ISTANBUL TECHNICAL UNIVERSITY ★ GRADUATE SCHOOL OF SCIENCE ENGINEERING AND TECHNOLOGY

A CONCEPTUAL FRAMEWORK FOR PROGRAMMABLE SPACES

M.Sc. THESIS

Tuğgen KUKUL

Department of Informatics

Architectural Design Computing Programme

MAY 2014

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İSTANBUL TEKNİK ÜNİVERSİTESİ ★ FEN BİLİMLERİ ENSTİTÜSÜ

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Tuğgen KUKUL, a **M.Sc** student of ITU **Institute of / Graduate School of Science, Engineering and Technology** student ID **523101012**, successfully defended the **thesis/dissertation** entitled "A Conceptual Framework for Programmable Spaces", which she prepared after fulfilling the requirements specified in the associated legislations, before the jury whose signatures are below.

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To my Father's Father,

FOREWORD

First of all, I would like to thank my primary supervisor, Prof. Dr. Gülen Çağdaş for her great guidance and encouragement which made it possible for me to complete this research.
During my studies in Vienna University of Technology, I obtained much help and support from my co-advisor, Dipl.-Ing. Dr. Gabriel Wurzer. I wish to thank him for his contributions and willingness to spend so much of his time helping me especially in programming and further advicing me throughout the whole process of completing this research.
Thank you my family for supporting me in all ways possible and my grandparents, for words of wisdom and great memories which I always remember.

May 2014

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(Architect)

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ABBREVIATIONS

SU	: Space Utilization
BM	: Building Model
UBS	: User Behaviour Simulation
BD	: Building Data
AS	: Activity Schedule
BU	: Building User
ICT	: Information and Communication Technology
HST	: High Speed Train
ABM	: Agent Based Model
ABS	: Agent Based Simulation
App	: Application
CA	: Cellular Automata

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A CONCEPTUAL FRAMEWORK FOR PROGRAMMABLE SPACES

SUMMARY

Today's buildings are not capable of responding to changing needs over time in relation to their static spatial configurations programmed to predifened uses. On the other hand, information and communication technologies (ICT) present new challenges for our daily life where we move between physical and digital spaces via interfaces. New solutions might be found in adaptable, reconfigurable and intelligent systems and structures, by turning programmed character of building spaces into a programmable one in which all functions of spaces are provided for users and their changeable needs. Taking its departure point from programmable spaces, as a case study, this thesis focuses on railway stations where intensive flow of people produces a great potential of human interaction and multiple uses.

Stations should stay connected with their users through digital technologies, since information and communication tools are transforming our behaviour and expectations in our daily life. Today, although these technologies are commonly used in booking, way-finding, route-planning and informing people of delays (e.g. airports), the integration of digital into physical still needs to be explored towards letting buildings truly embrace bidirectional communication rather than being only informative. In fact, this could be managed by embedding information as a material into space, giving the ability to interact with its users and to adapt to their needs. Considering the dynamic nature of information, this attempt will lead physical spaces to be dynamic rather than static, active rather than passive.

Adaptation of the buildings to changeable needs is not a new issue. It has been investigated from the first machine thoughts appeared under the influence of industrial revolution to mid-20th century avant-garde movements. These projects envisioned a new kind of architecture; adaptable to users' changing needs by movable walls, units, pods and/or capsules in which spaces are not programmed but programmable. Today, this architecture is defined within various terms ranging from adaptable, kinetic, responsive, and interactive to intelligent and so on. This architecture allows users to cooperate not only in the design process and fabrication of building but also adaptation of the building to ever-changing needs and environmental conditions.

In railway stations, the user spectrum is diverse and one's activity greatly varies during one day. However, the functions of the spaces are static; even though, a dynamic reconfiguration (e.g. bookable meeting rooms, temporary sleeping rooms) would be easy to implement as digital technologies and devices have become widespread use for route-planning, booking and communication. We argue that this experience should be extended from digital to physical spaces by letting the building adapt to the users' changeable needs through a programmable space organization.

Within this thesis, we propose a test bed that is based on Agent Based Simulation (ABS), simulating such reassignments of functions and visualizing how areas can be

utilized in a truly multi-functional manner. In the development process of the model, applied processes are summarized as follows:

First, we look at functional attribution and user behaviour found in railway stations, taking the case of the recently renovated Vienna West Train Station as an example. The presented elaboration targets both spatial configuration and activity patterns occurring in physical space, as well as infrastructure in the digital domain, which can help to transform a station into an adaptable building.

In order to compare the current situation of static functions with the proposed adaptable building, we have written an Agent-Based Simulation (ABS) that visualizes how areas can be turned into programmable spaces, which are controlled by building users and owners. When simulating, the following steps are performed:

First, the schema of the building is imported as three-dimensional map, in which layers indicate programmable areas. Then, the path network connecting these areas is loaded as a graph, in which the building functions work as nodes. There are two different cases for the mentioned functions: (1.) functions which are located "in an area" (e.g. shopping, storing luggage) being seen as destinations, (2.) functions which lie on connections between two areas are "bridging functions" connected to the circulative system as waypoints (e.g. buying tickets, watching media displays).

Second, the appearance of people is sumulated at time t by creating agents in entrance nodes (e.g. from subway lines, main entrance, train platforms). Each agent has its own protocol of functions to be visited, based on either observational data or assumed future scenarios. The protocol drives the transition of people over the way network from one area to the other.

Finally, the simulated building records usage both in terms of space (i.e. cell-based occupancy) and functions (i.e. how many agents cross a functional node at a certain time). The results are visualized on the spaces, such that an analyst can then re-attribute functions according to the proposed outcomes (e.g. transformation of shopping space to a bookable meeting lounge), and thus also changing the flow of people through the system.

When being used as an application for digital devices (e.g. smart phones), the envisioned booking/info concept can allow people to interact with the physical environment in order to decide on their next activities. Also this simulation can be used as a design tool, helping stakeholders to make decisions both in the case of future buildings (i.e. during planning) as well as for refurbishments and adaptations of existing ones.

PROGRAMLANABİLİR MEKANLAR İÇİN KAVRAMSAL BİR ÇERÇEVE

ÖZET

Bugünün yapıları programı önceden belirlenmiş statik mekansal konfigurasyonları ile ilişkili olarak zamanla değişen ihtiyaçlara cevap verememektedir. Öte yandan bilgi ve iletişim teknolojileri (ICT) fiziksel ve dijital mekânlar arasında ara yüzler ile gezindiğimiz günlük hayatta yeni olanaklar sunmaktadır. Yeni çözümler, mekanların programlanmış karakterinin programlanabilen bir karaktere dönüştürüldüğü ve böylece mekanların tüm fonksiyonlarının kullanıcılar ve onların değişken ihtiyaçları için temin edildiği; adapte olabilir, rekonfigüre edilebilir, akıllı sistemler ve yapılarla sağlanabilir. Çıkış noktasını programlanabilir mekanlardan alan bu tezde vaka çalışması olarak, yoğun yaya akışının insan etkileşimi ve çoklu kullanım potansiyelini ürettiği tren istasyonları üzerinde durulmuştur.

Bilgi ve iletişim teknolojileri günlük hayatımızda davranışlarımızı ve beklentilerimizi dönüştürürken, tren istasyonları dijital teknolojiler aracılığıyla kullanıcıları ile iletişimde kalmalıdır. Bugün, bu teknolojilerin yaygın olarak rezervasyon, yol bulma, rota planlama ve gecikmeler hakkında insanları bilgilendirmekte (havaalanı örneği) kullanılmasına rağmen binaların sadece bilgilendirici olmaktan ziyade gerçekten kullanıcıları ile çift yönlü etkileşimin benimsendiği yapılar olması için dijitalin fiziksel olan ile entegrasyonu halen araştırılmalıdır. Aslında bu durum bilginin malzeme gibi mekana embed edildiği ve böylece kullanıcıları ile etkileşimli ve onların ihtiyaçlarına adapte olabilen yapılar ile sağlanabilir. Bilginin dinamik yapısı göz önüne alındığında, bu girişim fiziksel mekanların statik yerine dinamik, pasif yerine aktif olmasına yol açacaktır.

Binaların değişken ihtiyaçlara adaptasyonu yeni bir konu değil. Sanayi devriminin etkisiyle ortaya çıkan ilk makine düşünceler ve 20. yüzyılın ortalarında ortaya çıkan avargard hareketler ile incelenmiş ve uygulanmıştır. Bu projeler hareketli duvarlar, paneller ve/veya kapsüller ile kullanıcıların değişken ihtiyaçlarına göre uyarlanabilen yeni bir mimarlık öngörüyordu. Bugün, bu mimarlık adapte olabilir, kinetik, yanıt verebilen, etkileşimli, zeki vb. terimlerle tanımlanmıştır ve bütün bu konseptler sadece tasarım sürecinde veya yapının üretiminde değil aynı zamanda binanın sürekli değişen ihtiyaçlara ve çevresel koşullara adaptasyonunda kullanıcıya çeşitli olanaklar sağlar.

Bu tezde “programlanabilir” terimi ile algılayabilen, iletişim kurabilen ve tepki verebilen sistemler ile kendi çevresindeki değişime ve kullanıcıların ihtiyaçlarındaki değişime adapte olabilen bir yapıya işaret edilmiştir. Programı kullanıcıların geçici ihtiyaçlarına göre belirlenir, doğaçlamadır, kullanıcı faaliyetlerini destekleyen mekânların oluşturulması ve değerlendirilmesinde kullanıcıların aktif olmasını sağlar.

Bugün, tren istasyonları milyonlarca yolcuyu hedefledikleri varış noktalarına dağıtan aktarma merkezleri görevi görürler. Aynı zamanda, alışveriş, dinlenme, yeme-içme, eğlence vb. işlevler için çok amaçlı mekanlar olarak kullanılan toplayıcı mekanlardır. Bu çoklu karakteri tren istasyonlarını, sosyal, ekonomik ve çevresel paradigmaların yanı sıra yeni teknolojilerin getirdiği dinamiklere cevap vermesi beklenen karmaşık

mekansal formasyonlara dönüştürür. Yapılı çevre bu dinamiklere uyum için yetersiz olduğundan yeni ulaşım yöntemleri (hızlı tren örneği) ve ek kullanımlar için talepler, mevcut istasyon yapılarının yenilenmesi ve/veya yeni yapıların inşa edilmesi ve böylece yapılaşmış alanların artmasına neden olur. Yapılaşmış alanı arttırmak yerine, mevcut mekanın kullanımını geliştirmek daha faydalı olurdu. Aslında, bu durum üç faktör asındaki güçlü ilişkiyi görmeyi gerektirir: kullanıcı, zaman ve işlev.

Tren istasyonlarında kullanıcı spektrumu çeşitlidir ve bir kişinin aktivitesi bir gün boyunca değişiklik gösterir. Ancak, dijital teknolojiler ve cihazların rota planlama, rezervasyon ve iletişim için yaygın olarak kullanıldığı günümüzde her ne kadar dinamik mekansal konfigürasyonlar (örneğin geçici uyku odaları, kiralanabilir toplantı odaları) kolayca uygulanabilir olsada mekanların işlevleri önceden programlanmış ve statiktir. Bu tezde kullanıcıların değişen ihtiyaçlarına cevap verebilen programlanabilir bir mekan organizasyonu ile dijital ortamdaki deneyimin fiziksel ortama aktarılması gerektiği savunulmuştur.

Bu tez kapsamında, kullanıcı ihtiyaçlarına bağlı olarak mekanların farklı kullanımlarla dönüştürülmesini simüle eden ve bu alanların gerçekten çok fonksiyonlu bir şekilde nasıl kullanılacağını görselleştiren etmen tabanlı simülasyona dayalı bir test yatağı önerilmiştir. Önerilen modelde bina mekanları fiziksel ve dijitalden elde edilen veriye göre yeniden programlanabilir düğümlerden oluşan bir ağ örgüsü olarak temsil edilmiştir. Etmenlerin varacakları yerleri kendi ihtiyaçlarına göre seçtiği bir yaya akış simülasyonu Netlogo platformu (açık kaynak) kullanılarak uygulanmıştır. Modelin ilk gelişim aşamasında uygulanan süreçler aşağıda özetlenmiştir:

Yakın zamanda yenilenmiş Viyana Batı Tren İstasyonu binasını vaka çalışması olarak alarak, tren istasyonlarında bulunan fonksiyonel kullanımlara ve kullanıcı davranışlarına bakıldı. Bu değerlendirmede tren istasyonunu adapte olabilir bir yapıya dönüştürmek için mekansal konfigürasyon ve fiziksel mekanda meydana gelen aktivite paternleri ile birlikte dijital domaindeki altyapıyı incelemek hedeflendi.

Önerilen adapte olabilir bina modeli ile binanın mevcut statik fonksiyonlarının karşılaştırılması için, bina alanlarının kullanıcı ve sahipleri tarafından kontrol edilebildiği programlanabilir mekanlara nasıl dönüşecebileceğini görselleştiren etmen tabanlı bir simülasyon modeli oluşturuldu. Simülasyon sırasında aşağıdaki adımlar izlenmiştir:

İlk olarak bina şeması, katmanların programlanabilir alanları gösterdiği üç boyutlu bir harita olarak simülasyona yüklenmiştir. Daha sonra bu programlanabilir alanları birbirine bağlayan bir yol ağı, binanın fonksiyonlarınının düğümler olarak çalıştığı bir diyagram olarak simülasyona yüklenmiştir. Bahsedilen fonksiyonlar için iki farklı durum belirlenmiştir. İlk durum bir mekanda var olan ve varış yerleri olarak tanımlanan fonksiyonlardır (alışveriş, bagaj depolama). İkinci durum ise iki mekan arasında yer alan, sirkülasyon sistemine ara bağlayıcı noktalar olarak bağlanan fonksiyonlardır (bilet satın alma, medya ekranlarını izleme).

İnsanların görünümü etmenlerin girişler ve düğüm noktalarında yaratılması ile (metro hatları, ana girişler, tren platformları) t zamanda simüle edilmiştir. Her etmenin ziyaret edeceği fonksiyonlar için gözlemler sonucunda elde edilen veriye ya da gelecek senaryolarına dayalı kendi protokolü vardır. Bu protokol insanların yol ağı üzerinden bir alandan diğerine geçişinde kullanılır.

Son olarak, simüle edilen yapı, hem mekansal (hücresel doluluk) hemde işlevsel (belli bir zamanda fonksiyonel bir düğümden geçen etmenlerin sayısı) bakımdan kullanımı kaydeder. Önerilen sistem gözlem yapan uzman bir kişinin sonuçlara göre mekanlara yeni fonksiyonlar atamasını (bir alışveriş mekanının rezerve edilebilir toplantı mekanına dönüşmesi) ve böylece etmenlerin akışını değiştirerek yeni sonuçlar elde etmesini mümkün kılar.

Özünde, bu model hem adapte olabilir yeni tren istasyonlarının planlanması hem de eski tren istasyonlarının kullanıcı ihtiyaçlarına cevap verebilir dağıtıcı mekanlar olarak yenilenmesini sağlar. Geliştirilen model ile amaçlanan hedefler aşağıda özetlenmiştir:

- ICT ara yüzü üzerinden kullanıcı katılımını sağlamak ve insanları rezerve edilebilir mekanlar hakkında bilgilendirmek.
- Kullanıcıların bir sonraki aktivitelerini seçmeleri için mevcut kullanımlar ve servisler hakkında insanları bilgilendirmek (ne zaman, nerede ve ne kadar kapasitede hangi kullanımlar sunulmuş).
- Uzman kişinin mekanların mevcut fonksiyonel kullanımını gözlemlemesini sağlamak (hangi mekanlar az kullanılmış ya da kullanılmamış, hangi mekanlar daha çok kullanılmış, hangi mekanlar talep edilmiş ancak mevcut değil, hangi mekanlar eş zamanlı ve art arda kullanılmış).
- Mekanların mevcut kullanım durumunu gözlemleyen uzman kişinin bu kullanımların erişilebilirliğini arttırmak ve mekanların daha verimli kullanılmasını sağlamak için bina verilerini güncellemesini sağlamak (mekan kullanımlarının yerlerini değiştirmek, az ya da hiç kullanılmamış bir mekan fonksiyonu yerine talep edilmiş ancak mevcut olmayan bir işlevi atamak).

Önerilen simülasyon ve test yatağı planlama çalışmaları için tasarlanmıştır ama aynı zamanda insanları bina girişlerinde izleme, hedeflerinin istatiksel dağılımına göre simülasyonlar yapma ve yapı alanlarında olası trafik tahminleri yürütme gibi gerçek zamanlı değerlendirmeler için kullanılabilir. Sonuçların ayrıca bina kullanıcılarına gösterildiği akıllı telefon aplikasyonları ve ya medya ekranları gibi donanımlar zaten mevcuttur. Öngörülen rezervasyon ve bilgilendirme konsepti, insanların bir sonraki faaliyetleri hakkında karar vermesi için fiziksel çevre ile etkileşimlerini mümkün kılar. Ayrıca önerilen simulasyon bir tasarım aracı olarak kullanılabilir ve böylece ilgili kişilerin ve tasarımcıların hem gelecekteki yapıların tasarımında hemde mevcut yapıların adaptasyonu ve yenilenmesinde kararlar almasında yardımcı olur. Rezervasyon ve bilgilendirme konsepti binanın kullanılmayan ve ya az kullanılan mekanlarının talep edilen mekanlara dönüştürülmesini sağlayarak mekan kullanımını iyileştirir.

1. INTRODUCTION

Information and communication technologies (ICT) have major impacts on our daily life and cause great variations in how we use spaces and how we move between spaces. On the other hand, built environments with envisioned and finished configurations are inadequate to adapt to these changes. New solutions might be found in adaptable, reconfigurable and intelligent systems and structures, by turning concrete and programmed character of building spaces into a programmable one in which all functions of spaces are provided for users and their changeable needs. Taking its departure point from programmable spaces, as a case study, this thesis focuses on railway stations where intensive flow of people produces a great potential of human interaction and multiple uses.

Today, railway stations act as hub spaces, distributing millions of passengers to their respective destinations. They also act as gathering spaces, being used as multi-functional spaces for shopping, dining, recreation etc. This multi-purpose character turns station buildings into complex spatial formations, challenging the dynamics of social, economic and environmental paradigms as well as new technologies. Since the built environment is inadequate to adapt to these changes, the addition of new transportation modalities (e.g. high speed trains) and the demand for additional facilities lead to an increase in built area either through refurbishment of old stations or construction of new ones. We argue that instead of increasing the built area, improving the use of space would be more beneficial. In fact, this requires seeing the strong relation between three factors: user, time and function.

In railway stations, the user spectrum is diverse and one's activity greatly varies during one day. However, the functions of the spaces are static; even though, a dynamic reconfiguration (e.g. bookable meeting rooms, temporary sleeping rooms) would be easy to implement as digital technologies and devices have become widespread use for route-planning, booking and communication. We argue that this experience should be extended from digital to physical spaces by letting the building adapt to the users' changeable needs through a programmable space organization.

Within this thesis, we propose a test bed that is based on Agent Based Simulation (ABS), simulating such reassignments of functions and visualizing how areas can be utilized in a truly multi-functional manner. In essence, this allows for both planning new railway stations that are adaptable, as well as refurbishments of old ones into responsive hub spaces, which are closely connected to the users' needs. Figure 1.1 shows our simulation approach. Our goals are summarized as follows:

- To provide the possibility for user participation over the ICT interface and to inform people about free spaces that can be booked to be utilized.
- To inform people about the current situation of existing facilities (i.e. in which time, which facilities are offered, where and in which capacity) in order to choose their next activities.
- To provide an analyst to observe the functional utilization (which facilities are less or not used, which facilities are used more, which facilities are requested but not available, which facilities are simultaneously and sequentially used).
- To provide an analyst observing the current utilizations the possibility to change the building data (i.e. changing the location of functions, re-assigning a less or not used function to the missing function) as well as activity schedules in order to increase accessibility and reduce the occupied area.

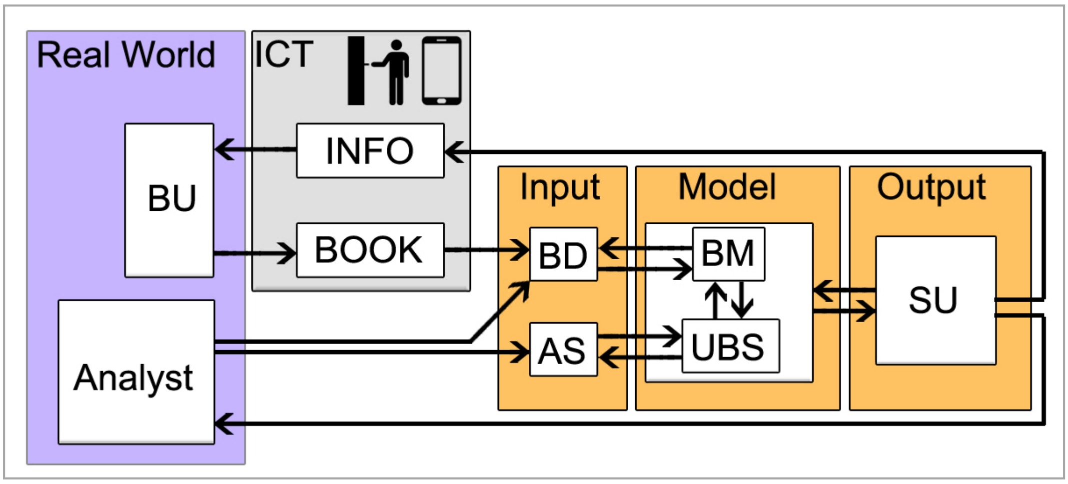


Figure 1.1 : Simulation Approach. BU: Building User, BD: Building Data, AS: Activity Schedule, BM: Building Model, UBS: User Behaviour Simulation, SU: Space Utilization.

1.1 Problem Definition

Bertolini and Spit (1998) define the railway station as a combination of two identities. It is a transportation node where many different transportation modalities (tram, bus, car, metro, train etc.) are connected. At the same time, it is a place in the city with a concentration of infrastructure featuring a diverse group of buildings and open spaces (see Figure 1.2).

As a transportation node, railway stations act as hub spaces, distributing millions of passengers to their respective destinations. This distribution produces an intensive pedestrian flow and thus, potential for human interaction which is the main factor of public transport oriented policies applied here (Bertolini 1999). Today, intermodal passenger transport is the essence of transport policies, defined as increasing accessibility for passengers by “the combination of different modes in order to enable seamless travel” (Kite Consortium 2007). On the other hand, the diverse requirements of passengers have given rise to additional facilities for both social and commercial use (Stark and Uhlmann 2009). Thus, the station buildings have also become gathering spaces with a wide range of functionalities like shopping, dining, recreation etc. This implies that there is not only an intensive flow of people but also a multiple use of space there.

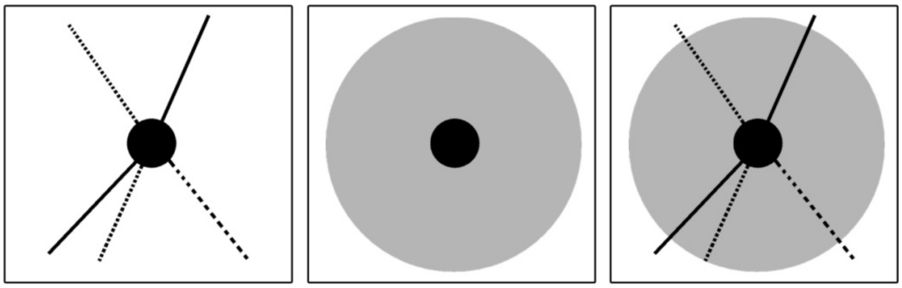


Figure 1.2 : (left) Station as a Node, (middle) Station as Place, (right) Station as Node and Place (Bertolini and Dijst, 1998).

“The development potential of railway station areas is closely connected to their features both as nodes and as places”. On the one hand, a high level of accessibility fed by transport policies may induce the demand for additional activities. On the other hand, the enhancement of activities stimulates the further development of transportation modalities. Therefore, the development process of railway stations and their environments is under the influence of both transportation and urban development issues (Bertolini and Spit 1998). In fact, the correlation between transport and land use policies can be explained as a feedback cycle (see Figure 1.3). While land use policies determine the usage of given spaces as living, working, commercial and leisure places, transportation systems support the mobility of the users by improving accessibility of these places and contributing to the attractiveness of them (Bertolini 2009). Thus, the development of the station buildings and their environment is a complex process, integrating dynamics of different factors.

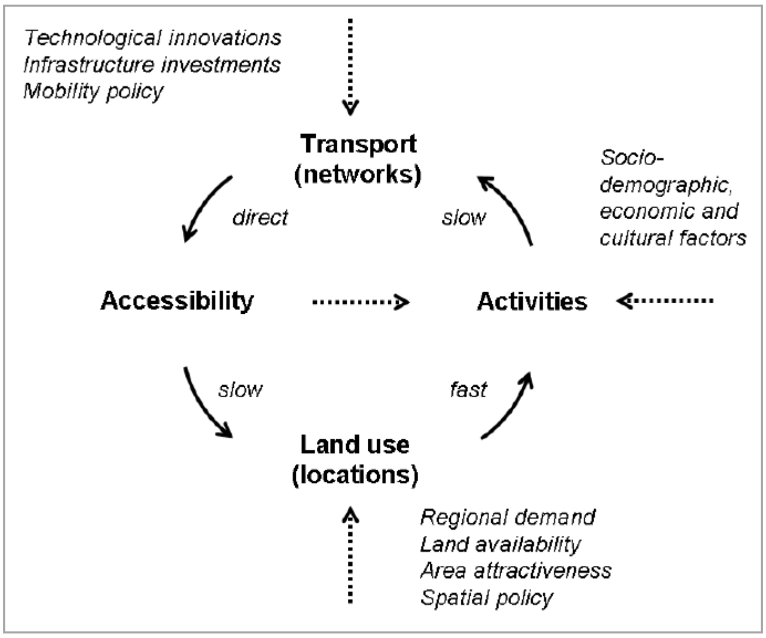


Figure 1.3 : Transport Land Use Feedback Cycle (Bertolini 2009).

Today, railway stations and their environments are redeveloping due to the dynamic nature of social, economic and environmental paradigms and new technologies. High speed trains (HST), construction of light rail connections and metro systems present new opportunities and challenges for transportation in terms of speed and capacity (Rodrigue et al., 2009). These technological innovations trigger changes not only in transportation networks but also in spatial organization of the station buildings. An increase in the number of passengers using the railway stations stimulates the demand for additional facilities for social and commercial use. On the other hand, changes in land use (i.e. location choice of activities such as shopping, business, residential) affect the space use in the station buildings and vice versa (i.e. construction of a shopping centre near to the station building affects the use of shopping facilities both in the station building and the new shopping centre). Even though a coordinated transport and land use is managed, the demand for investments of public and private sectors create potentials for growth and expansion to increase commercial facilities in these areas (see Figure 1.4).

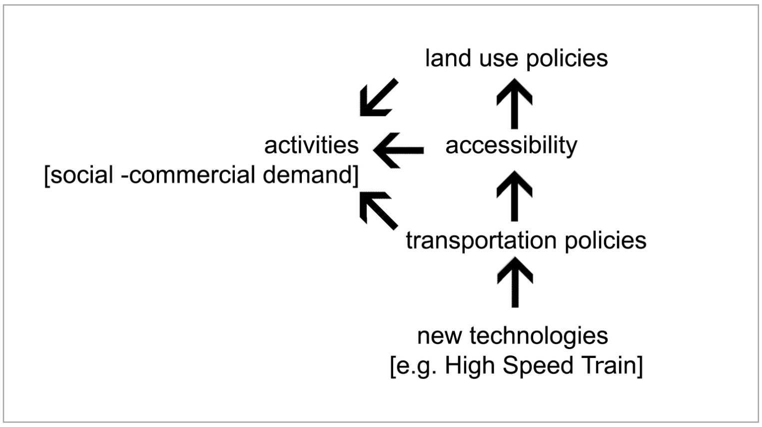


Figure 1.4 : Development Potential of Railway Stations (based on Bertolini).

Railway stations are challenging the management of these dynamics in a limited area surrounded by urban fabric. Addition of new facilities and modes of transport lead to both increase in built area and adaptation of railway infrastructure through long refurbishment and construction processes (see Figure 1.5, 1.6).

Today, railway stations are inadequate to adapt to these changes with their static spatial configurations. On the other hand, they should be flexible for adaptation since the requirements change over time. Flexibility is defined within both functional arrangement of the building and the railway infrastructure. The flexibility of the railway infrastructure is a technical aspect, defined as "... being able to lengthen or widen platforms and move tracks and switches after the railway infrastructure has been built over". The flexible functional arrangement deals with the spaces that can be used for different functions in the course of time (Wilde 2006). In fact, it requires improving space use for sustainable developments.

Figure 1.5 : Wien Mitte Station Refurbishment Process (Url-1).

Figure 1.6 : Vienna West Train Station Refurbishment Process (Url-2).

Multiple and intensive use of space is defined as spatial planning concepts for improving utilization of spaces. Multiple use of space is the matter of combining different functions in a certain space as intensive use of space is the matter of increasing occupation rates (Wilde 2006). For a longer useful lifespan, “intensive use in time” (extended use in time) and “multiple use in time” (adaptability to other functions) are essential indicating the fourth dimension of the space. A practical example for intensive use in time can be extending the opening hours of a shopping area with cultural functions. For multiple uses in time, adapting the use of spaces to other functions is beneficial for a repetitive and cyclic use of spaces (a cinema that can be used as conference space during one day) (Wilde and Dobbelsteen 2004, Wilde 2006). Therefore, improving the use of space requires seeing strong relations between three variables: user, function and time.

1.2 Research Objectives and Questions

The main objective of this research project is to develop a system that can be implemented for analysing and evaluating space utilization in railway stations through three variables: user, function and time. In order to realize this objective, this research focuses on the following research questions:

- Today, railway stations are already multi-functional, being both used as transportation nodes and spaces for shopping, dining, recreation etc.
    - What are the functional attributions found in railway stations?
- In railway stations, user spectrum is diverse and one’s activity greatly varies in the course of time. For a person travelling to work, the station building can be seen as an intermediate waypoint (travelling through a transition space). In this case, the station needs to have quick functions like buying tickets, coffee and newspapers, getting information about departures, etc. On the way back from work, the station is transformed into a space for activities like shopping, dining

and meeting friends. Such a leisure activity can be more unpredictable, being possibly also connected to functions like accommodation, renting a car or sightseeing. Intermediate functions like storing luggage or waiting can furthermore always apply.

  - In which time, which types of activities do users perform and in which order?

- Related to the previous two questions, it is aimed to correlate the functional attributions of spaces and users' activities for evaluating the actual utilization of spaces.

  - How is the utilization of functions according to the users' time-based activities?

- Since it is aimed to improve the use of spaces, the final question is:

  - How can spaces be utilized in a truly multi-functional manner for efficient and effective space use?

1.3 Research Approach

In order to simulate the space utilization, this research first focuses on the functional groups found in railway stations, taking Vienna West Train Station as an example. The elaboration targets both, spatial configuration and activity patterns occurring in physical space (shopping areas, service areas, circulation, exists, office and hotel facilities) as well as infrastructure in the digital domain (e.g. vending machines, info points, cell phones, tablets). The process is summarized as follows:

- All functional groups found in Vienna West Train Station are refined into functions of approximately equal granularity (see section 4.1.1.).
- By observing the space use during 24 hours a day, the sequentially and simultaneously used functions are analysed (see section 4.1.2.).

From this analyse, it is obvious that there are many cases in which functions are not used during the day, which in turn makes re-assignments of functions and booking by users possible. There is a variety of technical infrastructure that can be used for either booking or informing people of free spaces to be utilized: info points, vending machines or cell phone apps (see Figure 1.7).

Therefore, this thesis aims to propose a test bed that is based on Agent Based Simulation (ABS) simulating such reassignment of functions and visualizing how areas can be utilized in a truly multi-functional manner. Since the actual utilization of space depends on the station user's behaviour, which can vary greatly, to experiment with possible scenarios is the domain of the simulation. The process is summarized as follows:

- The varying needs of different users are considered with possible scenarios (see section 4.2).
- These scenarios are turned into individual queries and activity schedules (see section 4.2.1).
- These activities are correlated with the offered facilities at the building domain (see section 4.1.3).
- The achievement of users' goals is evaluated. While doing this, two main tasks are determined: the accessibility of functions (location of activity) and availability of functions (type of the activity, start-end time and duration of the activity) (see section 4.2.2).

Figure 1.7 : (left) Vending machine and info panel (right) Building users in Westbahnhof Train Station.

1.4 Thesis Contributions

The main contribution of this research project is the development of a test bed which can be used for analysing the space utilization in station buildings and improving the use of spaces by means of user participation. Up to now, (to the best of our knowledge) there is no simulation tool implemented for simulating space utilization in transfer stations; even though these environments are frequently refurbished due to the increase in facilities requested by travellers, customers and commercial groups of interest as well as due to the implementation of new technologies (e.g. high speed trains).

Our simulation can be used as a design tool, which helps stakeholders and designers to make decisions both in the case of future buildings (i.e. during planning) as well as for refurbishments and adaptations of existing ones. Records of the simulation provide an analyst to evaluate the current functional utilization of spaces and thus, [s]he can make decisions towards re-assignments of less or not used functions to the ones requested more often. Also [s]he can evaluate the functional arrangements so functions can be positioned adjacently in order to increase accessibility and reduce the occupied area. Furthermore, when being used as an application for digital devices (e.g. smart phones, info screens), the proposed test bed can be used for informing people about "which facilities are available and where" as well as informing about free spaces that can be booked to be utilized.

1.5 Thesis Outline

The rest of this thesis is organized in three chapters. The first chapter is the motivation, in which state of the art architectural concepts are introduced and discussed. The second chapter presents an overview of the literature about both, user behaviour simulation and building simulation. It first gives a description of the state of the art pedestrian flow theory. Second it introduces the current approaches for simulating pedestrians' decision making processes. Third, it gives an overview about existing pedestrian walking behaviour models. Finally, building simulation models and models implemented for simulating space utilization are introduced and discussed. The last chapter presents our methods used for simulating space utilization. First, the methods for preparing the building data for simulation are introduced, namely functional decomposition, functional utilization and activity mapping. Second section describes our methods for user behaviour simulation. The last section presents the implementation of our model.

2. MOTIVATION

> As the world keeps turning we will need to redefine the foundations of architecture from time to time. Now more than 20 years have passed since the introduction of the PC, since the emergence of the global Internet, and since embedding miniaturized information technology in our consumer products. Today we have become familiar with remote control, wireless Internet, with intelligent agents active on the internet, with intelligent agents embedded in consumer products like printers, cars and computers, but we have not seen much change in the very building blocks of the built environment as of yet. Neither have we seen much change in the way we design and build our environment. (Oosterhuis, 2012)

Information age, digital and media technologies, remote communications have led the transformation of a new paradigm of architecture which in further extended its scope into an interactive and dynamic character to cope with the new material: information. This new architecture is defined within various terms ranging from adaptable, kinetic, responsive, and intelligent to interactive and so on. “Whether buildings in this context are described as flexible, interactive or dynamic, they embrace the notion of architecture being adaptive rather than being a static artifact, often with an emphasis on computer supported adaptation” (Schnädelbach, 2010). This architecture allows users to cooperate not only in the design process and fabrication but also adaptation of the buildings to ever-change.

2.1 Industrial Age / Machine Age

Adaptation of the buildings to changeable needs is not a new issue. It has been investigated from the first machine thoughts (Le Corbusier’s Villa Savoy: Machine for Living in, 1929) appeared under the influence of industrial revolution to mid-20th century avant-garde movements. The most significant examples of adaptable machine thoughts can be found in Cedric Price’s works: Fun Palace (London, 1961), Potteries Thinkbelt (Staffordshire 1964), Generator (Florida, 1976), the InterAction Centre (Kentish Town, 1976); Yona Freidman’s Spatial City (New York, 1960); Constant Nieuwenhuys’ New Babylon (1954-74); and Archigram’s / Peter Cook’s Plug-in City (1964), Archigram’s Computer City (1964). These projects envisioned a new kind of architecture; adaptable to users' changing needs by movable walls, units, pods and/or capsules. Instead of a building programmed to a list of envisioned functions, they defined a new kind of space which is programmable for time-based variations.

Among these projects, Cedric Price's Fun Palace was one of the most influential projects within its dynamic form and variable program (Figure 2.1). Prefabricated elements that are assembled to a structural grid (tartan grid) by using cranes would provide enless spatial variations in order to build temporal spaces like hanging theatres. Movable walls, pivoting escalators and stairs would provide users to have control over the building where they build their own spaces according to their wishes (see Figure 2.2).

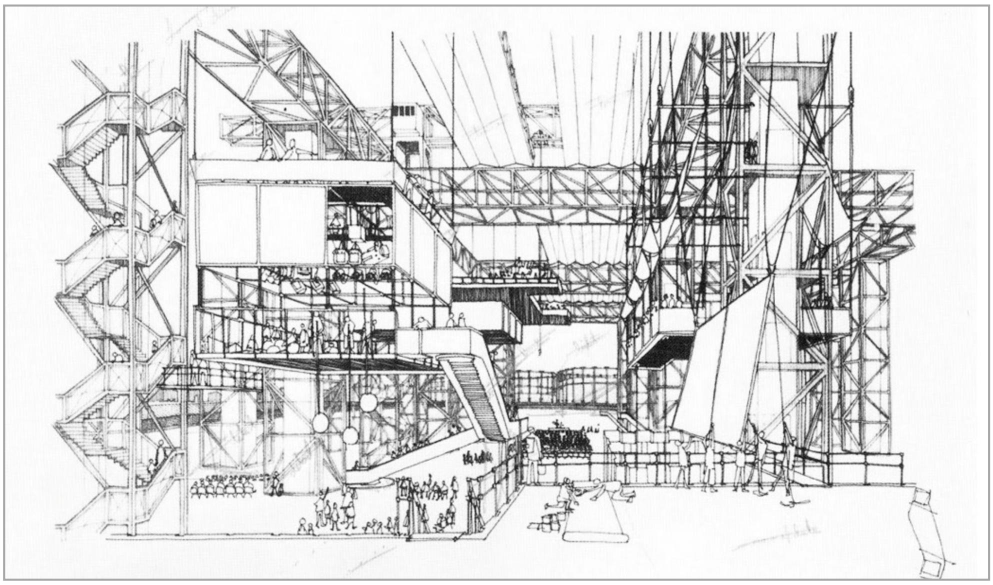


Figure 2.1 : Fun Palace for Joan Littlewood Project, 1961 (Url-3).

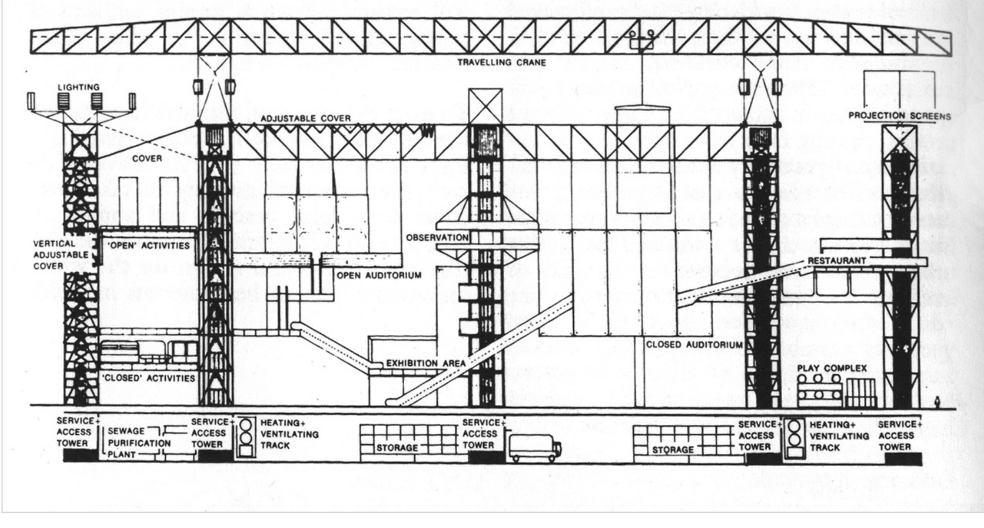


Figure 2.2 : Fun Palace for Joan Littlewood Project, Section, 1961 (Url-4).

2.2 Information Age / Digital Age

> The shift from mechanical to digital forces architects to reposition themselves: Architects generate digital information, which can be used not only in designing and fabricating building components but also in embedding behaviours into buildings. This implies that, similar to the way that industrial design and fabrication with its concepts of standardisation and serial production influenced modernist architecture, digital design and fabrication influences contemporary architecture. ... Digitally-driven architecture implies, therefore, not only digitally-designed and fabricated architecture, it also implies architecture - built form - that can be controlled, actuated, and animated by digital means. (Bier and Knight, 2010)

In this information age, digitally driven architecture offers an adaptation "through the use of kinetic mechanisms and embedded computation such as wireless networks, micro-processors and sensor-actuator electors" (Yiannoudes, 2012). In terms of dealing with these technologies (sensors and processors), different concepts of adaptation are introduced. Kamman et al. (2006) describes "adaptation" as applying motion in buildings by means of three different reasons: for visual means "for architectural reasons defined as beauty of the motion or expressing some input like weather or emotions", for controlling or influencing climate inside the building "can be done by creating openings (visual or physical) or by adjusting volumes to control the amount of light, air or water entering the building" and for improving spatial functionality "where scenarios are created to modify spatial relations-altering volumes or moving objects" (Kamman et al. 2006).

In this thesis, the term programmable refers to a building space that is adaptive to the users' time-based needs through sensing, reacting and communicating in which its program is determined by temporal needs. Instead of building spaces programmed to the static functions, programmable spaces allow users to become active participants in the creation and evaluation of spaces. Programmability of building spaces could be managed through systems and structures equipped by new technologies and materials. In fact, this idea is already investigated and implemented within several architectural concepts.

Today, buildings and their components can be in motion. They can respond to an external stimulus via computing and sensor technologies and can further interact with people through interfaces. Due to the increase in use of personal electronic devices like smart phones, individualization and adaptation of buildings to personal wishes and environmental conditions is a growing interest.

In the next sections, state of the art architectural concepts are detailed through three concepts: motion, reaction and interaction. It is important to note that this examination does not target a detail classification through the projects. Instead, it is intented to explain the possibilities and potentials offered within these concepts in order to give an overall idea about what is done and what could have been done in the creation of programmable spaces.

2.2.1 Kinetic Architecture

Being in motion, kinetic architecture is defined as "buildings or building components with variable mobility, location and/or variable geometry" (Fox, 2002). Motion is the physical adaptation providing multiple uses, flexible functional arrangements and variable spatial configurations. The main motivations can be described as spatial optimization through transformable objects; flexible spatial adaptability and multifunctional design through component-based and deployable systems and mobility (see Figure 2.3).

Figure 2.3 : M-House, Jantzen 2000 (Url-5).

M-House designed by Michel Jantzen is a movable house that is built with seven interloced cubes composed with a series of rectangular panels. Within reconfigurable and relocatable components and interchangeable panels allow people to change the parts of the house and manipulate or create their own spaces (Url-5).

Sliding house designed by dRMM can be seen as another example of kinetic architecture (see Figure 2.4). By using electric motors on wheels hidden in the walls, the outdoor skin can be moved along rails connecting three parts of the house: static main house, guest annexe and greenhouse. The mobile wall-roof system is used to create variable spaces according to the current needs and to enable flexible arrangements according to the season, weather and desired lighting conditions (Url-6).

Figure 2.4 : Sliding House, dRMM, 2009 (Url-6).

2.2.2 Responsive Architecture

Being responsive, the building has the ability to react/respond to the environment (light, air, sound) and human presence. This architecture uses responsive technologies: sensors, processors and actuators for measuring environmental conditions (via sensors) in order to adapt their form, shape, colour or character (via actuators). The building responds to human presence in this way but not allows user participation and/or allows users to be active in the creation of space. The main motivations are saving energy and thus making buildings more sustainable or fulfilling aesthetic needs (see Figure 2.5).

Figure 2.5 : Media-ICT Façade, Cloud 9, 2010 (Url-7).

Media-ICT Façade appearing as a mosaic of concave and convex triangles is designed for reducing carbon emmision of the building. Façade is made of inflatable ETFE (Ethylene Tetrafluor Ethylene) bubbles acting as an external mobile screen opening in winter to afford heat savings and closing in summer to control sun. Multiple tempreture sensors embedded into façades and offices, are used to collect outdoor information. Energy simulation of the building evaluates and accounts energy use in order to adjust indoor climate according to the demands of heat and cold (Url-7). Responsive architecture may not be supplied by the use of sensor technologies, the response can be occurred by mechanical means and/or by smart materials (see Figure 2.6, 2.7).

Figure 2.6 : Bloom, Dosu Studio, 2012 (Url-8).

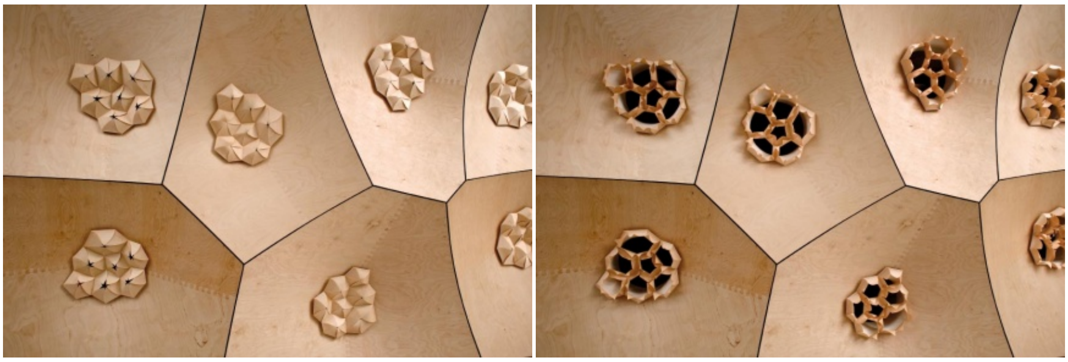


Figure 2.7 : HygroSkin, Achim Menges, 2012 (Url-9).

2.2.3 Interactive Architecture

Being interactive, the building has the ability/sense of understanding its users and responding their needs. Interaction occurs as a "conversation" between the building and its user and the building becomes responsive by not only reacting to users but also communicating with them via interfaces and then acting accordingly. Interactive architecture combines physical and virtual spaces in a new kind of space, a hybrid space in which interfaces become the main sources of buildings.

Aegis Hypo Surface developed by Decoi is an interactive wall, consists of a latent surface with pixels given ability to interact with users via haptic and gesture interfaces. Behind the facade/surface, pneumatic pistons, springs and metal plates are used to deform the surface and a computer is programmed to move each piston and its attached metal plate in order to respond to the external stimuli (sound, movement, body) by using sensor technologies and hyper-surface techniques (see Figure 2.8).

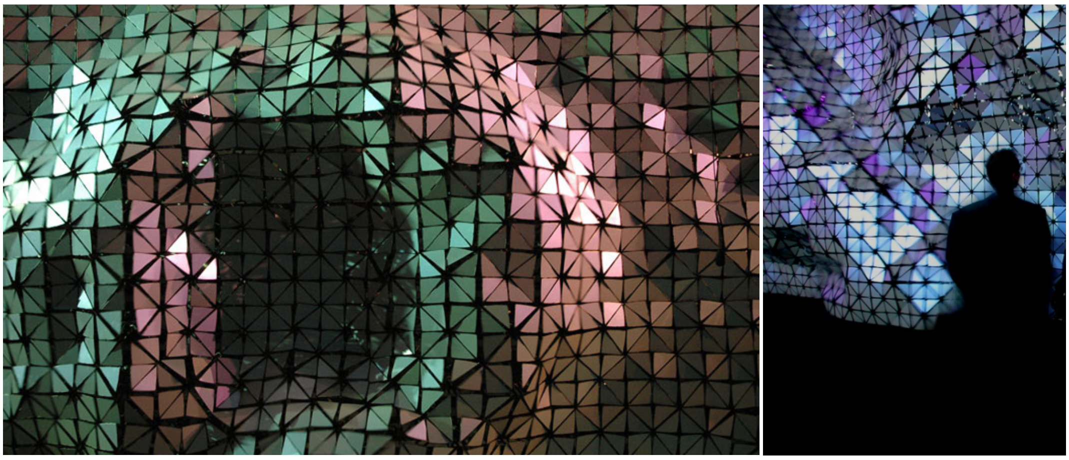


Figure 2.8 : Interactive Wall, Aegis Hypo Surface, Decoi, 1999 (Url-10).

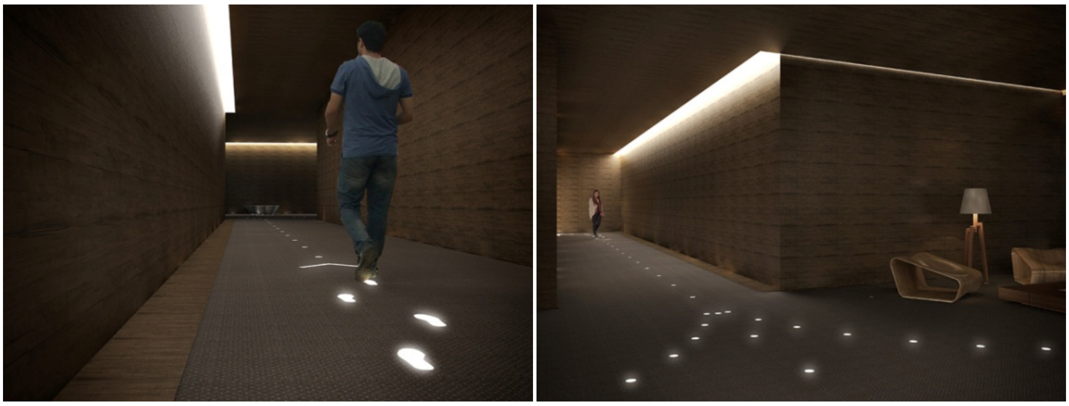


Figure 2.9 : Digital Carpet, Transstudio, 2013 (Url-11).

The Digital Carpet designed by Transstudio is an interactive floor designed for pedestrian way-finding in buildings (see Figure 2.9). Carpet is made of conductive thread, pressure-sensitive piezoelectric film, and embedded LEDs. Software algorithm is used to track pedestrian walking speed and direction. Further, it projects “potential future paths by illuminating the floor ahead and taking into account multiple routes, open doorways, and heavier circulation zones. The floor may also be linked to a visitor's personal GPS route for building interior navigation" (Url-11).

Ada is an interactive pavilion given the ability to sense and interact with its users through haptic and gesture interfaces and then generate its own real-time reactions through sound, light and projections (see Figure 2.10). A central interaction space built with a floor surface made of pressure sensors, neon tubes and a microcontroller identifies and tracks users and interacts with them through different games. Ada remembers its visitors, movements, sounds, learns from its experiences (in the level of storing an event/action to use later) and draw conclusions by linking various information as interpretations (Url-12).

Figure 2.10 : Ada, Intelligent Space, 2002 (Url-12).

The new contemporary architectural discourse is introducing a new understanding of space, reality and experience. This is mostly noticeable in digital space which still waits for further explorations. This new territory's possibilities are not fully understood or explored. Developments in computer technologies caused to come out new approaches with new frontiers in the architectural process and in discourse. The term interactivity is the main idea behind the digital age of architecture. The new contemporary architectural discourse celebrates this new term while introducing a new understanding of space, reality and experience.

New experiences that are the results of media and electronic technologies lead us to rethink about the context of the space. The idea of combining digital and physical brings out a new kind of space that will need a new way of understanding, exploring and experiencing possibilities. We are living in an information age / in a digital world which is based on communication, availability, processing, accessing, representing etc. and we are surrounded by physical and digital interfaces; (i.e. smart phones, online social networks). It is not about invention of another detached world but it is about exploring it with different tools (i.e. smart phones). These new tools of digital age change the character of our movement and usage of the space. “Next to the pace of the development of advanced electronic devices, and the growing commercialization on this field, the customization of these products plays a very important role. Individualism and the adaptation of the building on the personal wishes of the users and environment is, in relation to technological developments, a current subject of research” (Lelieveld et al., 2007).

3. THE METHODS OF SIMULATING SPACE UTILIZATION

User behaviour can be considered in two contexts: (1) pedestrian movement through a flow network and (2) pedestrian activity at a certain point at this flow network. Simulating user behaviour in railway stations requires considering entire flow networks of different pedestrians as well as their activities in order to obtain the reasons of the movements and processes behind them.

3.1 Pedestrian Flow Theory

Hoogendoorn et al. (2001) and CROW (1998) have described pedestrian behaviour at three levels: (1) strategic, (2) tactical and (3) operational.

Strategic Level

At the strategic level people decide which activities they want to perform and in which order. These activities are sorted as “discretionary” (e.g. buying a newspaper) and “mandatory” (e.g. validating a ticket before getting on a train). Dealing with this level of pedestrian behaviour modelling, activity set choice models have been developed by several researchers (Arentze and Timmermans, 2004; Penn, 2003; Timmermans et al. 1992). At this level, pedestrians do not have any idea about the infrastructural network or their route alternatives.

Tactical Level

At the tactical level pedestrians start to gather information about the network of the walking infrastructure. They make short-term decisions according to the activities determined at the strategic level. The activity list determined at the strategic level may change due to the time constraints (activity scheduling). Pedestrians decide which route to follow as an optimal decision between destinations (Daamen, 2004).These activities may be performed at different locations and optimal locations are chosen at this level (activity location choice).

Operational Level

At the operational level, people choose their walking speed and direction to avoid collisions with obstacles and other pedestrians. It describes the actual walking behaviour referring to how pedestrians adjust their direction to perform their activities defined at previous levels (Sahaleh et al., 2012).

Each level consists of different decision making processes and actions with possible interactions between each other (see Figure 3.1).

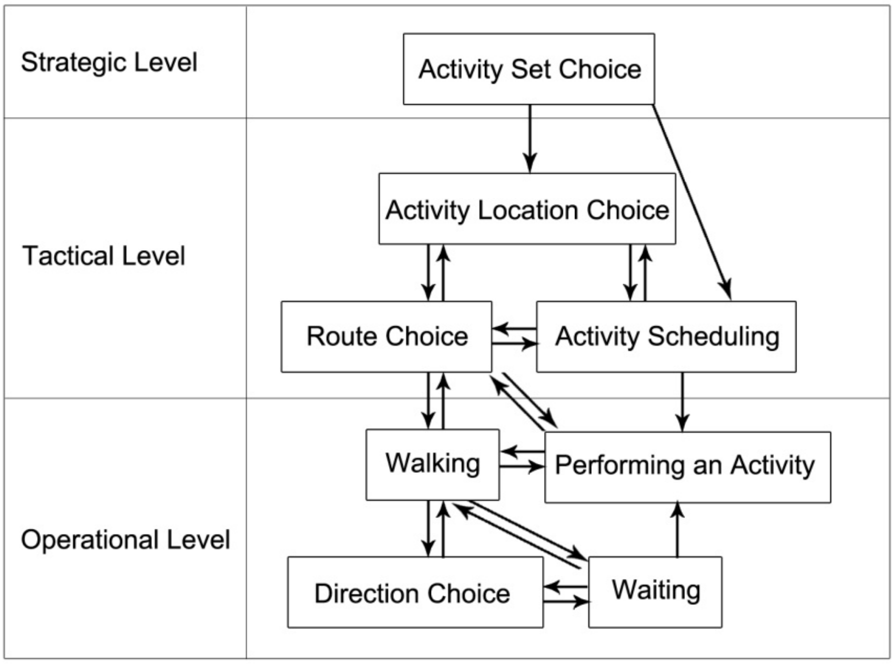


Figure 3.1 : Interactions between processes of pedestrians (Daamen, 2004).

3.2 Choice Models

Individual behaviour consists of a decision making process as a choice between alternatives such as a route to follow, a destination to visit or an activity to perform which is influenced by many facts (Borgers and Timmermans, 2005). Zhang et al. (2004) characterized these facts within the term "context dependence" corresponding to the number of alternatives and their attributes (alternative specific context), circumstantial situations (circumstantial context) and the individual situations such as their previous choices or others' choices (individual specific context). It is asserted that each individual decision is an attempt for a relative utility maximization meaning that he/she only decides on an alternative with the highest relative utility due to his/her relative interest. The authors propose a random utility choice model based on the notions of a relative utility and a relative interest. Relative utility defines an individual choice process for an alternative among others.

Many researchers use the relative utility theorem in order to simulate people's choice behaviour between destinations, activity patterns and routes to follow. Several approaches have been developed to simulate pedestrians' decision making processes at different levels.

3.2.1 Activity Scheduling

Activity scheduling is defined as a cyclic decision making process by individuals deciding which activities to perform, which location to choose and route to follow and in which time and duration to participate (Arentze and Timmermans, 2004; Penn, 2003; Timmermans et al. 1992).

Root and Recker (1981) propose a theoretical framework for analysing complex travel behaviour within the context of "activity pattern". An activity pattern is defined as a sequentially ordered activity schedule which is determined by both pre-travel and travel stages. In a pre-travel stage, individuals have a set of desired activities and expected durations for these activities to perform. Therefore, the activity program is at first determined by the highest utility expected. At the travel stage (during execution), due to the possibility that this pre-defined activity program may not occur as expected, an activity re-scheduling is required to adjust the activity program by adding or removing activities, changing the sequence of activities, changing their durations or locations for these activities (Ettema, Borgers and Timmermans 1993).

Following this theoretical framework, several models have been developed for simulating activity schedules: STARCHILD (Recker et al. 1986a-1986b), SCHEDULAR (Gärling et al. 1989), SMASH (Ettema et al. 1995), GISICAS (Kwan 1997), ALBATROSS (Arentze and Timmermans 2008). Most of these models aim to determine a rule for the sequential order of activity scheduling based on the priority context mostly defined by activity types such as mandatory and discretionary or planned and unplanned activities (Doherty 2000). Broadly, the goal of the activity scheduling is "finding the schedule with the highest possible satisfaction by maximizing the utility" (Tabak et al. 2004).

3.2.2 Activity Location Choice

The activities in the activity schedules may be performed at different locations. Optimal locations are chosen according to different parameters. These parameters are defined as (1) time limit for performing activities (Hoogendoorn and Bovy 2004), (Borgers and Timmermans 1986), (2) the distance between the current location and places, (3) attractiveness of places and (4) the pedestrians' awareness of places (Willis et al., 2001; Schelhorn et al., 1999; Dijkstra et al., 2011; Daamen, 2004).

3.2.3 Route Choice

Bovy and Stern (1990) described a route as, "a route is a chain of consecutive road segments connected by nodes. Such chains connect trip origins and destinations." The route choice is the selection of a path a pedestrian follows from an origin to a chosen destination.

Several authors have stated that preferences of travellers, their purposes and their knowledge acquired from previous experiences influence their route choices (Borgers and Timmermans 1986, Hoogendoorn and Bovy 2004, Hill 1982). In most models, it is assumed that pedestrians take the shortest path to reach/choose a location (Dijkstra et al., 2011; Borgers and Timmermans, 1986; Bovy and Stern, 1990; Smith et al., 1995). In some models, the route choice is generated randomly, assuming that pedestrians choose the path with the maximum utility (Balmer and Nagel, 2006). Hoogendoorn-Lanser et al. (2004) proposes a rule based approach, applying branch and bound techniques for route choice set generation.

Based on these approaches (activity scheduling, route choice, activity location choice), various pedestrian walking models have been developed. The next chapter provides an overview of existing pedestrian walking models.

3.3 The Models for Simulating User Behaviour

Up two now, two different scales of modelling have been applied for simulating user behaviour: microscopic or disaggregate models and macroscopic or aggregate models.

3.3.1 Macroscopic Models

In macroscopic models, crowd and group behaviour of pedestrians is taken into account instead of single pedestrian behaviour and individual situations. These models are developed to analyse human behaviour in emergency and normal situations (Stahl 1982, Ozel 1993, Brennan and Thomas 2001, Yung et al. 2001, Boer et al. 2005, Oswald et al. 2007 etc.) as well as for efficient and safe pedestrian traffic systems (Goldschmidt 1977, Griffiths et al. 1984). The main goal of these models is to investigate "a level of service concept" for pedestrians in order to find out the amount of space that people need for their activities to determine the characteristics of walkways, stairs, corridors, exists etc. (Fruin 1971, Khisty 1994). SimPed is an example of a macroscopic pedestrian simulation tool. It is developed to evaluate the means and variability of walking times and visualizes the walking patterns of pedestrians by modelling the walking behaviour of pedestrians within processes like walking, performing activities and deciding on route and activity locations (Daamen 2002).

The macroscopic models do not take individual situations of pedestrians and the activities constituting the process of the movement into account. Instead, they have been developed to get an overview of the "level of comfort" in a large area with a lot of pedestrians in relation to crowd densities, mean speed and flow.

3.3.2 Microscopic Models

Microscopic models deal with the individual situations of pedestrians within time-space contexts and interactions between them. For simulating individual pedestrian behaviour, several approaches have been developed, and each of these models has different targets and modelling methods. The goals of these models vary from modelling more realistic pedestrian flow behaviour in normal and evacuation situations to modelling pedestrians' individual decision making processes between routes and activities during their travels to the locations/spaces. To address these various goals different simulation methods are used. A classification of the existing methods is given in Figure 3.2, in relation to the level of modelling.

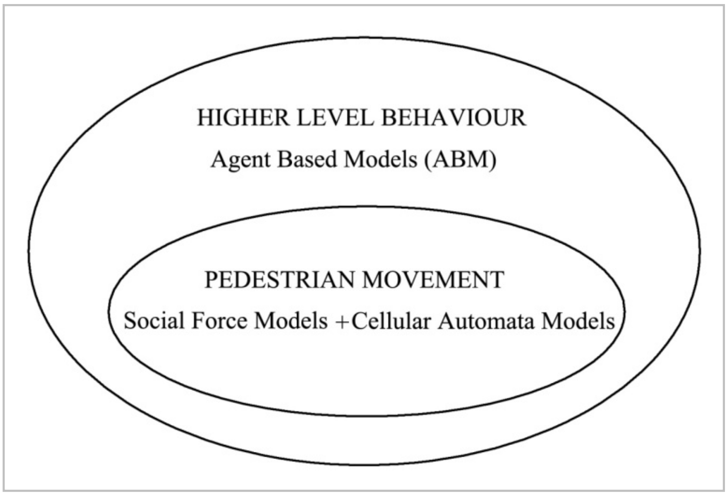


Figure 3.2 : Modelling Approaches in relation to the level of User Behaviour.

According to their scales of modelling, models for pedestrian movement simulations can be subdivided into two categories: continuous time-space models (social force models) and discrete time-space models (cellular automata models).

3.3.2.1 Social Force Models

Social force models are microscopic and continuous time-space models that deal with the external forces as "internal motivations" of pedestrians to perform their activities as "reactions". A well known model is Helbing's physics and social force model which presents a fluid dynamic model for pedestrian movements based on the similarity between the dynamics of a crowd and fluids or gases. The pedestrian movement is described as a reaction to social forces that models "intentions" of pedestrians (e.g. motivation to reach a goal, repulsive effects of walls and other people) as well as to physical forces modelling "interactions" between pedestrians described as pushing and friction situations when crowds of people reach a higher density. The model elaborates the behavioural changes by "a route choice behaviour model". The behavioural changes are sorted as stimulus sensors like perceptions of the situation and environmental and personal aims and interests leading to behavioural reactions (Helbing, 1992).

These reactions are behavioural changes based on physiological and mental processes like utility maximization, decision making and the motivation to act. The movements are based on external forces explained as acceleration towards the desired velocity of motion, the desired distance from other pedestrians and borders, and attractive (e.g. an existing shopping mall) and repulsive forces (Helbing et al. 1992, 1995). However, the model is much more a physical model than behavioural model (Sahaleh et al. 2012). Although the important features of crowd behaviour are taken into account, the dynamic decisions of people between options are not considered (Luber et al. 2010).

Daamen, Bovy and Hoogendoorn (2001) have developed a model for simulating pedestrian behaviour in transfer stations to analyse the impacts of "station design and layout" and "public transportation timetables" on pedestrian behaviour to quantify the level of service of the pedestrians. Their work takes into account the dynamics of pedestrian flows in both, a macroscopic (level of comfort of a walkway) and microscopic level (individual situations of a pedestrian). They stated that variations in spatial design, spatial form, timetable and train frequencies, type of trains and different types of passengers can cause different behaviour characteristics. In terms of dealing with the individual situations, activities besides walking which are performed by pedestrians like buying tickets, waiting, different walking paces according to the behaviour of different types of passengers and the impacts of public transportation timetables on the variables of pedestrian crowds are considered.

NOMAD is developed to simulate pedestrian behaviour. In this model, different types of pedestrians are considered within variables of walking speed and patterns due to the pedestrians' size, age, gender, trip purpose etc. Within these variables, the model calculates optimal routes and locations of facilities due to the sequence of activities in order to evaluate the walking comfort in public areas (Hoogendoorn and Bovy 2002). The model deals with the walking infrastructure rather than with the relations between activities and places for activities. Human decision making processes should be detailed by analysing the building usage according to activity choices in order to evaluate the space utilization and to obtain the reasons of the movements and processes behind them.

3.3.2.2 Cellular Automata Models

Cellular automata models have been developed to model pedestrian flows through dynamic processes (Blue and Adler 1998-2001, Burstedde et al. 2001, Dijkstra et al 2001-2002, Schadschneider 2001, Klüpfel 2003). Contrary to social force models, CA models are discrete in state, time and space. In a cellular automata model, the environment is represented as a grid of cells that is discrete in space corresponding to a defined size of cells. Pedestrians are represented as agents and each cell can be empty or occupied by one or more agents. The evaluation of the model occurs in discrete time steps and during the process each cell is reassigned into a state from a finite set of state rules (Klüpfel 2003). The movements of agents are bi-directional and comprises of three elements: side stepping (lane changing), forward movement (braking and acceleration) and conflict mitigation (deadlock avoidance). A macroscopic level of pedestrian movement (collective behaviour) such as dynamic multiple lane formations and speed-flow-density curves is derived from these microscopic paradigms (Blue and Adler 2000).

A two dimensional cellular automata model is developed to simulate the pedestrian dynamics in evacuation processes according to two different situations: evacuation of a large room (people leaving a quadratic room with one door only) and lane formation in a long corridor (two species of pedestrians moving in opposite directions). The model is used to reproduce the collective effects and self-organization phenomena encountered in pedestrian dynamics (Burstedde et al. 2001). These early models are mostly considered for simulating pedestrian movement in hazardous situations and they are focused on movement rules, lane formations, and crowd dynamics (Dijkstra el al. 2005, Blue and Adler 2000).

3.3.2.3 Agent Based Models

Agent based models (ABM) have been widely used to simulate human behaviour in built environments due to their capabilities of simulating complex human decision making processes and emergent behaviour from the interactions of individuals (Schelhorn et al. 1999, Kerridge et al. 2001, Ulicny and Thalmann 2001, Wei and Kalay 2005, Sharma and Tabak 2008, Dijkstra et al. 2011). “The entities in the model are software agents, who have the ability to perceive, make decisions, act, and learn from their environment” (Ronald et al. 2007).

Willis et al. (2001) developed a multi agent model, PEDFLOW, to simulate pedestrian flow on a side walk. The environment is represented as a grid based structure and pedestrians as agents. Agents move in this environment with five pre-determined behavioural rules: (1) static awareness (a measure of length that shows how far in front the pedestrian perceives changes in the environment), (2) preferred gap size (smallest space into which the pedestrian is willing to move), (3) desired walking speed of the pedestrian, (4) personal space measure (the amount of space that a pedestrian wishes to maintain around his/her person) and (5) choice of the direction.

TRANSIMS (Transport Analysis and Simulation System) can be seen as an agent based model that simulates the individual behaviour of travellers by means of their activities (activity schedules) and the trips for performing their activities. The model aims to analyse the impacts of transportation policies and infrastructure on these trips and activities (Smith et al. 1995).

STREETS model, developed by Schelhorn et al. (1999), simulates the movement of pedestrian population in sub-regional and urban districts. In this model, pedestrians are represented as agents with socio-economic (e.g. income, gender) and behavioural characteristics (e.g. speed, visual range, fixation). The environment is represented within vector data (building outlines with the land-use categories), raster data (walkability of non-building spaces) and network data (street network and building entrances). Agents have pre-defined activity schedules with a sequence of waypoints (a route plan). For possible distractions during the agents' movement between waypoints, different parameters are defined such as the match between agent types and building types (the possibility of being attracted to another shopping location), the attractiveness of the building, the level of fixation of the agent (the time that an agent stays at one place).

SMART Move is a network based people flow simulation model developed for design optimization of circulation spaces in the built environment. The model integrates a graph-theory based network which is based on links (paths) and nodes (origins, destinations, junctions) and a time based origin-destination matrix model which provides scenarios for people to follow (desired circulation). The individuals "compete for resources" and "target a destination favourable to them". The model simulates the pedestrian flow within multiple choices in both, normal and evacuation situations occurring in circulation areas. Other spatial activities are not taken into account (Sharma and Tabak 2008).

Although the models mentioned above simulate walking behaviour of pedestrians with a high level of environmental cognition, they only consider pedestrian's path and destination choices. Simulating pedestrian behaviour requires realizing all possible activities performed by users in built environments in order to obtain reasons of the movements and the processes behind them. The next section presents an overview of the building simulation and existing models implemented to simulate user activities in built environments.

3.4 The Models for Building Usage Simulation

Research in building simulation has mostly concentrated on performance of the buildings within physical parameters like lighting, acoustics, heating, cooling etc. In this field, the behaviour of the building is considered as adjusting the building parameters to environmental qualities through control oriented user systems such as lighting systems, heating-cooling systems, shading systems etc. (Hensen et al. 2004, Zimmermann 2006, Mahdavi et al. 2008 etc).

Recently, the presence and actions of building occupants is realized as the key factor for measuring the energy consumption, comfort (temperature and humidity ranges and light levels) through indoor and outdoor environmental conditions (Nicol, 2001; Mahdavi and Pröglhöf, 2009; Zimmermann, 2007). However, most of the existing simulation programs do not take variable users' activities and temporal situations into account in order to acquire actual utilization of spaces (Zimmermann, 2003; Robinson, 2006; Tabak, 2009; Hoes et al., 2009). The simulation of space utilization through user behaviour is crucial to improve the relevance and performance of the building simulation tools (Tabak et al., 2006).

Nevertheless, research in building usage simulation is limited to very few studies. Tabak et al. (2006) developed a model (USSU-User Simulation of Space Utilization) for the simulation of human movement and utilization of space capacity in office buildings. USSU starts with an organizational model. The user of the system should define the structure of the organization comprising of a number of roles (e.g. secretary, manager) and a number of organizational units (e.g. the sales or complaints unit). Each employee has an activity schedule detailed in time and order. In order to assign the activities, primary (skeleton) and secondary (intermediate) activities are determined. Skeleton activities are the main activities in the workflow model and first the user of the system has to input the data about each role in the organization as a set of tasks for a specific work day. For intermediate activities a limited set of activities is determined.

Within a building model, the floor plan of the building is represented as a network of abstract spaces. The facilities found in the working environment (e.g. workplaces, printers, PCs etc.) are represented as nodes and an abstract space comprise of a collection of these nodes. The size of the collection results in the capacity of the space. Each activity has one or more location probabilities. The choice of the location for one activity is determined with a shortest path algorithm. The major shortcoming of this model is its time and resource intensive process as the model is based on a large number of input parameters.

Dijkstra et al. (2011) have developed a model, AMANDA (a multi-agent system for network decision analysis) implemented to predict the actual pedestrian movements in shopping areas through activity scheduling and route-destination choice mechanisms. The environment is represented as a cell-based network of streets and stores and each cell has a node where an agent is located. Each pedestrian has a scenario comprising of a set of activities (i.e. a shopping list to be completed) and moves to other nodes to complete the activities from its agenda. The movement of agents is identified within three behavioural stages: perception, activation and completing an activity. Before performing the activities, agents make decisions such as which store or establishment to choose, in which order and which route to follow for conducting their activities.

It is asserted that agents have motivational states like being goal-oriented, implying that agents already know which store to visit or vice versa and perceptual fields which are variable due to their motivations and characters (e.g. age, eye-sight etc.) and the degree of noticing the facilities in the physical environment (e.g. signalling intensity of the store based on distance, visibility, attractiveness and awareness threshold of the agent). When a store included in agent's perceptual field, it has to decide to act (visit the store) or not. If the agent decides to visit the store, then the agent acts to perform the activity from the agenda and completes the activity which will later be removed from the agenda. The main drawback of this model is the limited source of activities (e.g. shopping, having lunch). The other possible activities (e.g. sitting on a bank, meeting with a friend, going to the toilet) are not taken into account.

The most of the existing models for simulating space utilization in built environments are planned to be used for offices, residential and shopping buildings. Up to now, (to the best of our knowledge) there is no simulation tool implemented for simulating space utilization in transfer stations. Although many attempts have been made for simulating pedestrian flows, these models only deal with the walking behaviour of building users on train platforms and walkways within a limited consideration of facilities found in the station buildings.

A simulation tool, implemented for evaluating space utilization in transfer stations is an increasing need to use existing buildings more efficiently rather than increasing the built area. This model should also allow modifications in both represented built environment and represented human behaviour. "Every building design is based on assumptions about how the building will be used, but from its opening day, a building will be used differently than its designers assumed or planned. Over time the intended use will change too. The building designed as a warehouse suddenly has a dropped ceiling and an air-conditioning system and is now an office; two years later kitchen equipment turns it into a restaurant" (Crawley, 2008). We are all aware that buildings with envisaged and concrete functional programs are under the influence of social, economical and environmental changes. On the one hand, modifications in functional programs of buildings change the behaviour of the building users. On the other hand, the changing demands and requirements of building users trigger variations in functional utilization of spaces.

Most of the models found in literature represent the built environment as a static spatial organization. The behaviour of the building users is considered as the only dynamic, using a concrete environment in order to fulfil their tasks. The only benefit from such an approach is to measure the user satisfaction instead of improving the functional program. Wurzer et al. (2010) emphasizes the requirement of a model that allows building users to take part in the functional organization of buildings before their constructions. They propose a game-like environment in which building users (avatars) perform actions on the design. While functions of the spaces are assigned by an architect, actions represent the demand of users for performing their activities. The proposed model provides architects to test their design in terms of analysing which functions are used, in which time and for what purpose and which functions are missing. This user participative modelling approach is the domain of this thesis. In addition, the novelty of our model is the idea of providing this participation by means of digital devices.

Information and communication technologies (ICT) have major impacts on user behaviour. Up to now, only some theoretical models are developed for modelling user choice behaviour (e.g. route choice, activity scheduling and location choice) within the consideration of travel information (e.g. public transport timetables, information about a possible delay) (Parvaneh et al., 2011, Sun et al., 2009). This research project is based on user participation over the ICT interface which is used for informing people about the current situation of existing facilities (type, location, and capacity) as well as free spaces which can be booked by users to be utilized. Booking requests (done over digital devices such as smart phones, vending machines) directly influence the building data and therefore indirectly the simulation part. An analyst observing the current utilizations of spaces may additionally impact the simulation by altering the activity schedules.

4. A PROPOSAL FOR PROGRAMMABLE SPACES

This chapter presents our methods for simulating space utilization in railway stations taking the case of the recently renovated Vienna West Train Station as an example. It is organized in three sections. First section decribes the methods used for preparing building data for simulation. Second section introduces our approach for simulating user behaviour. The last section gives a detailed description of the proposed simulation model.

4.1 Preparing Building Data for Simulation

Vienna West Train Station is one of the major railway stations in Vienna, where long-distance trains and local transport modalities like subway lines (U-Bahn), suburban metro railways (S-Bahn), trams and buses come together. Apart from its dense transportation network, the station building consists of a shopping centre with different numbers of restaurants, stores and service facilities, a parking area, offices and accommodation spaces. However, station's relation with its local environment is weak, since it works as a powerful stand-alone building, rather than part of its environment. Functions are predefined as zones of a dense program, even though the station is directly located at the end of one of the busiest shopping streets which offers similar facilities. In contrast to that, we propose to see the station as a hub space distributing people to the local environment with its associated functions provided for users and their wishes. Our approach depicts functions as nodes, rather than zones, and simulates the flow through a dynamic network in which activities and movements take place according to the users' needs, sampled by statistical means.

The functional groups of Vienna West Train Station are comprised of private (office and hotel) and public facilities (service, eating-drinking, shopping) (see Figure 4.1). Since private spaces are occupied by their users and owners, public spaces serving more people have a greater meaning in usage at different periods of time. Therefore, it is aimed to focus on the station's public spatial structure (see Figure 4.2).

Figure 4.1 : Vienna West Train Station; Spatial Layout for Public and Private Activities.

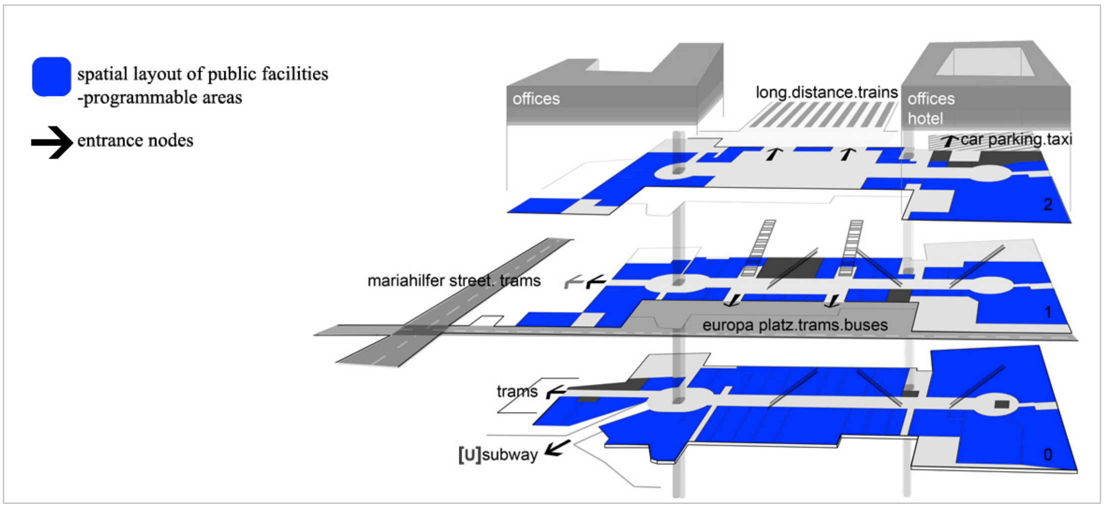


Figure 4.2 : Vienna West Train Station; Spatial Layout for Public Activities.

4.1.1 Functional Decomposition

Functional decomposition targets both, spatial configuration and activity patterns occurring in physical space (shopping areas, service areas, circulation, exists, office and hotel facilities) as well as infrastructure in the digital domain (e.g. vending machines, info points, cell phones, tablets). The process is summarized as follows:

- The existing functional groups are refined into functions by turning all facilities (e.g. exists, circulation, restaurant, cafe, kiosk, store, hotel, office etc.) into activities (e.g. getting into tram, having breakfast, shopping for newspapers, sleeping, working) (see Figure 4.3, 4.4).
- Public and private facilities (i.e. shopping, eating-drinking) are marked with activity icons depicting the intended usage (i.e. restaurant, cafe, market) or showing the quality of a given use / activities assigned to the facilities such as having instant meal, having breakfast, car parking, shopping for clothes etc.

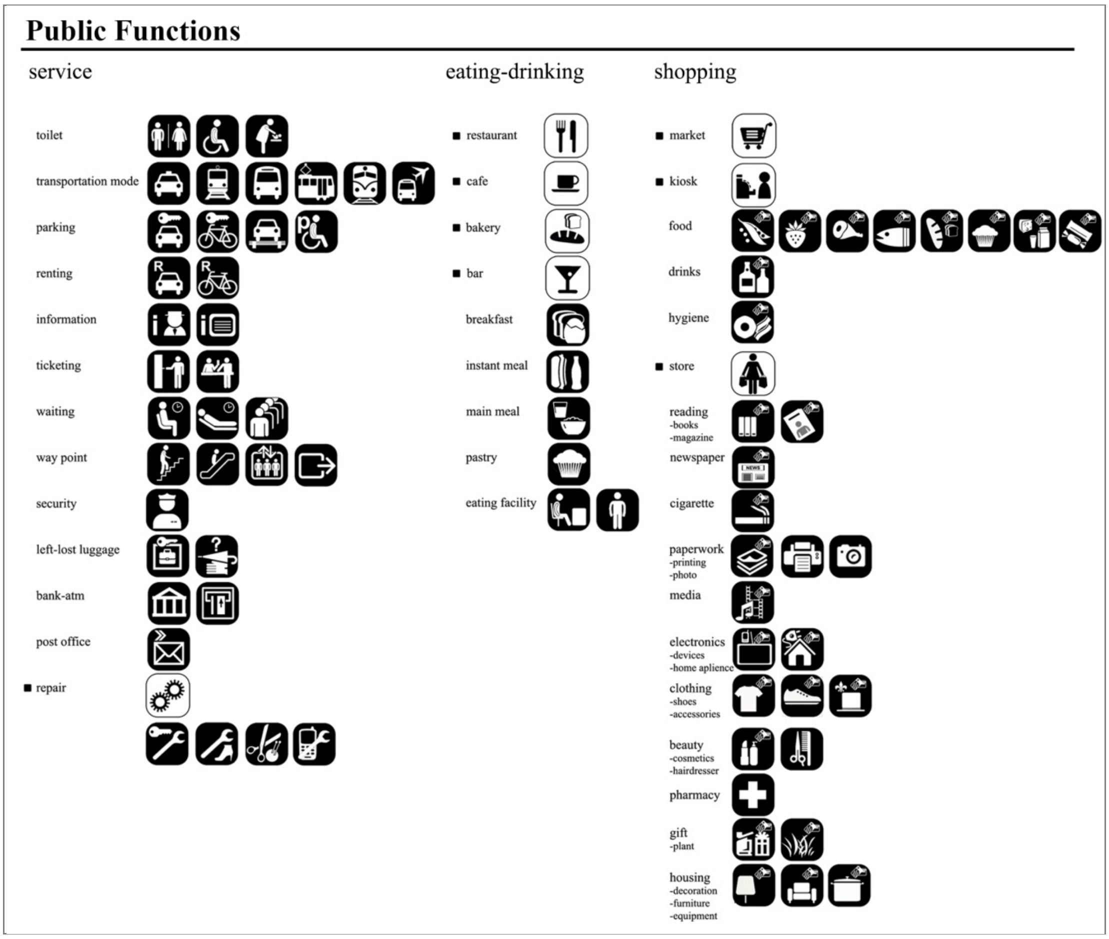


Figure 4.3 : Existing Functional Groups and Activity Icons; Public Facilities.

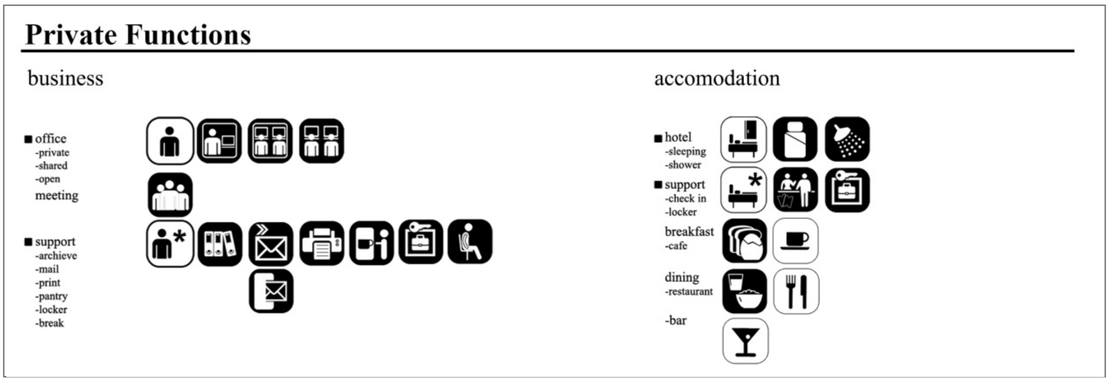


Figure 4.4 : Existing Functional Groups and Activity Icons; Private Facilities.

There are two different cases for the mentioned activities:

- Activities which are located “in an area” (e.g. having main meal, storing luggage) are seen as destinations (see Figure 4.5).
- Activities which lie on connections between two areas are “bridging functions” connected to the circulation system as waypoints (e.g. buying tickets, watching media displays) and act as distribution mechanisms (see Figure 4.6).

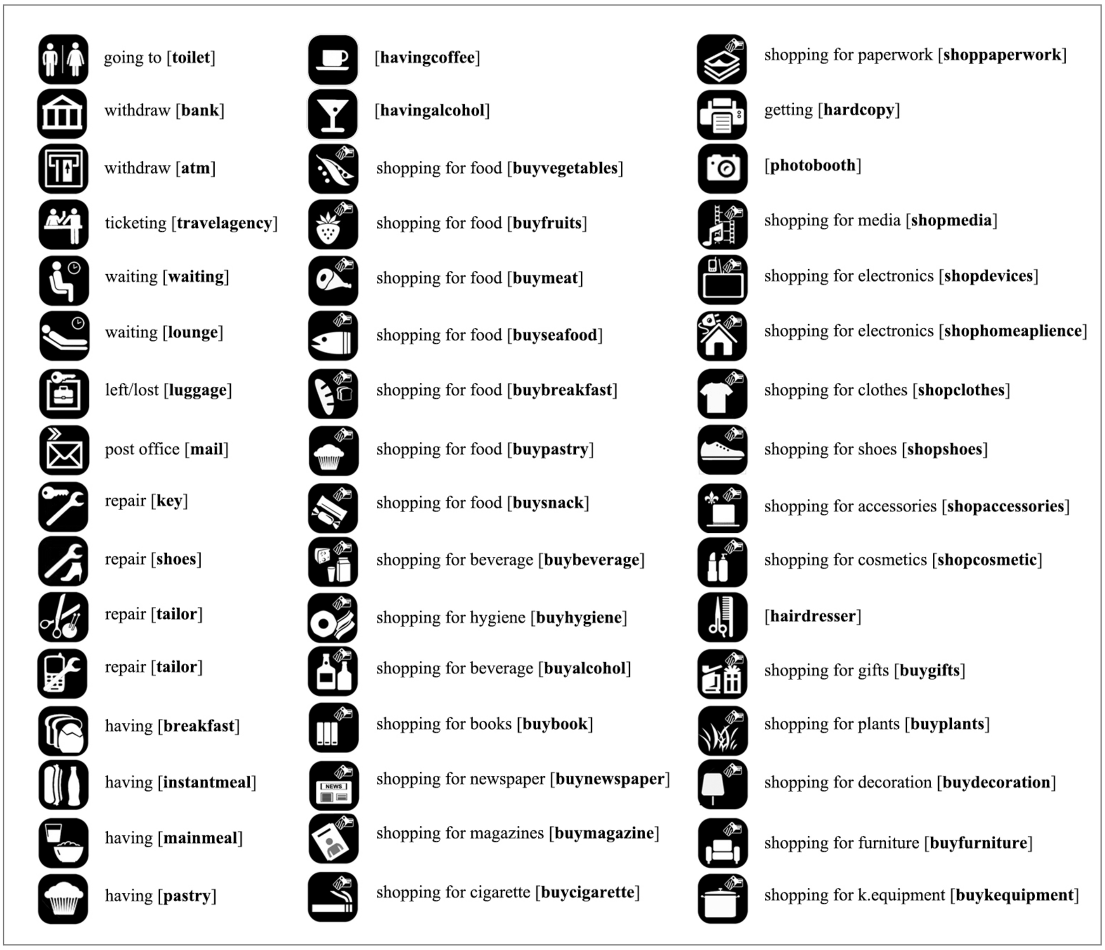


Figure 4.5 : Functional Decomposition; Destinations.

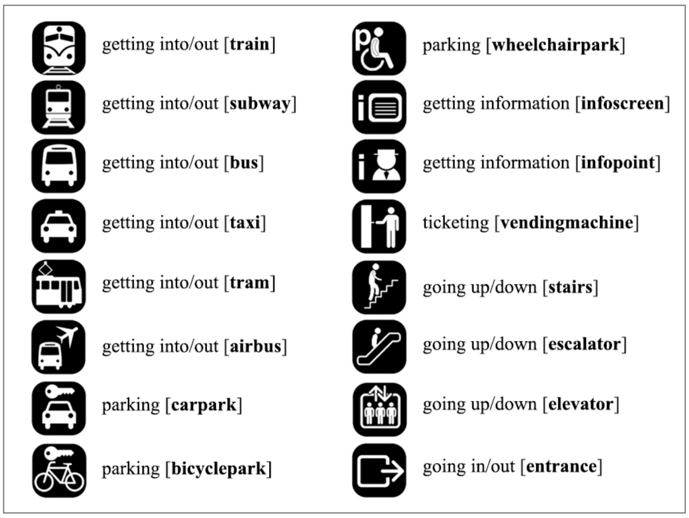


Figure 4.6 : Functional Decomposition; Bridging Functions.

4.1.2 Functional Utilization

According to the refined functions, a timetable showing the available activities during 24 hours of a day is prepared. While doing this, the differentiations in weekdays and weekends are taken into account (see Figure 4.7, 4.8).

- For weekday and weekend, different time intervals are defined (for weekday the working hours and for weekend entertainment oriented activities are taken into account).
- Since sleeping and working activities are served within private facilities in hotels and office buildings, their secondary facilities (meeting and resting spaces of office buildings; casual meeting, eating and drinking facilities of the hotel building) which could be easily served within the same services offered in the public spatial structure are taken into account.
- Then, a chart model is prepared at chosen time intervals in order to analyse how these activities are simultaneously used at different time intervals and sequentially used at different times (see Figure 4.9, 4.10).

Based on this analysis, it is proposed that the reassignments of unused or less used functions to required functions can optimise the occupied floor area for an efficient use of space. For example in working days, from 06 am to 05 pm, the facilities for having breakfast and pastry can be easily reassigned to the shopping and casual meeting activities (see Figure 4.9). For weekends, since the working activity is not available, the shopping and other entertainment activities (e.g. casual meeting, visiting a bar) need to increase in intensity as well as changing in their variety. From 08 am to 13 pm, shopping for magazines, newspapers, food and drinks will compete with shopping for media, electronics, books, clothes and thus the required space for shopping increases. In fact, facilities for having breakfast or pastry could easily be reassigned to these shopping facilities (see Figure 4.10).

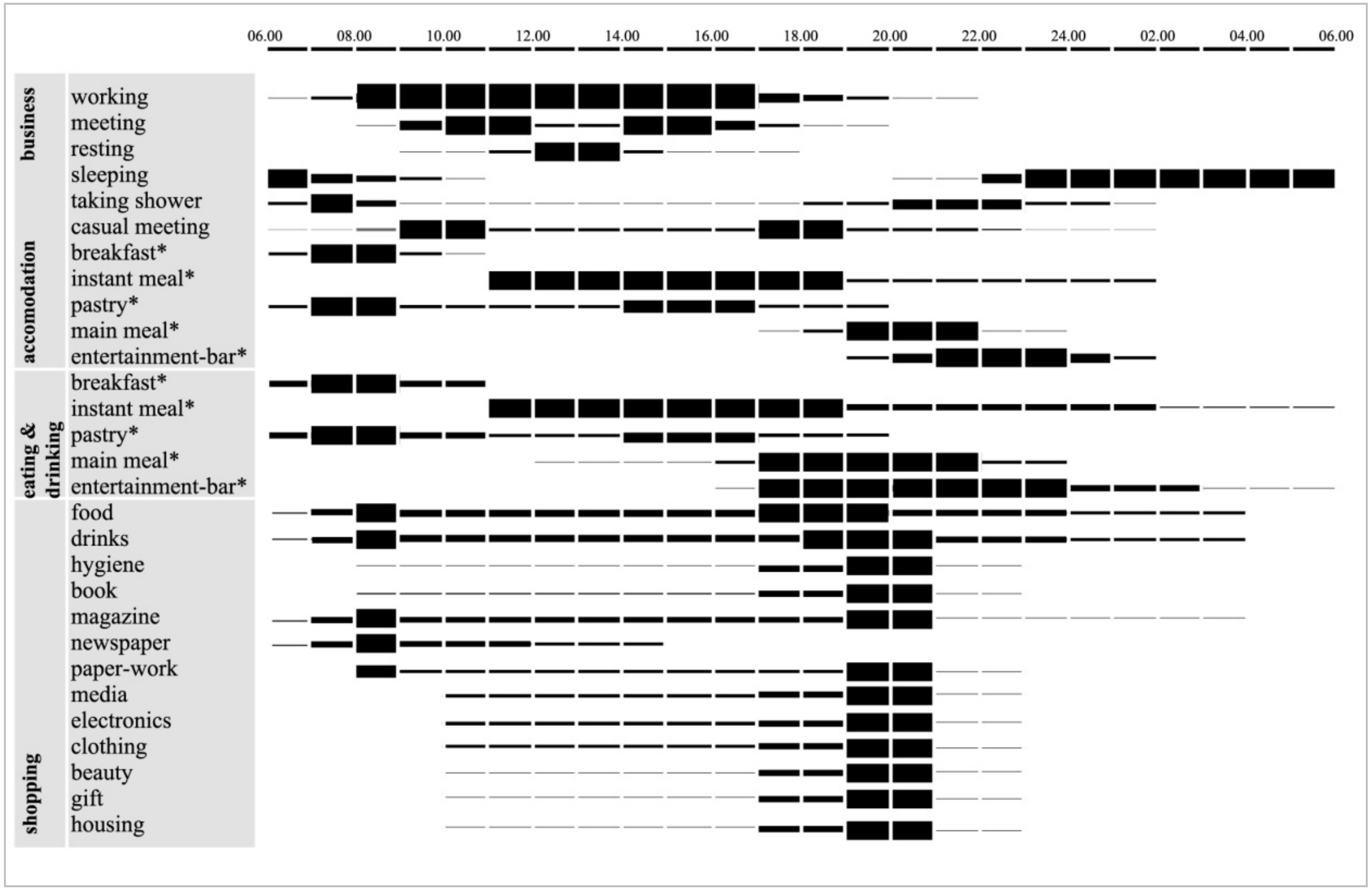


Figure 4.7 : Timetable showing the availability of functions during one day; weekday.

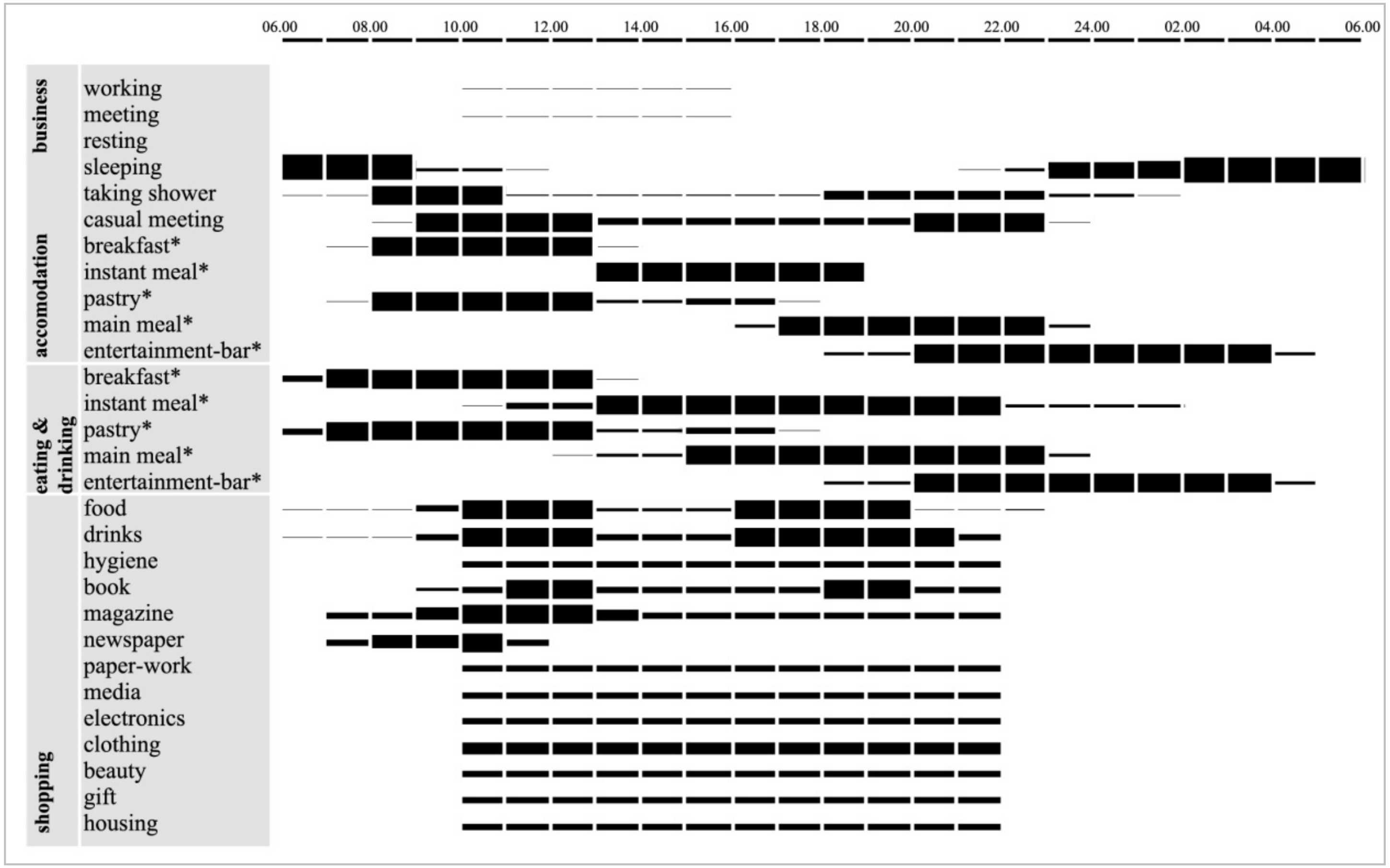


Figure 4.8 : Timetable showing the availability of functions during one day; weekend.

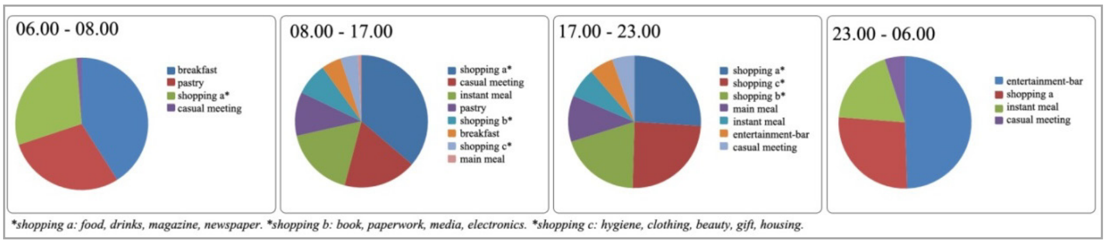


Figure 4.9 : Functional Utilization Charts showing the simultaneously and sequentially used functions at weekday

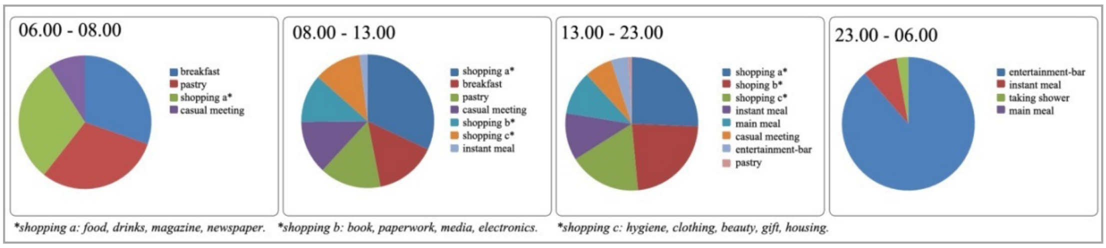


Figure 4.10 : Functional Utilization Charts showing the simultaneously and sequentially used functions at weekend

4.1.3 Activity Mapping

Floor plans of the building are elaborated according to the location of the activities in the spatial organization. All floor plans are turned into activity mappings in which all building spaces (e.g. restaurant, market, and kiosk), bridging functions (e.g. stairs, elevators) and digital infrastructures (e.g. info screen, ticket machine) are marked with activity icons (see Figure 4.11, 4.12, and 4.13).

There are two different types of activity icons: activity icons depicting the activity pattern (i.e. restaurant) and activity icons depicting its related activities (i.e. sitting, having main meal, having coffee, having instant meal etc.). As one indicates the intended use (i.e. restaurant or market), the others show availability of further usages in detail (i.e. if a given restaurant is a place for having an instant meal and/or having a main meal and if it has a sitting area or not).

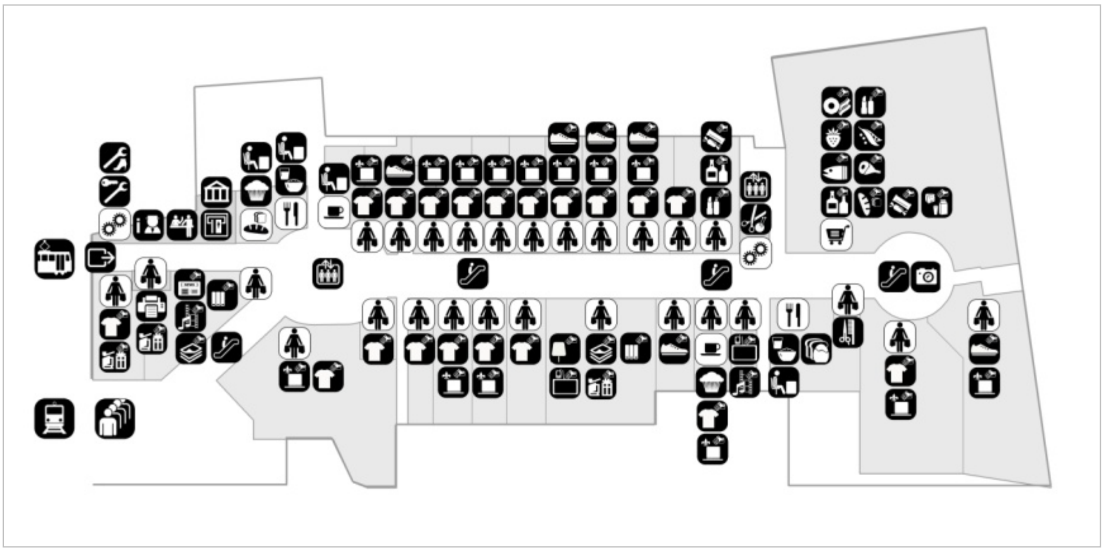


Figure 4.11 : Activity Mappings; Entrance Floor Plan.

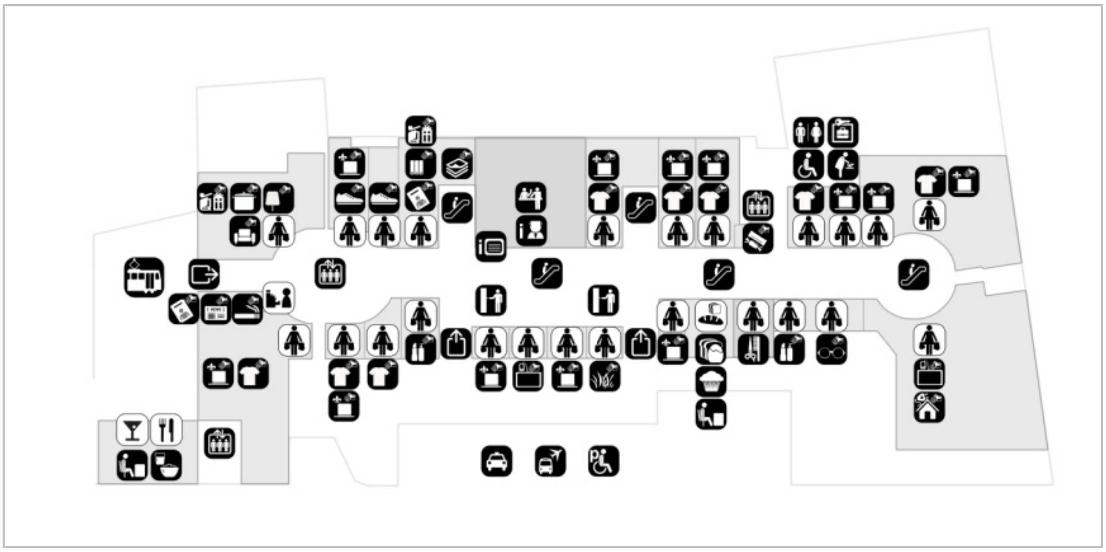


Figure 4.12 : Activity Mappings; First Floor Plan.

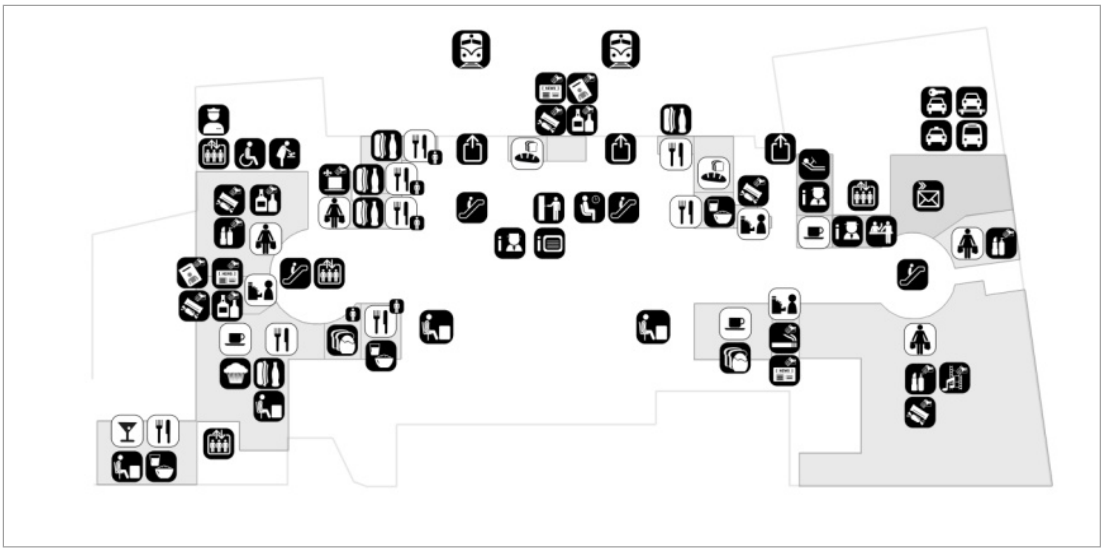


Figure 4.13 : Activity Mappings; Second Floor Plan.

Representation of Building Spaces through Activities

Building spaces that can host different functions are represented in the detail of activities. All spaces are refined into sub-spaces in which each space unit (sub-space) is assigned to an activity pattern. Each activity pattern is an abstraction of a building space and comprises of one or more activities (see Figure 4.14).

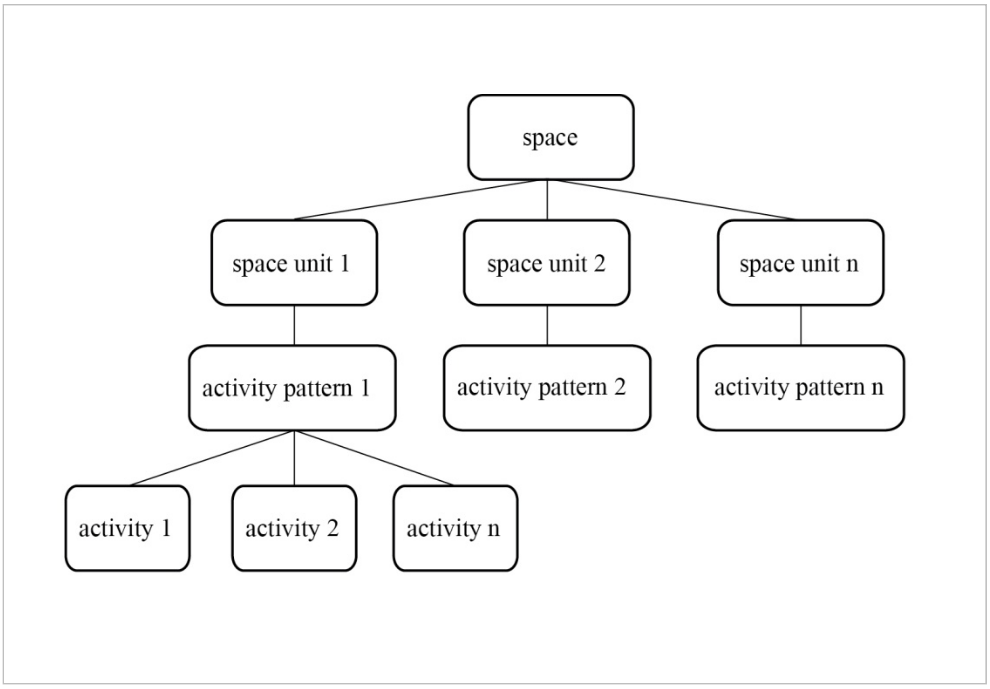


Figure 4.14 : Representation of Building Spaces through Activities.

Each activity pattern comprises of one or more activities, (i.e. an example restaurant: dining pattern comprises of three activities: having main meal, having coffee, and sitting). Figure 4.15 shows an example for the abstraction of a building space (restaurant) in which all space units (kitchen, service, dining area, entrance) are represented as activity patterns (preparation pattern, service pattern, and dining pattern). Further, activity patterns are introduced as nodes showing the activities assigned to building spaces (see Figure 4.16, 4.17).

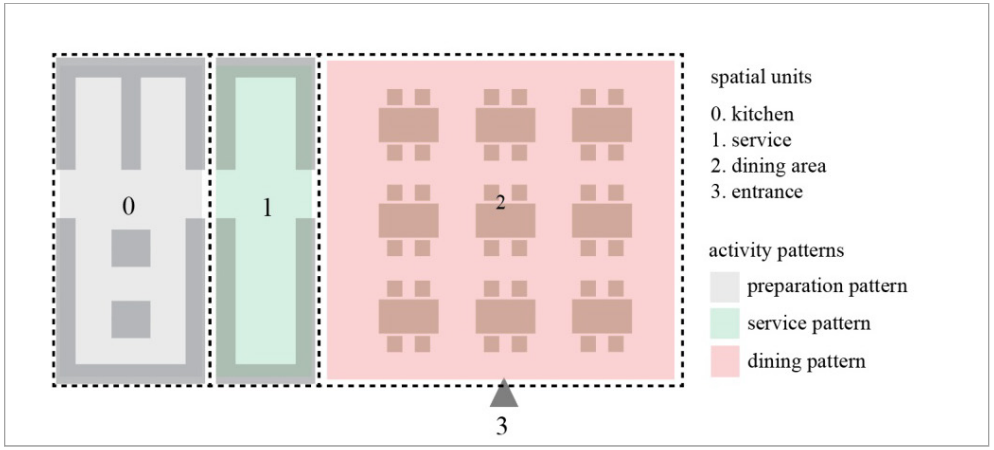


Figure 4.15 : Spatial Units and Activity Patterns of an Example Space; Restaurant.

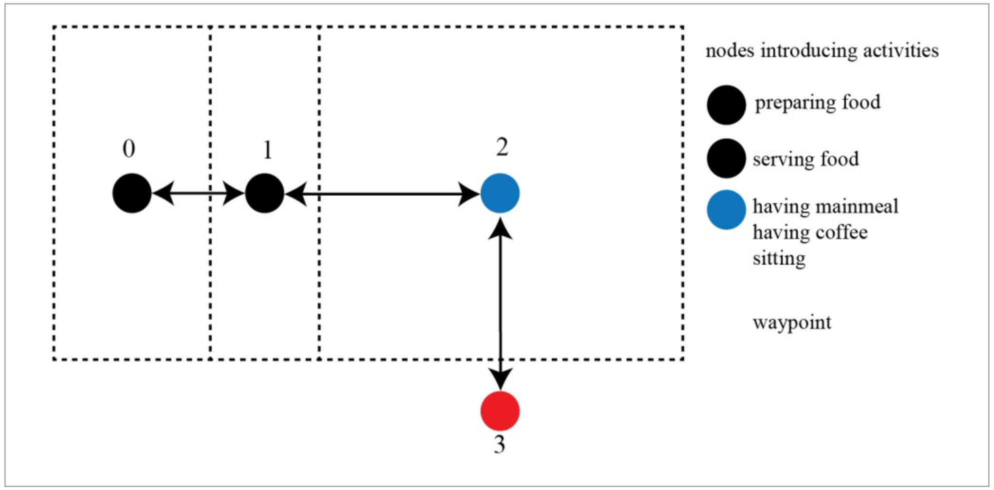


Figure 4.16 : Activity patterns are introduced as nodes showing the activities assigned.

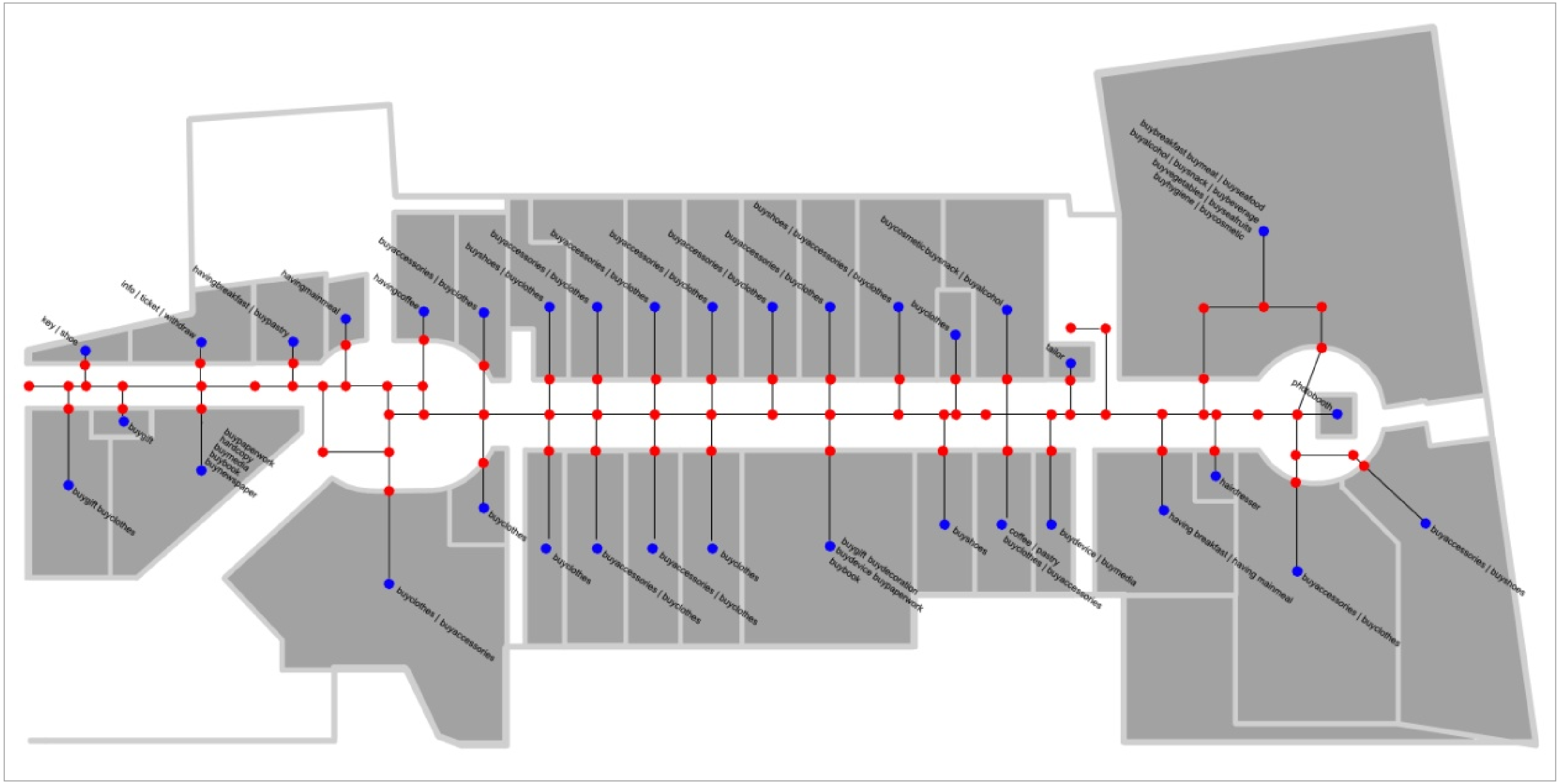


Figure 4.17 : Abstraction of Building Spaces as Nodes and Links; Entrance Floor Plan.

4.2 The Method for User Behaviour Simulation

A station building connects travelers through an internal flow network to their intended destinations. Its quality depends on the features of the local environment and the changing intent of its users: For people travelling to work, it simply is an intermediate waypoint (travelling through a transition space). In this case, the station needs to have quick functions like buying tickets, coffee and newspapers, getting information about departures. However, on the way back from work, the station is transformed into a leisure space for activities like shopping, dining and meeting friends. Thus, the profile of the same person may change during one day. Also, for leisure purposes, such leisure activity can be more unpredictable, being possibly also connected to functions like accommodation, renting a car or sightseeing. Intermediate functions like storing luggage or waiting can furthermore always apply.

User behaviour in railway stations is very complex, since activity schedule of individuals vary according to their purpose of using the station (e.g. commuting, shopping, dining etc.) and time interval/limit spent in the station. On the one hand, identification of pedestrian types (e.g. short term-long term travellers, commuters, costumers etc.) and the purposes of their behaviour (both walking and performing an activity) are essential for simulating user behaviour. On the other hand, there are many external factors that may disproof such conclusive scenarios. These factors are summarized as follows:

- Variations in spatial design and functional arrangement (i.e. a space used as a restaurant may turn into a store) have impacts on user behaviour
- Variations in public transport time-tables and train frequencies influence the intensity of the pedestrian flow.
- Addition of a new transportation modality (e.g. high speed train) triggers changes in both, the transportation network and the spatial layout of the station which in turns results in different pedestrian densities and diversities.

Based on these variations, a model for simulating pedestrian behaviour and space utilization should enable to update user activity schedules (scenarios) and spatial organizations serving these activities. In this research project, implemented simulation model imports activity schedules of different passengers from a tabular data and the one using the simulation tool is able to assign different activities at any time. These activity schedules are prepared as "what if" type scenarios giving the possibility to question what the building-users want and what they get. In a broader definition, these questions are:

- Which functions are less or not used and which functions are required but not available:Is it possible to re-assign these functions into other functions requested more?
- Which functions are sequentially and simultaneously used: Is it possible to locate these functions adjacently in order to increase accessibility and reduce the occupied area?

In order to answer these questions, first, possible activities are detailed in terms of different type of users and their purposes of using the station (see Figure 4.18). It is important to note that this elaboration only targets Vienna West Train Station users.

1. Long Distance Traveller
1.a. People who come from Salzburg, Innsbruck etc.
1.a.a. People who want to transfer another line
--- getting information (about departure time, facilities at the station)
--- ticketing
--- waiting *
1.a.b. People who want to stay at the location for a period of time
--- getting information (about facilities at and around the station)
--- storing their luggage
--- ticketing
--- eating and drinking
--- shopping
--- accomodation
--- renting vehicle
1.b. People who want to go to Salzburg, Innsbruck etc.
--- parking vehicle
--- getting information (about available connections, departure time)
--- ticketing
--- waiting *

* duration of activity depends on the departure time, so a multi-functional space is needed where people can:
--- *sitting and waiting for the train*
--- reading
--- shopping for newspaper, magazine, book
--- eating and drinking
--- having instant food
--- *shopping*
--- buying instant stuff that will be neded for travel
--- shopping for food and drinks
--- shopping for hygiene, cigarette, paperwork, media, clothing, beauty, health, gift
--- *storing their luggage*
--- *withdraw*
--- *having service for technological devices*
--- *eating and drinking*
--- *watching movies, listening music, playing games*
--- *meeting*
--- *resting, sleeping, taking shower*
--- *joining - watching the instant activities at or around the station like existing exhibition, concert, workshop etc.*

Figure 4.18 : Different types of users with possible scenarios.

2. Short Distance Traveller

2.a. People who want to commute

2.a.a. People who want to go to work

--- ticketing
--- getting information (about departure time)
--- waiting
--- *sitting and waiting for the train*
--- *reading*
--- shopping for newspaper, magazine
--- *shopping*
--- shopping for food and drinks
--- eating and drinking
--- *having quick breakfast*

2.a.b. People who want to go to home from work

--- ticketing
--- getting information (about departure time)
--- waiting
--- *sitting and waiting for the train*
--- *reading*
--- shopping for newspaper, magazine
--- *shopping*
--- shopping for food and drinks
--- eating and drinking
--- *having instant meal, main meal, pastry*
--- shopping

2.b. People who travel for leisure activities

--- shopping
--- eating and drinking
--- joining - watching the instant activities at or around the station like existing exhibition, concert, workshop etc.

Figure 4.18 (continued) : Different types of users with possible scenarios.

4.2.1 Activity Schedules

Activity schedule (AS) of an individual comprises of different activities which [s]he wish/need to perform (i.e. getting information, having breakfast, shopping for newspapers, getting into a train). Each activity from this schedule is a query to the activity map (i.e. an activity: having breakfast is a query: breakfast) in order to find its availability (i.e. if there is a facility in which a given function exists) and location (i.e. if there is, where is this facility). Each activity schedule has a start time implying that each user has an arriving time to the station and stays at the station until completing his/her activities (see Figure 4.19).

arrival time: 06.00 am

1 What do I wish/need to do? | 2 What is available?

sequence of activities: schedule	time span	query:	facilities for planned activities:
[1] getting information for next connection	10 min	info	information screen, information desk, travel agency
[2] buying ticket	15 min	ticket	ticket machine, travel agency
[3] going to toilet	10 min	toilet	toilet
[4] going to pharmacy	10 min	pharmacy	xxx not available
[5] having breakfast	20 min	breakfast	bakery, cafe
[6] buying newspaper	10 min	newspaper	kiosk
[7] reading	30 min	waiting	waiting area, sitting area, lounge
[8] getting into train		train	train

Figure 4.19 : Activity Schedule and Query Example of a Long Distance Traveller.

In order to prepare data for the simulation, activity schedules are prepared as queries to the activity maps showing in which time (arrival time) and in which location, how many users will start to perform their activities from their activity schedules (sequence of activities) (see Figure 4.20).

What do I wish/need to do? 1

arrival time startseconds | enseconds	howmany	where	sequence of activities
0 | 2	20	node 1	info,ticket,toilet,pharmacy,breakfast,buynewspaper,waiting,train
0 | 2	10	node 2	breakfast,buynewspaper,coffee,ticket,tram
4 | 8	40	node 3	luggage,dining,toilet,ticket,train
1 | 3	20	node 3	info,ticket,airbus
2 | 4	15	node 4	buyclothes,ticket,instantmeal,subway
2 | 4	15	node 1	dining,withdraw,buybeverage
2 | 4	30	node 2	info,ticket,dining,withdraw,buybeverage,train

Figure 4.20 : Activity Schedule Example Prepared for Simulation.

4.2.2 User Behaviour on Activity Mapping

Each user has a start time for performing his/her activities in an activity schedule and each activity has a time span. At a certain location on activity maps (e.g. exists of subways, trams, train platforms, main entrance etc.), different users start to perform their activities according to their activity schedule. Figure 4.21 shows an example of a user performing a sequence of activities through queries according to her/his activity schedule. Each activity is marked on floor plans.

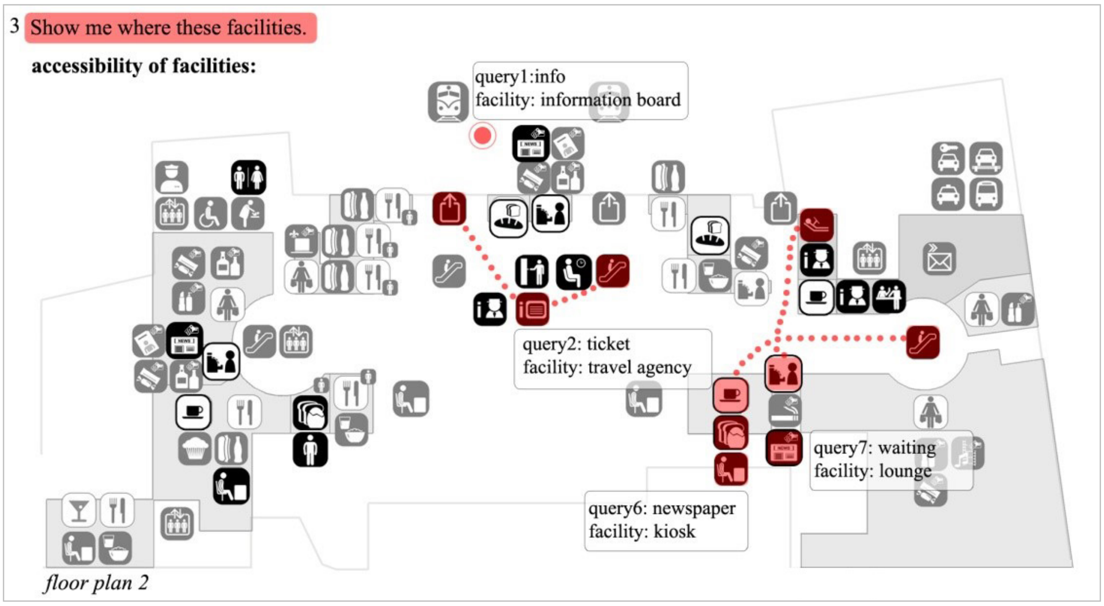


Figure 4.21 : User Performing a Sequence of Activities.

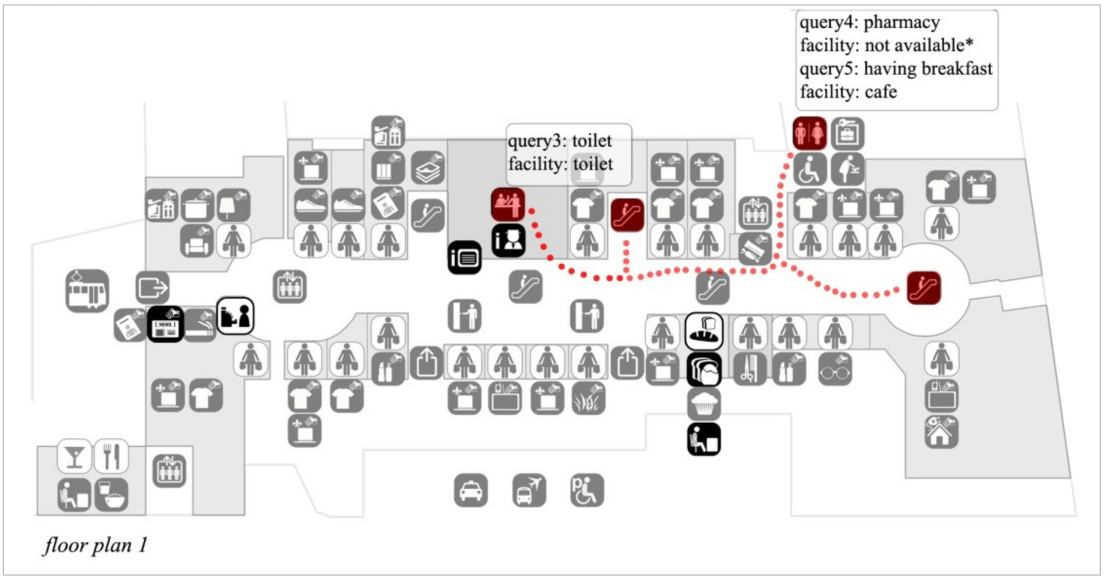


Figure 4.21 (continued) : User Performing a Sequence of Activities.

The users' location at a time determines the distance to the facilities. At a certain location on activity maps, a user has one or more planned activities (e.g. having breakfast, getting information, ticketing), each activity refers to a query (e.g. breakfast, info, ticket) and each query refers to one or more facilities (e.g. bakery, cafe, vending machine). In case there is more than one facility in which a given activity exists, then the one with the shortest distance to the user will be chosen. In this case user will occupy the space during a time depending on the type of the activity. In other case, if the closest one is occupied, then the user will wait for the resource (being in the queue). If there is no facility offered for the planned activity, then the user will skip this activity and continue with the next one. Further, the system will record this situation to give feedback to the analyst who may re-assign a less or not used function to the one requested more.

4.3 The Simulation Model

Activity maps and activity schedules are the main inputs for the simulation. Activity maps are used to prepare three dimensional building data in which all building spaces perform as nodes and links. Each node represents an activity pattern and comprises of one or more activities. Each node has the data about its activities in terms of four variables: type (e.g. having breakfast), capacity, service time, and time span. This data is updated according to the current utilization of functions and in case of variations in the spatial organization. Programmability of space is supplied by giving the ability to the re-assign different activities to the space (nodes) in order to improve space utilization.

Activity schedules are prepared as queries. Every query refers to an activity and has a service-time to be completed. Installations of the simulation provides building users information about “which facilities are offered and where” in order to decide their next activities. Further, building users can book a free space to be used. In this case, building data will be changed according to the current utilization (see Figure 4.22).

Proposed model deals with the building spaces as a network of nodes that can be re-programmed according to data derived from both physical and digital. A preliminary pedestrian flow simulation is implemented based on the free NetLogo platform (open-source), in which agents choose their destination according to their activies in order. The simulation itself proceeds in the following steps:

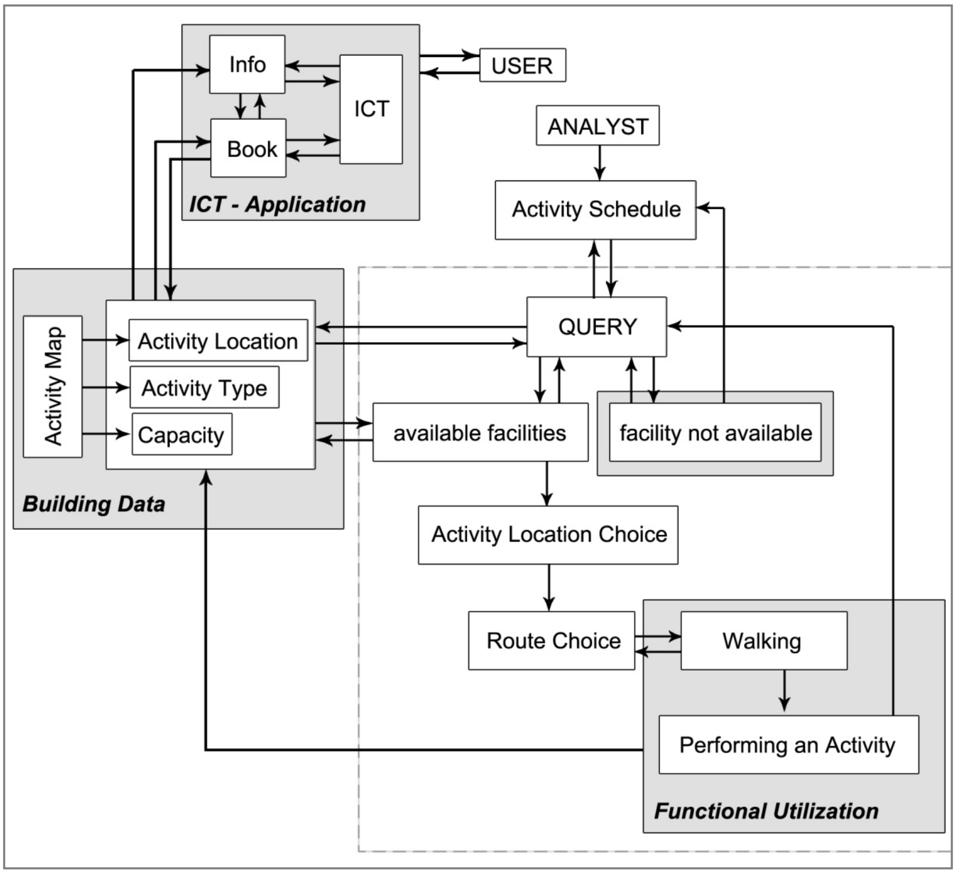


Figure 4.22 : Simulation Process.

4.3.1 Importing Building Data

The schema of the chosen station building is imported as a three-dimensional map, in which layers indicate programmable areas. Then, the path network connecting these areas is loaded as a graph, in which the building spaces work as nodes (see Figure 4.23, 4.24). Node is the abstraction of space (e.g. restaurant) and comprises of one or more activities (i.e. a space restaurant is represented as a node comprises of activities such as having instant meal, having breakfast, sitting).

There are two different cases for the mentioned functions:

- Function Container Node (F): Functions which are located "in an area" (e.g. shopping, storing luggage) are seen as destinations.
- Waypoint Node (W): Functions which lie on connections between two areas are "bridging functions" connected to the circulation system as waypoints (e.g. exits, stairs, escalators, elevators) and act as distribution mechanisms.

All function container nodes are linked to at least one waypoint node in order to create a spatial network of building spaces that are programmable (see Figure 4.25) Furthermore, each function container node has the required data about its activities in terms of four variables: type, capacity, service time, and time span. When simulation runs, this data is updated according to the current utilization of functions and in case of variation in the spatial organization.

Properties of Function Container Nodes

- Type: Each function/usage container node refers to one or more functions/activities (e.g. having breakfast, buying newspaper) (node-5: functions "b" "d" "e" node-10: functions "a" "b" "c").
- Service Time: Each function/usage has a service time showing the duration of the activity, the time it takes within the node.
- Time Span: Each function/usage has a time span represented as time intervals (0-1-2-3-4-5-6-7-8-9-10-11-12) in order to check the availability of functions (i.e. opening-closing times of the activity) at requested time.
- Capacity: Functions that are limited or unlimited: Each function/usage has a capacity (maximum number of agents that can book the function at the same time). In general, the notion of functions used is resource-limited (i.e. a sitting function has the data about number of available tables), meaning that there is a finite capacity agents can book (e.g. there are 20 places for function/activity).

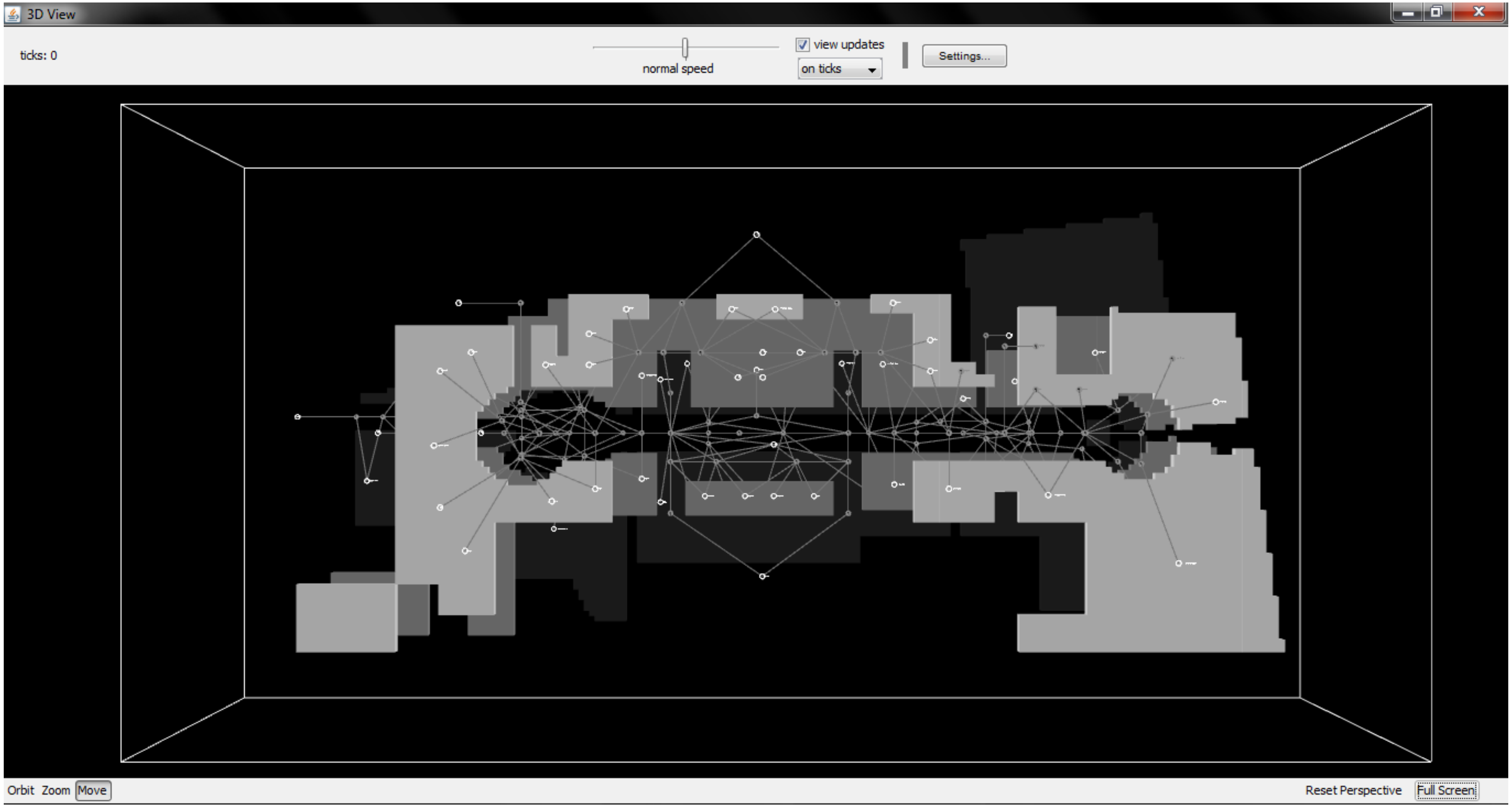


Figure 4.23 : Simulation showing the way network with functions as nodes; plan view.

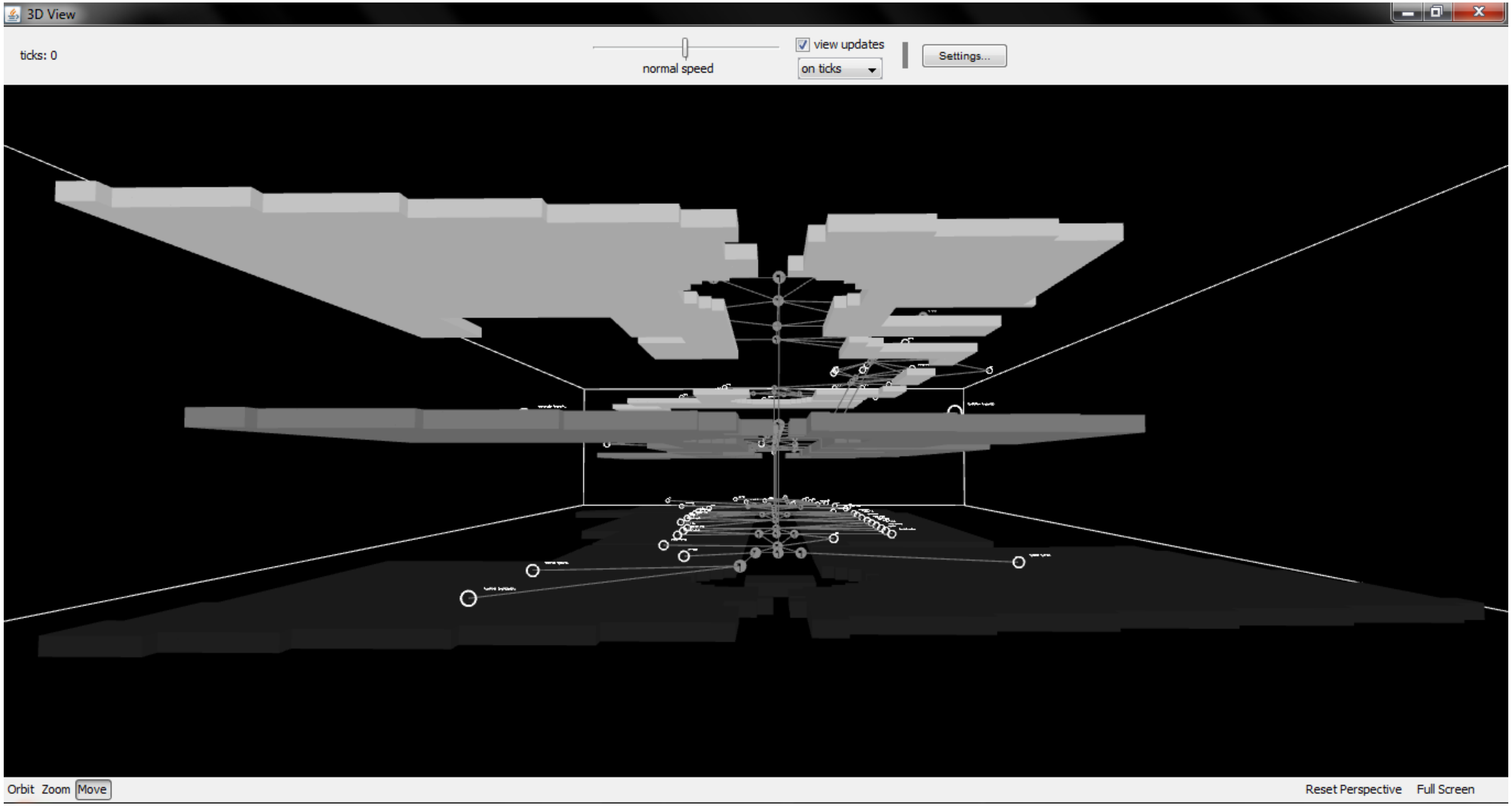


Figure 4.24 : Simulation showing the way network with functions as nodes; perspective view.

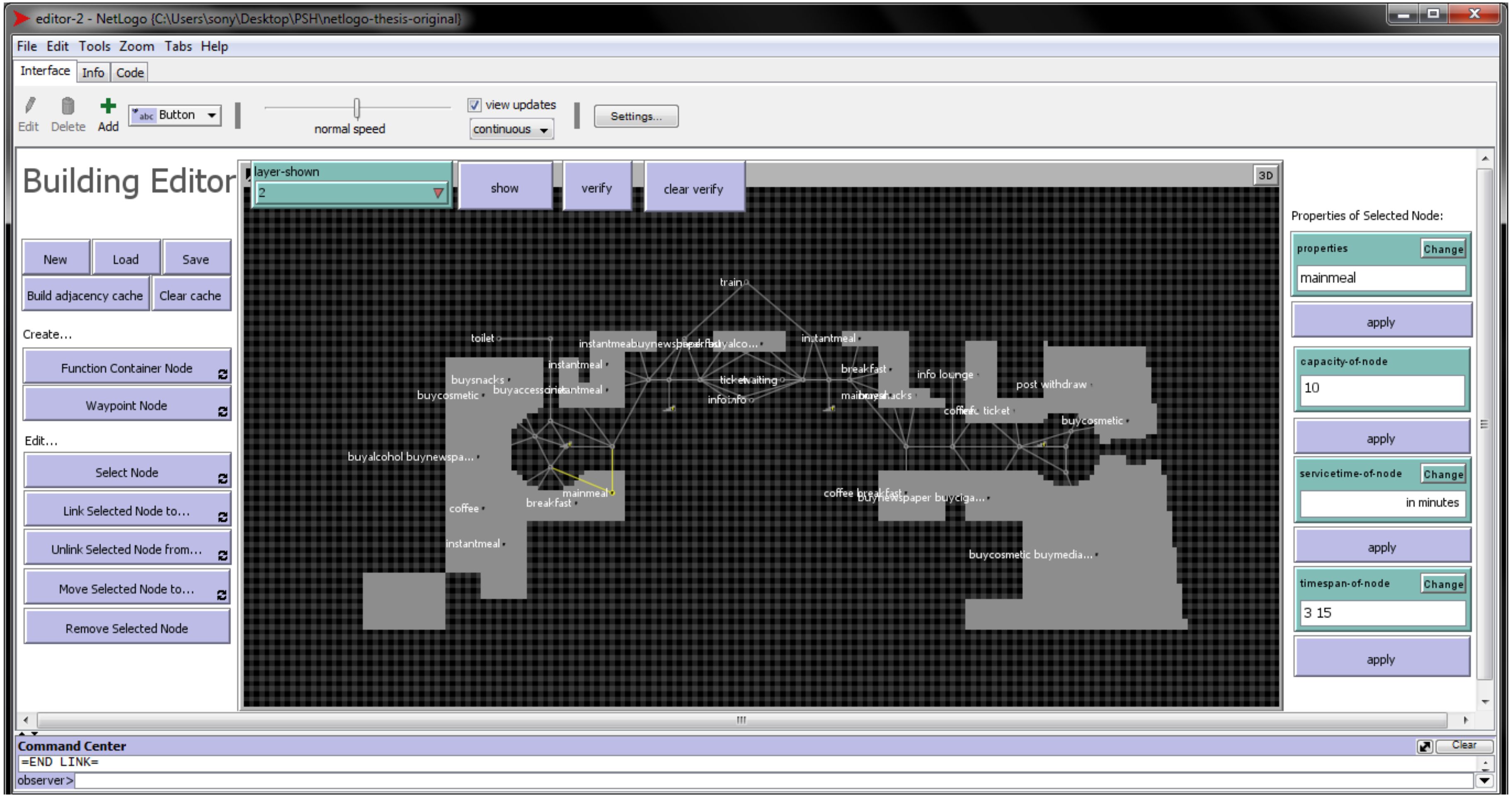
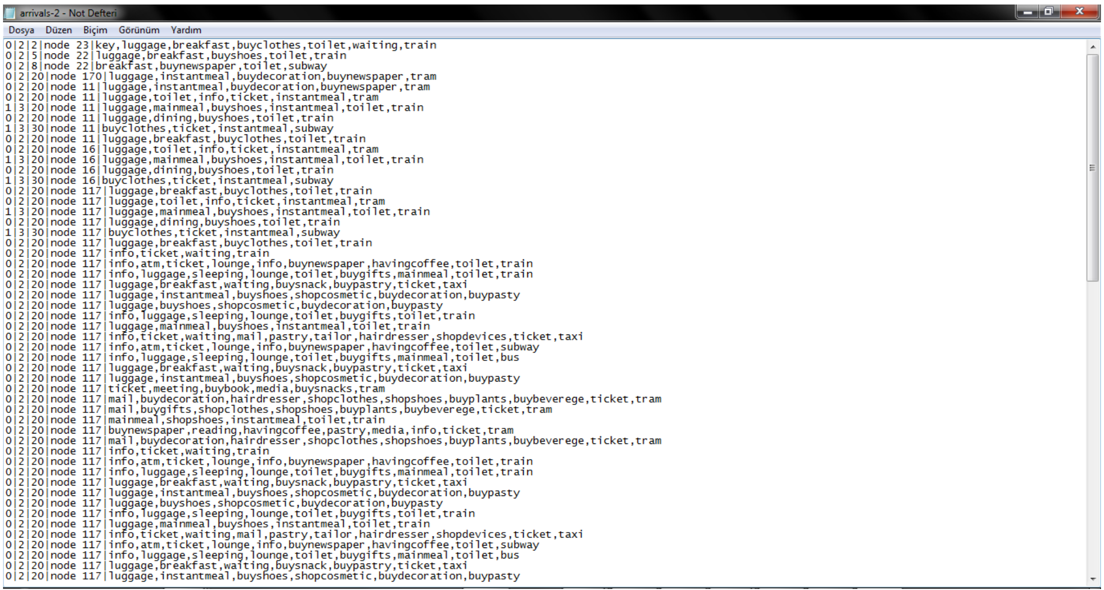


Figure 4.25 : Building Editor; creation of abstract spaces as nodes and links.

4.3.2 Creating Agents

Implemented simulation imports a pedestrian flow from tabular data prepared as a priority queue for all agent waiting to be born (see Figure 4.26), in which the passage of users is given as consecutive functions to visit (e.g. entrance, shopping, info). This protocol is imported into the simulation which animates agents that act accordingly (see Figure 4.27). The appearance of people is simulated at time t by creating agents in entrance nodes (e.g. from subway lines, main entrance, train platforms). Also, active elements such as info points distribute the agents to different spaces, depending on the current utilization of functions. The initial mental concept of functions to visit is then registered, meaning that the agent has a pre-defined sense of what functional sequence it wants to go through (see section 4.2.1).

Re-distribution of agents happens either in a pre-step (when entering the station), or ad-hoc (when there is not enough capacity to utilize a function). User of the test bed can also generate agents manually by giving the node id (in which location/where), the number of agents (how many) and the functions to visit (sequence of activities to be visited/goals) in order to test/analyse the results of the new situations.



```
arrivals-2 - Not Defteri
Dosya  Düzen  Biçim  Görünüm  Yardım
0|2|2|node 23|key,luggage,breakfast,buyclothes,toilet,waiting,train
0|2|5|node 22|luggage,breakfast,buyshoes,toilet,train
0|2|8|node 22|breakfast,buynewspaper,toilet,subway
0|2|20|node 170|luggage,instantmeal,buydecoration,buynewspaper,tram
0|2|20|node 11|luggage,instantmeal,buydecoration,buynewspaper,tram
0|2|20|node 11|luggage,toilet,info,ticket,instantmeal,tram
1|3|20|node 11|luggage,mainmeal,buyshoes,instantmeal,toilet,train
0|2|20|node 11|luggage,dining,buyshoes,toilet,train
1|3|30|node 11|buyclothes,ticket,instantmeal,subway
0|2|20|node 11|luggage,breakfast,buyclothes,toilet,train
0|2|20|node 16|luggage,toilet,info,ticket,instantmeal,tram
1|3|20|node 16|luggage,mainmeal,buyshoes,instantmeal,toilet,train
0|2|20|node 16|luggage,dining,buyshoes,toilet,train
1|3|30|node 16|buyclothes,ticket,instantmeal,subway
0|2|20|node 117|luggage,breakfast,buyclothes,toilet,train
0|2|20|node 117|luggage,toilet,info,ticket,instantmeal,tram
1|3|20|node 117|luggage,mainmeal,buyshoes,instantmeal,toilet,train
0|2|20|node 117|luggage,dining,buyshoes,toilet,train
1|3|30|node 117|buyclothes,ticket,instantmeal,subway
0|2|20|node 117|luggage,breakfast,buyclothes,toilet,train
0|2|20|node 117|info,ticket,waiting,train
0|2|20|node 117|info,atm,ticket,lounge,info,buynewspaper,havingcoffee,toilet,train
0|2|20|node 117|info,luggage,sleeping,lounge,toilet,buygifts,mainmeal,toilet,train
0|2|20|node 117|luggage,breakfast,waiting,buysnack,buypastry,ticket,taxi
0|2|20|node 117|luggage,instantmeal,buyshoes,shopcosmetic,buydecoration,buypasty
0|2|20|node 117|luggage,buyshoes,shopcosmetic,buydecoration,buypasty
0|2|20|node 117|info,luggage,sleeping,lounge,toilet,buygifts,toilet,train
0|2|20|node 117|luggage,mainmeal,buyshoes,instantmeal,toilet,train
0|2|20|node 117|info,ticket,waiting,mail,pastry,tailor,hairdresser,shopdevices,ticket,taxi
0|2|20|node 117|info,atm,ticket,lounge,info,buynewspaper,havingcoffee,toilet,subway
0|2|20|node 117|info,luggage,sleeping,lounge,toilet,buygifts,mainmeal,toilet,bus
0|2|20|node 117|luggage,breakfast,waiting,buysnack,buypastry,ticket,taxi
0|2|20|node 117|luggage,instantmeal,buyshoes,shopcosmetic,buydecoration,buypasty
0|2|20|node 117|ticket,meeting,buybook,media,buysnacks,tram
0|2|20|node 117|mail,buydecoration,hairdresser,shopclothes,shopshoes,buyplants,buybeverege,ticket,tram
0|2|20|node 117|mail,buygifts,shopclothes,shopshoes,buyplants,buybeverege,ticket,tram
0|2|20|node 117|mainmeal,shopshoes,instantmeal,toilet,train
0|2|20|node 117|buynewspaper,reading,havingcoffee,pastry,media,info,ticket,tram
0|2|20|node 117|mail,buydecoration,hairdresser,shopclothes,shopshoes,buyplants,buybeverege,ticket,tram
0|2|20|node 117|info,ticket,waiting,train
0|2|20|node 117|info,atm,ticket,lounge,info,buynewspaper,havingcoffee,toilet,train
0|2|20|node 117|info,luggage,sleeping,lounge,toilet,buygifts,mainmeal,toilet,train
0|2|20|node 117|luggage,breakfast,waiting,buysnack,buypastry,ticket,taxi
0|2|20|node 117|luggage,instantmeal,buyshoes,shopcosmetic,buydecoration,buypasty
0|2|20|node 117|luggage,buyshoes,shopcosmetic,buydecoration,buypasty
0|2|20|node 117|info,luggage,sleeping,lounge,toilet,buygifts,toilet,train
0|2|20|node 117|luggage,mainmeal,buyshoes,instantmeal,toilet,train
0|2|20|node 117|info,ticket,waiting,mail,pastry,tailor,hairdresser,shopdevices,ticket,taxi
0|2|20|node 117|info,atm,ticket,lounge,info,buynewspaper,havingcoffee,toilet,subway
0|2|20|node 117|info,luggage,sleeping,lounge,toilet,buygifts,mainmeal,toilet,bus
0|2|20|node 117|luggage,breakfast,waiting,buysnack,buypastry,ticket,taxi
0|2|20|node 117|luggage,instantmeal,buyshoes,shopcosmetic,buydecoration,buypasty
```

Figure 4.26 : Activity Schedule as a Tabular Data.

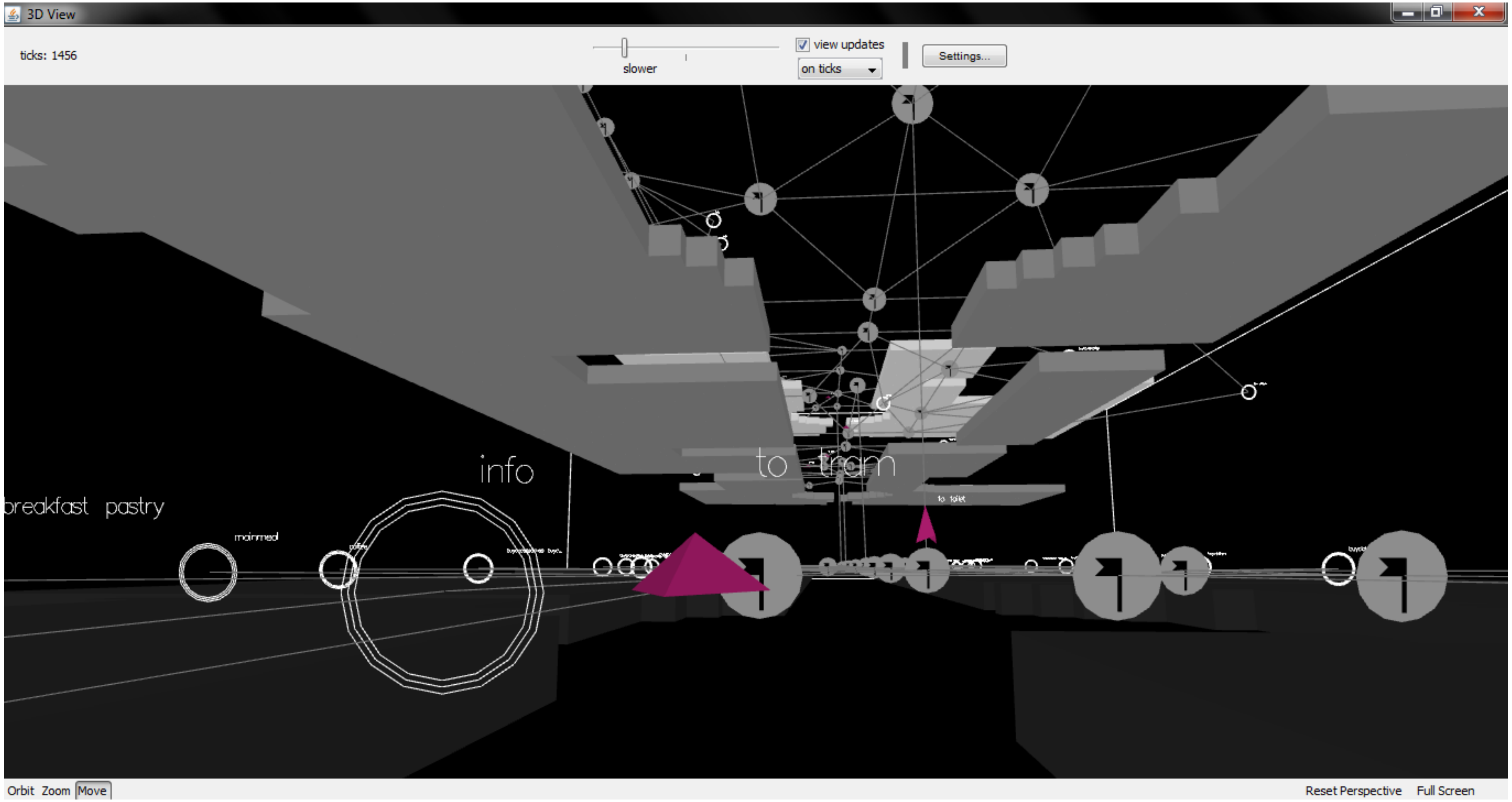


Figure 4.27 : Re-distribution of Agents.

4.3.3 Behaviour Simulation

The passage from and to each function to visit is based on graph analysis of the path network. Each agent has a start time for performing its activities in the activity schedule (sequence of activities). Each activity in activity schedule is a query to the activity map in order to find the data about the candidate nodes for the requested activity. When the simulation is running, first activity from the activity schedule asks for its function to the activity map (building data) in order to find the candidate nodes for the function (if the function is available for the activity). Then, it checks the candidate nodes in order to choose the destination (node selection between candidates) (see Figure 4.28).

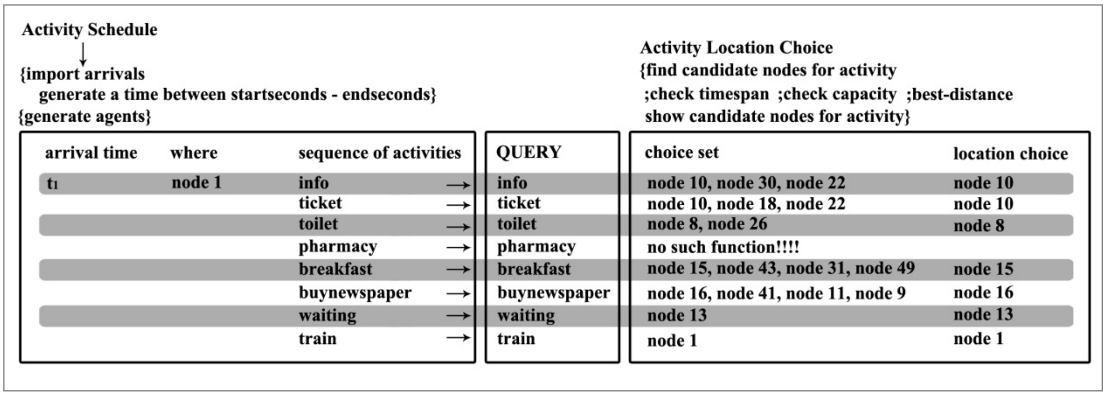


Figure 4.28 : Activity Schedules as a Query to the Activity Maps.

While agents are implementing their activities in order, they act according to the following rules:

Activity Location Choice: What function does each agent want to visit next?

- If there is a node or list of nodes containing the function, for each candidate node, simulation first checks if the function available at that time (checking time-span of the function container node).
- If there is still more than one node for performing requested activity (if there are still candidate nodes), then the closest function container node is chosen (Dijkstra's shortest path algorithm).
- If the activity in the function container node is resource limited (has limited capacity), the agent will try to acquire node and this will put the agent into "active list" (i.e. node has free place – active agent: agent occupying the

resource) or queue list of the node (node is out of capacity – passive agent: agent waiting for resource). If an agent is in the active list of the node, then it waits at the node / occupies the node during service time of the node. When the resource becomes available, agent in the queue list waiting for the resource become activated to occupy the node.

- If there is no facility offered for the activity, then the activity will be skipped and the next activity from the activity schedule will be performed. In this case, the system will record this situation to provide feedback to the analyst who may re-assign a less or not used facility to the activity requested more often.

Route Choice: What route leads to this function?

- Agents use the shortest path to reach each location. The proposed route choice model is based on Dijkstra's shortest path algorithm which is also used by activity location choice algorithm.

Walking and Performing an Activity: How to get to the next goal within that route?

After activity location and route choice, agents move to the location (their goal) within the route by implemented pedestrian dynamics based on Blue and Adler's cellular automata model (modified by a 360° movement). After agents perform an activity, they will continue with the next one until completing all activities from their schedule. The flow simulation is the looping concept, meaning that each agent will be active for as long it has functions to visit. The building data is updated according to the current utilization of functions and in case of variations in the spatial organization.

4.3.4 Visualization of Results

The simulated building records usage both in terms of space (i.e. cell-based occupancy) and functions (i.e. how many agents cross a functional node at a certain time). The results are visualized on the spaces, so that an analyst can then re-attribute functions according to the proposed outcomes (e.g. transformation of shopping space to bookable meeting lounge), and thus also changing the flow of people through the system. Visualization of results is provided in two levels:

- First level is the high level where space utilization is visualized as bubble diagram. Figure 4.29 and 4.30 shows a screenshot from simulation where agents' movements are visualized on a graph based network. Size of the nodes shows the current occupation and thickness of the link shows the number of agents crossing it.

- Second level is the low level, where space utilization is visualized as cell-based occupancy. Blue and Adler's CA movement model (2001) is extended with higher level network model (bubble diagram) in which pre-defined paths applying high-level goals stored in the grid (see Figure 4.31, 4.32).

Statistics

Statistics are visualized in two tables (see Figure 4.33). First table shows utilized functions (how many functions are utilized in this tick) and missed functions (how many functions are missed in this tick). Second table shows further detail about missed functions (in which time, which function is missed and how many times).

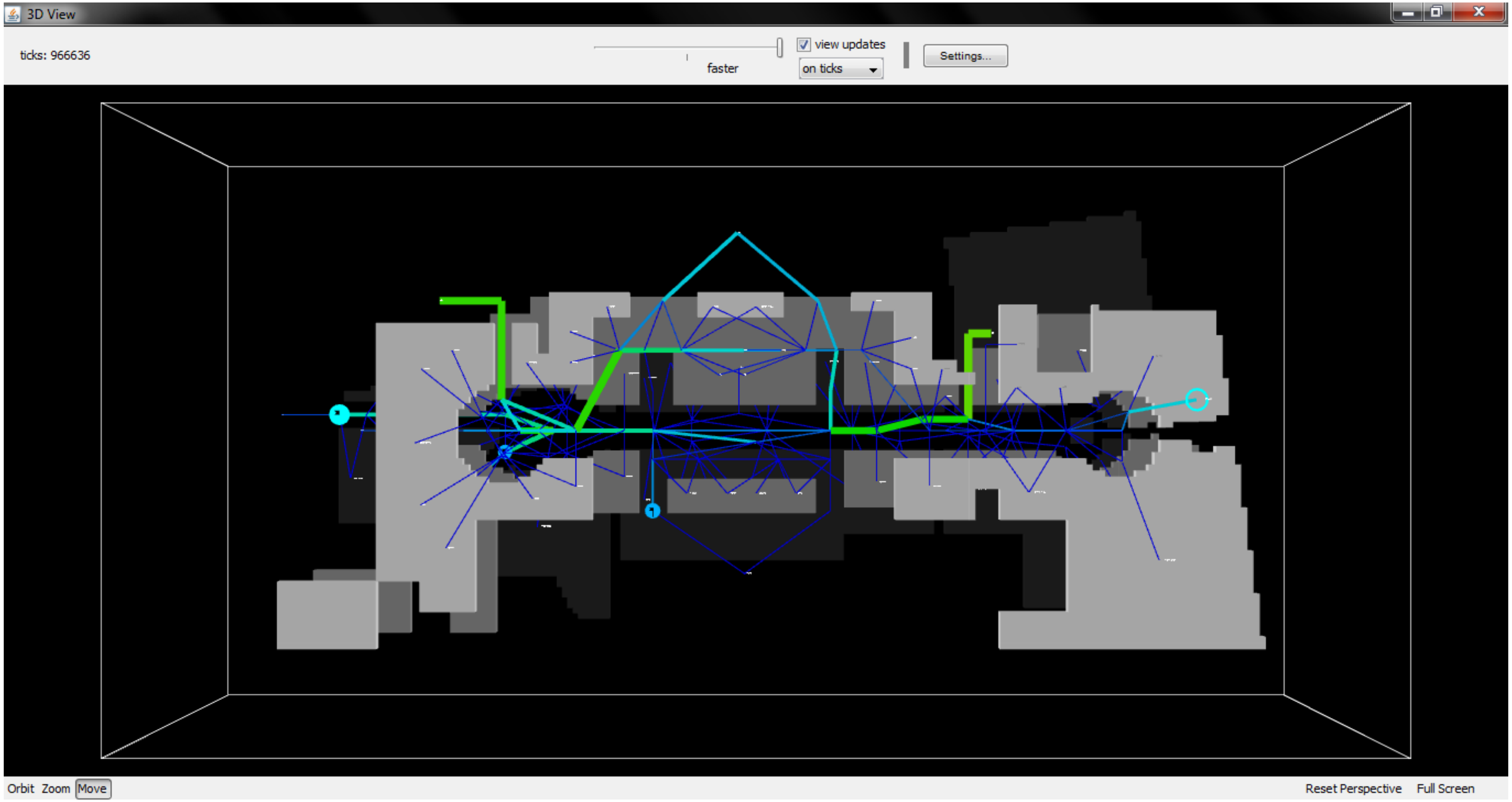


Figure 4.29 : Bubble Diagram: Visualizing Usage and Throughput; plan view.

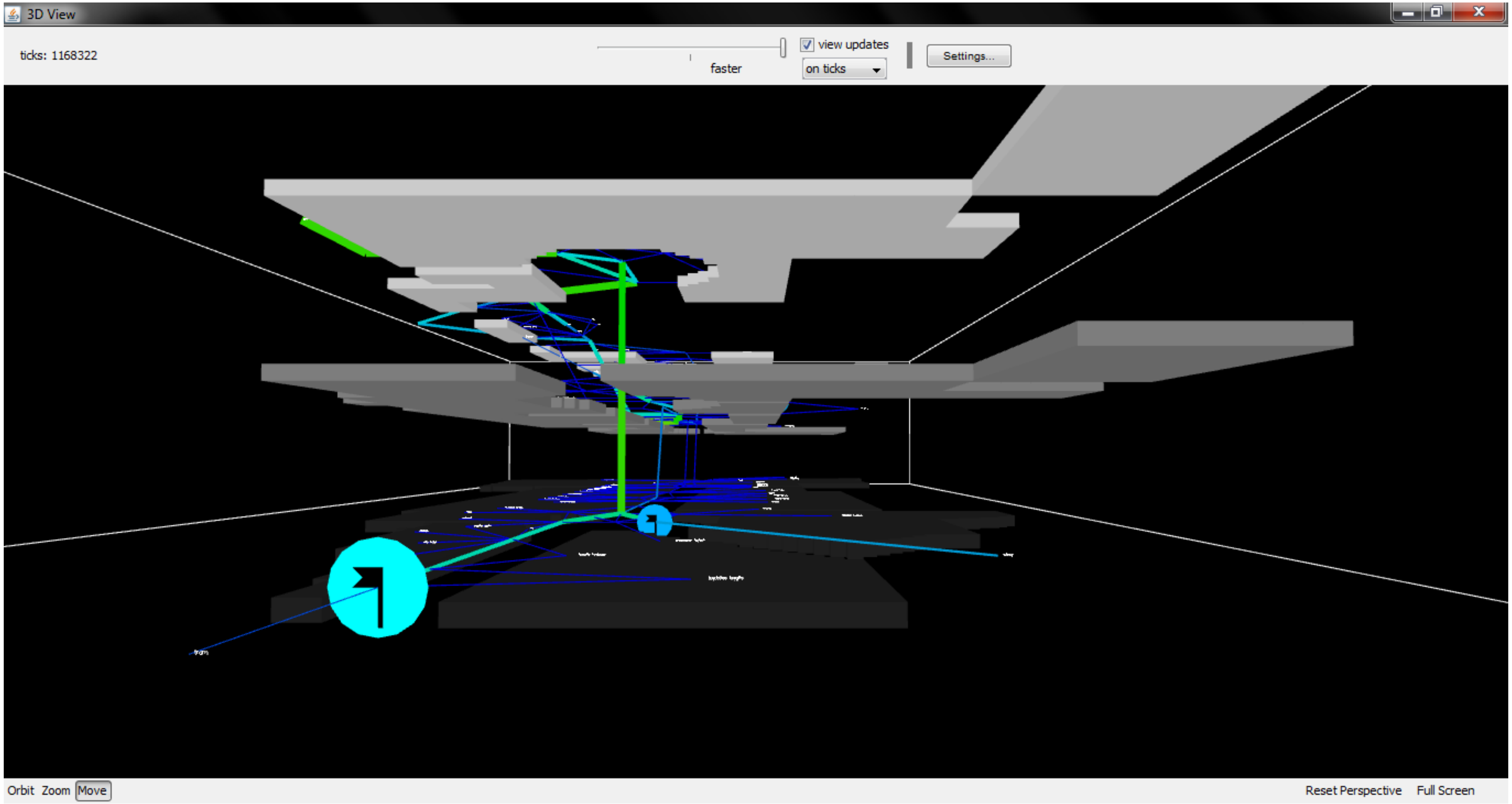


Figure 4.30 : Bubble Diagram: Visualizing Usage and Throughput; perspective view.

Figure 4.31 : Visualizing Occupancy on cell-based environment; plan view.

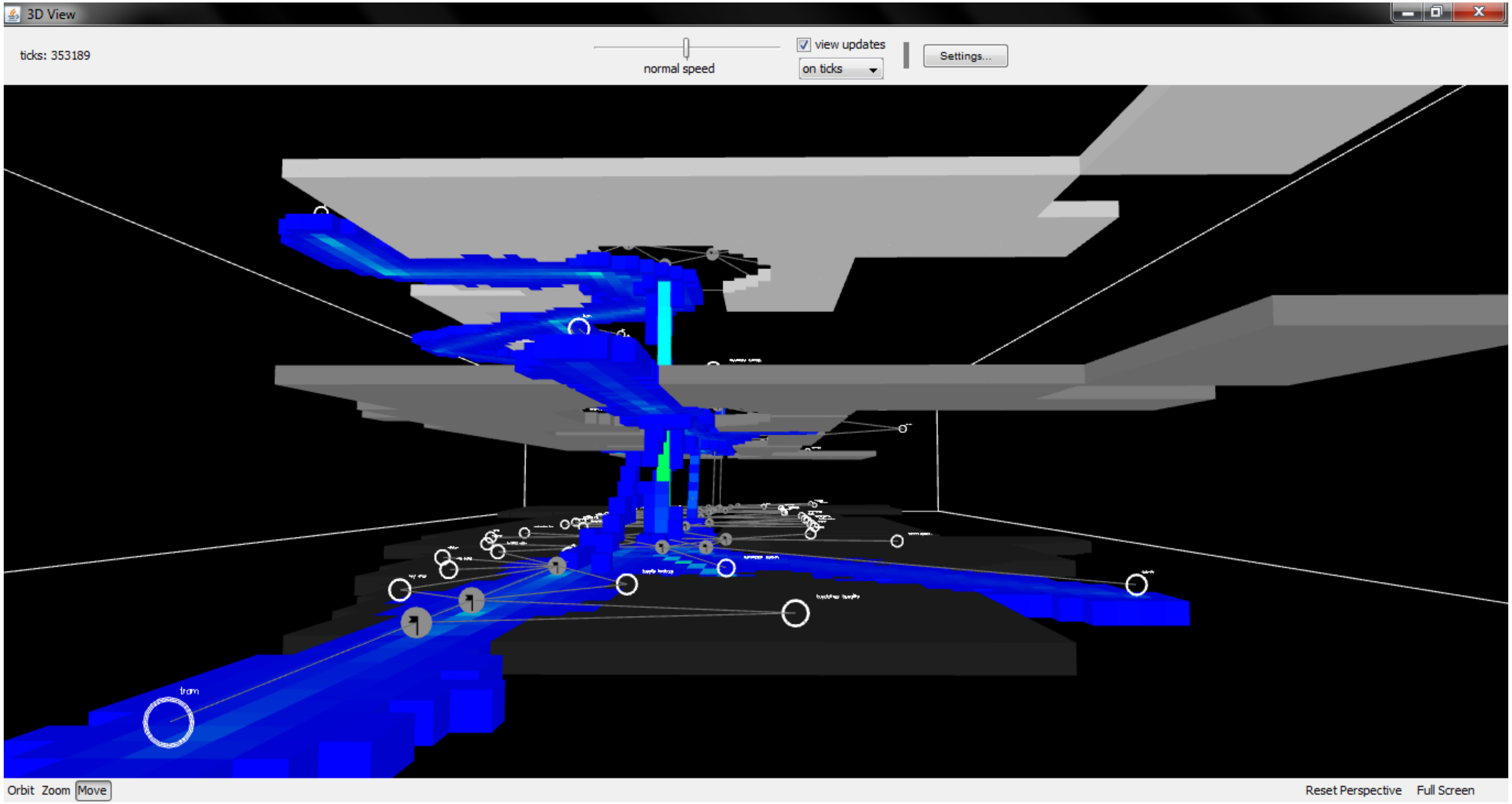


Figure 4.32 : Visualizing Occupancy on cell-based environment; perspective view.

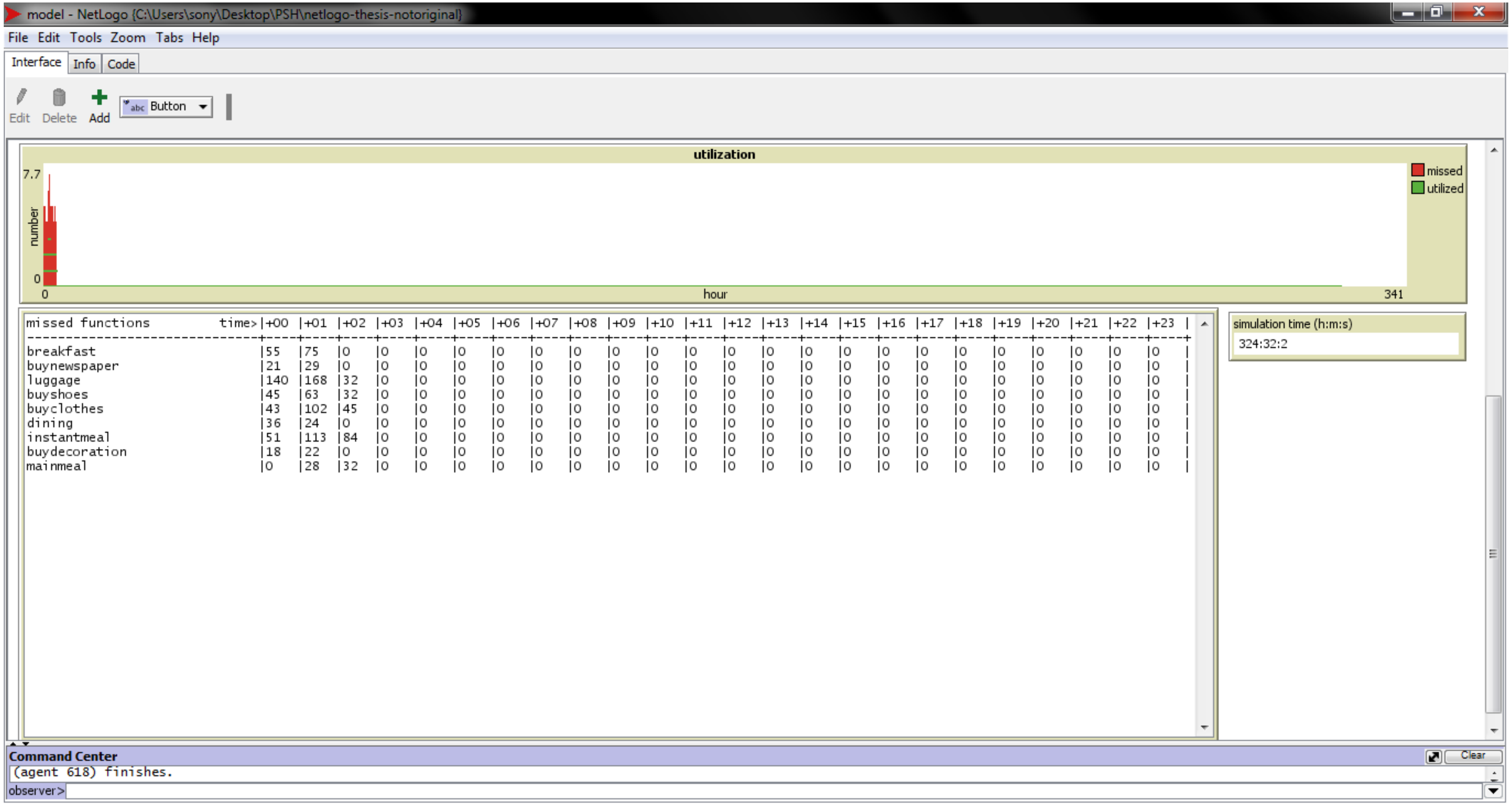


Figure 4.33 : Tables showing utilized functions and missed functions.

5. CONCLUSIONS AND RECOMMENDATIONS

This research focused on development of a test bed that can be used for analysing the space utilization in railway stations and further improving the use of spaces by means of user participation. In the course of the development process of our system, we have developed a user-oriented approach in which the users explore a given functional program on their own demands. While doing this, we have prepared “what if” type scenarios, giving the possibility to question “what the users want and what they get”. These scenarios are turned into activity schedules (AS) detailed in terms of different types of users, their arrival time to the station, and time span for concluding their activities. The building data (BD) is imported as a path network in which all building spaces work as nodes and links.

Records of the simulation are visualized on the spaces and an analyst observing the current utilizations has the possibility to modify the inputs of the system (BD, AS) according to the proposed outcomes. Records of the simulation can also be used to inform people about the current situation of existing facilities (type, location, and capacity) as well as free spaces, which can be booked to be utilized. Booking requests can be done over digital devices directly influence the building data and therefore indirectly the simulation part.

The proposed simulation and test bed is intended for planning work but could as well be used in a real-time fashion (e.g. by tracking people at entrances, performing simulations based on statistic distribution of goals and predicting probable traffic in building areas). The installations for showing the results also to building users, thus allowing truly physical/virtual interactions, are already in place - in the form of screens in arrival halls or smart phone applications. When being used as an application for digital devices (e.g. smart phones, vending machines), the envisioned booking and info concept can allow people to interact with the physical environment in order to decide their next activities. This booking/info concept further improves space use by turning less or not used spaces into efficient spaces being utilized by people.

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