousness are determined by auditorium design, and so suggest possible ways of designing for auditory spaciousness, and suggest a possible explanation for the lack of this attribute with certain designs. Rectangular and fan-shaped halls are the two simplest common designs for symphonic and multi-purpose auditoria. Beranek (1996) shows that among the world’s best nine halls, seven are rectangular, and the rectangular form is advantageous for spaciousness, with associated low IACCE and high LF$_E$ measurements. The parallel sidewalls give strong lateral reflections, which influence the IACCE and LF$_E$ measurement. The laterally reflected sounds appear to broaden the source, thereby increasing the apparent source width. In a fan-shaped hall, the sidewalls reflect sound to the rear of the hall rather than onto the audience. The last 30 years have seen several new hall types developed. Among those, the elliptical Christ Church Town Hall (see figure 2.3) has been considered a successful design. Large tilted panels reflect the sound evenly.
throughout the seating areas, contributing greatly to spatial impression. These panels also prevent focussing that might otherwise occur in an elliptical room (Barron, 1993, pp100-102; Marshall & Barron, 2001).

However, Beranek argues that this hall is designed for envelopment rather than spaciousness, and that a rectangular hall such as Boston Symphony Hall (Figure 2.4) can achieve greater spaciousness (Beranek, 1996, p385).

In symphonic concert halls, halls of less than 2000 seats are better acoustically than ones with more than 2500 seats. Once the hall is larger than 2500 seats the sound is scarcely able to reach the farthest seat, posing definite acoustical problems (Beranek, 1996, pp413-415, 439-440). For a given reverberation time, the volume of a room determines the build-up of sound energy in the room, with smaller rooms being ‘louder’ than larger ones – implying that a smaller hall can achieve greater spaciousness.

In the visual world, one way to sense the spaciousness of a room is to move around it. This is called a kinesthetic experience. Kinesthesia helps us reconfirm the size of a room that only our vision could estimate (Hall, 1966, p52&62-63). The perception of spaciousness is a relative concept, and varies from one individual to another. This experience of space is derived from the visual space, which is our visual perception of the three-dimensional world around us (Gilinsky, 1951). Gilinsky conducted several experiments to confirm the perceived distance formula she derived. One of these was the “Perceived Distance by Equal-Apparent Intervals” experiment. A subject stood at point 0 feet and directed the experimenter to move a “pointer stick” along a straight line away from the subject at a “nearly constant rate” and

![Figure 2.3: Christ Church Town Hall Auditorium](image1)
![Figure 2.4: Boston Symphony Hall](image2)
marked the incremental distances. This incremental distance is a “subjective foot rule” that the subject memorized. The subject attempted to match the perceived distance to the “subjective foot,” thus marking each increment. The data collected showed similar results when compared to those generated by the “perceived distance formula.” Gilinsky concluded that the formula was a valid predictor of perceived distance, and the subject’s perceived distance decreased in differentiation at a greater incremental rate than actual distance (Gilinsky, 1951).

This visual space is not identical to the physical space, and is a distorted transformation of the other (Ogle, 1950, p11). A representation of such transformation is illustrated through van Gogh’s painting “Bedroom at Arles”, where the artist’s spatial impression is very different from the reconstructed bedroom (Figure 2.6 & 2.7) (Heelan, pp114-127). One of the models of visual space is “hyperbolic space.” Heelan theorises that, unlike physical space (geometric space in the Cartesian model), hyperbolic visual space is more representative of how we see the world. In the hyperbolic visual space, in our perceived ‘picture’ of the world, parallel lines seem to diverge at near zones, and depth at distant zones seems to be shallower than actual depth (Heelan, pp. 28-35). Among the evidences, Heelan suggested that van Gogh’s painting “Bedroom at Arles” illustrated this model of visual space. How we perceive spaciousness in the visual world is generally an understudied area. However, discussion on visual space has been extensive. This section will attempt to discuss the perception of spaciousness using the components of a visual space, and to suggest how these components
may change to influence the perception of spaciousness. This discussion is focussed solely on
the ‘visual experience’ rather than the ‘kinesthetic experience’ as this experience is not
significantly relevant to the perception of spaciousness in auditoria.

The perception of visual space has two essential components, the visual angle and the
perception of depth (Gilinsky, 1951; Itelson, 1960, p65; Gibson, 1950a, pp26-32, & 145).
The apparent size of the visual angle (or retinal image) and apparent depth of the visual image
are varied; thus the visual space size is varied. It is suggested here that human perception of
the changes of the visual space influences our perception of spaciousness. Because this
specific discussion excludes ‘kinesthesa’ and involves only stationary observation of a space,
the surface (of the form) substantially contributes to the perception of depth.

As the spatial impression is perceived through seeing the surface and edges, which
defines the extent of the space, “the fundamental ‘sensation’ of space is assumed to be the
impressions of surface and edge” (Gibson, 1950a, p8), and “the elementary impressions of a
visual world are those of surface and edge” (Gibson, 1950b). There are several visual
determinants for the size of the visual angle and depth. In an outdoor space, the visual space
is determined by the maximum visible extent of the retinal image (or visual angle) and the
depth. It is quite different for interior spaces where the physical boundaries of the space are
set by the walls or edges, and the extent of the farthest boundary. Thus, in our visual space,
we are able to perceive the distance from our eyes to the furthest edge in front of us and
beside us by seeing the texture density (or pattern gradient) of surfaces, which is referred to as
the stimulus for visual depth and distance (Gibson, 1950a, pp77-92; Gibson, 1950b). However,
there is a difference between ‘perceived’ and ‘estimate’ distance (or depth). The
perceived distance is what appears in our mind, or the apparent distance. ‘Estimate’ distance
(or depth), however, is a result of an intellectual process that we use in attempt to estimate the
true distance. The intellectual process includes a correction of perceived distance, which is
probably derived from training and past experience (Gilinsky, 1951; Hall, 1966, p63). We are
also able to determine whether the space is narrow or wide, or low or high depending on how
the space controls our perspective view (or visual angle). Perspective is considered a cue for
depth. As visual space is a limited representation of infinite physical space (unless one is in a
room), thus a perspective drawing assumes a viewing distance. When looking at a drawing
showing a perspective of a room (or space), one must view the drawing from this ‘assumed
viewing distance” (Itelson, 1960, p80). Viewing it at any other distances, the constructed
perspective – as a visual cue, may not be accurately used to estimate distances of elements in the drawing. This has a significant implication for choice of the method of presenting visual experiment. This will be discussed in detail in a later chapter.

In an auditorium, as in any space, we use cues to perceive and interpret what we see. There is no conclusive evidence that the designers have deliberately used human spatial perception in their designs so as to engender a greater sense of spaciousness. However, one may turn to architectural history, and this Chapter suggests that there is a pattern of constructing public buildings with substantial empty interior space. This pattern probably began with the large Greek temples of the Doric order in the 5th century BC, when the Temple for Athena was constructed with a naos (atrium or nave) measuring approximately 10 m x 25 m (Fletcher, 1987, pp 97 & 130). This tradition continued after the Romans imported much of Greek architecture, then constructed the Basilica of Ulpia (circa 2nd century AD.) (Figure 2.8) in the Trajan’s building complex.

Due to the more successful designs of longer span roof trusses of about 25 m, this interior space is substantially larger than the Greek version (Fletcher, 1987, pp239-241).

This pattern of designs for large public spaces began with religious edifices and later translated into the secular spaces of the neo-classical concert auditoria, in particular. Among the neo-classical halls, the Vienna Grosser Musikvereinssaal (1870) (Figure 2.9), Boston Symphony Hall (1900), Ozawa Hall in Lennox, Massachusetts (1994) (Figure 2.10), have

Figure 2.8: Basilica of Ulpia

Figure 2.9: Vienna Grosser Musikvereinssaal
similar visual and spatial relationships (Beranek, 1996, p79 & p117). This pattern seems to reflect a need for the sense of familiarity and historic continuity. The neo-classical concert hall, in particular, is one space that would help to engender that experience. This pattern of classical concert hall designs is also reinforced by the successful acoustical development of the rectangular hall type, which is best suited for the performance of symphonic classical music such as that of Haydn, Mozart, and Beethoven.

2.2.2. Envelopment

Envelopment or ‘listener envelopment’ (LEV) according to Beranek, based on his surveys of concert halls, is related to the fact that “the reverberant sound that reaches the listener after 80 ms is most pleasant if the listener hears it coming from all directions.” Subjective experience of envelopment is a sense of being surrounded by the reverberant sound resulting from late lateral reflections (Morimoto & Maekawa, 1989), unlike spaciousness or ASW, which resulted predominantly from early reflections (Bradley & Soulodre, 1995a & 1995b).

The several objective acoustical measurements that relate to this attribute of spatial impression are late interaural cross-correlation coefficient (IACC<sub>L</sub>), late lateral sound level (LG<sub>80</sub>), late lateral energy fraction (LLF), late lateral energy level (GLL), and the theoretical late level (Gl) related to the source receiver distance.

IACC<sub>L</sub> is the interaural cross-correlation coefficient after 80 ms in the impulse response. Beranek used IACC<sub>L</sub> to evaluate LEV of a group of 18 halls. In this group the “Excellent” ones had a median value of 0.13, and the “Good” ones a median value of 0.15. He also suggests that the LEV changes depending on the seating position in a hall – for example, with seats on a steeply raked balcony receiving less LEV then those on the main floor (Beranek, 1996, pp. 37 & 473).

From their experiments, Bradley and Soulodre concluded that the angle of reflections, and the “temporal distribution of late arriving reflections” influence LEV. (Bradley & Soulodre, 1995a, 1995b). Their favoured measure, LG<sub>80</sub>, is related to the laterally reflected sound level after 80 ms. Bradley and Soulodre also found the overall sound level and reverberation time to both positively affect LEV.
In 2001, Barron supported Bradley’s & Soulodre’s (1995a & 1995b) findings and also proposed a new objective predictor for LEV, the ‘theoretical late level’ (GL). This calculation relates to the measured volume of an auditorium, source-receiver distance, and reverberation time. The equation assumes that Sabine’s reverberation time equation is valid. It also takes into account the reflected sound after 80 ms, and arrival time of the direct sound after being emitted from the source. This suggests that sense of listener envelopment should decrease as the listener moves away from the source (Barron, 2001).

The auditorium’s physical parameters that have the most influence on these objective measurements are the diffusivity, shape, and possibly the size. The hall’s diffusivity depends on its surfaces. Many rectangular classical historic halls have significant areas of surface irregularities due to ornamentation on the sidewalls and ceilings. The surface irregularities act as diffusing surfaces that enable sound to be reflected in a greater distribution enhancing the sound reaching the listener after 80 ms. Some modern halls create diffusion through relief textures, or other surface complexities. Devices such as the Quadratic Residue Diffuser (QRD) (Figure 2.11) enable sound to be diffusely reflected over a wide range of frequencies without taking too much space. Most halls are not equipped with such devices, but still have good diffusion due to a wide range of irregular surfaces that are primarily composed of decorations. In an architectural design perspective, the flexibility of irregular surface gives greater freedom for the architect to create surfaces that are visually intriguing without using traditional ornamentation, and which are in keeping with the contemporary design. Recently, new halls have been designed without QRDs, but the designers customised walls and ceiling surfaces to create a diffuse field, at the same time engendering an architectural identity for the hall (figure 2.12).

Marshall also asserted that LEV is affected primarily by the lateral reflections much more than reflections from above or behind, although those would enhance the overall impression (Barron & Marshall, 1981). He also stated that a fan-shaped auditorium is less...
likely to provide as much LEV compared to a rectangular-shaped one. Barron’s (2001) objective measurements of the United Kingdom’s 17 concert halls on LEV, found that “when late lateral energy fractions are averaged by hall, the hall means only vary between 0.25 and 0.34, a range of 0.09.” Wigmore Hall, the narrowest, is one of three halls with the highest measured LLF. The widest, Wembly Conference Centre, has the lowest LLF. Interestingly, despite its problems relating to the elliptical form, the Royal Albert Hall is regarded as well behaved in this respect. The LLF of the Royal Albert Hall, with the mean widths almost the same as the Wembly Conference Centre, was measured at 0.32. The analysis shows that “the listener envelopment should be high in small halls and low in large ones” (Barron, 2001).

Envelopment, in the visual world, is a feeling of being surrounded by objects, surfaces, people, light, and more. Envelopment, in the phenomenological writings, refers to the body in the centre surrounded by the experiential world (Bachelard, 1964, p231-241; Pallasmaa, 1996, p26). According to this theory, we experience the world not only through vision, but also through the body. Hence, the perceived envelopment involves more than just stationary vision. If we perceive the surroundings only by looking in one direction then we only see what the visual angle allows us to see.

The size and shape of a room are two of the spatial cues enabling the observer to perceive the space. The spatial experience relies on spatial perception, and on the visual definition of texture, colour, and surface illumination (Itelson, 1960, pp43-46&64-83). These complex relationships of spatial attributes influence how a space can engender a feeling of envelopment.

The size of the room does not exclusively determine the perception of envelopment. It is possible that, regardless of the size of the room, significant envelopment should be perceivable. Perhaps, along with vision, kinesthesia may help one determine the degree of spatial envelopment of rooms with size variations. Small rooms such as kitchens seem to restrict movement, and most surfaces can be touched without moving around (1996, p51). This suggests that there is a connection between constrictiveness and envelopment. Thus, a large room might be less enveloping than a smaller one.

Room shape appears to influence envelopment, with round rooms facilitating a body-centred perception. Bachelard relates a sense of being to roundness in his essay “The phenomenology of roundness” through poetic and philosophical references (Bachelard, 1964,
p232-241). Western Architectural history shows that we have been fascinated with the idea of roundness, and round-shaped buildings. Domes exemplify the appeal of the sense of being surrounded by roundness. One of the best-preserved domed buildings from the Roman Empire (but probably not the first) is the Pantheon in Rome (c. 128 AD). The spectacular space of the dome has a span of 43.2 m and was unchallenged until the building of a dome of slightly greater span of Brunelleschi in 1436 (Fletcher, 1987, pp232-237). The human fascination in building large round spaces continues to the present day. However, a round room could prove acoustically disastrous as a concert hall. There are a number of elliptical-shaped auditoria that were considered a compromise between a rectangular and a round auditorium, such as Christchurch’s Town Hall (figure 2.3) and Wellington’s Michael Fowler Centre in New Zealand. It seems likely that the auditorium might have characteristics that are partially influential to the perceived visual envelopment (Barron, 1993, pp100-103).

In designing an auditorium, the architect attempts to design a space that provides visual cues having sensory appeal. One of the visual cues that influences envelopment is surface texture, which is enhanced by the light level. This relationship between light, shadow, and texture generates an intriguing attraction to the eye, which has been applied in great abundance in certain religious, palatial and monumental architecture. It seems that the decorations in such interiors provoke the sense of an overwhelming feast to the eyes. Whether or not one may want to look at them, their presence is hard to ignore. There is a large number of elaborately decorated concert hall interiors in the world, one of which is the Grosser Musikvereinssaal (figure 2.10). This classically-designed rectangular hall was completed in 1870, with many successive renovations and alterations (Clements, 1999). Today, the Grosser Musikvereinssaal is an architectural gem and acoustically superior due to several physical factors (Beranek, 1996, p181). Many authors and visitors comment on the overwhelming decorations. It seems that the decoration is a visual cue that creates great visual envelopment.

2.2.3. Intimacy

Benarek suggests that small halls have already created the sense of intimacy visually because they are small. “A hall is said to have ‘acoustic intimacy’ if music played in it gives the impression of being played in a small hall” (Beranek, 1996, p22). The subjective impression of acoustical intimacy may come from a feeling that the music seems to be closer
to the listener than the actual source, or merely from the source actually being close. Barron suggests that, “Intimacy refers to one’s degree of identification with the performance, whether one felt acoustically involved or detached from it.” Baron’s study contained a questionnaire where one question asked the listener to rate the intimacy of the auditorium sound quality on a scale of a distance from ‘remote’ to ‘intimate’ (Barron, 1993, p41).

The several objective acoustical measurements that relate to this aspect of spatial impression are Initial Time Delay Gap (ITDG or t1), the source-receiver distance, and sound level. However, findings in the auditory distance perception literature have yet to be systematically applied to this area of auditorium acoustic.

ITDG is an acoustical measurement for the delay of the first reflection after the direct sound has reached the receiver, which relates to the subjective spatial impression of intimacy (Ando, 1989, p48&50-51; Barron, 1993, p38; Beranek, 1996, p35). Barron (1993) suggests that a best-liked concert hall would have a delay gap of 21 ms or less. ITDG can be calculated using ray geometry with drawings of the hall plan, or by inspection of impulse responses. A wide hall results in a longer distance for the reflection and hence a longer ITDG (Beranek, 1996, pp34-35). This metric has been criticised by Baron, considering that the geometry also shows that the ITDG will be shorter for the receiver at a remote seat compared to a position close to the source (Barron, 1993, p39). Barron contends that acoustic intimacy may not depend primarily on ITDG, and more simply suggests that “intimacy is related to proximity to the performers.” (Barron, 1993, p40). Barron (1993) also finds that intimacy is better related to sound level than the ITDG (p43), where loudness is related to sound level and seems to be an overlap between the judgment of loudness and intimacy.

The auditory distance perception literature finds sound pressure (greater = closer), reverberation time (greater = further), direct-to-reverberant ratio (greater = closer), high- and low-frequency spectral effects, sound production effort (eg whisper versus shout – greater = further) and source familiarity (affects cue weighting) to be among the factors that have a substantial effect on perceived distance in rooms (Nielsen, 1993; Zahorik, 2002). With the exception of near-field estimation, subjects tend to underestimate distance when relying only on sound.

Certain types of music demand greater intimacy. Music composed for small ensembles is generally performed in small halls (up to 800 seats) – a small ensemble performing in a large hall (over 2000 seats) will sound remote.
In the visual world, intimacy relates to distance or proximity of the body to surrounding physical elements such as surfaces, objects, or people. Visual intimacy is also associated with the ability to see clearly facial details or surface textures. The body’s response to that proximity involves not only the visual, but also tactile, thermal, and olfactory senses (Hall, 1966, p110). The range of distances, as discussed on Hall’s survey (1966, pp107-122), describes the various distances in relation to visual intimacy. In terms of holistic perception, perceived intimacy relates largely to perceived distance. In public spaces, intimacy may be related to the concept of ‘personal distance’ and how this zone may be compromised or accommodated (Cheyne & Efran, 1972). It is suggested that perceived distance in itself is quite different from physical distance (Gibson, 1950a, pp42-43, 1950b; Gilinsky, 1951; Ittelson, 1960 pp63-64). Hence, this section suggests that this perception of distance plays a role in the spatial impression of intimacy in an auditorium.

Hall identifies several distance ranges with various levels of intimacy (Hall, 1966, pp110-122). The first distance zone is ‘intimate distance,’ followed by ‘personal distance,’ then ‘social distance’, and lastly ‘public distance.’ Intimate distance has interpersonal distance of up to 0.3 m, while social distance has a median of 2 m. Within these distance zones, there are ‘close’ and ‘far phases.’ This concept of distance may be applied to performances in auditoria. The visual distances between performers and observers according to Hall’s system would be classified between the ‘far phase’ (3 m) of ‘social distance’ and ‘public distance’ (3.5 m to 10 m and beyond). Intimacy as defined by Hall is the ability for a person to touch and see various details of the other person’s body and facial characteristics. Hall’s qualitative study of distance perception is quite different to the following quantitative studies in perceived distance and the physical attributes that affect the perception of distance.

Gilinsky (1951) developed a mathematical formula to predict visual distance from physical distance, based on and confirmed with experimental data. Results show a consistent underestimation of far-field visual distance, similar to the aforementioned underestimation of far-field auditory distance. In both senses, there appears to be a limiting horizon, which may nevertheless be context sensitive (Heelan, 1983). In a concert auditorium, this might suggest that the furthest seats may not suffer as much of a loss in intimacy as implied by their distance.
For concert auditoria and some smaller rectangular concert halls with large first level balconies, the effect of immediacy should be similar to that of opera houses. This effect is possible because the balcony edge prevents the eye from seeing most of the ground floor, and makes it seem much closer to the stage. However, results from visual experiments in this thesis may suggest otherwise.

Hall’s (1966) ‘public distance’ is considered ‘close phase’ from 4 m to 8 m, and ‘far phase’ begins at 8 m. It is suggested that the transition zone of the social distance and the far phase of public distance may be a cue to a “subliminal form of flight reaction” (Hall, 1996, p116). Cheyne & Efran (1972) propose that spatial variables, such as size, may play a role in situations of invasion of group-controlled territories. They go on to suggest that changes in the size of the space, the number of people, and activity in the space may have an impact on behaviour, specifically on their reluctance to invade others’ personal zones. The personal and social distances used in this study are the same as those in Hall’s. The spatial boundaries of the room force its inhabitants to allow others to invade the personal zones, thus the public distance should seem to be compressed depending on how much further the personal zones are intruded upon. However inconclusive this may be, there seems to be a connection to the aspect of environmental behaviour in a concert hall. This section suggests that the size of a concert hall is a major factor in engendering the sense of visual intimacy. Beranek suggests that a small hall is already visually intimate because of its size (Beranek, 1996, p22).

2.3. ANALYSIS METHODS IN AUDITORIUM ACOUSTICS

2.3.1. Binaural impulse response measurements technique

An important part of audio stimulus generation, in preparing the auditory experiments, is completed using the HATS. As mentioned earlier in this chapter, HATS replicates the human head and torso along with the outer ears. There are several reasons for binaural recording of sound in an auditorium. Humans hear through both ears, so HATS records the sound and it is reproduced as it is recorded, the human experience of sound is assumed to be reproduced (Møller, 1992). It is useful in the case of this thesis, because an acoustic documentation of the auditorium could be completed, reproduced through convolution, and replayed through a pair of headphones. It then would replicate a very similar auditory experience as if one is sitting inside a concert hall, given the environment in which the play-
back takes place is a quiet room with minimal reverberance (ie. Anechoic room.) This method ensures that the headphones accurately reproduce the same sound received through the ears. If using two loudspeakers, this would introduce crosstalk between the ears because the sound from each of the loudspeakers would be heard with both ears.

Binaural recordings and playback presentation through headphones, nevertheless, has some disadvantages. One of the important disadvantages is frontal localisation of the sound source. Sound sources, such as those used in the studies in this thesis, were frontally positioned. However, some listeners perceived that the sound is coming from behind or inside the listener’s head. Since the impulse responses were measured using HATS, which has different outer ears, it would have a different head-related transfer function (HRTF) than that of the listener. Therefore, the sound received through a listener’s ears would be different than that through HATS. Many listeners localise sound by turning head left or right. By doing so, the listener could detect the sound coming from the front, as the sound is arriving earlier at the ear that is closer to the front (Møller, 1992). Since the HATS is stationary during recording and the playback stimuli is presented through headphones, frontal localisation would be difficult for the listener. Although binaural recording may pose some disadvantages, the advantages of this method are more important to the aims of the experiments in this thesis as auditory spatial impression is likely to depend more on the usefulness of the binaural technique. Other issues of binaural technique are discussed throughout the thesis as it became relevant to the experiments.

2.3.2. Statistical analysis of the data

The majority of data collection in this thesis involves results of subjective tests. This thesis uses the statistical method for the behavioral sciences. As this thesis involves auditorium acoustics and human perception, this method of data analysis seems most appropriate. The computer program, Statview, is used to assist in the analysis process.

The participants in the various subjective experiments, assuming that they are representative of the population, would provide responses to the stimuli present to them. Thus the responses would yield responses that may be generalised to the larger population (Roscoe, 1975, p170); this is also called “probability” (Roscoe, 1975, p139).

Analysis of variance (ANOVA) (Roscoe, 1975, pp292-303), is used to analyse the subjective results. It is a statistical technique for analysing data that tests for a difference
The significance of the responses is expressed by the probability value (p-value). It is a number calculated by using the data compiled from the subjective test results. It is the probability of getting a value of the test statistic as extreme as or more extreme than that observed by chance alone, if the null hypothesis is true. It is the probability of wrongly rejecting the null hypothesis if it is in fact true. The p-value is equal to the significance level of the test for which the analyst would only just reject the null hypothesis. The p-value is compared with the desired significance level in the ANOVA and, if it is smaller, the result is significant (or shows significant difference). That is, if the null hypothesis were to be rejected at the 5% significance level (or 95% confidence level), this would be reported as "p < 0.05". This thesis specified for a 5% significance level in the ANOVA (Roscoe, 1975, pp170-177).

Small p-values suggest that the null hypothesis is unlikely to be true. The smaller it is, when comparing to the significant level specified in the ANOVA, the more convincing the evidence is that null hypothesis is false. It indicates the strength of evidence rather than just simply concluding, "Reject" or "Do not reject" the null hypothesis.

The Scheffe Test for All Possible Combination is another test used in the analyses. It compares all the possible combination between means of the rating responses to find significant differences between them. It uses the significance level specified in the ANOVA. This thesis uses the Scheffe Test as the primary test for significant between ratings. Another test, much less stringent than the Scheffe Test, is the Fisher’s Least Significant Difference Test (Roscoe, 1975, pp213-215). It is usually used as a secondary analysis when the ANOVA shows little or insignificant results.

Correlation is also used in the analyses to find a relationship or degree of correspondence between a pair of variables. A correlation matrix shows the correlation of all the possible pairs of variables in an experiment. The pair of correlated variables is one that tends to vary together, such that when one variable is larger, the other is also larger. A pair of variables is negatively correlated when one of the variables is increasing the other would decrease. Thus, for the positive correlation, when one variable is increasing the other would also increase. The
perfect positive correlation is expressed by the correlation coefficient \( r \) of 1, and –1 expresses a perfect negative correlation. When there is no relationship between two variables, \( r \) is 0. Since the results in this study are from subjective experiments, it is likely that achieving perfect correlation would be difficult (Roscoe, 1975, pp93-105).

2.4. CONCLUSION

This chapter attempts to give an overview of the auditory and visual-spatial factors that relate to the experience in auditoria. It shows that the terms ‘spaciousness,’ ‘envelopment,’ and ‘intimacy’ are can be discussed as both acoustic subjective impressions and spatial visual phenomena, and both relate to almost the same physical characteristics of auditoria.

However, it seems that the acoustical and spatial desirability is not always the same when comparing one auditorium to another. This occurs when an acoustical aspect contradicts a visual one. Most noticeable is ‘spaciousness,” in that rectangular concert hall seems to be better at rendering auditory ‘spaciousness,’ as compared to a fan-shaped auditorium. In visual terms, ‘spaciousness’ seems to apply to any spaces regardless of size or shape. This then suggests that when focussing on a specific design of an auditorium, it is possible to predict, optimise or improve upon the physical aspect to engender a greater sense of spaciousness.

There are some indications that listener preferences for spatial qualities vary, with Barron finding that some listeners favour intimacy over reverberance and vice versa (Barron, 1993, p41). Listener preference is an important issue in determining the acoustical and aesthetic design objectives.

Other aspects of the visual perceptions yet to be examined are: perceived object size as related to perceived distance, the effects of sloped ground on perceived distance, surface texture density, and surface colour and illumination. At least in terms of the generic visual perception of space, there has been a lack of investigation in part of the subjective effects of an auditorium on the audience. It seems that the acoustic and spatial terms being discussed together only correlate when focussing on a specific auditorium. Therefore, the two modes of design may be effective when they work together to predict, optimise or improve upon the desirability of a specific auditorium.
2.5. AN ADDITIONAL NOTE ON RESEARCH APPROACH

As revealed through the literature review, and seeing that the advantage in feasibility of a quantitative (empirical based) research approach is more appropriate for this enquiry, as in numerous research theses, the author’s actual research process is far different from the initial intention.

Considering the author’s background is not from a scientific discipline, conducting empirical research could be quite a challenging task. However, because of the increasingly narrowing research question, questioning the feasibility of an aesthetic-leaning research approach would be counterproductive, given the time frame of the project.

The majority of the project’s major data-gathering consists of auditory and visual experiments. There is quite an extensive experiment protocol in conducting subjective tests of musical stimuli generated from impulse response recorded in an auditorium. However, there is much less consistency on the visual counterpart. The visual subjective tests in similar contexts to this research are uncommon or replication is found to be infeasible. Thus, during the research, many opportunities arose to try several methods of presenting visual subjective tests using auditoria interior photographs. Throughout the thesis, there are discussions on the process and justification of visual subjective experiments.

This chapter contains the primary reviews of the topic background information. Additional literature reviews are included with each succeeding chapter as relevant to the topic of each chapter. The conclusion of this chapter sets up the direction in which this research thesis is explored. The series of experiments are designed to build upon one another, thus the thesis is divided into chronological order of experiments, each with its own section on discussion and conclusion, which will be taken into consideration in the successive experiments. The next chapter (3) begins the analysis of the results of the first experiment and defines the terms used in the visual counterparts to auditory spatial impression.