A SIMULATION APPLICATION FOR VISITOR CIRCULATION IN EXHIBITION ENVIRONMENTS

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May, 2009

I certify that I have read this thesis and that in my opinion it is fully adequate, in scope and in quality, as a thesis for the degree of Master of Fine Arts.

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ABSTRACT

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MFA in Interior Architecture and Environmental Design

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The layout of the exhibit elements in an exhibition environment affects the visitor behavior whose receptivity and time are limited. This study proposes a simulation application for visitor circulation in exhibition environments in order to increase the number of visual contacts and active engagements received by each exhibit element. Consequently, the interior designer delivers an increase in the quality of the exhibition environment. The calculations of the proposed simulation application are based on the data that are collected from the previous literature related to visitor and exhibit element characteristics. The parameters of visitor characteristics involve the interest level, visit plans and fatigue level of visitors. The parameters of exhibit element characteristics involve the physical dimensions, viewing distance, attraction index and holding power of exhibit elements. In order to assess the functionality of the proposed simulation application, an example simulation of an exhibition environment is conducted. In the simulation of an exhibition environment, while all the input parameters are kept constant, the change in the layout of the exhibit elements resulted in different visitor circulation patterns and different visual contact and active engagement outcomes for each exhibit element. Observing and evaluating the various outputs of the simulation application that involve changes in the layout of exhibit elements might help a designer in judging his/her design decisions more clearly. Additionally, comparing the simulation application outputs of design alternatives might help the designer to prevent possible design errors in his/her exhibition layout.

Key words : Behavior simulation, Exhibition design, Exhibit elements, Visitor behavior, Visitor circulation.

ÖZET

SERGİ MEKANLARINDA ZİYARETÇİ DOLAŞIMI İÇİN BİR SİMULASYON UYGULAMASI

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Sergi elemanlarının bir mekan içerisindeki yerleşimi, zamanı ve algı gücü sınırlı olan ziyaretçilerin davranışını etkilemektedir. Bu çalışma, sergi elemanlarının görsel temas ve aktif incelenme sayılarını artırmak amacıyla sergi mekanlarında ziyaretçi dolaşımı için bir simulasyon uygulaması önermektedir. Sonuç olarak iç mimar, tasarladığı sergi mekanının kalitesinde bir artış sağlayabilmektedir. Önerilen simulasyon uygulamasının hesaplamaları ziyaretçi ve sergi elemanları ile ilgili daha once yapılmış çalışmalar üzerine kurulmuştur. Ziyaretçi özellikleri ilgi düzeyi, ziyaret planı ve yorgunluk düzeyi ile ilgili verileri kapsar. Sergi elemanları özellikleri fiziksel boyutlar, izleme uzaklığı, çekicilik katsayısı ve izlenme gücü ile ilgili verileri kapsar. Önerilen simulasyon uygulamasının işlevselliğini değerlendirmek için örnek bir sergi mekanı simulasyonu düzenlenmiştir. Bu sergi mekanı simulasyonunda, tüm girdi değerleri sabit tutulmuştur. Sergi elemanlarının yerleşimindeki değişiklikler farklı ziyaretçi dolaşım yolları, farklı görsel temas ve aktif incelenme çıktı değerleri elde edilmesine sebep olmuştur. Sergi elemanları düzeninde değişiklik içeren önerilen simulasyon uygulaması çıktı değerlerinin gözlemlenmesi ve değerlendirilmesi tasarımcıya tasarımlarını daha açık bir biçimde yargılama olanağı sağlayabilir. Ek olarak, değişik tasarım alternatiflerinin önerilen simulasyon uygulaması çıktı değerlerinin karşılaştırılması, tasarımcının hazırladığı sergi yerleşimindeki tasarım hatalarının oluşumunun engellemesine yardımcı olabilir.

Anahtar Sözcükler : Davranış simulasyonu, Sergi elemanları, Sergi tasarımı, Ziyaretçi davranışı, Ziyaretçi dolaşımı.

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1. INTRODUCTION

Museum and gallery administrators have long been concerned to know their visitors. Starting from the early 20th century, many studies related to visiting times and visitor behavior were conducted (Loomis, 1987; Screven, 1976). The research has revealed that the key factors in visiting experience are such as: age, gender, education, income, specific interests and previous museum experience (Soren, 1999). These factors play a critical role in understanding of visitors and their circulation patterns in exhibition environments. Besides the preferences and profile of a visitor, the design and planning of an exhibition environment affect the circulation pattern of a visitor. In the previous studies, the researchers stated that the proper planning of an exhibition environment plays a crucial role in visitor satisfaction level (Bitgood and Loomis, 1993; Bitgood, Patterson and Benefield, 1988).

Although an exhibition design process mostly relies on artistic preference and personal judgment (Eckel and Beckhaus, 2001), it also requires previously acquired knowledge of visitor needs and expectations (Dean, 1994; Eckel and Beckhaus, 2001). There are many ways to prevent false assumptions and direct the designer's attention on visitor needs and expectations. One way is visually aiding the designer with sketches or cardboard models (Neal, 1987). However, the resulting visual aid may still contain design deficiencies, since such models and sketches can provide only limited feedback.

Aiding the designer during design process is universally accepted and simulation applications have been aiding the designers on different design problems for decades (Kicinger, Arciszewski and De Jong, 2005). There are researches on simulation applications that use exhibition design as implementation cases (Jun, Sung and Choi, 2006; Saunders and Gero, 2004). However, these studies do not intend to aid the designer during an exhibition design process. In order to fill this gap in the literature, this thesis tries to elaborate on the following question: “Can simulating visitor circulation behavior in an exhibition environment help the designer during the layout planning process?”

1.1. Aim of the Study

The complexity of the design process may induce many errors as the product advances (Lawson,1997). Simulation applications are one way to detect these errors and improve the quality of the design. There is a collection of statistical data regarding visitors and their behavior in exhibition spaces (Bollo and Pozollo, 2005; Serrell, 1997). It is possible to benefit from this statistical data with a simulation application.

The main purpose of this thesis is to propose a simulation application for visitor circulation in exhibition environments. The proposed simulation application is based on the collected statistical data and observations published in the previous researches. It is believed that by implementing the data collected in the previous researches to a simulation application, the designer will be able to integrate the academic knowledge into the his/her design process.

The proposed simulation application is expected to be helpful to design professionals in designing exhibition layouts. Also it is expected that this research will shed light to further research on adapting simulation applications into the early phases of similar interior design processes.

1.2. The Structure of the Thesis

This thesis is composed of five chapters. The first chapter is an introduction to the thesis. In this chapter the difficulties of layout planning and the previous visitor research is briefly mentioned. The aim of the thesis is explained and the proposed simulation application is briefly introduced.

In the second chapter, the general exhibition dynamics are explained. In order to define the operation of the simulation application, there is a need to understand the basics of visitor behavior and the exhibition environment. Visitor profiles, expectations, needs and motivations are explained as the visitor indicators. Major gallery types, physical and mental plans, attraction power and viewing times of exhibit elements are explained as the exhibition indicators.

In the third chapter, the framework of the simulation application and the implementation of the literature data are explained. The user interface, the input and output parameters and the simulation processes of the simulation application are explained in detail.

In the fourth chapter, the example design problem experiment is explained. The aim of the design problem experiment, the preparation and simulation processes of exhibition environments are explained. The comparison of the simulation outputs of the exhibition environments are made and the results are evaluated.

In the fifth chapter conclusions about the study are made. Limitations of the study are discussed and suggestions for further research are proposed.

2. VISITOR AND ENVIRONMENT INDICATORS

Visitor behavior in an exhibition space is influenced by many factors that can be resulting from environmental conditions or visitors themselves. These factors are listed and thoroughly analyzed in the previous researches (Bitgood and Loomis, 1993; Bitgood, Patterson and Benefield, 1988; Gorman, 2008; Loomis, 1987; Screven, 1976; Serrell, 1996; Soren, 1999). In this thesis, data regarding visitor and environment characteristics are based on the findings of the previous researches.

In an exhibition environment, visitors and exhibit elements have different functions and roles, therefore, show distinct characteristics (Bollo and Pozzolo, 2005). The role of a visitor in an exhibition environment directs him/her to explore the exhibition space. This behavior renders the visitor as the active element of the exhibition environment. On the other hand, exhibit elements and the exhibition space influence the behavior of visitors, thus, becoming the passive elements of the exhibition environment (Bicknell and Mann, 1993; Bitgood, 2002; Bitgood et al., 1991; McManus, 1991; Peponis et al., 2004).

Within the scope of the above statements, the literature is analyzed under two sections. These sections are named as 'the visitor indicators' and 'the environment indicators' in order to explore visitor and environment characteristics, respectively.

In 'the visitor indicators' section, literature related to the visitor behavior in an exhibition environment are explored. This section is composed of two sub-sections. The first sub-section is named as ‘visitor characteristics’. In this sub-section, visitor profiles, the concept of identity and the effects of identity on the visitor needs and motivations are explored. The second sub-section is named as ‘visitor behavior patterns’. In this sub-section, the effects of visitor motivation and needs on the visitor attention, orientation, movement, and viewing times are explored.

In ‘the environment indicators’ section, literature related to exhibition types, exhibition layouts and properties of exhibit elements are explored. This section is divided into two sub-sections. The first sub-section named as ‘the exhibition space indicators’ explores the literature related to the layout and visitor circulation in the exhibition space. The second sub-section named as ‘the exhibit element indicators’ explores the literature related to the influences on the attraction power and the holding time properties of an exhibit element.

2.1. The Visitor Indicators

2.1.1. Visitor Characteristics

Various researchers stated that, visitors satisfaction should be the primary goal of the designer (Bitgood, 2002; Bitgood and Loomis, 1993; Bitgood, Patterson and Benefield, 1988; D’agostino, Loomis and Webb, 1991; Kelly, 2002a; Kelly, 2002b, Kelly, 2002c). The satisfaction level of a visitor can be assessed by the degree of his/her expectations and needs are met. In this section, visitor characteristics involving the effects of visitor profiles, visitor motivation and visit plans are explored.

2.1.1.1. Visitor Profiles

Visitor expectations and needs are closely related to the visitor profiles. Age, gender, educational level, cultural profile, and leisure values are all important issues in understanding a visitor's characteristics (Andrews and Asia, 1979; Bitgood, 2002; Davies, 1994; McManus, 1991; Sparacino, 2002). Understanding the characteristics of a visitor's profile is important for understanding his/her behavioral patterns.

Researchers have identified numerous visitor profiles according to different characteristics of visitors. Several visitor groups are identified by Hooper-Greenhill (1999) according to the visitors' physical and social characteristics. These visitor groups are families, school parties, other organize educational groups, leisure learners, tourists, the elderly, and people with visual auditory, mobility or learning disabilities. Dean (1994) identified visitor groups under three categories according to their attention and viewing times in the exhibition space:

1- *Casual visitors* involve people who move through the exhibition space too quickly without interacting with the exhibit elements too much. Dean (1994) also defined this group as 'people who rush'.
2- *Cursory visitors* wander around the exhibition space however they are more responsive to the stimulus of the exhibit elements and if any exhibit element is targeted, a close exploration might be observed. Dean (1994) also defined this group as 'people who stroll'.

3- *Learners* spend the most time in galleries closely examining exhibit elements. This group is considered a minority by Dean (1994).

Other researchers have grouped visitor profiles into three categories similar to the one proposed by Dean (1994). Serrell (1996) categorized visitor profiles as 'transient', 'sampler' and 'methodological' viewers. These three groups proposed by Serrell (1996) are very similar in behavioral tendencies to 'the casual visitors', 'the cursory visitors' and 'the learners' proposed by Dean (1994). Serrell (1996) suggested that grouping visitors according to the time they spent in exhibitions is more appropriate. Doering (1999) also classified visitors into three categories as 'strangers', 'guests' and 'clients' according to the approach of the museum to its visitors. Doering's (1999) visitor profiles are shaped by the museums approach to their visitor's but they show similar properties to Serrell's (1996) and Dean's (1994) visitor profiles.

Besides the visitors' profiles that are shaped according to their physical and behavioral characteristics, their visiting patterns as a social group or an individual contribute to the complexity of interactions in the exhibition environment. McManus (1991) described the single visitors' behavior as brief visits to exhibit elements, as they try to understand exhibit elements while showing special interest to labels.

The way people see themselves and their expectations about the museum experience, which is also defined as the identity of the visitor by Leinhardt and Crowley (1998), affect the overall behavior of visitors in an exhibition. A visitor's profile and his/her identity affect the motivation and interests that is a result of his/her exhibition experience. Identity is also claimed by Leinhardt and Crowley (1998) as a filter through which museum experiences are interpreted.

2.1.1.2. Visitor Motivation

Exhibition dynamics are bound to a simple rule regarding the visitor: a visitor has to move and stop in order to be able to see specific exhibit elements in an exhibition space (Klein, 1993). There are three specific actions performed by the visitor in an exhibition environment: exploration, visual contact and viewing (Peponis et al., 2004). The continuity of exploration, visual contact and viewing depend on the cues that generate interest for the visitor. As Bicknell and Mann (1993) stated, visitors like to orientate themselves in the exhibition space but they also continue this orientation in order to find some cues to make them stop. This phenomenon is also explained by Graf (1994) as behaving in a mass-media manner and shopping around until something useful comes.

The continuity between exploration, visual contact and viewing in the exhibition space can also be understood with the 'flow' state defined by Csikszentmihalyi and Hermanson (1995) and Csikszentmihalyi and Robinson (1991). During the 'flow' state people are motivated by the activity itself. Several researchers defined three general rules in order to create motivation as follows: the activity should have clear and appropriate rules, it should provide immediate and unambiguous feedback and it should require skills that are matching with the visitors' abilities (Alt and Shaw, 1984; Boisvert and Slez, 1995; Borun and Dritsas, 1997; Csikszentmihalyi and Hermanson, 1995; Deci and Ryan, 1985; Koran et al., 1984, 1986; Melton, 1972; Peart, 1984; Schiefele and Rheinberg, 1997).

Another view on visitor motivation is the ‘general value principle’ defined by Bitgood (2005; 2006). This principle argues that the value of an experience is usually unconsciously calculated by the visitor as a ratio between the benefit and the cost of the experience. Viewing an exhibit element is strongly interrelated to the value of the experience of viewing it. In order to achieve a ‘high value’, the exhibit element should be interesting enough and also the time and effort costs should be low. Since exhibit elements are passive and their qualities cannot be immediately changed, visitors adjust the value of the exhibit element by reducing the cost of time and effort spend for it. This behavior reflects to the exhibition environment as visitors spending less effort in viewing the exhibit elements.

Visitors need to be motivated in order to keep their attention on exhibit elements (Bitgood, 2002). However, people have a limited attention and the attention decreases with mental and physical effort. As Bitgood (2002) explained “The rate of depletion and renewal is dependent upon the total amount of effort expended, the amount of cognitive emotional arousal and the amount of time” (p. 13). During the course of a visit the familiarity and comfort levels of a visitor also change with time and this level of comfort and familiarity may cause the visitor to respond differently to the exhibit elements (Falk, 1993).

2.1.1.3. Visitor Plans

Visitors arrive an exhibition with expectations depending on the experiences of their previous exhibition visits (Falk and Dierking, 1992; Leinhardt and Crowley, 1998). The circulation of the visitor through the exhibition space may depend on the expectations and experiences that constitute 'the pre-visit agenda' (Hooper-Greenhill and Moussouri, 2001). Hooper-Greenhill and Moussouri (2001) defined three circulation plans that act as a pre-visit agenda for the visitor:

1- *Open plans* may include first time or occasional visitors, who browse through the exhibition trying to see everything. The attraction levels of individual exhibit elements pose an important variable for this group of visitors.

2- *Flexible plans* include people who have been to the exhibition space before and already familiar with the environment. This group of visitors has a specific plan about what to see and do inside the exhibition space.

3- *Fixed plans* include visitors whom are frequent visitors of the exhibition and they also visit other exhibitions frequently. Their visit is planned in advance however they might still change their circulation plans during the visiting period.

A research conducted by Falk, Moussouri and Coulson (as cited in Hooper-Greenhill and Moussouri, 2001) argued that a visitor with a 'fixed plan' has an ability to comprehend the subject of the exhibition better and also engage in longer visits then visitors with an 'open plan' or 'flexible plan' (p. 10).

2.1.2. Visitor Behavior Patterns

The goal of an exhibition layout is to get exhibit elements viewed by visitors. The exhibit elements are often stationary. Therefore, in order the exhibit elements to be viewed, the visitors are needed to be active and make contact with the exhibit elements (Choi, 1999; Peponis et al., 2004). Depending on the visitor's expectations and physical abilities, every visitor develops their own attention and movement characteristics. Although these characteristics vary between individuals, some are common among all visitors (Loomis, 1987; Screven, 1976).

Rounds (2004) suggested that a visitor's movement in the exhibition space can be understood with the following three rules: 'search rules' allow the visitor to find interesting items, 'attention rules' tell the visitor which exhibit element to focus on and 'quit rules' tell the visitor when to give up on an exhibit element, an area or the exhibition. Peponis et al. (2004) suggested that the movement of a visitor can be understood with three behavioral states which are exploratory movement, visual contact and active engagement. In this thesis, relating to the studies of Peponis et al. (2004) and Rounds (2004), the visitors' exploration and contact pattern inside the exhibition space is explained with the following five parameters: *visitor attention, visitor orientation, exploratory movement, visual contact and active engagement*. These five parameters can be considered as distinct action phases of a visitor during the course of a visit. Visitors will perform these action phases which will make a cycle between each exhibit element until the visitor exits the exhibition.

2.1.2.1. Visitor Attention

The visitor initially looks for cues to begin his/her visitation pattern. Attention to exhibit elements is selective and only one exhibit element is attended by the visitor at a time (Bitgood, 2002). Attention to an exhibit element might be decided according to the distinctiveness or 'salience' of the exhibit element and the distance of the element to the visitor or his/her pathway inside the exhibition space (Bitgood, 2002).

Another aspect that influences a visitor's attention is the exit gradient. Visitors are attracted by the exit of the exhibition space. The attention of visitors on exhibit elements decreases gradually when approaching to the exit (Melton, 1935). Klein (1993) gave the exiting behavior a role as the means to the end of exploration or as the satisfaction of curiosity for other elements of the exhibition. The exiting behavior also can be influenced by the visitor's fatigue level. Both mental and physical activity might deplete the visitor's attention. In previous research, it is noted that after 30 minutes the visitor's attention decreases significantly (Hein, 1998).

2.1.2.2. Visitor Orientation

Orientation in an exhibition environment is a challenge for a visitor and it affects his/her exhibition experience (Talbot et al., 1993). Soren (1999) described two different visitor orientation behavior depending on the frequency of visit: "first time occasional visitors tend to be confused and disoriented initially. Then they 'cruise' or 'browse' exhibits, may look intensively at exhibit elements, than leave. Frequent visitors tend to look intensively at exhibit elements, and then leave – they only occasionally 'browse'" (p.

58). This statement points out that having a visiting experience of the exhibition layout will help the user to create a visit plan in his/her mind. This visit plan may lead to a more unified visitation pattern. On the other hand the lack of this plan may result in chaotic movement patterns.

'Right-turn bias' appears to have an important effect on the visitor's orientation in an exhibition space. Bitgood (1996) stated that when all other factors considered equal, visitors tend to turn in the direction of the closest exhibit element. However, in the absence of interesting cues people have the tendency to turn right when entering an exhibition space (Bitgood, 1996). This behavior can be explained by the previously mentioned 'general value theory' (see Section 2.1.1.2). When the visitor is already following a right-hand path, it will be less effort consuming to continue to the right when confronted with a turn. Visitors always choose a direction involving the less effort. Klein (1993) also commented on the right turn bias in his research: "Paintings to the right of the entrance, even when interchanged were viewed in may series of tests as having the highest attraction power, followed by additional paintings displayed on the length of the right side" (p. 796). Also, the studies of Whyte (1980; 1988) stated that people tend to walk on the right side and tend to turn right, in city streets and plazas.

The 'saliency' of an exhibit element might also influence the orientation of a visitor. As stated by Bitgood (2002), visitors may ignore relatively less attractive exhibit elements in order to approach and view a more attractive one. This effect may be caused by a goal seeking behavior, where the goal is a specific exhibit element or an area. The goal seeking behavior may overpower other factors influencing the orientation of the visitor (Bitgood, 1996).

2.1.2.3. Exploratory Movement

There are two important movement tendencies for a visitor: ‘inertia’ and ‘exit gradient’. Visitors have a tendency to follow a straight path unless an exhibit element distracts them. This behavioral tendency is named as ‘inertia’ by Bitgood (1996; 2002). Researchers stated that due to the security of the main pathway, it is always followed by the visitor unless there is a highly interesting exhibit element. When main pathways are cut off with other pathways the visitor keep following the main pathway (Deans et al., 1987).

Other researches argued that, despite the right turn bias, when visitors enter a gallery along the left wall they tend to follow the path along the left wall, unless any other exhibit element or factor attracts them away (Bitgood, 1996; Bitgood et al., 1992). Opposing to this idea McLean (1993) claimed that “people’s flow through space is generally non-linear” (p. 124). This non-linearity may depend on the saliency or the attractiveness of the exhibit elements on the path of the visitor.

The second movement tendency is the ‘exit gradient’, where the force pulls the visitor from the entrance towards the exit of the exhibition space through the shortest path in between (Melton, 1935). People have a tendency to approach the exit of the exhibition space when they encounter an open doorway even if they have not viewed all of the exhibit elements (Bitgood, 1996). Additionally, as mentioned earlier, visitors have a tendency to follow the right hand wall and exit from the first open door. Although whenever visitors are forced to exit the exhibition from the same door they entered, they are observed to generate more interest on exhibit elements and move more completely through the gallery (Bitgood, 2002). Furthermore, some researchers stated that if two display paths are used on both sides of the exhibition, visitors only follow one wall and exit the exhibition space (Melton, 1935; Parsons and Loomis, 1973; Weis and Boutourline, 1963).

There are also other studies that argue that a visitor does what he/she wants to do in an exhibition space despite the best effort put out by the designer to create a path to be taken by the visitor (Melton, 1972; Porter, 1938; Serrell, 1997). This statement points out that even though there is predictability in a visitor's behavior, chaotic behavior should be expected. On the other hand, Shettel (2005) argued that although the visitor behavior may seem independent and chaotic, in the design of the exhibition layout it is always a factor and should not be ignored.

'Backtracking' has also been argued as an important phenomenon in exhibition spaces. Taylor (1986) and Klein (1993) argued that, although many exhibitions require backtracking in order to get all the exhibit elements viewed, visitors are usually reluctant to backtrack and see the exhibit elements which they have not viewed yet. This can be thought as a reason for why most exhibit elements are left unviewed.

2.1.2.4. Visual Contact and Active Engagement

In order to distinguish the acts of detecting an exhibit element and viewing it, the concepts of 'visual contact' and 'active engagement' were introduced (Peponis et al., 2004). The difference between visual contact and active engagement is, when a visitor is browsing, a visual contact is made with the browsed exhibit elements, however in active engagement, a visitor stops at an exhibit element and studies its content.

Most people spend only a little time at most of the exhibit elements and pass until there is something that tempts them to stop (Bicknell and Mann, 1993; Davies, 1994). Most people spend a much longer time looking at a small portion of the exhibit elements, then browsing through other exhibit elements (Bicknell and Mann, 1993). In an exhibition space, the percentage of the active engagements received by an exhibit element is often less than 50% (Bicknell and Mann, 1993; Hein, 1998; Serrell, 1997). This phenomenon is explained by Bicknell and Mann (1993) as follows: "Few, if any, visitors will have the time, concentration, determination, or interest to look at everything in the exhibition" (p. 144). Visitors tend to ignore most of the exhibit elements especially if they are not on their 'inertia' path.

The viewing time of an exhibit element may vary greatly depending on the visitor profile (Sandifer, 2003). Serrell (1997) claimed that visitors usually spend much less time for viewing exhibit elements then the designer anticipated. In some studies, the average viewing time and the viewing time of the majority of visitors varied as much as 300% (Alt, 1979). Serell (1997) noted that the average viewing time of a single visitor for the whole exhibition was usually less than 20 minutes. However, the time limit might be deceiving since exhibitions greatly vary according to their sizes and contents. Serrell (1996) reported that scanning an average of less than 28 square meters per minute was recorded as a successful visitor exploration speed.

2.2. The Environment Indicators

2.2.1. The Exhibition Space Indicators

Visiting an exhibition is a complex experience that can have individual, social, aesthetic, challenging and inspirational features (Hooper-Greenhill and Moussouri, 2001). The activity of visiting may take place in galleries or exhibition spaces. Visiting an exhibition in an architectural space, like a galleries or an exhibition space, requires special attention in planning the exhibition layout and the circulation paths. These two concepts would be explained in detail in the following sections.

2.2.1.1. The Exhibition Layout

A layout can be thought as an array of individual elements that are conceptually related (Falk, 1993). The layout structure becomes more definite as exhibit elements and boundaries are emplaced in the exhibition space. In an exhibition environment, the exhibit elements and their boundaries work as obstacles that might limit the movement and block the vision of a visitor. Hooper-Greenhill (1994) defined a good layout as uncrowded and not overly structured or sequential.

Peponis and Stravroulaki (2003) stated that, the greater the limitations on visitors' sight in an exhibition space there will be more movement patterns distributed according to the layout. As the numbers of obstructions increase, the limitations on visitor movement and sight strongly affect the visitor's behavior patterns. Therefore, increasing the complexity of a visitor's behavior in an exhibition space resulting in a chaotic flow, and people start to miss the exhibit elements unintentionally (Bitgood, 1993; Peponis et al., 2004). Kaynar (2004) argued that visibility in a three dimensional physical environment is a more elusive variable than accessibility. Also, she suggested that visibility can be strategically planned in an exhibition space to direct the attention and motivation of visitors.

A clearly defined visitor path in an exhibition space may increase the chances of getting more attention for the exhibit elements (Bitgood, 2002). Getting the attention always does not require a strongly defined path. Peponis et al. (2004) claimed that higher level of visibility of an exhibit element from the viewing distance of another exhibit element may also increase the attraction levels of an individual exhibit element dramatically. This enables conceptually structured exhibitions also to be less chaotic. According to Falk (1993), exhibition information can be sequenced in one of two ways:

1- Strongly linear, logically structured with exhibit elements that are hierarchically arranged.
2- Non-linear unstructured with self-contained exhibit elements.

Gallery shape also poses an import role in defining the exhibition layout. Although the shape of a gallery is usually rectangular, different forms have been applied by many contemporary architects. Simple geometric forms as circles, rectangles and cloverleaves help visitors in forming cognitive maps easily. As the intersections start to create angles other than 90 degrees, forming a cognitive map becomes a harder task for visitors (Bitgood, 1996). Some of the planning decisions that have to be made before starting to shape the layout are defined by Spencer (1999) as follows:

1. The layout can be a *Linearly Progressing* one in which a visitor is expected to follow a path from the beginning of the exhibition to the exit.
2. The layout can be an *Open Plan* which allows visitors to explore the exhibition according to his/her own choice of viewing, duration, and in a linear or non-linear fashion.

Often exhibition spaces are constructed with fixed walls, that is appropriate for permanent exhibitions, linear progression. Open plan layouts may require flexibility. Moveable walls and panels provide maximum flexibility in an exhibition environment but may result in clustered appearance and noise (Spencer, 1999).

2.2.1.2. The Circulation Paths

Visitor circulation is largely influenced by the arrangement of the exhibit elements in the exhibition space, however in each exhibition space there are some points or areas that have their own attraction power that is independent from the exhibit elements around the area (Bollo and Pozzolo, 2005). In every exhibition space some intersections, areas and points gain the role of being hot and cold spots depending on the visitor attention and their circulation patterns (Bitgood, 2002). Peponis et al. (2004) suggested that more critical exhibit elements should be placed in more attractive points or areas in order to make them more visible to increase the chance of viewing. Bollo and Pozollo (2005) also suggested that hot and cold spots can also be used to manipulate visitor circulation.

2.2.2. The Exhibit Element Indicators

There are two measurable characteristics of an exhibit element. These characteristics are ‘the attraction power’ and ‘the holding time’ of an exhibit element (Sandifer, 2003). Peponis et al. (2004) described the visitor movement in an exhibition space in three phases: the exploratory movement, the visual contact and the active engagement. The last two of these movement phases, the visual contact and the active engagement, are directly related to the attraction power and the holding time of an exhibit element, respectively. The attraction power of an exhibit element determines the frequency of the visual contacts and the holding time of an exhibit element determines how long an active engagement will last. These relationships will be explained in detail in the following sub-sections.

2.2.2.1. The Attraction Power

The attraction power of an exhibit element is synonymous to the popularity of the exhibit element in an exhibition environment. The salience or distinctiveness of the exhibit element and the traffic flow patterns in an exhibition environment are interconnected issues in deciding the attraction power of an exhibit element. The more salient an exhibit element, the more attractive it becomes (Bitgood, 2002). Additionally, as mentioned previously, the traffic flow in the exhibition environment also influences the attraction power of an exhibit element (see Section 2.2.1.2). Exhibit elements that are located along the shortest route between the entrance and the exit of the exhibition space receive a high amount of interest (Bitgood, 1996; Parsons and Loomis, 1973). As Bitgood (2002) stated, exhibit elements that are situated along the pathway taken by the visitors of the exhibition space have a reasonable chance of being seen when compared to the exhibit elements outside this pathway.

Sandifer (2003, p. 131) defined the attraction power of an exhibit element with the following formula:

$$attraction\ power = \frac{number\ of\ people\ who\ stopped\ at\ the\ exhibit\ element}{number\ of\ people\ who\ observed\ the\ exhibit\ element}$$

This formula provides an index that determines the attraction power of the exhibit element. The research conducted by Sandifer (2003) indicated that the attraction powers of exhibit elements are usually between the values ‘0.21’ and ‘0.50’.

Besides the salience of an exhibit element and the traffic flow, the distance from the exhibit element to the visitor plays an important role in determining the attraction power. According to the general value principle is previously explained (see Section 2.1.1.2), the closer the exhibit element is to the visitor the less effort is needed to view it, which will result in viewing the closest exhibit element. Visitors show a tendency to move to the closest exhibit element in their vicinity (Bitgood, 2002). Additionally, Peponis et al. (2004) mentioned that exhibit elements that are visible from other exhibit elements have high chance of generating interest therefore generating higher attraction power compared to the invisible ones.

When a new exhibit element is introduced to the exhibition environment, it does not only affect the layout of the exhibition space, but also affects the way other exhibit elements are perceived (Bitgood and Patterson, 1993). The new exhibit element might compete with other exhibit elements by distracting the visitor. Melton (1973) claimed that as the number of exhibit elements in an exhibition space increases, the viewing time for each exhibit element decreases. Kaynar (2004) stated that when the density of the environmental information is minimal, the attention of the visitor is directed to exhibit elements.

Bitgood (2002) has outlined some general properties that influence the attraction power of exhibition elements:

- If an exhibit element is emplaced further at a distance between other exhibit elements, then it will generate more attraction power.
- If the size of an exhibit element increases, then its attraction power also increases.

- The size of the exhibit element might also have an influence on the circulation of visitors. Larger exhibit elements might attract the visitors who are entering the exhibition space.
- If an exhibit element is blending into the background, then it may generate less attraction power.
- If an exhibit element is in the vision angle of a visitor, then it will generate more attraction power.

2.2.2.2. The Holding Time

The duration of active engagement can be determined with the holding time of an exhibit element. The holding time can be defined as the average time spent examining an exhibit element by a visitor during the exhibition period (Bollo and Pozollo, 2005; Sandifer, 2003). Sandifer (2003, p. 131) defined the calculation of the holding time of an exhibit element with the following formula:

$$holding\ time = \frac{total\ time\ spent\ at\ the\ exhibit\ element\ by\ engaged\ visitors}{total\ number\ of\ engaged\ visitors}$$

Average holding time may change according to the characteristics of an exhibit element. Sandifer (2003) observed that 35% of exhibit elements had average holding times between 0.6 minute and 1 minute. The holding time value has no upper or lower limits, but Sandifer (2003) noted in his research that the holding time may be as high as 5.9 minutes and as low as 0.2 minute.

This chapter explained the different elements of an exhibition environment and their iterrelations. In the next chapter the implementation of the explained literature data to the different domains of the simulation application will be explained in detail.

3. FRAMEWORK OF THE SIMULATION

In this thesis, a computer application is proposed to simulate the circulation behavior of visitors in an exhibition environment by considering the interaction of visitors with exhibit elements. The proposed application works as a plug-in with 3d Studio Max as the host program. 3d Studio Max (hereafter 3ds Max) is a 3d modeling, animation and rendering program developed by Autodesk (Autodesk, 2006). 3ds Max is a widely used and well practiced program among interior designers, thus, it is chosen as the host program for the simulation application (Bozdağ, 2008).

The proposed simulation application is composed of the following three domain elements: 'the user domain', 'the information domain' and 'the process domain' according to their function, objects, data and relationships (Iyer and Gottlieb, 2004; Kang et al., 1990) (see Figure 3.1). 'The user domain' includes the user and the user interface (Kang et al., 1990). 'The information domain' includes the inputs and the outputs of the simulation application that are required to support various functions (Iyer and Gottlieb, 2004). 'The process domain' includes processes, procedures that interpret the user functions with the input data from 'the information domain' and generate output data for review and evaluation (Iyer and Gottlieb, 2004).

This chapter is composed of the following three sections: 'the user domain', 'the information domain' and 'the process domain'. The details of these three domains is explained in the following sections.

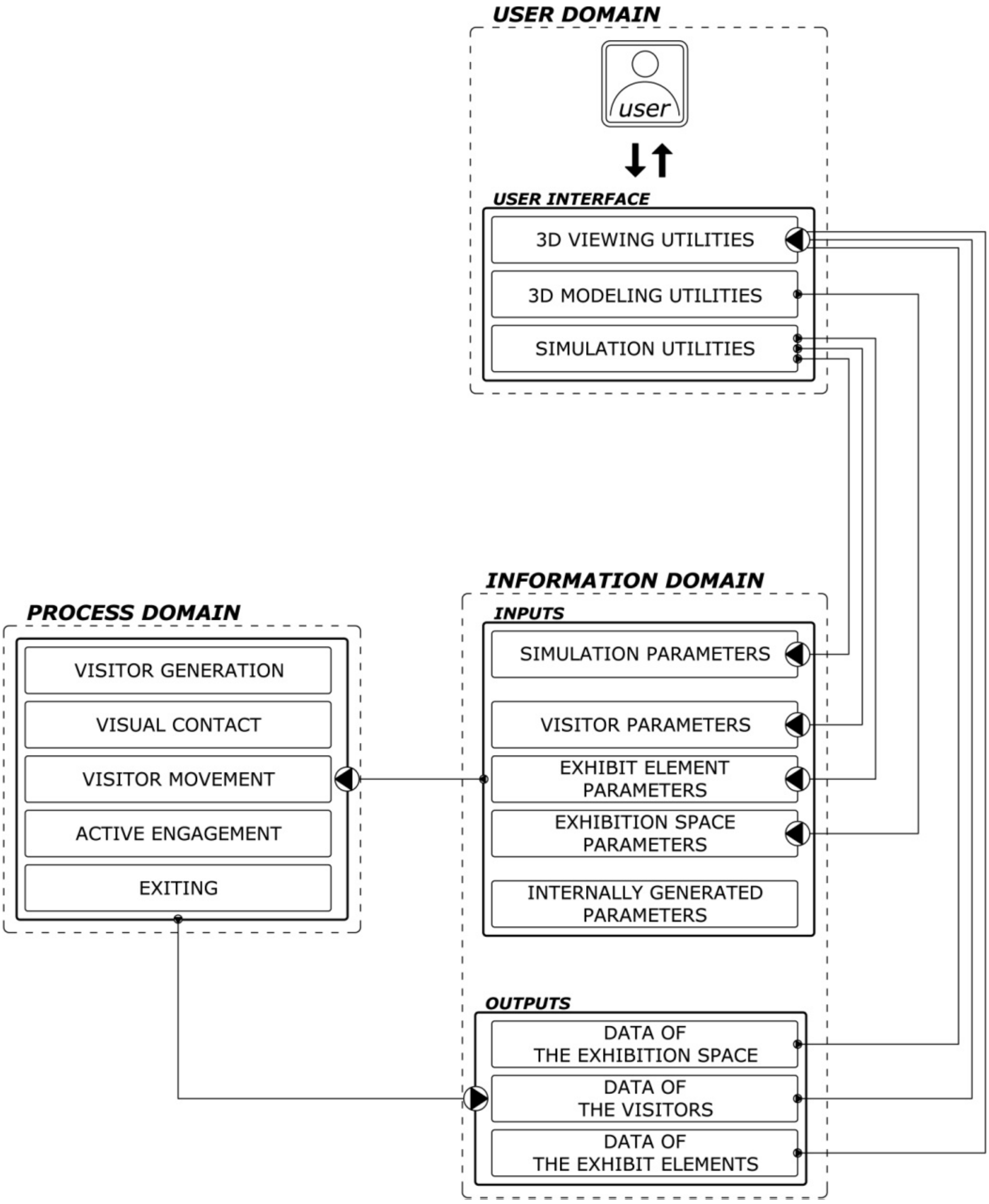

Figure 3.1. The domain elements of the proposed simulation.

3.1. The User Domain

The user domain consists two elements: the user and the user interface. The user operates the simulation application through the user interface. He/she is required to provide inputs and evaluate the outputs of the simulation application. The user handles the tasks and the products of the proposed simulation application using the 3ds Max interface (see Figure 3.2).

The following sections explain the main utilities of the user domain, their tools and the uses of these tools during the operation of the simulation application.

3.1.1. The 3d Viewing Utilities

The 3d viewing utilities are used for viewing the 3d data within the viewports. Viewports are defined as the separated windows in the 3ds Max interface that display the area in which the designer works on, from different angles (Autodesk, 2006).

In the context of the proposed simulation application, there are two significant groups of 3d viewing utilities within the 3ds Max interface: the viewport controls and the animation tools (see Figure 3.2). Viewport controls can be used to rotate and zoom to the 3d space (Autodesk, 2006). Animation tools can be used to playback an animation or to display a certain time segment (Autodesk, 2006).

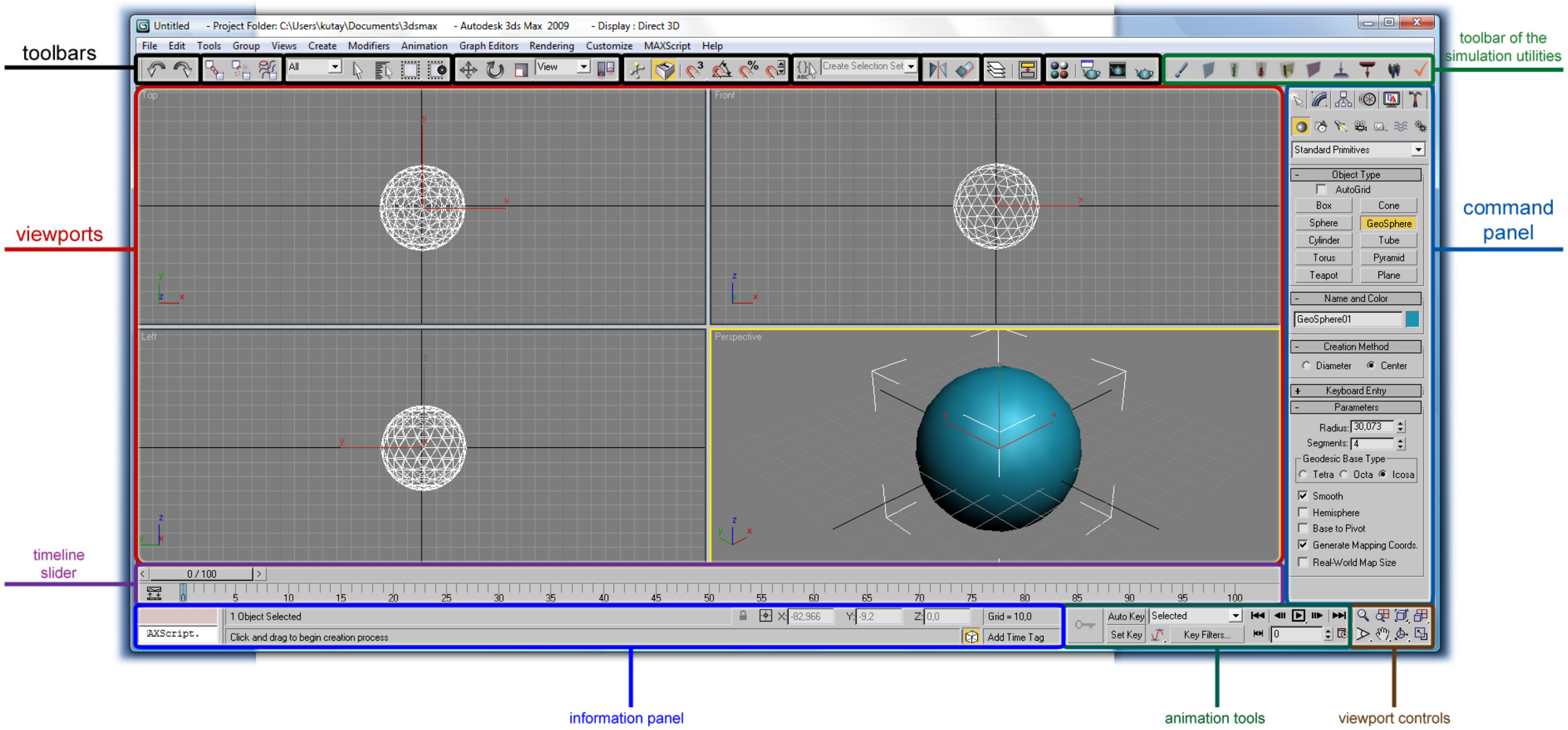

Figure 3.2. The 3d Studio Max interface.

3.1.2. The 3d Modeling Utilities

3d object modeling process in 3ds Max is based on creating, combining and modifying simple geometrical shapes (Autodesk, 2006; Breton and Gerhard, 2007). 3ds Max provides geometry creation, modification and transformation tools for the 3d object modeling processes (Autodesk, 2008). The 3d modeling utilities in 3ds Max can be listed as follows:

1- *Geometry creation tools*: Geometry creation tools can be reached from the command panel under the 'create tab' (Autodesk, 2006) (See Figure 3.3).

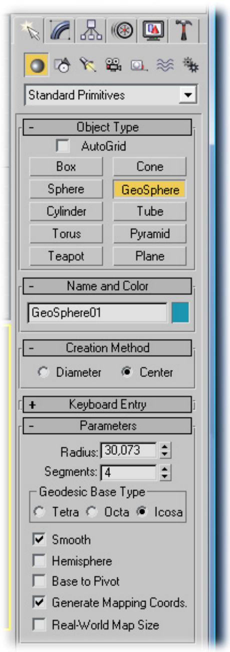

Figure 3.3. The 'create tab' in the command panel.

2- *Object modification tools*: Object modification tools can be reached from the command panel under the 'modify tab' (Autodesk, 2006a) (See Figure 3.4).

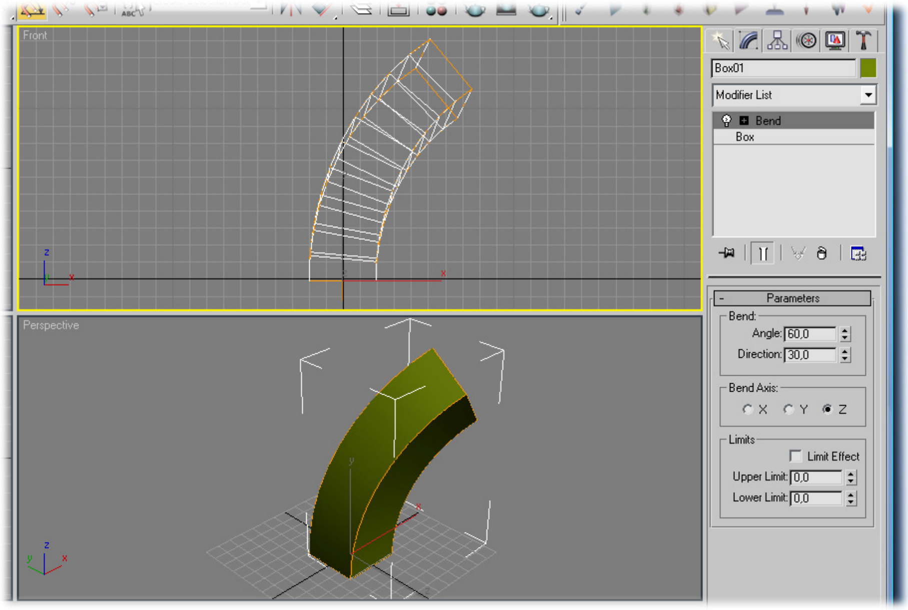

Figure 3.4. The ‘modify tab’ in the command panel and
the effect of the bend modifier on a rectangular prism.

3- Transformation tools: The transformation tools in 3ds Max are used for moving, rotating and scaling 3d objects in the 3d environment (Breton and Gerhard, 2007) (See Figure 3.5).

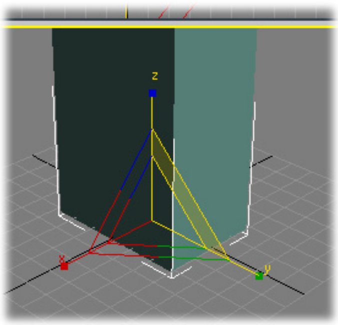

Figure 3.5. The scale transformation tool.

3.1.3. The Simulation Utilities

The simulation utilities allow the user to access the functions of the simulation application (see Figure 3.6).

Figure 3.6. The simulation utilities toolbar.

The simulation utilities consist the following three groups of tools:

1- *Exhibit element tools:* The exhibit element tools enables the user to quickly create exhibit elements (see Appendix A.2 for details). The user is expected to specify the following parameters (see Figure 3.7):

   a. Exhibit element width
   b. Exhibit element depth
   c. Exhibit element height
   d. Viewing distance of the exhibit element
   e. Attraction index of the exhibit element
   f. Holding power of the exhibit element

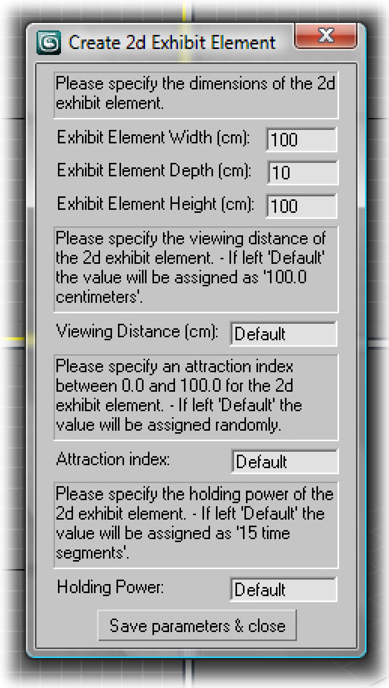

Figure 3.7. Exhibit element tool dialog.

2- *Location tools:* The entrance and the exit of an exhibition space can be specified with the location tools. The entrance specification function is important for identifying the location of the entrance so the visitors can be generated at this location. The exit specification function is important for identifying the location of the exit of the exhibition space so the visitors can exit the exhibition space.

3- *Simulation tool:* The simulation tool is used for specifying the following parameters which will be used during the simulation calculations (see Figure 3.8):

a. Average interest level of the visitors

b. Average visit plan index of the visitors

c. Average fatigue level of the visitors

d. Number of expected visitors during the simulation

e. The interval between each new visitor generation

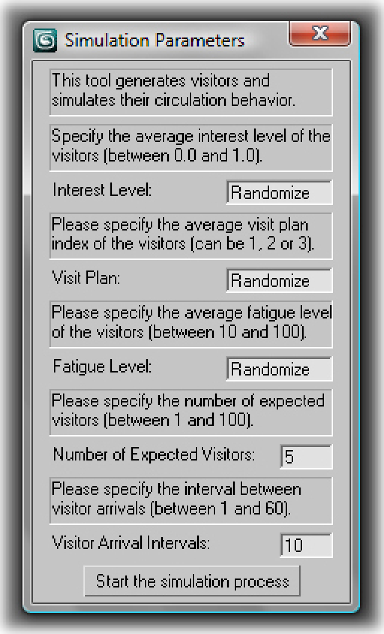

Figure 3.8. The simulation tool dialog.

3.2. The Information Domain

The data of the exhibition environment is stored in the information domain and retrieved during the simulation process. The information domain is categorized into two groups: 'the inputs' and 'the outputs', according to their role in the simulation process (see Table 3.1 and Table 3.2). The next sections deal with these two categories of data in detail.

Table 3.1. The input parameters, their explanations and values

	Parameter name:	Explanation:	Values properties:			Default value:	User settable:
Visitor parameters	*Visitor interest level*	Determines the effect of the profile of the visitor.	positive	float	0.0 - 1.0	random	yes
	Visit plan	The randomly assigned visit plan may affect the visiting times and active engagement numbers of exhibit elements	N/A	array	Affects Visit Plan Index	random	yes
	Fatigue level	Simulates the depletion of the attention level of the visitor. As Fatigue level increases the attraction level of exhibit elements decreases.	positive	integer	unlimited range	10	yes
Exhibit element parameters	*Dimensions*	The dimensions of the exhibit elements are only used for visual feedback.	positive	integer	unlimited range	varies	yes
	Viewing distance	The viewing distance determines from how far an exhibit element can be viewed by a visitor.	positive	float	unlimited range	100.0	yes
	Attraction index	The attraction index of an exhibit element determines the level of attention it will be generating.	positive	integer	1 - 100	random	yes
	Holding power	The holding duration of an exhibit element determines the length of time a visitor will be spending viewing it.	positive	integer	unlimited range	15	yes
Exhibition space parameters (e.s. = the exhibition space)	*Plan and dimension of e.s.*	Plan and dimensions of the exhibition space affects the visitor circulation.	pos - neg	point3	unlimited range	N/A	yes
	Layout of the e.s.	Layout of the exhibition space affects visitor circulation.	pos - neg	point3	unlimited range	N/A	yes
	Entrance coordinates of the e.s.	Entrance coordinates of the exhibition space determines the point where the visitors will be generated.	pos - neg	point3	unlimited range	N/A	yes
	Exit coordinates of e.s.	Exit coordinates of the exhibition space determines the point where the visitors will be exiting the exhibition space.	pos - neg	point3	unlimited range	N/A	yes
Simulation parameters	*Visitor arrival intervals*	This value defines the time interval between the generation of two visitors.	positive	integer	0 - 60	10	yes
	No. of expected visitors	The number of visitors that will be generated and simulated during the course of the simulation.	positive	integer	1 - 100	1	yes
Internally generated parameters	*Visit plan index*	If an exhibit element is found in the visit plan array, then it will be assigned a visit plan index of 1.3, if not then it will be assigned a visit plan index of 1.0.	positive	float	1.0 / 1.3	1.0	no
	Wall collisions	Wall collisions check if an object is in the line of sight of the visitor or not.	N/A	boolean	0 / 1	1	no
	Distances	Distances are calculated in order to determine which exhibit element is near to the visitor and will generate relatively more attraction power.	positive	float	unlimited range	N/A	no
	Previously viewed exhibit elements	Exhibit elements are recorded into an array whenever they are viewed. This value prevents them from being viewed again.	N/A	boolean	0 / 1	0	no

Table 3.2. The output parameters, their explanations and values

	Parameter name:	Explanation:	Values:			Default value:	User settable:
Regarding the exhibition space	*Total exhibition time*	Indicates the time length of the simulation until all the specified number of visitors complete their visit.	positive	integer	unlimited range	N/A	no
	% of visual contacts	Indicates the percentage of exhibit elements that have been noticed by the visitors during the course of the exhibition.	positive	float	0.0 - 100.0	N/A	no
	% of active engagements	Indicates the percentage of exhibit elements that have been viewed by the visitors during the course of the exhibition.	positive	float	0.0 - 100.0	N/A	no
Regarding the visitor	*Total time spent by each visitor*	Indicates the time spent by each visitor between their enterance to the exhibition space and exit.	positive	integer	unlimited range	N/A	no
	Distance travelled by each visitor	Indicates the distance walked by each visitor during the course of their visit.	positive	float	unlimited range	N/A	no
Regarding exhibit elements	*Average attraction power generated by each exhibit element*	Indicates the average attraction power each exhibit element generated during the whole simulation period.	positive	float	0.0 - 1.0	N/A	no
	Number of visual contacts for each exhibit element	Indicates how many times an exhibit element get noticed by a visitor during the whole simulation period.	positive	integer	0 - 100	N/A	no
	Number of active engagements for each exhibit element	Indicates how many times an exhibit element get viewed by a visitor during the whole simulation period.	positive	integer	0 - 100	N/A	no
	Average holding time generated by each exhibit element	Indicates the average attraction power each exhibit element generated during the whole simulation period.	positive	float	unlimited range	N/A	no

3.2.1. Inputs

3.2.1.1. Visitor Parameters

The visitor parameters consist the following three inputs:

1- *Visitor interest level:* As mentioned previously (see Chapter 2.1.1.1), a visitor's behavior is closely related to his/her profile. During the simulation the profiles of the visitors are determined according to their interest level (see Table 3.1 for details).

The interest level of a visitor affects the attraction powers and holding times of the exhibit elements, therefore affecting the number of visual contacts, the number and the duration of the active engagements (see Appendix B for details).

2- *Visit plan:* As explained previously (see Chapter 2.1.1.3), the circulation of the visitor in the exhibition space may depend on the expectations and the experiences that constitute his/her 'pre-visit agenda' (Hooper-Greenhill and Moussouri, 2001).

The visit plan constitutes a percentage of exhibit elements that are planned to be seen or preferred over the others (see Table 3.1 for details). The specified visit plan will randomly generate a visit plan array for each newly generated visitor which will include a number of exhibit elements from the exhibition (see Appendix B for details).

The visit plan affects the attraction power of an exhibit element, the number of visual contacts and active engagements it will be receiving from the visitors. The visit plan may lead to a more random visitor behavior, therefore to a more realistic circulation simulation (Robinson, 2004).

3- *Fatigue level:* As explained before (see Chapter 2.1.1.2 and Chapter 2.1.2.1), the physical and mental effort of the visitor depletes the visitor's attention. This change in attention may cause the visitor to respond differently to the exhibit elements (Falk, 1993; Hein, 1998).

In the proposed simulation, the fatigue level of a visitor is defined with a positive integer number (see Table 3.1 for details). During the visiting period This value linearly increases 1 point if the visitor performs an activity at a time segment.

The fatigue level has a negative effect on the attraction power and holding time of exhibit elements. On the other hand the fatigue level has a positive effect on the attraction power of the exit, therefore, it may cause early exiting behavior of the visitors.

3.2.1.2. Exhibit Element Parameters

The visitor parameters consist of the following four inputs:

1- *Dimensions:* As explained previously (see Chapter 2.2.2.1), dimensions of an exhibit element might influence its attraction power and the surrounding circulation (Bitgood, 2002).However, in the proposed simulation application, the dimensions of the exhibit elements are only effective as a visual feedback for the user for preventing complexity (see Table 3.1 for details).

2- *Viewing distance:* is the optimum distance that a user should view an exhibit element (Neal, 1987). In the proposed simulation application, the viewing distance does not affect the attraction power or the holding time of any exhibit element (See Table 3.1 for details).

3- *Attraction index:* As mentioned previously (see Chapter 2.2.2.1), the saliency of an exhibit element is proportional to the attraction power it generates (Bitgood, 2002). In the proposed simulation application, the saliency of an exhibit element is expressed with the attraction index.

The attraction index affects the attraction power of the exhibit element and is directly related to the number of visual contacts and active engagements with the exhibit element (see Table 3.1 for details).

4- *Holding power:* As explained previously (see Chapter 2.2.2.2), holding time determines the duration of an active engagement (Sandifer, 2003). In the proposed simulation, the holding power is a variable that expresses the capability of an exhibit element for keeping the attention of a visitor.

The holding power is a user definable integer value and it primarily determines the length of time the visitors is spending while viewing the exhibit element (see Table 3.1 for details).

3.2.1.3. Exhibition Space Parameters

The exhibition space parameters consist of the following three inputs:

1- *Plan and dimensions of the exhibition space:* As mentioned previously (see Chapter 2.2.1.1), the exhibition space and the exhibit elements work as obstacles that might limit the vision and the circulation of visitors (Peponis et al., 2004). The exhibition space model is prepared using the modeling tools of 3ds Max (see Section 3.2.2).

The main function of the exhibition space model is to provide virtual stimulus to the visitors to obtain realistic visitor circulation behavior by allowing them to detect wall collisions on their circulation path. The exhibition space model also provides visual feedback for the user during the design process as well as inevaluating the simulation process (see Table 3.1 for details).

2- *Layout of the exhibition space:* As mentioned previously (see Chapter 2.2.1.1), the layout of an exhibition space influences the visitor circulation (Bitgood, 1993; Bitgood, 2002; Peponis et al., 2004). The layout of the exhibition space constitutes the locations of the exhibit elements (see Table 3.1 for details).

The primary function of the layout of the exhibition space is to store the coordinates of the exhibit elements, consequently, the distances between the exhibit elements and the visitors can be calculated. Distances between exhibit elements and their relative distances to the visitors directly affect the circulation patterns of the visitors. Additionally, the layout of the exhibition space provides a visual feedback to the user.

3- *The entrance and the exit coordinates of the exhibition space:* These parameters are crucial in providing the starting and ending locations for the visitor circulation. Entrance coordinates of the exhibition space determine the location where visitors are generated (see Table 3.1 for details). Exit coordinates of the exhibition space determine the location of the visitors who exit the exhibition space from (see Table 3.1 for details).

The exit of the exhibition space is also important in creating the exit gradient effect that was explained previously (see Chapter 2.1.2.1). An attraction index is assigned to each exit of the exhibition space. Therefore, the exit has an attraction power that is greater than the exhibit elements. A high attraction power of the exit may cause early exiting behavior of the visitors.

3.2.1.4. Simulation Parameters

The simulation parameters consist the following two inputs:

1- *Visitor arrival interval:* This parameter defines the time interval between the generation of two visitors (see Table 3.1 for details). This value might affect the density of visitors inside the exhibition space, therefore, affecting the circulation behavior of the visitors. Additionally, the visitor arrival interval may influence the total length of the exhibition.

2- *Number of expected visitors:* This value determines the total number of visitors that is generated during the course of the simulation (see Table 3.1 for details). This value affects the total exhibition time.

3.2.1.5. Internally Generated Parameters

The internally generated parameters consist of the following four groups of data:

1- *Visit plan index:* The visit plan index is an internally generated value which is the result of the visit plan of a visitor (see Section 3.3.1.1). During the simulation, if an exhibit element is found in the visit plan array of a visitor, then the exhibit element will generate 30% more attraction power (see Table 3.1 for details). The visit plan index affects the numbers of visual contacts and active engagements with an exhibit element.

2- *Wall collisions:* As previously explained (see Section 3.3.1.3), the plan of the exhibition space affects the visitor behavior. Wall collision index is represented by a Boolean value that determines if an exhibit element is visible to the visitor or blocked by an obstacle. (See Table 3.1 for details).

3- *Distances:* As explained previously (see Chapter 2.1.1.2), the general value principle is an important motivational factor for visitors (Bitgood 2005; 2006). The general value principle argues that the cost of an experience is unconsciously calculated by the visitor and compared with the benefit of the experience (Bitgood, 2005; 2006).

According to the above statements in order to achieve a high value, an exhibit element should be interesting while the effort of viewing it is minimal. In this thesis, the distance between the visitor and the exhibit element is interpreted as the effort that a visitor has to be spent to view the exhibit element.

For each time segment the distances between each exhibit element and each visitor are calculated. The distance affects the attraction power of an exhibit element and also is used to determine if the visitor is close enough to the target object for active engagement or not (see Table 3.1 for details).

4- *Previously viewed exhibit elements index:* As mentioned earlier (see Chapter 2.1.2.3), visitors are reluctant to view exhibit elements that are left behind or previously viewed (Klein, 1993; Taylor, 1986). The previously viewed exhibit element index is used for determining if an exhibit element is previously viewed by the visitor or not (see Table 3.1 for details). For practical purposes the visitors simulated with the proposed simulation application do not view a previously viewed exhibit element a second time.

3.2.2. Outputs

3.2.2.1. Output Data of the Exhibition Space

The output data regarding the exhibition space consist of the following three inputs (see Figure 3.9):

1- *Total exhibition time:* Indicates the number of time segments spent in the exhibition between the entrance of the first visitor and the exit of the last visitor (see Table 3.2 for details). This parameter aims to help the designer to check if his/her expected exhibition time is achieved.

2- *Percentage of visual contacts:* Indicates the percentage of exhibit elements that have been noticed by visitors during the course of the simulation (see Table 3.2 for details). This parameter aims to help the designer to determine the percentage of exhibit elements that were noticed at least once during the course of the simulation.

3- *Percentage of active engagements:* Indicates the percentage of exhibit elements that were viewed by visitors during the course of the simulation (see Table 3.2 for details). This parameter aims to help the designer to determine the percentage of exhibit elements that were viewed at least once during the course of the simulation.

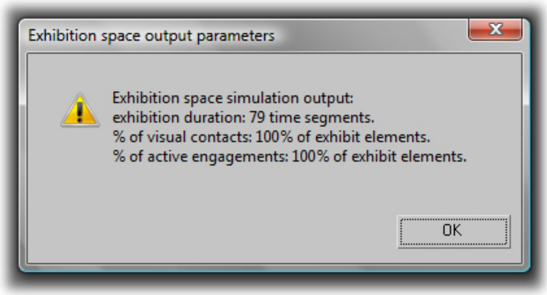

Figure 3.9. The exhibition space output parameters dialog.

3.2.2.2. Output Data of the Visitors

The output data regarding the visitor consist of the following two inputs (see Figure 3.10):

1- *Total time spent by each visitor:* Indicates the number of time segments spent by each visitor between the entrance to the exhibition space and from the exit (see Table 3.2 for details). A time segment represents *one second* in real world terms. This output enables the designer to compare, how the duration of the visit varied according to the interest level and the visit plan of the visitor.

2- *Total distance travelled by each visitor:* Indicates the distances walked in meters by each visitor during the course of visit (see Table 3.2 for details). This output enables the designer to compare how the walking distances varied according to the interest level and the visit plan of the visitor.

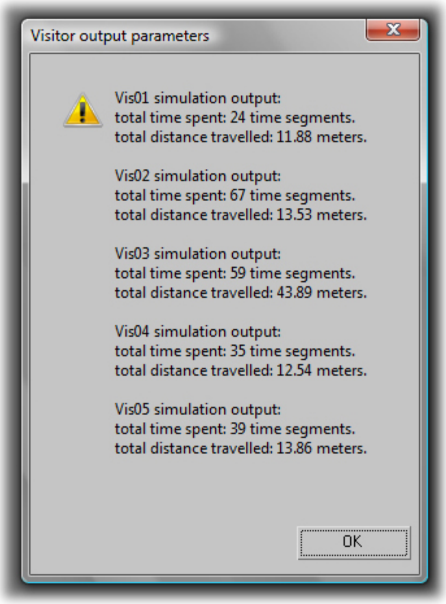

Figure 3.10. The visitor output parameters dialog.

3.2.2.3. Output Data of the Exhibit Elements

The outputs regarding the exhibit elements consist of the following four inputs (see Figure 3.11):

1- *Average attraction power generated by each exhibit element:* Indicates the average attraction power of each exhibit element generated during the whole simulation period (see Table 3.2 for details). This output aims to help the designer to compare the attention generated by each exhibit element in relation to its attraction index.

2- *Number of visual contacts received by each exhibit element:* Indicates how many times an exhibit element gets noticed by the visitors during the whole simulation period (see Table 3.2 for details). This output helps the designer to compare the number of visual contacts generated by each exhibit element in relation to its attraction index.

3- *Number of active engagements received by each exhibit element:* Indicates how many times an exhibit element is viewed by the visitors during the whole simulation period (see Table 3.2 for details). This output aims to help the designer to compare the number of active engagements generated by each exhibit element in relation to its attraction index.

4- *Average holding time generated by each exhibit element:* Indicates the average holding time of each exhibit element generated during the whole simulation period (see Table 3.2 for details). This output aims to help the designer to compare the average holding time generated by each exhibit element in relation to its holding time.

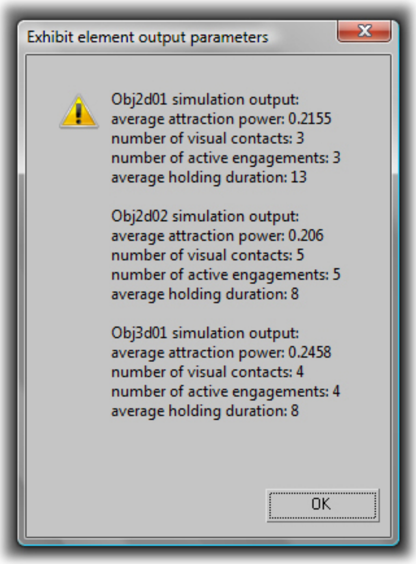

Figure 3.11. The exhibit element output parameters dialog.

3.3. The Process Domain

The process domain is responsible for calculating the visitor circulation inside the exhibition space according to the data provided by the information domain (see Appendix A.1 for details). The process domain is separated into the following five processes: the visitor creation process, the visual contact process, the visitor movement process, the active engagement process and the exiting process. The next sections deal with these five processes in detail.

3.3.1. The Visitor Creation Process

The visitor creation process generates visitors at the entrance location of the exhibition space according to the inputs provided by the user (see Appendix A.3 for details).

The visitor creation process involves reading and assigning the visitor and simulation parameters inputted by the user and setting the time interval between each visitor generation (see Appendix B for details). This process provides a realistic visitor arrival behavior compared to generating visitors at random locations (McLean, 1993; Peponis et al., 2004; Weis and Boutourline, 1963).

3.3.2. The Visual Contact Process

The visual contact process is based on 'the visit order model' of Jun, et al. (2006). The visual contact process calculates the attraction power values for each exhibit element at each time segment for each visitor (see Appendix A.4 for details). After all the attraction power values for all exhibit elements are calculated, the visitor targets the exhibit element with the highest attraction power. The following formula is used to calculate the attraction power AP_e of the exhibit element e at a time instance:

$$AP_e = \frac{IL_{\text{v}} * AI_e * VP_{ev} * C_e * V_e}{{D_{ve}}^2 * (N_{ve}+1) * \log F_v}$$

Where IL_v is the interest level of the visitor v, AI_e is the attraction index of the exhibit element, VP_e is the visit plan index of the exhibit element e, C_e is the wall collision check value of the exhibit element, V_e is the viewing history value of the exhibit element, D_{ve} is the distance between visitor v and the exhibit element e, N_{ve} is the number of current viewers of the exhibit elements and F_v is the fatigue level of visitor v.

3.3.3. The Visitor Movement Process

The visitor movement process decides at a certain time segment if the visitor will be walking, waiting or viewing (see Appendix A.5 for details).

As stated by Bruderlin and Calvert (1989) the walking speed for an adult may vary between 0.50 meters and 1.05 meters a second. According to Bruderlin and Calvert (1989), a natural walking speed is 0.77 meters per second. Therefore, for every time segment a visitor moves a length of 0.77 meters. Pedestrians also adjust their walking speeds according to other pedestrians along the path (Ashida, et al., 2001). Therefore, if there is a visitor collision on the path of the visitor, then the visitor slows his/her walking pace (see Appendix B for details).

For each time segment, the position and the rotation of each visitor are recorded as key frames into the visitor circulation animation. After the simulation is processed, the position of the animation time slider returns to its starting point and the user can view the processed circulation of the visitors as an animation (see Figure 3.2).

3.3.4. The Active Engagement Process

The active engagement process is based on ‘the appreciation time model’ of Jun, et al. (2006). The active engagement process assigns a viewing time value for the visitor in viewing distance (see Appendix A.6 for details). The visitor stays at the viewing distance of the exhibit element for the length of the holding time specified by the active engagement process. The following formula is used for calculating the holding time HT_e of exhibit element e:

$$HT_e = \frac{IL_v * HP_e}{(N_{ve}+1) * \log F_v}$$

Where IL_v is the interest level of visitor v, HP_e is the holding power of the exhibit element e, N_{ve} is the number of visitors viewing the exhibit element e and F_v is the fatigue level of visitor v.

3.3.5. The Exiting Process

In order to simulate the exit gradient behavior defined by Melton (1935) a constant attraction index is assigned to the exit locator which generates an attraction power value similar to the exhibit elements (see Section 3.4.2). If the highest attraction power value of exhibit elements fails to exceed the attraction power of the exit then the exit is targeted for visitor movement (see Appendix A.7 for details). The following formula is used for calculating the attraction power AP_x of the exit locator at a time segment:

$$AP_x = \frac{AI_x * C_x * \log F_v}{IL_v}$$

Where AI_x is the attraction index of the exit, C_x is the wall collision value of the exit, F_v is the fatigue level of visitor v and the exit locator and IL_v is the interest level of visitor.

In this chapter, the integration of the collected literature data and the simulation application is explained. In order to assess the functionality of the simulation application, an example simulation of an exhibition environment is conducted. The details and the outcomes of the simulation of the exhibition environment will be explained in the next chapter.

4. SIMULATION OF AN EXHIBITION ENVIRONMENT

In this thesis, an example simulation of an exhibition environment is conducted in order to assess the functionality of the simulation application during the exhibition layout design process. Two exhibition environments are prepared as two phases of the design problem according to the values proposed to the following requirement:

1- All exhibit elements should generate an average attraction power value greater than 0.
2- Visual contacts with the exhibit elements should involve at least 60% of the visitors.
3- Active engagements with the exhibit elements should involve at least 60% of the visitors.
4- Holding times of the exhibit elements should be longer than 15 time segments.

During the two phases of the example design problem experiment two different exhibition environments are designed and simulated with different exhibit element layouts, but identical input parameters. The input and output parameters of both exhibition environments are explained in the following sections. In the discussion section, the output parameters of both exhibition environments are compared and the outcomes are evaluated.

4.1. The Input Parameters

4.1.1. The Virtual Exhibition Space

Virtual environments provide control over environmental variables while evaluating simulation applications. Virtual environments can be designed in such a way that specific properties and outputs of a simulation can be controlled and evaluated. Virtual environments were also used in the previous researches for implementing and evaluating various simulation applications (Choudhary, et al., 2004; Jun, et al., 2006; Pan, et al., 2006).

In this design problem experiment, a virtual exhibition space is designed for use in both exhibition environments A and B (see Figure 4.1). Main considerations while designing the virtual exhibition space were as follows:

1- The exhibition space should be able to accommodate circulation paths between the entrance and the exit that can be both linear and non linear.
2- A relatively large hall area should be included in order to capture circulation behavior where visitors are spaced loosely.
3- A relatively narrow entrance and exit areas should be included in order to capture the circulation behavior where visitors are spaced densely.

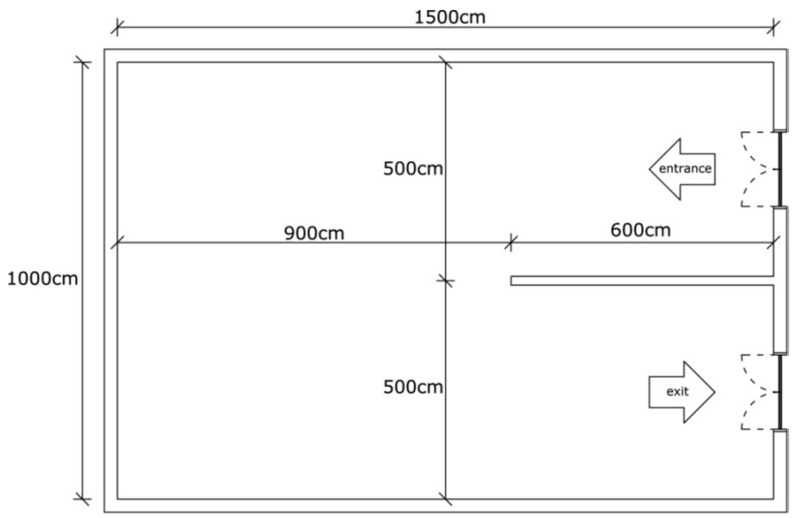

Figure 4.1. Plan and dimensions of the virtual exhibition space.

The design of the exhibition space is modeled in 3ds Max with the tools and processes explained previously (see Section 3.1). The completed virtual exhibition space is then used for creating both exhibition environments A and B (see Figure 4.2).

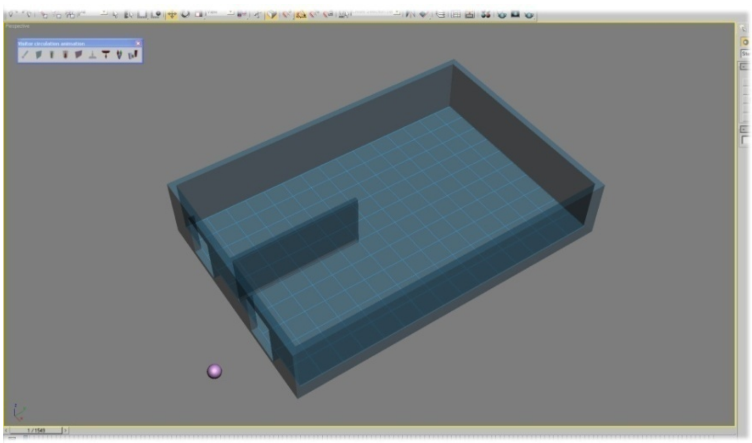

Figure 4.2. The 3d model of the virtual exhibition space in 3ds Max.

4.1.2. The Exhibit Element Parameters

The input parameters for the exhibit elements are shown in Table 4.1. These exhibit element parameters are used for exhibit elements of both exhibition environments A and B . In both exhibition environments the exhibit elements are placed according to the order presented in Table 4.1.

Table 4.1. The exhibit element input parameters

Name	Viewing Dist. (cm)	Attraction Index	Holding Power (sec)
2d01	100	80	15
2d02	100	80	15
2d03	100	20	15
2d04	100	20	15
3d01	100	70	15
3d02	100	70	15
Inst01	100	30	15
Inst02	100	30	15
mean	100	50	15
σ	0.00	27.26	0.00

4.1.3. The Visitor and Simulation Parameters

The simulation input parameters and the visitor input parameters for exhibition environment A and B are shown in Table 4.2. These parameters are used for four runs of the simulation application with 50 visitors each time. The average of the outputs of the four runs of the simulation is listed as the outcome.

Table 4.2. The visitor and simulation parameters

(a) The visitor input parameters	**Value**
Average visitor interest level	0.70
Average visitor visit plan index	2
Average visitor fatigue level	10
(b) The simulation input parameters	
Number of expected visitors	50
Average visitor arrival interval	20

4.2. The Exhibition Environment A

4.2.1. The Layout

The exhibit elements for the exhibition environment A are placed according to the layout shown in Figure 4.3. In the layout for exhibition environment A, the exhibit elements are placed on the outer walls of the exhibition environment.

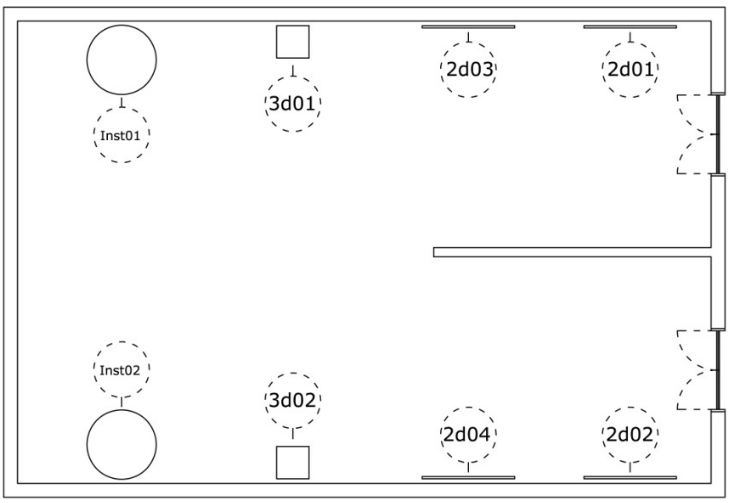

Figure 4.3. The exhibition layout for the exhibition environment A

4.2.2. The Simulation Outputs

After the completion of the simulation process, the simulation outputs are collected and organized. The simulation output parameters of exhibition environment A regarding the exhibition space, the visitors and the exhibit elements are shown in Table 4.3.

Table 4.3. The simulation output parameters regarding the exhibition environment A

(a) Output parameters of the exhibition space	**Value**
Length of the simulation	1269.75
Percentage of visual contacts	100%
Percentage of active engagements	100%
(b) Output parameters of the visitors	
Average time spent by the visitors	204.88
Average distance travelled by the visitors	34.82
Average fatigue level of the visitors	110.54
(c) Output parameters of the exhibit elements	
Average attraction power	0.0938
Average length of holding time	15.75
Average number of visual contacts	42.5
Average number of active engagements	40.31

The simulation output parameters of exhibition environment A regarding the exhibit elements are shown in Table 4.4. A screenshot from the simulation output of the exhibition environment A is shown in Figure 4.4.

Table 4.4. The simulation output parameters regarding the exhibit elements in exhibition environment A.

Name	Viewing Dist. (cm)	Attraction Index	Holding Power (sec)	Visual contact (visitors)	Active engagement (visitors)	Average att. power	Average Holding Time
2d01	100	80	15	50	50	0.2457	21
2d02	100	80	15	46	44	0.1080	13
2d03	100	20	15	46	42	0.0565	18
2d04	100	20	15	42	42	0.0308	14
3d01	100	70	15	50	42	0.1267	15
3d02	100	70	15	44	41	0.0979	14
Inst01	100	30	15	36	36	0.0469	15
Inst02	100	30	15	27	25	0.0382	16
	mean	50.00	15.00	42.5	40.31	0.0938	15.75
	σ	27.26	0.00	7.89	6.47	0.0707	2.60

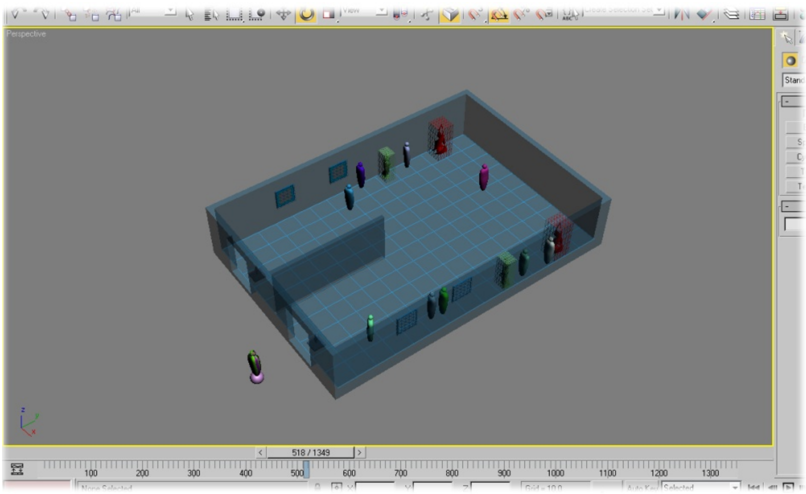

Figure 4.4. A screenshot from the exhibition environment A

4.3. The Exhibition Environment B

4.3.1. The Layout

The layout design of the second phase proposes a different arrangement of the same exhibit elements from exhibition environment A. The exhibit element layout for the exhibition environment B is shown in Figure 4.5. In the layout for exhibition environment B, the exhibit elements are placed along the center line of the exhibition space.

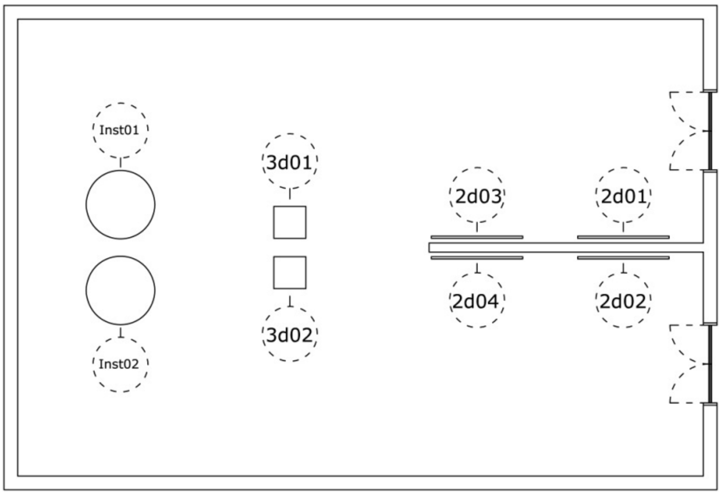

Figure 4.5. The exhibition layout for the exhibition environment B

4.3.2. The simulation outputs

The simulation output parameters of exhibition environment B regarding the exhibition space, the visitors and the exhibit elements are shown in Table 4.5.

Table 4.5. The simulation output parameters regarding the exhibition environment B

(a) Output parameters of the exhibition space	**Value**
Length of the simulation	1019.00
Percentage of visual contacts	100%
Percentage of active engagements	100%
(b) Output parameters of the visitors	
Average time spent by the visitors	189.02
Average distance travelled by the visitors	28.03
Average fatigue level of the visitors	111.42
(c) Output parameters of the exhibit elements	
Average attraction power	0.1378
Average length of holding time	12.50
Average number of visual contacts	49.37
Average number of active engagements	41.25

The simulation output parameters of exhibition environment B regarding the exhibit elements are shown in Table 4.6. A screenshot from the simulation output of the exhibition environment B is shown in Figure 4.6.

Table 4.6. The simulation output parameters regarding the exhibit elements in exhibition environment B.

Name	Viewing Dist. (cm)	Attraction Index	Holding Power (sec)	Visual contact (visitors)	Active engagement (visitors)	Average att. power	Average Holding Time
2d01	100	80	15	50	50	0.3004	20
2d02	100	80	15	50	50	0.1270	12
2d03	100	20	15	50	50	0.0595	16
2d04	100	20	15	49	49	0.2130	6
3d01	100	70	15	50	38.5	0.1588	13
3d02	100	70	15	50	49	0.1424	10
Inst01	100	30	15	47	20	0.0524	13
Inst02	100	30	15	49	16	0.0486	10
	mean	50.00	15.00	49.3	41.25	0.1378	12.50
	σ	27.26	0.00	1.06	14.45	0.0879	4.21

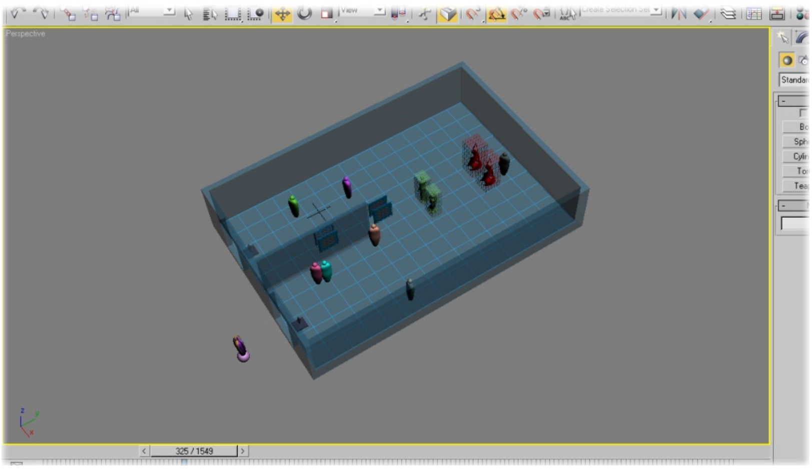

Figure 4.6. A screenshot from the exhibition environment B

4.4. Discussion

As seen in Tables 4.3 and 4.5, the average length of the simulation is decreased from 1269.75 to 1019.00 time segments in exhibition environments A to B, respectively. Additionally, the average time spent by the visitors decreased from 204.88 to 189.02 time segments in exhibition environments A to B, respectively. This was an expected outcome, since the total distance between the exhibit elements are decreased in the exhibition environment B. In the average traveling distance of visitors, a decrease of 6.79 meters (from 34.82 to 28.03 meters) can also be observed in the exhibition environment B.

According to the simulation outputs of the exhibition environment A and B, the average attraction power generated by the exhibit elements is increased from 0.0938 to 0.1378 in exhibition environment B (see Table 4.7).

Table 4.7. The simulation output parameters comparison table

	Layout A value	**Layout B value**
Average attraction power	0.0938	0.1378
Standard deviation of attraction powers	0.0707	0.0879
Average length of holding times	15.75	12.50
Standard deviation of length of holding times	2.60	4.21
Average number of visual contacts	42.50	49.30
Standard deviation of visual contacts	7.89	1.06
Average number of active engagements	40.31	41.25
Standard deviation of active engagements	6.47	14.45

According to the output data of the exhibition environment B, the exhibit elements generated more interest. This outcome might be due to the increased visibility and narrow placement of exhibit elements in exhibition environment B.

The average holding powers for exhibition elements are decreased in the exhibition environment B by 3.25 time segments (see Table 4.7). The average holding time ranges from 13 to 21 time segments in the exhibition environment A and ranges from 6 to 20 time segments in the exhibition environment B. Additionally, the standard deviation value is increased from 2.6 to 4.21 in the exhibition environment B (see Table 4.7). The narrow placement of exhibit elements in exhibition environment B might have caused some visitors to disturb others during their active engagement processes, therefore causing slightly shorter viewing times.

The average number of visual contacts is increased from 43 visitors to 50 visitors in exhibition environments A to B, respectively. Additionally, the standard deviation value is decreased from 7.89 to 1.06 (see Table 4.7). As seen in Figure 4.7, all the exhibit elements get evenly distributed visitor attention in the exhibition environment B.

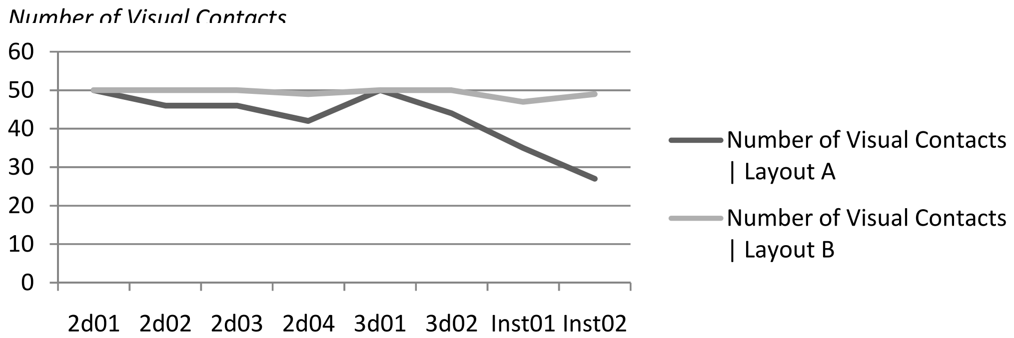

Figure 4.7. The comparison of visual contacts for both exhibit environments.

As seen in Table 4.7, the average number of active engagements is increased from 40 visitors to 41 visitors in the exhibition environment B. Additionally, the standard deviation value is increased from 6.47 to 14.45. As seen in Figure 4.5, although the visual stimulus from all exhibit elements was nearly equally apparent to the visitors, the visitors were not eager to view all the exhibit elements in the exhibition environment B.

As seen in Figure 4.6, ObjInst01 and ObjInst02 had a smaller number of active engagements compared to the other exhibit elements in the exhibition environment B, despite the fact that all other exhibit elements got similar number of active engagements. Additionally, as seen in Figure 4.8, the number of active engagements of ObjInst01 and ObjInst02 were also low in the exhibition environment A. This data suggests that, since both ObjInst01 and ObjInst02 are placed far from both the entrance and the exit, they generated less attention. However, Obj2d01 and Obj2d02 generated the highest attention of all exhibit elements in relation to their attraction indexes (see Tables 4.4 and 4.6).

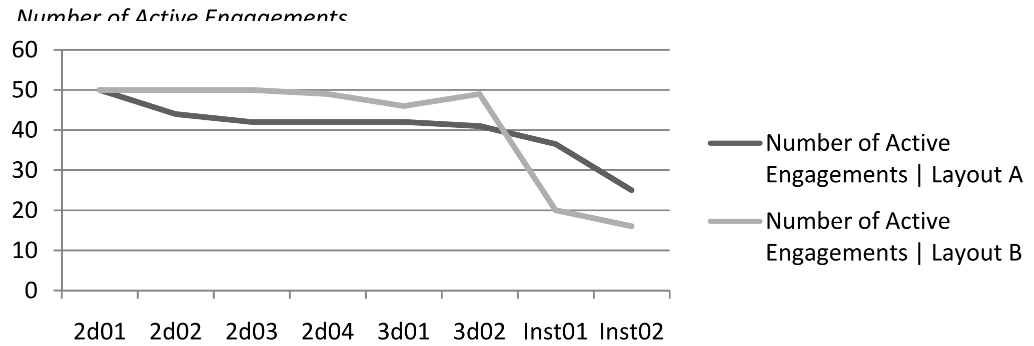

Figure 4.8. The comparison of active engagements for both exhibition environments.

5. CONCLUSION

In this thesis, a simulation application for visitor circulation in exhibition environments is proposed. The model of this simulation application is based on the data collected from the previous studies, so that the possible outcomes of a simulation process will generate realistic outputs. These outputs can help the designer in preventing possible design errors due to the lack of knowledge of visitor behavior.

As a result of the simulation application, the outputs obtained from both exhibition environments suggested that, the change in the layout design of an exhibition space results in a different visitor circulation patterns. Additionally, this change in behavior can be clearly observed through the outputs of the proposed simulation application before the exhibition elements are allocated in the real exhibition space. Additionally, the outputs of the simulation application for both exhibition environments matches with the real-world data collected in the previous researches (Kaynar, 2004; Peponis et al., 2004). One more benefit of the simulation application is, with the visitor circulation animation, it is possible to examine the visitor circulation paths, manipulate them and take precautions before the final application of the exhibition environment.

During the development of the simulation application, Maxscript provided the programming environment, however this scripting language was largely dependent on the host program 3ds Max and was not very flexible. Therefore, some possibly useful functions such as, displaying exhibit element and visitor properties at a certain time segment while viewing the visitor circulation animation or simulation of visitor groups, could not be implemented. However in the future studies, using the software development kit of 3ds Max rather than the scripting language might prevent this drawback.

The benefit from the simulation application proposed in this thesis can be extended beyond exhibition environments. In the future studies, it is possible to propose similar simulation applications for other interior design problems. Additionally architectural features like ceiling height or effects of openings can also be implemented in the future studies.

As a conclusion, the proposed simulation application offers a method for improving the quality of the design of exhibition environments. The thesis may contribute to the literature since it proposes a method for implementing a simulation application to the early phases of the interior design process. The proposed simulation application may also be useful to interior designers during the professional practice, since it helps the designer to see, before the implementation of a design, if his/her assumptions and decisions on certain qualities of the design will cause problems during the use of the interior space before the final application of the product.

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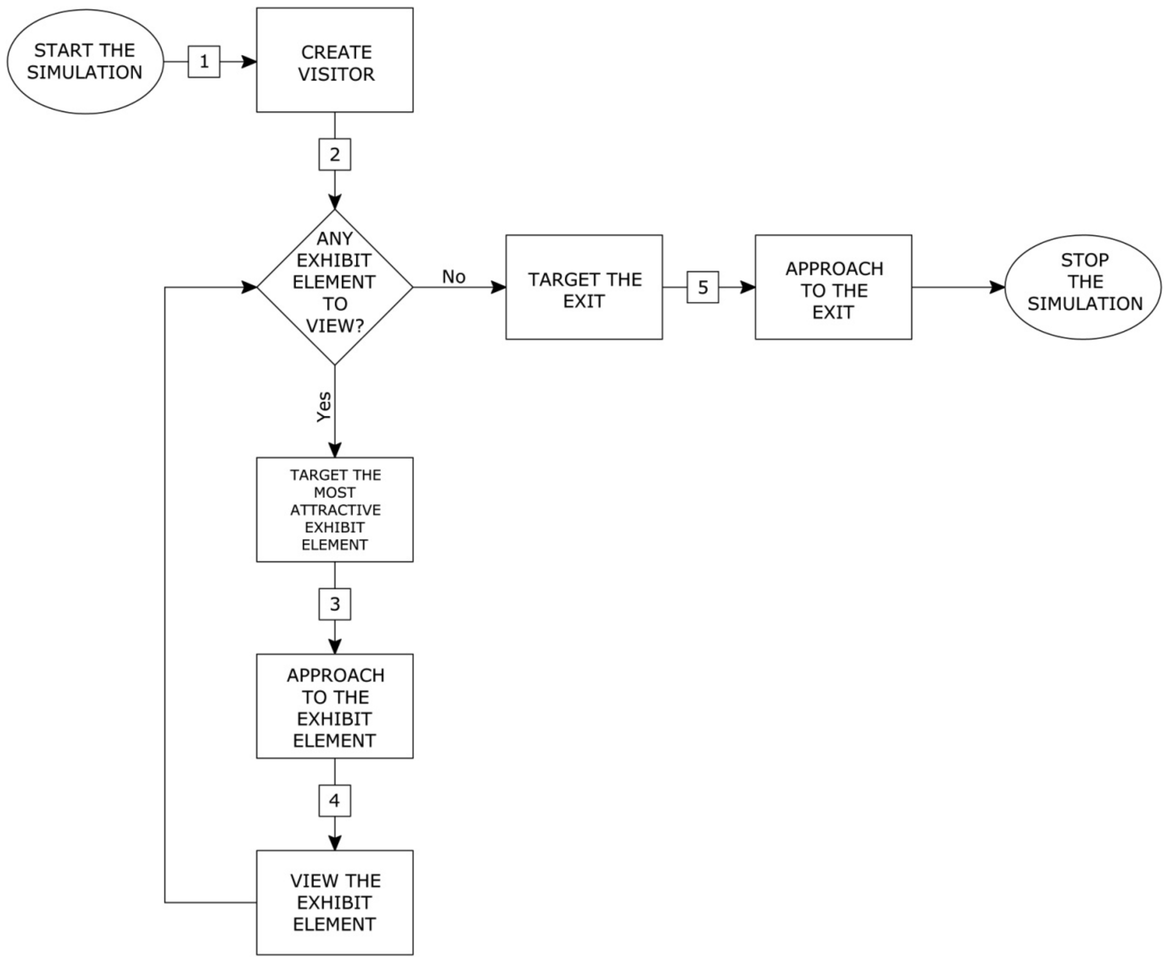
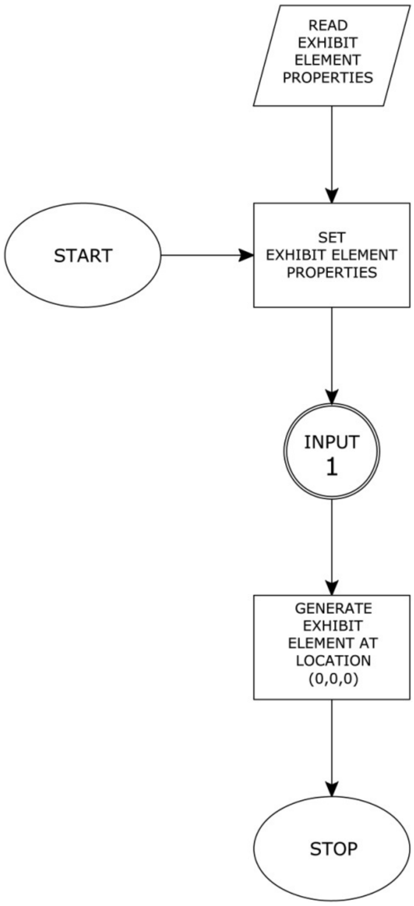
APPENDIX A

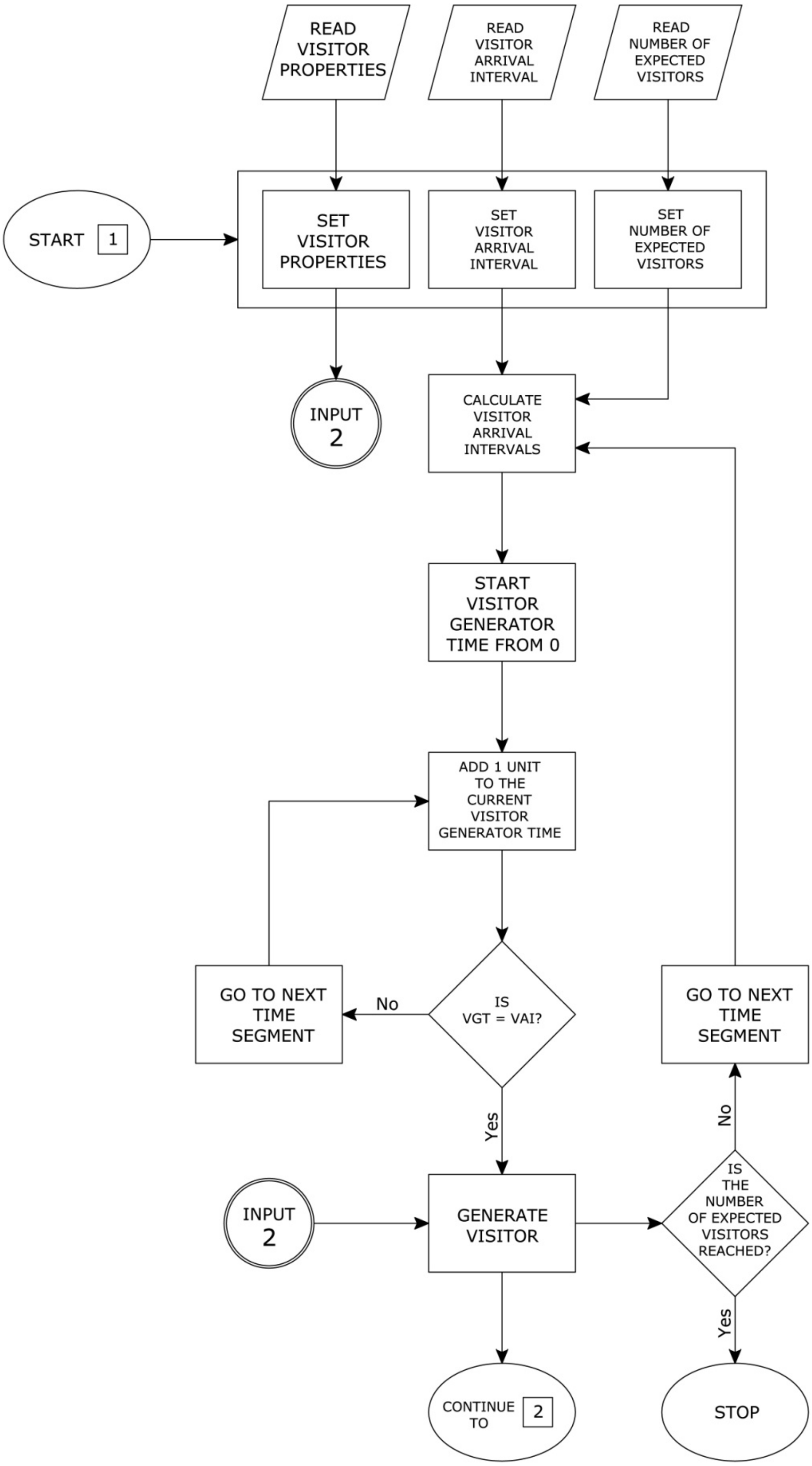
APPENDIX A.1. High Level Flowchart of the Visitor Circulation Simulation



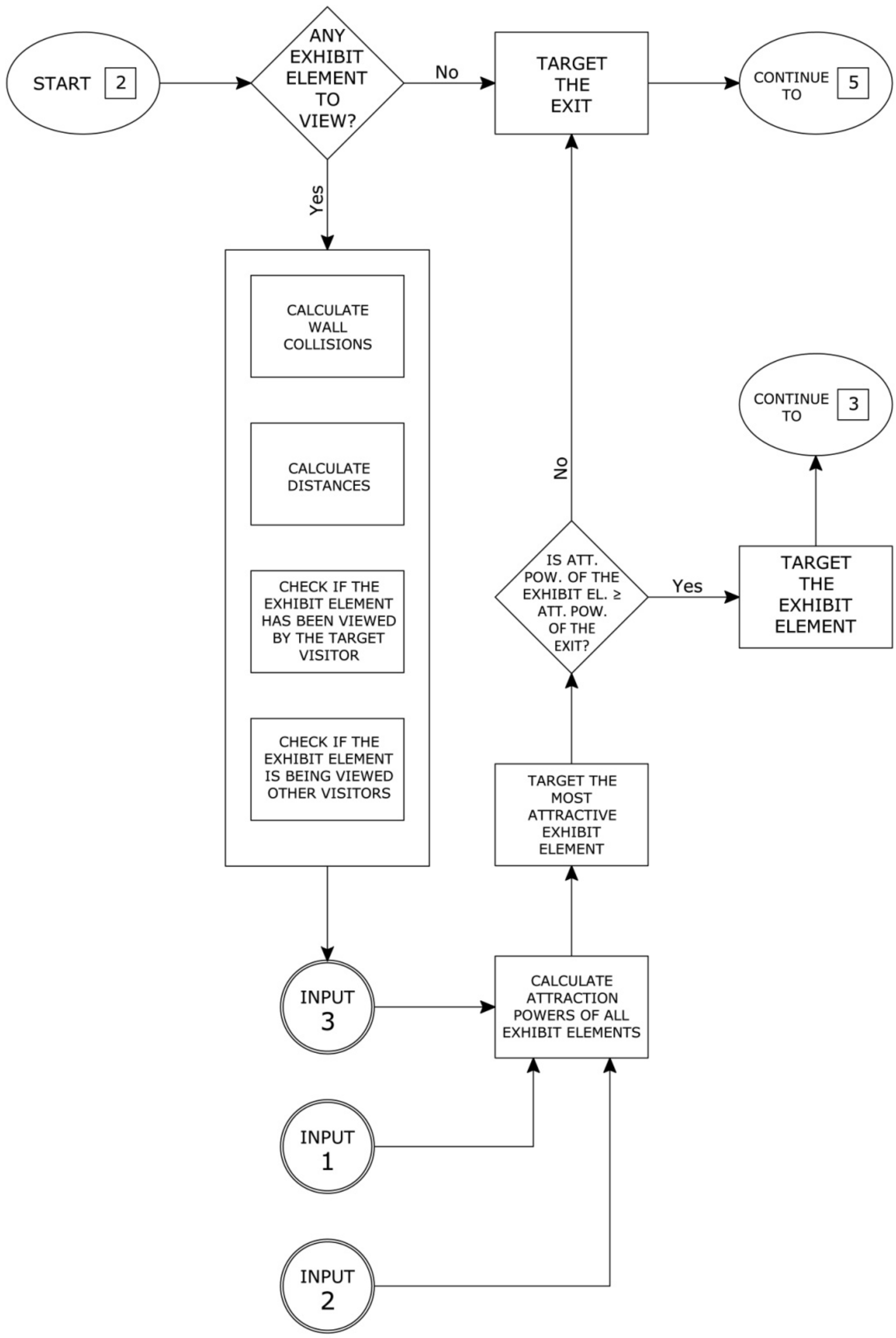
APPENDIX A.2. Exhibit Element Creation Flowchart



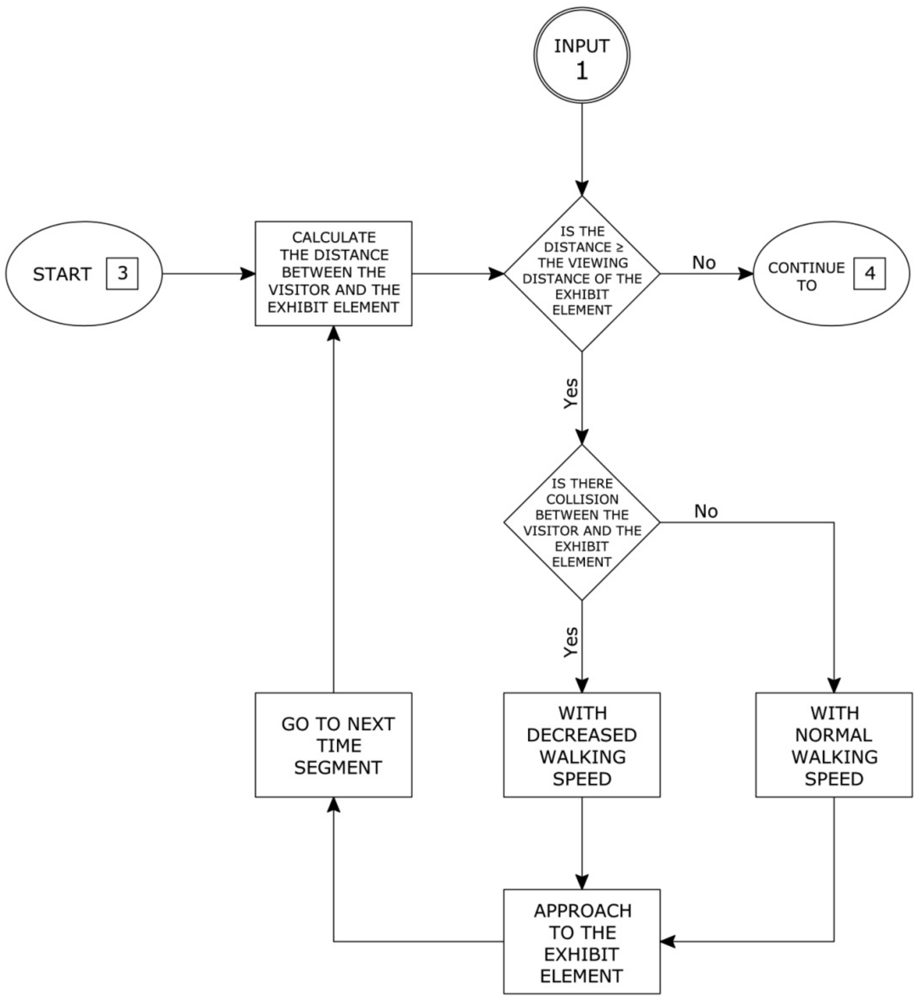
APPENDIX A.3. Visitor Generation Flowchart



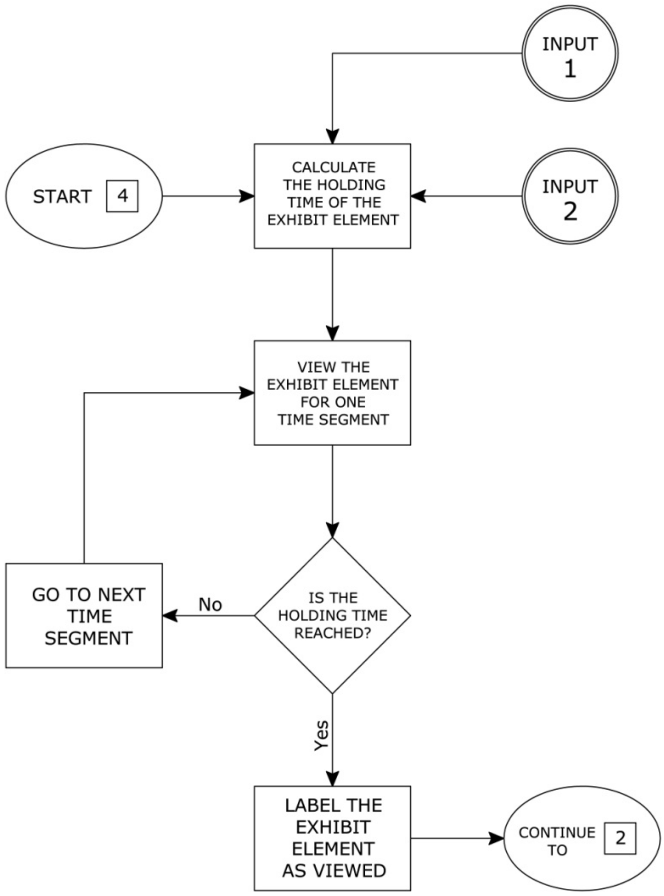
APPENDIX A.4. Visual Contact Flowchart



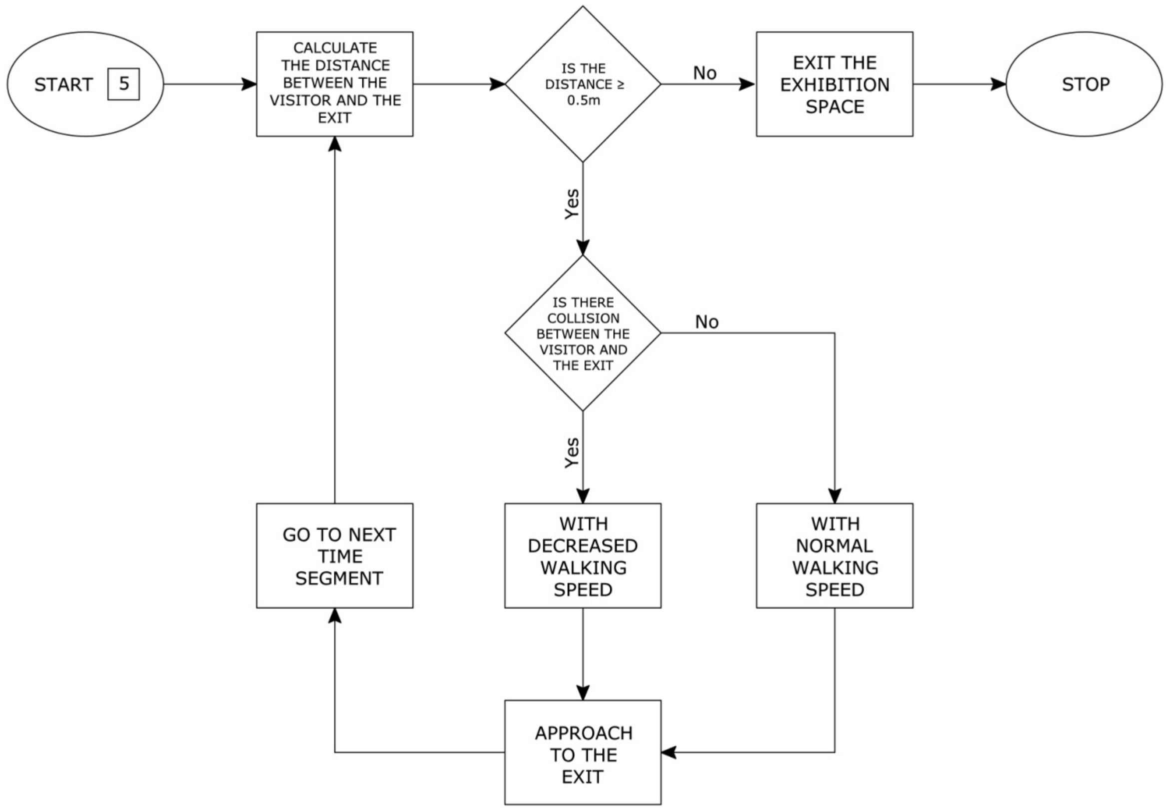
APPENDIX A.5. Visitor Movement Flowchart



APPENDIX A.6. Active Engagement Flowchart



APPENDIX A.7. Exiting Movement Flowchart



APPENDIX B

APPENDIX B. PSEUDO CODES FOR THE SIMULATION APPLICATION

-- pseudo codes for the object creation and generation processes

-- pseudo code for the exhibit element creation process

Read the following parameters from the user input
  D_e = dimensions of the exhibit element
  VD_e = viewing distance of the exhibit element
  AI_e = attraction index of the exhibit element
  HP_e = holding power of the exhibit element

Generate exhibit element at [0,0,0]
Assign following properties to the generated exhibit element
  D_e = dimensions of the exhibit element
  VD_e = viewing distance of the exhibit element
  AI_e = attraction index of the exhibit element
  HP_e = holding power of the exhibit element
Stop

-- pseudo code for determining arriving visitor intervals

Create variable current visitor generator time
Create variable current visitor arrival interval
Read the following parameters from the user input
  IL_v = visitor interest level
  VP_v = visit plan
  F_v = visitor fatigue level
  RI_v = visitor arrival interval
  N_{ev} = number of expected visitors
Set current visitor generator time to “0”
For every time segment do
 (Pick a random number between -30% and +30% of visitor arrival interval and add it to visitor arrival interval
 Set the resulting number as current visitor arrival interval)
 If passed current visitor generator time is equal to current visitor arrival interval
   Then
     (Generate single visitor at the entrance
     Assign following visitor properties to the spawned visitor
       IL_v = a random number between -30% and +30% of visitor interest level
       VP_v = visit plan
       F_v = a random number between -30% and +30% of visitor fatigue level
     Reset current visitor generator time to “0”
     Go to next time segment)
   Else
     (add 1 to the value of current visitor arrival interval
     Go to next time segment)

-- pseudo codes for calculating attraction power input parameters

-- pseudo code for checking wall collisions

For each exhibit element do
  Create variable exhibit wall check
  Create ray named Xray from the center of the visitor to the center of the exhibit element
  If Xray collides with a wall between the center of the visitor and the center of the exhibit element
    Then assign the value "0" to the exhibit wall check array for the exhibit element
    Else assign the value "1" to the exhibit wall check array for the exhibit element

-- pseudo code for calculating the distance between the visitor and exhibit elements

For each exhibit element do
  Create variable exhibit distances
  Measure the distance between the visitor and the exhibit element
  If the distance between the exhibit element and the visitor is larger than "20.0 meters"
    Then assign the value "20.0" to exhibit distances variable of the exhibit element
    Else continue
  If the distance between the exhibit element and the visitor is larger than the viewing distance of the exhibit element
    Then assign the value "the in between distance as float" to the exhibit distance variable of the exhibit element
    Else continue

-- pseudo code for checking visit plan index

For each exhibit element do
  Create variable visit plan index check
  If the exhibit element is listed in the visit plan array of the visitor
    Then assign the value "1.3" to visit plan index check varible for the exhibit element
    Else assign the value "1.0" to visit plan index check varible for the exhibit element

-- pseudo code for checking if the exhibit element has been viewed by the visitor before

For each exhibit element do
  Create array exhibit viewed check
  If the exhibit element is listed in the viewed exhibits array of the visitor
    Then assign the value "0" to the exhibit viewed check array for the exhibit element
    Else assign the value "1" to the exhibit viewed check array for the exhibit element

-- pseudo code for checking if the exhibit element is being viewed by other visitors

For each exhibit element do
  Create array viewing visitor check
  If the exhibit element is being viewed by other visitor(s)
    Then assign the value "number of viewers" to the viewing visitor check array for the exhibit element
    Else assign the value "0" to the viewing visitor check array for the exhibit element

-- pseudo code for calculating and assigning the attraction power for each exhibit element

For each exhibit element do
  Create array attraction powers
  Calculate the attraction power of the exhibit element with the following formula:

$$AP_e = \frac{IL_v * AI_e * VP_{ev} * C_e * V_e}{{D_{ve}}^2 * (N_{ve}+1) * \log F_v}$$

AP_e= attraction power of the exhibit element
IL_v= interest level of the visitor
AI_e= attraction index of the exhibit element
VP_{ev}= visit plan index of the exhibit element for the visitor
C_e= wall collision check value of the exhibit element for the visitor
V_e= viewing history value of the exhibit element for the visitor
D_{ve} = distance between the exhibit element and the visitor
N_{ve}= number of current viewers of the exhibit element
F_v= fatigue level of the visitor

-- pseudo code for calculating the attraction power of the exit of the exhibition space

```
For each visitor do
  Create variable exit wall check
  Create ray named Xray from the center of the visitor to the center of the exit
  If Xray collides with a wall between the center of the visitor and the center of the exit
    Then assign the value "0" to the exit wall check variable for the visitor
    Else assign the value "1" to the exit wall check variable for the visitor

  If  the value of the exit wall check variable is equal to "1"
    Then Calculate the attraction power of the exit with the following formula:
```

$$AP_x = \frac{AI_x * C_x * \log F_v}{IL_v}$$

AI_x= attraction index of the exit
C_x= wall collision check value of the exit for the visitor
F_v= fatigue level of the visitor
IL_v= preference level of the visitor

```
    Else continue
```

-- pseudo codes for creating the walking animation of the visitor

-- pseudo code for defining the target of the visitor movement

```
For each visitor do
  Target the highest valued exhibit element in the attraction powers array
  If the array value of the exhibit element is larger than the attraction power of the exit
    Then target the exhibit element
    Else target the exit of the exhibition space
```

-- pseudo code for moving the visitor towards an exhibit element

```
If target of movement is the exhibit element
  Then calculate the distance between the exhibit element and the visitor
  If the distance between the exhibit element and the visitor is larger than the viewing distance of the exhibit element
    Then create ray named Vray from the center of the visitor to the center of the exhibit element
      If Vray collides with a visitor
        Then assign the moving speed as "0.77 meters per time segment" for the visitor
        Else assign the moving speed as "0.50 meters per time segment" for the visitor
      With animation recording move the visitor for "assigned moving speed" towards the exhibit element
        Save the position and rotation of the visitor as animation keyframe
      Add "1.0" to the fatigue level of the visitor
```

-- pseudo code for viewing the exhibit element

If the distance between the exhibit element and the visitor is smaller than the viewing distance of the exhibit element
    Then calculate holding time of the exhibit element for the visitor with the following formula

$$HT_e = \frac{IL_v * HP_e}{(N_{ve}+1) * \log F_v}$$

HT_e= holding time of the exhibit element
IL_v= interest level of the visitor
HP_e= holding power of the exhibit element
N_{ve}= number of current viewers of the exhibit element
F_v= fatigue level of the visitor

    Add the visitor's name to the viewer list of the exhibit element
    With animation recording hold the position of the visitor for one time segment
        Save the position and rotation of the visitor as animation keyframe
    Add "1" to the viewing time value of the visitor
    If the viewing time of the visitor is equal to the holding time of the exhibit element
      Then add the name of the exhibit element to the viewed exhibit elements array of the visitor
      Add "holding time value as float" to the fatigue level of the visitor

-- pseudo code for moving the visitor towards the exit of the exhibition space

If target of movement is the exit of the exhibition space
  Then calculate the distance between the exit and the visitor
    If the distance between the exit and the visitor is larger than "0.10 meters"
      Then create ray named Vray from the center of the visitor to the center of the exit
        If Vray collides with a visitor
          Then assign the moving speed as "0.77 meters per time segment" for the visitor
          Else assign the moving speed as "0.50 meters per time segment" for the visitor
        With animation recording move the visitor for "assigned moving speed" towards the exhibit element
        Save the position and rotation of the visitor as animation keyframe
        Add "1.0" to the fatigue level of the visitor
    If the distance between the exit and the visitor is smaller than "0.10 meters"
      Then save the visitor information and delete the visitor model