Virtual reality and recommendation system to design mobility system

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***Abstract*— In the domain of urbanism and more particularly the design of mobility system, the end-users are poorly involved whereas they condition the success of new infrastructure. The generalization of policies for active mobility urges the importance of correctly design the system of mobility. The success goes through the consideration of end-user needs. However, there is always a gap between the needs of the users and reality. We assume that virtual reality can ease user-centered design approach by letting the users experiment the technical solutions. Although maps and mockup permit exchanges between designers and end-users to improve the final design, this research assume that immersive environment is more efficient. Virtual reality seems to be a relevant tool for a user-centered approach applied to mobility system. The difficulty remains providing the adapted information to the designers who are the responsible to make the decision of the solution. The aim is not only to use virtual reality in the design process but also suggests a methodology to imply users in the design process and assist the designer during the decision-making.**

Keywords- virtual reality; recommandation system; mobility system

I. INTRODUCTION

Creating new mobility system in urban space requires a long process from the programming of the activities, design the solution, up to validating and uses of the end-users. During this process, it is difficult to evaluate the final satisfaction of the end user. It is necessary to involve user as soon as possible in the design process to make evolve solutions. However, requirements and suggestions from end-users to designers are only possible on the basement of knowledge and experience of their everyday life. It remains difficult to end-users to imagine themselves into the solution suggested by the designer and evaluate it. A way to initiate the dialogue between end-users and designers remains the creation of prototype but creating it at human scale requires human and financial investment. If it is directly experimented on existing infrastructure, it could also represent a risk for the image of the company and eventually induce trouble to regular end user.

The concern of this research is about implying end-users in the design process of urban mobility systems while reducing risk and delay. In order to imply the end-users and collect information about mobility usages, there is three approaches: interactive online platform (crowdsourcing), direct experience with the solution, and the users survey [1]. Information collection can be active, as users give information intentionally, or passive, by collecting information about users' activity. Since information actively given by the user is based on their personal experience and implies verbalization bias. The first and the last approaches permit to collect information from the users in an active manner. The second approach of collecting information that consists to let users experiment physically the prototype of mobility system and observe their behavior. This passive collection of information is difficult to observe and expensive to implement. From the implementation aspect, Virtual Reality (VR) offers perspectives of a fourth approach to obtain information from the end-users by creating immersive environment of the mobility system [1]. In the domain of product design, VR is an intermediary step between sketches and the human scale prototype, however VR representations does not seem to bring a better understanding of the product notably due to the limits of simulating physical/tactile interaction [2]. In the field of architecture, VR permits to validate relations between the infrastructure and it environment [3]. However, application of VR technology to collect user information in the field of mobility has not been explored yet. Due to the use of digital environment, the collection of information can be automated in order to provide faster the valuable information to the designer. This can be done thanks to recommendation systems that are increasingly used to exploit user generated content [4].

In order to improve the design of mobility system, we admit the postulate that VR permits to collect information about the solutions of mobility systems and validate it based on the analysis of the information. VR permits to recreate situations closed to real situations that ease the user to project himself into use situation and so express recommendations based on this experience. Digital environment also permits to collect information of their behaviors that are mostly tacit. Based on these aspects, the issue of this research can be summarized by the following question:

How assist the user-centered design process thanks to virtual reality?

The hypothesis of this research is that approach from recommendation system can be introduced in the experimental process of validation in order to provide feedback to designers.

The first part of this article will present a state of art about the mobility of individuals, virtual reality and recommendation system. The second part will present the proposed methodology. Then, the third part will apply the methodology to the case of a train station and detail the software architecture associated.

II. Virtual Reality and Recommendation System Applied to Mobility

This research is focused on the individuals' mobility during their daily travel. The terms transport, mobility and travel will be used indistinctly to mean the movement of a person from a point A to a point B for any transport modality (walking, train, car, bus, bike…). First, the individual mobility will be presented, and then virtual reality and recommendations system will be reviewed in the perspective of mobility.

A. Individuals Mobility

Exchange hub is the system that organizes and eases the connection between different transportation modalities. It is a way to manage and help users to change the transport modalities [5]. Although there are different modalities for daily travel, this work will focus on the walking travel as it is the most common travel modality that permits to access to the other modalities. Improvement of the individuals' mobility on a territory implies the improvement of the user experience in these exchange hubs. The improvement of these exchange hubs implies the understanding of the humans' movement and their simulation.

1) Improving Hub

In order to stimulate the use of these exchange hubs and so the various travel modalities offered, it requires making these infrastructures more attractive. This improvement implies the modernization of the infrastructure for modalities exchange, lounge space, waiting area, arrival and departure signage, signage required for users' orientation, and needs' satisfaction of the reduced mobility persons [6]. The expected impact of this improvement is to increase the use of transport by people for any physical conditions, age, and culture [6]. In order to conceive these improvements, it requires setting up indicators. One of the first indicators is the satisfaction of the user. The second is the travel time between from a position to the transport [7]. This indicator is notably used for simulating crowd and users.

2) Simulating Users

Simulation is done to study the behavior of pedestrians in a place and design the signs that help them to orient during their daily life or emergency situation [8]. It is also used in the field of building construction, designing pedestrian zone [9] or designing pedestrian crossing [10]. The modeling and simulation of pedestrians permit to identify influencing factors of individual behaviors. There are two categories of factors: individual factors and environmental factors. One example of individual factors could be the fact that women walk slower than men [11]. The mean speed of men is around 1.5 m/s whereas mean walking speed of women is around 1.2 m/s [12]. The speed is also influence by others individuals factors as the physical conditions, the age and the occupation of the person [13]. For example, a housewife that use the public transportation for doing shopping has a better mobility than her husband [14]. The environmental factors also affect the behaviors of the users. According to [14], there are two kind of environmental factor :

- Physical environment from the interaction between the user and the infrastructure
- Social environment from the interaction between users

These factors are as elements to consider in order conceiving a building and an infrastructure dedicated to receiving persons. However, tools as SimWalk, which ease the design of building and urban space [15] or NetLogo, which is notably used for model crowd evacuation [16], use generic and identical model for human modeling. In the perspective of designing user centered spaces and infrastructures, it is necessary to explore new tools and approaches to identify behaviors and feeling. One of these tools is virtual reality which has already been experimented for raise pedestrian awareness on crossing the street [15; 16]. Virtual reality technology possesses the characteristics required to experiment a place or a situation and collect information.

B. Virtual Reality for Mobility

Although it is studied since decades, the renewed interest for virtual reality is due to technical and financial evolution of head mounted display (HMD) and the relative accessibility of game engine. This section will present different application domain of virtual reality including mobility and design.

1) Application Domains

Virtual reality is used for understanding the characteristics of behaviors and factors of decision-making. It is also useful for sensitize and train persons for risky situation, treat phobia, or realize functional re-education. For example, the behavior and mechanism of decision-making for crossing a street was studied without taking risk thanks to VR [19]. Similarly, dangerous situations can be simulated to observe behavior as an hotel evacuation [20]. Also focused on the understanding of decisional mechanism, [21] tested the choice of the transportation according to gasoil price thanks to a VR game. From the point of view of learning and sensitizing, VR is applied in the industrial field as the academic field. For example, [22] simulated the activities of the assembling process of a metal frame in order to sensitize workers to security risks. In the academic field, the SimuSurvey experience explored the impact of VR on learning about mechanical assembly and sensitize students to engineering science [23].

2) Designing with Virtual Reality

During the stages of design and improvement of a space, the involvement of users could reach a better satisfaction and so better performance at the end of the project. This user-centered approach eases the decision-making of technical solutions based on the experimentation of various alternatives as for the design of lighting in a building [24]. According to the results obtained by [24], there is no significative difference between physical test and virtual test with RV. Based on the assumption that computer graphics are enough realistic, virtual simulation is an efficient tool to study behaviors and measure performance of different alternatives. Advantages are to permit the simulation of risky solution, totally control the environment and being able to quickly modify the virtual environment [18]. It also permits to realize more experimentations at reduced cost [18].

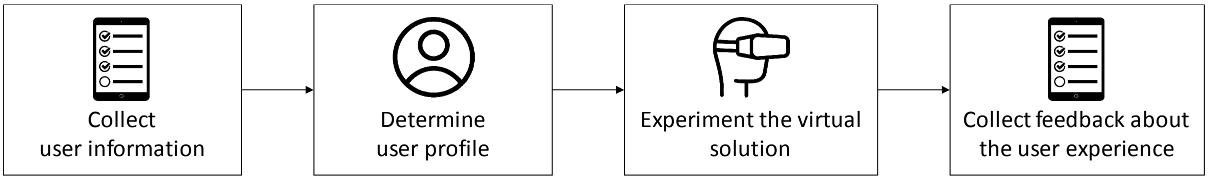

Figure 1. Stages of the user experimentation

However, VR admits several limits compared to physical experience notably concerning the interaction with object or movement. Wrong design or wrong equipment could induce motion sickness. As the actual issue does not concern the interaction with object, the different solutions will not be reviewed. In opposite, travel mode in the virtual environment has a direct impact on the perceptions of this environment and the results on the experimentation [21]. There are different techniques to travel in the virtual environment [25] :

- Natural walking when there is a direct relation between the move in the physique and the virtual environment.
- Redirected walking that correct the movement done in the physical environment that is limited to do it correctly in the virtual environment.
- Walk-in-place where the person mimics the walk to trigger moves in the virtual environment.
- Virtual flying that use devices as joystick to move in the virtual environment.
- Treadmills are devices that providing a better simulation of the act of walking without simulate obstacle and requires enough space to install it.

In this virtual environment, a large amount of data will be generated about the movement of the person. These data can provide information about the virtual environment and permits the evolution of the final solution. The next section will present the exploitation of these data in the perspective to recommend information to the designer.

C. Recommendation System

Recommendation systems (RS) are software tools and techniques providing suggestions for items to be of use to a user [26]. As it is highlighted by the author, "suggestions are related to various decision-making processes such as what items to buy, what music to listen to, or what online news to read". These approach and techniques are based on the observation that daily decisions often rely on peers recommendations [27]. RS ease the decision making when expertise and competences are missing but it is also a valuable tool for coping with the overload of information. The core of the recommendation system can be seen as the prediction of the utility of an item for a user [28]. The literature suggest various approaches to predict the utility of items that can be classified into six group [26]:

- Content-based: the system learns to recommend items that are similar to the ones that the user liked in the past.
- Collaborative filtering: the system recommends to the user the items that other users liked in the past.
- Demographic: the system recommends items based on the demographic profile of the user.
- Knowledge-based: it recommends items based on how certain item features meet users' needs and preference.
- Community-based: the system recommends items based on the preferences of the user's friends.
- Hybrid recommender system: these systems combine the above-mentioned techniques.

Although the present article talks about the users of mobility systems, the users of the RS are the designers of mobility solutions. In this context, the items, which are what the system recommends to the users, are the solutions of mobility systems. If RSs are primarily addressed to individuals who lack experiences or competences to make a choice between items, the aim of this RS is not to reach the satisfaction of the designer but those of the final users by influencing the decision of the designer. The next section will present the methodological approach to reach this goal.

III. METHODOLOGICAL APPROACH

In order to understand needs of users, it is necessary to collect information about its behavior in the virtual environment but also information that characterizes the user and there feeling about the experimented solution. Based on these requirements in term of information, we defined an experimental process composed by fours steps as illustrated by the Fig. 1. The virtual simulation of the mobility system is only one step of this process; the others are prerequisite to analyze data. Each step is described in the following subsections.

A. Collect user information

The demographic information about the user and notably personal information, needs and habits are collected thanks to a survey in order to determine the profile of the user.

B. Determine the user profile

This demographic information permits to adapt the virtual environment in order to observe the expected behavior. Thanks to these information and a sorting model, a user can be classified into a user group that share several characteristic and determine their specific behavior and needs in term of mobility [29].

C. Experiment the solution with virtual reality

By presenting the adapted environment and use case, it is possible to study how the solution of mobility system responds to needs and expectations of the users. In order to process this study, moves are record to observe how users adapt to different scenario [21].

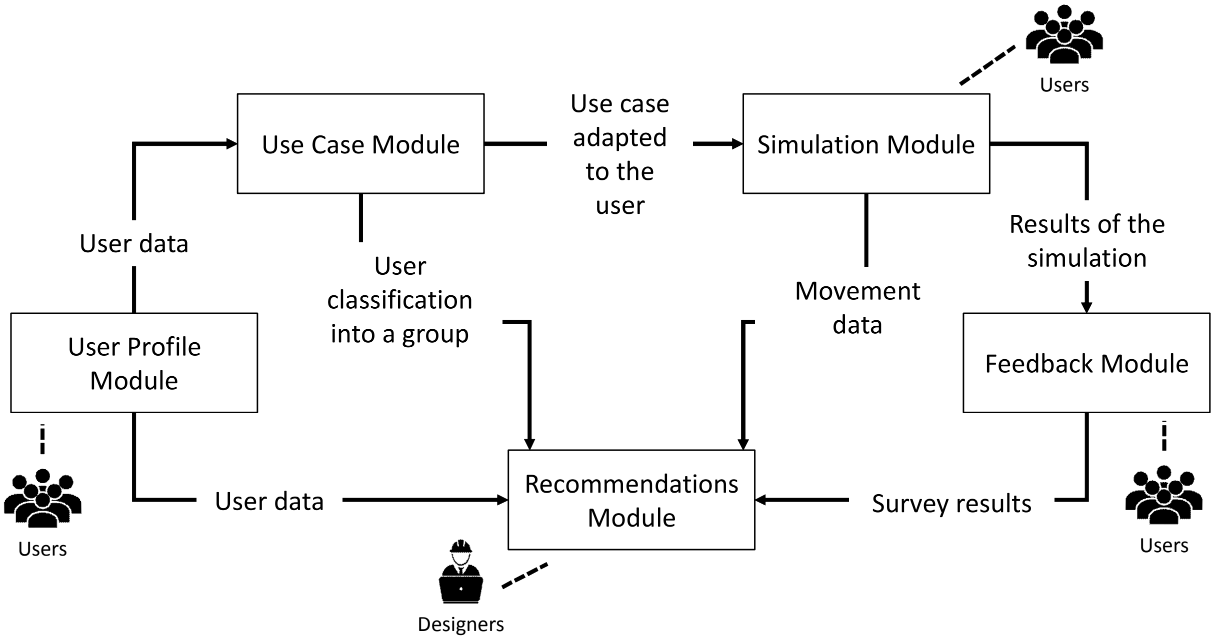

Figure 2. Architecture of the evaluation system

D. *Collect feedback about the experience*

After the explorations of the virtual environment through VR device, a second survey is done to collect feelings about the virtual solution of the mobility system. These experience feedback are required to evaluate the different solutions and so provide data to the recommendation system that would process it and suggest the best design solutions [30].

IV. DESIGN SUPPORT SYSTEM FOR MOBILITY SOLUTION

During the research, the case study was about assisting the design of the mobility solutions at proximity of the train station at Nancy, France. The aim was to facilitate the design of the improvement of mobility system by placing users in situations tanks to VR technology. The design support system was developed based on the methodology presented previously, the architecture of the design support system has been built from six modules as represented in Fig. 2 that are detailed in the following sub-sections.

A. *User profile module*

As presented in the methodology, the first step is about collecting information about the user who is going to experiment the virtual solution. There two kinds of information collected: demographic information (gender, ages …) and mobility habits (vehicles used, public transportation, frequency, distances, motivation …). This information was collected through a responsive web survey system developed in PHP and SQL. The information was collected thanks to a digital tablet then it was transmitted to the use *case module*.

B. *Use case module*

The aim of this module is to assign a simulation scenario to the user that permits to do meaningful observation based on their behavior. It means that if the person is accustomed to the train station, asking her to do its routine will not permit to observe the impact of the modification of the infrastructure on its behavior. The different scenarios are defined in collaboration between the virtual environment designer and the urban designer. Based on the information collected by the user profile module, the user is classified to one of the user group that is associated to an experimentation scenario. The use case module also manages the environmental variable as the density of the crowd that populates the environment, the luminosity, the weather and the time of the experimentation.

In this study case, the model for sorting users consider was three different scenarios (table 1). The model was created thanks to a clustering algorithm with RapidMiner [31] based on the profile of four researchers about their mobility habits. The affectation of the scenario to a user was done according to their use frequency of the various transportations available around the train station.

C. *Simulation module*

The simulation module concerns exclusively the virtual environment. The user is invited to put on the HMD in order to experiment the virtual environment of the mobility system. According to the classification of the user by the use case module, the instructions are given to the user and then the experimentation of the virtual environment starts. In background of the experimentation of the solution of mobility system, coordinates and head orientation of the avatar played by the user plus boolean presence indicators for several areas in the environment are recorded. This data is shared with the *recommendation module*. By default, data is generated for each image rendering which the frequency may vary according to the workload of the computer that is rendering the virtual environment. In order to have an order of magnitude, the standard image frequency of 60Hz can be considered that means 7200 coordinates for 2 minutes of simulation.

TABLE I. DESCRIPTION OF THE USER GROUP WITH THEIR ASSOCIATED OBJECTIVE AND SCENARIO DESCRIPTION

User group	Objectives	Description
Never or sparsely use the tram	Find the tram station	User starts the experimentation by exiting the train. He has to walk through the train station to find the exit corresponding to the tram station.
Never or sparsely use bicycle	Find the bike-park	User starts the experimentation by exiting the train. He has to walk through the train station to find the bike-park.
Never or sparsely use the bus	Find the bus station	User start the experimentation by exiting the train. He has to walk through the train station to find the exit corresponding to the bus station.

For this study, the virtual environment was modeled with SketchUp [32] and Blender [33], and then compiled for HMD with Unity [34]. The device used for displaying the environment was the HTC Vive. Due to the technology, the travel technique exploited was the combination of natural walking, which is permitted by the HTC Vive and the Virtual Flying thanks to controllers. Two solutions of infrastructure were modelled and experimented in virtual reality:

- actual signs of the train station (Fig. 3 left)
- lines on the ground (Fig. 3 right).

Once the experimentation was finished, the information was send to the *feedback module* to start automatically.

D. Feedback module

Once the experimentation of the solutions ends, the feedback module starts in order to collect the feelings of the user about the solution experimented through a survey.

The survey was designed to be a list of questions with two opposite adjectives and a 10-position scale. With the same technology as the *user profile module,* this survey was displayed through a digital tablet at the end of the virtual reality experiment.

E. Recommendations module

As illustrated by the previous Fig. 2, the four modules provide information to the *recommendations module*. It aims to process the data collected to suggest the best solution to designers.

The *recommendations module* was designed to have a hybrid approach. This approach is due the hybrid feedback that is implicit for the part of data about positions and explicit for the information directly collected from users thanks to surveys. This information was collected into a SQL database and sorted into five tables:

- Personal information required to build a digital profile.
- User habits needed to build a model of the user groups. This model is used by the use case module to attribute a scenario to a person.
- Positions of the users, the time to achieve the instructions and transits on defined areas in the virtual environment.
- Feedback from the users about the solutions of mobility systems.

The suggestion of the best infrastructure solution to the designer is done with the AHP method. The criteria used for the application of this method was the achievement of the instructions, the time to achieve it, the feedback about the solution experimented and the number of users who succeed the instructions.

V. PERSPECTIVES

One of the perspectives is the validation of the methodology in situations with users and designers. The entire tool was developed but the validation of principles functionalities was done in laboratory by the authors. However, some improvements have been identified. The first one in the proposed architecture is the adaptation of the classification model of the *user profile module* progressively users are surveyed. The second improvement is the analysis of the amount of data generated by the simulation module about travels and movements in the virtual environment. These two improvements imply to further explore machine learning aspects. The implementation of these improvements implies to respond to verify the feasibility to apply the machine learning algorithm to data from VR.

Another perspective emerges concerning the use of VR based on researches about evacuation [16]. It could be interesting for studying the environmental, social and

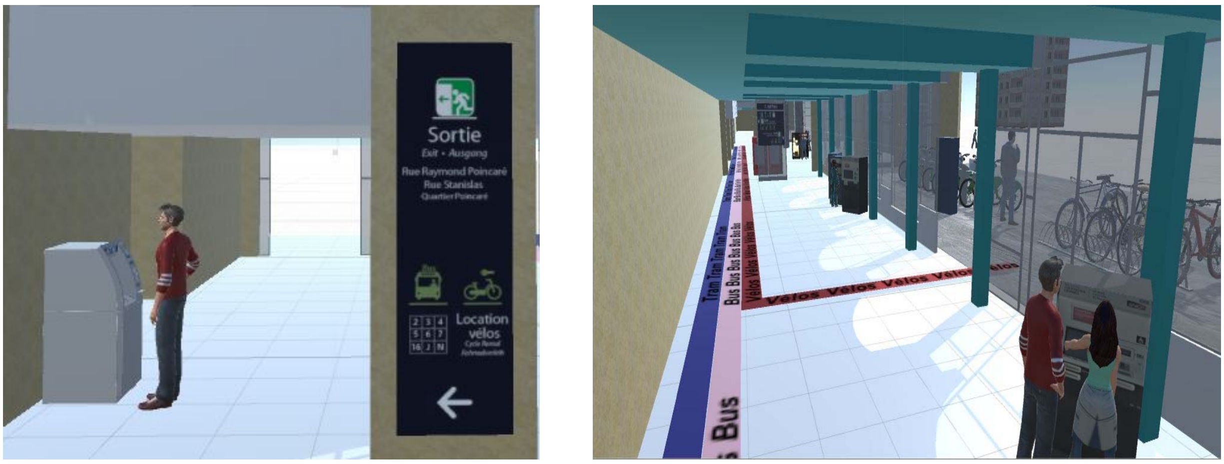

Figure 3. Left: example of actual sign in the virtual environment; Right: example of ground signs in the virtual environment

individual factors to put a person into a VR environment that simulate an emergency with digital agent.

VI. Conclusions

This research aims to propose a new approach to integrate the user in the design process of mobility system by exploiting the opportunity offered by virtual reality. This article presents a work in progress in the experimentation of using recommendation system with VR during the design process. The technical aspect has been developed. The experimentation is actually limited to functionalities testing. The next step is to use it with real users. The progress in the development of the design support system for mobility solution is encouraging for making evolve the user-centered design approach. Letting the users experiment the future mobility system in virtual reality permits to confront responses given in the survey by their behavior in the virtual environment.

To reliably support user-centered design approach with VR and design support system, some others aspects should be evaluated as the impact of the dimension and the openness of the virtual environment on the evaluation.

References

[1] H. Song, Q. Peng, J. Zhang, et P. Gu, « A VR-based Interactive System to Improve Users' Involvement in OAP Development », Procedia CIRP, vol. 56, p. 13‑18, 2016.

[2] M. Sööderman, « Virtual reality in product evaluations with potential customers: An exploratory study comparing virtual reality with concentional product representations », J. Eng. Des., vol. 16, no 3, p. 311‑328, 2007.

[3] W. A. Abdelhameed, « Virtual Reality Use in Architectural Design Studios: A Case of Studying Structure and Construction », Procedia Comput. Sci., vol. 25, p. 220‑230, 2013.

[4] F. Ricci, L. Rokach, B. Shapira, et P. B. Kantor, Éd., Recommender Systems Handbook. Boston, MA: Springer US, 2011.

[5] P. Ageron, « Université de Savoie L ' intermodalité-voyageurs au prisme de la mondialisation : vers la structuration d ' un méta-réseau intégré », 2013.

[6] Civitas, « Enhancing the quality of public transport services public transport services », Clean. Better Transp. Cities, p. 12, 2009.

[7] Transport for London, « Measuring Public Transport Accessibility Levels. PTALs: Summary », no April 2010, p. 1‑8, 2010.

[8] D. Helbing, I. J. Farkas, P. Molnár, et T. Vicsek, « Simulation of Pedestrian Crowds in Normal and Evacuation Situations », 2002.

[9] N. Ronald, L. Sterling, et M. Kirley, « An agent-based approach to modelling pedestrian behaviour », Int. J. Simul. Syst. Sci. Technol., vol. 8, no 1, p. 25‑38, 2007.

[10] A. Lili Lu, B. Gang Ren, C. Wei Wang, et D. Ching-Yao Chan, « Application of SFCA pedestrian simulation model to the signalized crosswalk width design », Transp. Res. Part Policy Pract., vol. 80, p. 76‑89, 2015.

[11] K. Fitzpatrick, M. A. Brewer, et S. Turner, « Another Look at Pedestrian Walking Speed », Transp. Res. Rec. J. Transp. Res. Board, vol. 1982, no 1982, p. 21‑29, 2006.

[12] F. H. Abadi, T. A. Muhamad, et N. Salamuddin, « Energy expenditure through walking: Meta analysis on gender and age », Procedia - Soc. Behav. Sci., vol. 7, no C, p. 512‑521, 2010.

[13] R. Knoblauch, M. Pietrucha, et M. Nitzburg, « Field Studies of Pedestrian Walking Speed and Start-Up Time », Transp. Res. Rec., vol. 1538, p. 27‑38, 1996.

[14] F. . Hodgson, M. Page, et M. . Tigh, « A review of factors which influence pedestrian use of the streets: Task 1 report for an EPSRC funded project on Measuring Pedestrian Accessibility », Transport, vol. 24, no 1, p. 103‑124, 2004.

[15] Z. A. Bohari, S. Bachok, et M. M. Osman, « Simulating the Pedestrian Movement in the Public Transport Infrastructure », Procedia - Soc. Behav. Sci., vol. 222, p. 791‑799, 2016.

[16] C. Natalie van der Wal, D. Formolo, et T. Bosse, « An Agent-Based Evacuation Model with Social Contagion Mechanisms and Cultural Factors », in IEA/AIE 2017: Advances in Artificial Intelligence: From Theory to Practice, Arras,France, 2017, p. pp 620-627.

[17] V. Cavallo, A. Dommes, N. T. Dang, et F. Vienne, « A street-crossing simulator for studying and training pedestrians », Transportation Research Part F: Traffic Psychology and Behaviour. 2016.

[18] S. Deb, D. Carruth, R. Sween, et L. Strawderman, « Efficacy of virtual reality in pedestrian safety research », Applied ergonomics. 2017.

[19] I. Feldstein, A. Dietrich, S. Milinkovic, et K. Bengler, « A Pedestrian Simulator for Urban Crossing Scenarios », IFAC-PapersOnLine, vol. 49, no 19. p. 239‑244, 2016.

[20] W. Klingsch, C. Rogsch, A. Schadschneider, et M. Schreckenberg, Pedestrian and evacuation Dynamics. 2008.

[21] M. Watcharasukarn, S. Page, et S. Krumdieck, « Virtual reality simulation game approach to investigate transport adaptive capacity for peak oil planning », Transp. Res. Part Policy Pract., vol. 46, no 2, p. 348‑367, févr. 2012.

[22] J. Irizarry et D. M. Abraham, « Application of virtual reality technology for the improvement of safety in the steel erection process », in International Conference on Computing in Civil Engineering, Cancun, Mexico, 2005.

[23] C. C. Lu, S. C. Kang, S. H. Hsieh, et R. S. Shiu, « Improvement of a computer-based surveyor-training tool using a user-centered approach », Advanced Engineering Informatics, vol. 23, no 1. p. 81‑92, 2009.

[24] A. Heydarian, J. P. Carneiro, D. Gerber, et B. Becerik-Gerber, « Immersive virtual environments, understanding the impact of design features and occupant choice upon lighting for building performance », Build. Environ., vol. 89, p. 217‑228, 2015.

[25] A. L. Simeone, I. Mavridou, et W. Powell, « Altering User Movement Behaviour in Virtual Environments », IEEE Trans. Vis. Comput. Graph., vol. 23, no 4, p. 1312‑1321, avr. 2017.

[26] F. Ricci, L. Rokach, et B. Shapira, « Introduction to Recommender Systems Handbook », in Recommender Systems Handbook, F. Ricci, L. Rokach, B. Shapira, et P. B. Kantor, Éd. Boston, MA, USA: Springer US, 2011.

[27] F. McSherry et I. Mironov, « Differentially private recommender systems: building privacy into the net », in Proceedings of the 15th ACM SIGKDD international conference on Knowledge discovery and data mining, 2009, p. 627–636.

[28] G. Adomavicius et A. Tuzhilin, « Toward the next generation of recommender systems: A survey of the state-of-the-art and possible extensions », IEEE Trans. Knowl. Data Eng., vol. 17, no 6, p. 734–749, 2005.

[29] R. Picot-Clémente, « Une architecture générique de Systèmes de recommandation de combinaison d'items: application au domaine du tourisme », Université de Bourgogne, 2011.

[30] F. O. Isinkaye, Y. O. Folajimi, et B. A. Ojokoh, « Recommendation systems : Principles , methods and evaluation », Egypt. Inform. J., p. 261‑273, 2015.

[31] RapidMiner, « RapidMiner, Data science platform », 2017. [En ligne]. Disponible sur: https://rapidminer.com/.

[32] Trimble Inc, « SketchUP, 3D model for Everyone », 2016. [En ligne]. Disponible sur: https://www.sketchup.com/.

[33] Blender, « Blender.org », 2017. [En ligne]. Disponible sur: https://www.blender.org/.

[34] Unity, « Unity - Game Engine », 2017. [En ligne]. Disponible sur: https://unity3d.com/. [Consulté le: 23-sept-2017].