Agents' movement_towards the reformation of public space

Step 1: select | implement | observe crowd rules

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In order to enable designers to envision the behaviour of pedestrians with reference to specific environments, computational models of crowds and their movement become indispensable tools of evaluation as well as tools of creativity. In this paper, the model under development constitutes a generic model which incorporates ideas about agent-based systems. The simulation program comprises a support system for the designer to place virtual users in a context that bears analogous environmental traits of the area under study. The design problem which is addressed by the implementation deals with public squares for which the programmatic demands involve a broad spectrum of users of diverse idiosyncrasies. Our study attempts to elucidate how the variation in preferences of pedestrian movement which depend on various personal, situational and environmental factors, may influence the current use of a selected public space and underpin qualitative alterations compared to its initial design. The intent of the methodology is not to create a predictive tool of naturalistic human movement but to explore how spatial configuration can be assessed and developed through a simulation model of pedestrian behaviour.

Keywords: *Crowd simulation, Spatial behaviour, Pedestrian movement, Public space*

INTRODUCTION

Crowd simulation has attracted the interest of several disciplines which, among others, are involved in organization and formation of public space. In spite of the fact that their principal aims are diverse, their specific scopes bring into focus pedestrian movement as a way of grasping and measuring traits of human spatial behaviour. The design of spaces that address the plethora in needs of an individual as well as the diversity of a crowd's consistency (as it occurs in public spaces) may benefit from an envisioning of how it could perform given particular assumptions on the usage conditions and the behaviours of the autonomous entities composing the crowd which would populate it. Outlined here is an investigation of pedestrian movement behaviour in the public space of a town square in the city of Athens, based on agent interaction and rule-based behaviour structure. The current project has been developed as a conceptual paradigm as well as a testing benchmark, aiming to produce a simulation of movement and behaviour of people in a public place, particularly the Syntagma Square, taking into account:i) simulated preferences and needs for each simulated agent separately, ii) the structure of space on a hierarchical and functional level, iii) the diverse qualities and conditions that the spatial clusters host and iv) the impact that the agents' aggregation and movement has over the other agents decision making and movement.

PEDESTRIAN MOVEMENT: MODELS

Simulation models

Research on pedestrian behaviour and more specifically movement has illustrated that there can be different simulation models which are in terms of scale, broadly categorised into three levels: macro, meso, and micro (Turner and Penn, 2002). Pedestrian studies have initially focused on a macroscopic level suited to transportation modeling, largely describing the characteristics of the flow rather than those of the individual pedestrians (Al-Gadhi and Mahmassani, 1991; Blue and Adler, 1998). The system's basic scope is space allocation for pedestrians in the pedestrian facilities without much interest in the direct interaction between pedestrians (Teknomo, 2002). On the other hand, as Turner and Penn (2002) describe, the mesoscopic level studies present a good example of urban-level simulation, referring though mainly to traffic modeling than pedestrian flow (Nagel et al., 1996; Daganzo, 1994). Microscopic pedestrian studies, in contrast to the aforementioned, conceive every pedestrian as an individual and measure the behaviour of pedestrian interaction (Helbing and Molnár, 1997; Hoogendoorn and Daamen, 2007; Pauls et al., 2007). Currently, literature's interest has shifted towards the models that operate at the level of individual pedestrians, trying to provide an overview of the impact that infrastructural change may have on pedestrian activity and behaviour (Kerridge et al., 2001). By incorporating the developed project in the design process of public space, one gains insight on the composite nature of crowd behaviour and movement and the complex outcomes that these processes have in the actual use of public space. Since knowledge of the possible outcomes of such complex systems cannot be acquired beforehand, that is before the actual use of the space by the users, the development of simulations and their incorporation in the design workflow may have a tremendous impact in the production and the evaluation of public space. During the project development, apart from pertinent research concerning human behaviour, knowledge and techniques developed and used by the game industry have been of significant impact, since currently, realistic simulation of crowd behaviour and movement has been proven a key feature in the acceptability and the engaging factor of games. To that end, algorithms, methods and solutions have been implemented, expanded and customised, within Unity 3D game engine, in order to respond to the necessities and needs of this particular research.

Implementation models

As simulation techniques have been ameliorating over the last decade with advances in computational technologies, various pedestrian simulation models have been studied through sophisticated behavioural algorithms. In terms of implementation characteristics, different approaches have been followed which can be classified mainly as:

Cellular Automata-based models (Blue and Adler, 1998; Hoogendoorn et al., 2001; Burstedde et al., 2001) whose dynamic behaviour is founded on the formula describing the state of a cell for the next time step, contingent upon the state of its neighbouring cells. Broadly, in CA-based models as one cell vacates, another cell is being occupied, thus rendering movement.

Force-based models (Helbing and Molnár, 1995; Okazaki and Matsushita, 1993) in which a physics approach is used in order to model pedestrians. Crowd movement in this case, is subject to behavioural forces resembling to gases, fluids and granular media.

Agent-based models (Schelhorn et al., 1999; Kerridge et al., 2001; Kukla et al., 2003) which exploit the analogies of interactions taking place among an assembly of autonomous agents with those deriving from the dynamic system of pedestrian behaviour.

DESIGN PROCESS: MOVEMENT

So far, modeling and simulation of pedestrian movement scenarios rely on the differentiated assumptions that stem from each researcher's goal, conceptual framework and tool of implementation. Most models of pedestrian movement behaviour address the prediction and assessment of pedestrian performance in the existing built environment. Methods in which movement behaviour influences and defines spatial design and organization, supporting the design process on its various stages, have not been adequately studied and tested. Nonetheless, the application of models, that can be scripted based on human movement behaviour rules and data, can significantly contribute to tackling design tasks whose complexity (as met in urban environments) due to asymmetrical and conflicting gravitational factors can often hinder the investigation of design possibilities. Therefore, the goal of this research is to develop a generic model that will allow different designs to emerge, be compared and selected according to the way that users negotiate space through movement. Thus, the structure of such a model should follow closely the human movement principles that condition the pedestrian behaviour in urban space, indicating the need for detail and suitability of a microsimulation approach (e.g. obstacle avoidance) that could probably also extend to a meso-scale one (e.g. individuals planning multi-stop trips). In such a model every pedestrian is treated as an individual unit whose movement characteristics are valorised. Respectively, the aggregate level of the pedestrian crowd is formed by taking into account the values of movement parameters and by complying with predetermined behaviour rules of acting and interacting. Insights to these elements can be acquired from pertinent literature that deals with empirical data. Of these, the most significant include walking speed and spatial use. Walking speed is affected by several factors which are contingent on personal characteristics of pedestrians (e.g. age group, gender), features of the urban infrastructure (e.g. attractiveness, protection) environmental conditions (e.g. weather, ambience), as well as pedestrian density (e.g. free flow, traffic hindrance) (Daamen and Hoogendoorn, 2003; Hoogendoorn and Daamen, 2007). Spatial use, on the other hand, comprises both lateral and longitudinal measurements of pedestrian walkway and can vary according to the number and type of entities (obstacles, other pedestrians etc.) that can alter the initial walking trajectory and speed (Willis et al., 2004).

DESIGN PROCESS: AGENT MODEL

Specifically, this approach aspires to delineate the behavioural elements concerning the pedestrian experience of space which are transparently embedded within the environment and have not necessarily been integrated to the initial design process. In order to incorporate diverse pedestrian characteristics and embody the range of factors influencing pedestrian behaviour an agent-based approach is implemented, offering the ability to simulate autonomous heterogeneous entities inside an environment, which enables their perception, interaction and action (Bandini et al., 2005). Agent models have been used to simulate various implications of pedestrian movement and are distinguished among different approaches for their quality of being akin to reality and therefore inherently suited to simulating people and objects in very realistic ways (Castle and Crooks, 2006). As Bhatta explains (2010), these models, while operating in a bottom-up way, have the ability to simulate the simultaneous operations of more than one agent, in an attempt to re-create and predict the actions of complex phenomena. For example, agents have been employed in order to: examine how the elaborate organisation of urban networks affects pedestrian movement (Resnick, 1997), to establish the correlation of pedestrian behaviour with route choice (Schelhorn et al., 1999); to study the dynamics of pedestrian behaviour in streets (Kerridge et al., 2001).

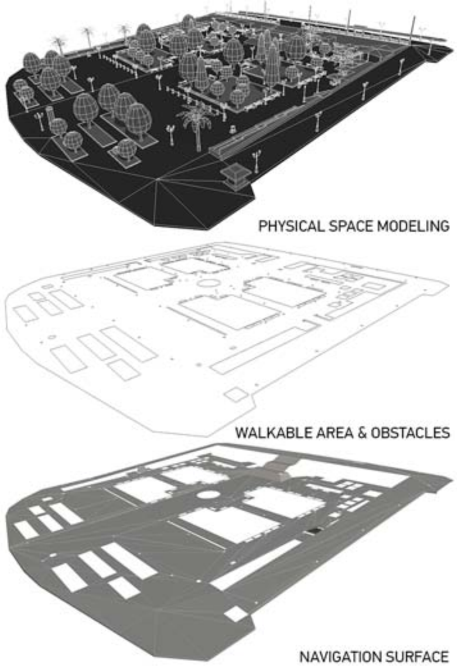
Figure 1
Syntagma Square _Town square in the city of Athens, Greece Original Photo: A.Savin 28/6/2013 Licensed under the terms of CC-BY-SA 3.0/FAL

IMPLEMENTATION: DESIGN TASK

The design problem which is addressed by the implementation deals with public space and in particular, public squares. The example of Syntagma square (figure1) in the city of Athens offers variety in types of users, levels of actions and interactions, environmental features and conditions etc. The selected town square is located in the city centre and constitutes a landmark and point of interest with frequent use during day and night. Its size in spite of its significant role in socio-political and commercial activities is relatively moderate compared to other European town squares. The eastern side of the square is higher than the western. Both, the northern and the southern side of the square include two green areas with shade trees, while in the centre of the square a large water fountain is located. Moreover, Syntagma Square comprises a hub for many forms of public transportation and is located within walking distance from several historical sites, government buildings, shops and offices. It is within the scope of this research to employ micro-scale principles with regard to the detailed movement coordination of agents (e.g. collision avoidance, speed variations, interactions rules) in combination with features that can also appear in meso-scale trip organisation and wayfinding (e.g. decision making, arrangement of connectivity graph among goal locations) following simple rules of interactions. The model's aspiration is to enable the visualisation of human movement into virtual spatial configurations, and thus, provide a testbed for animation experiments that can contribute to the designer's understanding and creative thinking.

The implementation consists of a tentative framework for a pedestrian movement model which incorporates agent-based modeling techniques, assigning values of various parameters to individual agents representing pedestrians, and defining rules that act upon them.The model is informed by observational studies of human movement behaviour in urban spaces providing measurements regarding preferred speed and distance that people like to maintain around themselves. Agent systems emerge as a conceptual paradigm to simulate the interaction of autonomous agents in an environment; specifically, they facilitate the investigation of the individual's behaviour in micro-level associated to the patterns emerging through the interplay of numerous individuals in macro-level (Popov, 2009). A multi-agent system is composed of a number of possibly heterogeneous agents that act and interact within and possibly with their environment. Furthermore, aiming at dynamic environmental conditions and physical interactions, the current research utilises a cross-platform game engine that facilitates the simulation, Unity 3D. Nowadays, video game culture and artefacts are highly accessible and provide new media for designers to extend the physical spaces of built architecture into meaningful virtual domains and gather useful experience with yet to be constructed projects (Burrow and More, 2005). The model developed here synthesises algorithms concerning the navigation and collision-free pathfinding process of the pedestrian agents, as well as their steering behaviour in cases of static and dynamic threats such as other agents in complex environments. By doing so, the implementation aims to combine the advantages of the constituent algorithms (presented in the following section) in order to identify the selected town square's current use in terms of pedestrian movement and delineate possible behavioural elements that have not been integrated to the initial design process.

Figure 2
Layers of the model



Model structure: constituent tools

The model can be briefly described as an agent-based model that simulates movement behaviour within a 3D virtual environment that represents the area under study (figure 2). The structure of the model is outlined in the diagram presenting the key-features that compose the implementation script (figure 3). The pedestrian agents act according to predefined rules, navigational preferences and activity goals that the program user has set. Variation to the aforementioned is embedded according to differentiated: agent types (based on personal characteristics of pedestrians: age, gender, level of mobility, size etc.), trip specifications (walking purpose, flexibility of activity agenda), and environmental features (surroundings' characteristics, function of the pedestrian area and weather conditions). The agents may choose to modify their navigational plans in response to their surroundings, the behaviour of other agents or the activities that take place nearby presuming they fit in their agenda. The decision making process relies on the agent's activity goals that are taken into account by a multiplicative factor (based on the agent's activity hierarchy and the proximity of the challenging activity) returning a weighted outcome that defines the agent's current state. The selection of action alternatives depending on weight can lead to always picking the one with the highest weight. This feature leads to a deterministic model. As such, the model may result to having several actions dominating whereas others are being ignored.

Furthermore, as is often the case with actions that have very similar weight totals, an unfair disregard for the runner up occurs. As Kukla et al (2003) indicate, a solution to this shortcoming is to make a random choice, such that actions with a higher weight have simply greater chance of being selected. Following the outline of its state, the agent runs through the specifics of its forthcoming actions taking into account the distance between its current location and the following target's location. This information is stored and translated within the abstract data structure of a navigation mesh (figure 4). Navigation mesh is a technique to describe the traversable surface of the 3D environment using a set of convex polygons. Due to its simplicity and high efficiency in 3D representations, navigation mesh has become a mainstream choice for 3D games. According to the number of sides of polygons, navigation mesh can be cat-

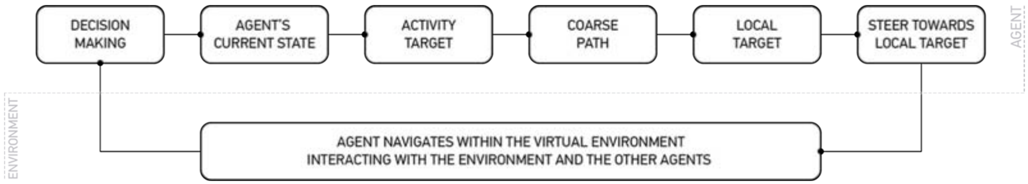


Figure 3
Diagram of model structure

egorized into triangulation and polygonization. It is a highly intuitive floor plan, which agents can use for navigation and pathfinding in virtual worlds (Cui and Shi, 2011). Thereupon, the A* algorithm is applied in order to configure the optimum path (Hart and Nilsson, 1968). A* constitutes a robust heuristic search method for many problems, pathfinding just being one of them. For pathfinding in particular, A* algorithm repeatedly examines the most promising unexplored location it has traced. When a location is explored, the algorithm has completed its task if that location is the goal; otherwise, it makes note of all that location's neighbours for further exploration (Cui and Shi, 2011).

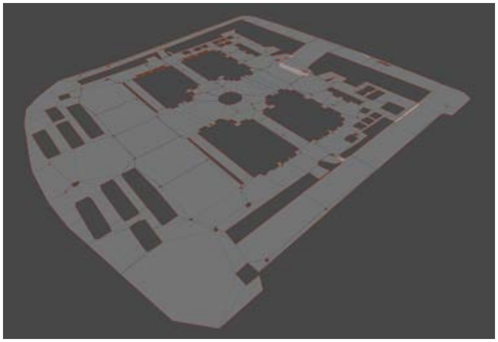


Figure 4
Syntagma Square _Navigation Mesh

The square's moderate size and geometrical characteristics facilitate the endeavour in terms of agent-perception, allowing the assumption that actual pedestrian vision can in this specific case, be established through a territorially pre-informed agent. Based on the above, A* can be applied avoiding encumbering computational cost. In different spatial configurations where familiarity of the surroundings cannot be included in the predefined knowledge of the agent, adjustments of the program should take place. For the refinement of the resulting path, the implementation of funnel algorithm computes the shortest Euclidean path between two points in a triangulated polygon in linear time (Hershberger and Snoeyink, 1991). Hence, in order to reach the activity target, the path is analysed in a series of "local" targets. During their attempt to reach a particular goal location, the agents navigate through the virtual environment and interact with features of the environment as well as with other agents. Apart from carrying information regarding their heading and route formation, the agents also convey instructions on how to deal with obstacles that remain stationary or have dynamic behaviour such as its own. Rule-based approaches use various conditions in order to identify the situation of an agent and once that is defined, then the rules compute what steering decision the agent should make (Kapadia and Badler, 2013). The development process has been based on a range of computerised tools and libraries, which being modified according to the requirements of the specific case study, have been combined in order to address the needs of the simulation. The assembly of algorithms include primarily the Recast & Detour (open source toolset developed in C++, implementing navigation mesh, and A* pathfinding) by Mononen[1]; the respective Unity adaptation, CAINav, implemented by Pratt[2]; as well as, the OpenSteer (C++ library helping to construct steering behaviours for autonomous characters in games and animation) by Reynolds[3], and its transcription to UnitySteer (builds upon OpenSteer and OpenSteer-DotNet, ported to Unity) by Méndez[4].

Case study: Syntagma Square

The experimental model is based on empirical data that are retrieved from related literature (Willis et al., 2004; Daamen and Hoogendoorn, 2003; Ishaque and Noland, 2008) focusing on features that compose the individual pedestrian's characteristics and situational factors that affect walking speed and spacing behaviour: i) age, ii) gender, iii) level of mobility, iv) trip preferences and purposes, which are assigned to different pedestrian types that assemble the pedestrian crowd of the square: i) children/adults/elder, ii) women/men, iii) carrying weight/walking with company, iv) travelling towards work/going for shopping/seeing the sites. The program is implemented by using mean values of the aforementioned parameters from observational data in order to provide a generic testbed for further calibration in the future. However, it is within the intentions of this study to coordinate the agents according to measurements deriving from the town square and determine the overall composition of the pedestrian population associated with the area per se in terms of different types of people and their activities, so that the designer can have an imminent estimation of the spatial use under study. The changing pedestrian circulation according to day and night hours or diverse weather conditions can also be of interest based on attractiveness and comfort. Broadly, each pedestrian represented by an autonomous agent moves in virtual space (whose general plan is presumed as familiar or easily discernible due to the square's geometrical characteristics) towards a predefined target location. Initially, the emerging movement patterns are underpinned by the assumption that agents follow a path that comprises relatively straight lines and select the more short and suitable route that meets their requirements and purposes. However the actual path followed, affected by local interactions, is not merely a linear path abiding by the fact that actual people do not move in strictly straight trajectories and don't always follow the shortest path (Conroy Dalton, 2001; Golledge, 1995). The agents' navigation includes fulfilling predefined needs and interacting with mobile or immobile entities. Particularly, each agent begins its itinerary at a given walking speed and navigates through space towards a final location target according to the respective type of user that the agent represents. The pedestrian type is also intertwined with the complementary activity agenda that an agent is presupposed to undertake should the opportunity is given during its journey. At the same time, spacing preferences (distances maintained from other pedestrians or infrastructure objects), environmental attractiveness (shaded zones during summer or sheltered spaces in rain, lighted paths during night-time), steering restrictions or affordances are also considered and calculated providing a range of walking speeds and avoidance distances. Syntagma Square is being studied as a confined area with specific entry points from which agents appear. These pedestrian gateways are points of pedestrian street crossings (with traffic lights regulating the crowd's movement), stairs that connect the upper with the lower part of the square, metro station entrances near the centre of the square. During a model run, agents are despatched from these entry points and start their navigation to the modelled area (figure 5).

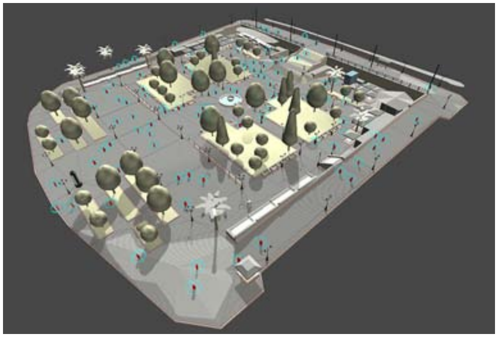


Figure 5
Agents _Navigation

Each agent has an intended destination and within the flexible or rigid limits of its preconfigured activity schedule, its movement evolves as a sequence of closer targets, like a sequence of nodes inside the navigation mesh. Should the surroundings within a certain range induce the initiation of an activity, then the agent pursues its updated goal, refines its schedule and redefines its path respectively based on weighted factors that satisfy the agent's needs and preferences through the shortest possible route.

Rescheduling and adjusting represent tasks which are computed on the fly, including the variations in speed, direction and spatial use which contribute to the detailed behaviour of agents. Variations of this sort, allow different and unpredictable behaviours to occur in the dynamic setting (Haklay et al., 2001). The 3D model of the square offers an elaborate virtual environment in which the agent population negotiates space, and thus, the program-user has the opportunity to observe the movement decisions as well as the crowd's overall pedestrian behaviour while analysing or organising spatial configurations of the modelled area.

CONCLUSIONS

The amount of information embedded in built environment questions the self-sufficiency of traditional design representations that can be significantly enriched by incorporating alternative methods such as animation techniques and virtual environments, in the design process. Enhancing the simulation model with diverse types of agents (representing pedestrian users) to act autonomously, and interact, enables the exchange of information between agents and the environment to take place in virtual terms and be imprinted onto the architectural creation procedure. It is within the scope of this paper and from an architectural point of view to examine the attempt to develop a pedestrian model in three-dimensional environment that follows principles of human movement behaviour. Within the framework of a case study that deals with public space, the program has been found useful to observe and evaluate movement behaviour. By observing the situated virtual users while navigating on their own simulated volition through the virtual model of the environment under study, the designer has the opportunity to discover under different terms the reciprocal relation between space and its users. The model's geometry is representative of built-form offering direct visible results of the agents' behaviour inside the 3D environment and therefore, achieves to promote potential exposure of any hidden parameters facilitating the role of the designer. Being based on the established familiarity with the 3D visualisation tools which contemporary architects use, the model takes precedence over more abstract approaches. Based on the above, the simulation model can be used in different levels of design investigation, like micro and meso (see Simulation models section), providing the rules of movement behaviour that the scale of the model necessitates.This can be very helpful when imperative decisions on the selection of design solutions are made as it provides the basis for scientifically justified solutions where otherwise decisions could only stem from theoretical assumptions or basic and biased experience. The investigation, through simulation models, of how the various personal, situational, and environmental factors, shape pedestrian behaviour, reflects the designer's need for an interface through which a putative urban space can be constructed and explored; thus, enabling a more comprehensive appreciation of the use and formation of space. Combining empirical data with several techniques of movement simulation applied in the film and game industry, the experimental model can be used as a complementary investigative design tool for pedestrian behaviour in relation to spatial organisation, requiring further expression and elaboration by traditional manual acquirements.

FUTURE WORK

As research objectives for further investigation, principal goal will be to identify potential inadequacies of the present design and articulation of space in question, and stress the need for improvements (these may refer to mere addition of signage systems or to intricate suggestions of re-routing pedestrian paths). Additional aim will be to obtain empirical data deriving from video recordings of the pedestrian behaviour exhibited at the public square in question and compare the simulation's results to the findings inferred by the collected observation data analysis.

Furthermore, as a following step in the development of the project, the interaction of the crowd with the structure and the features of space will be implemented not only as a one way relationship "space affecting crowd", but also as a dialectical relationship "space and crowd reciprocally influencing each other". Based on the aforementioned, crowd behaviour and movement will be studied as a factor that shapes and transforms the crowd's surrounding space in the early stages of the design process rather than after construction.

ACKNOWLEDGMENTS

This research has been co-financed by the European Union (European Social Fund - ESF) and Greek national funds through the Operational Program "Education and Lifelong Learning" of the National Strategic Reference Framework (NSRF) - Research Funding Program: Heracleitus II. Investing in knowledge society through the European Social Fund.

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