SPACE AND MOTION: Data based rules of public space pedestrian motion

by

Paloma Gonzalez Rojas

Submitted to the Department of Architecture in partial
fulfillment of the requirements for the degree of

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[Abstract]
The understanding of space relies on motion, as we experience space by crossing it. While in motion we sense the environment in time, interacting with space. The vision of this thesis is to incorporate people's motion into architecture design process, enabled by technology.

Simulation tools that introduce human motion into the design process in early stages are rare to nonexistent. Available tools are typically used for deterministically visualizing figures and simulating pedestrians with the goal of analyzing emergency exits or egress. Such simulations are built without consideration for non-goal oriented interaction with space; this presents a gap for design. Additionally, simulations are generally governed by assumptions regarding people's motion behavior or by analogous models such as collision avoidance methods.

However, the use of data from people can elucidate spatial behavior. Advancements in depth camera sensors and computer vision algorithms have eased the task of tracking human movements to millimetric precision.

This thesis proposes two main ideas: creating statistics from people's motion data for grounding simulations and measuring such motion in relation to space, developing a Space- Motion Metric. This metric takes pedestrian motion and spatial features as input, seeks actions composed by speed, time, gestures, direction, shape and scale. The actions are elaborated as Space-Motion Rules through substantial data analysis. The non-prescriptive combination of the rules generates a non-deterministic behavior focused on design.

This research maps, quantifies, and formulates pedestrian motion correlation with space and questions the role of data for projecting what space could be.

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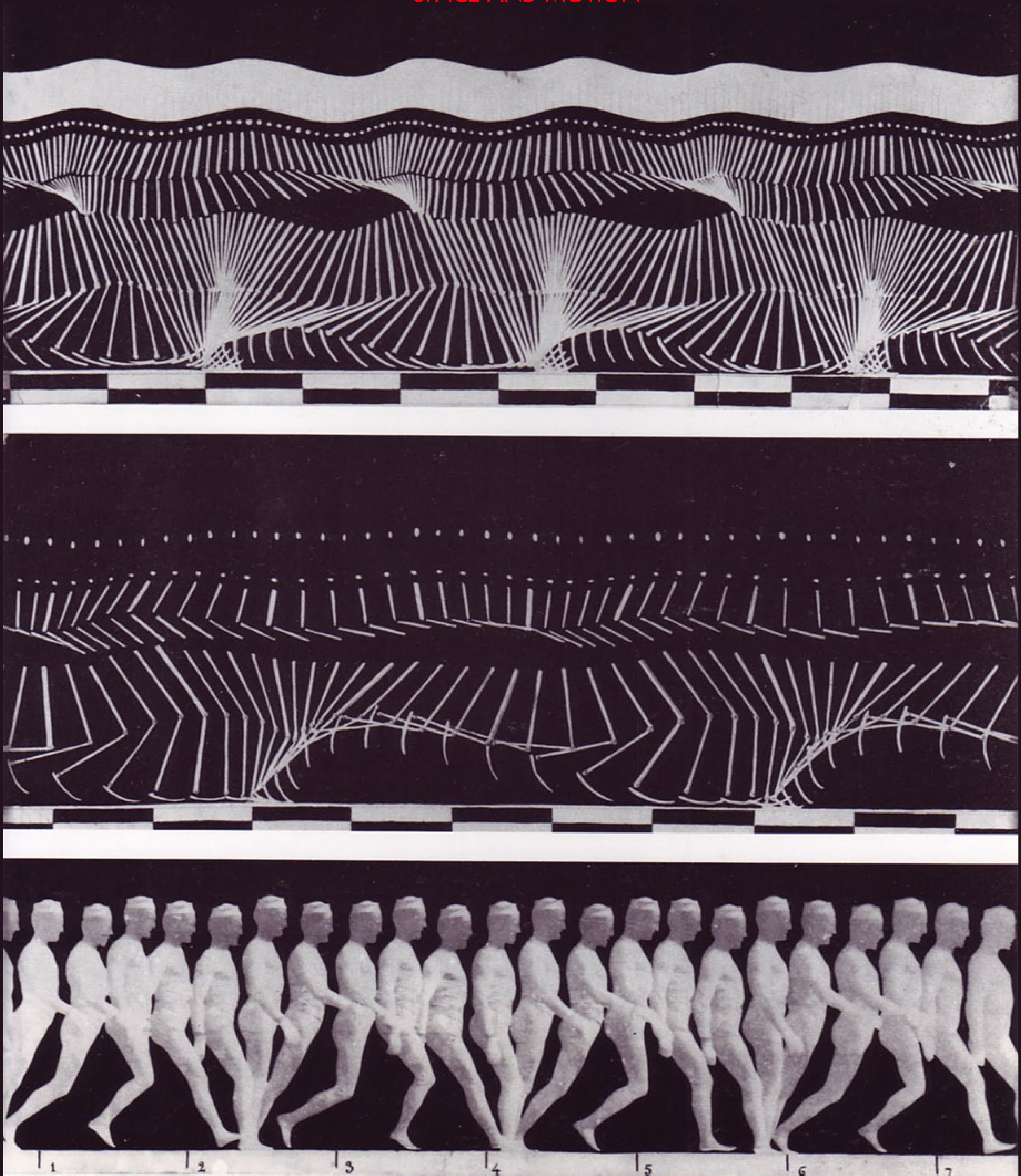
This thesis is dedicated to Diego, my family.

Cover: Etienne Jules Marey chronophotographs from The Human Body in Action Scientific American 1914. ("Chronophotographs from 'The Human Body in Action' – Experiments In Motion," n.d.)

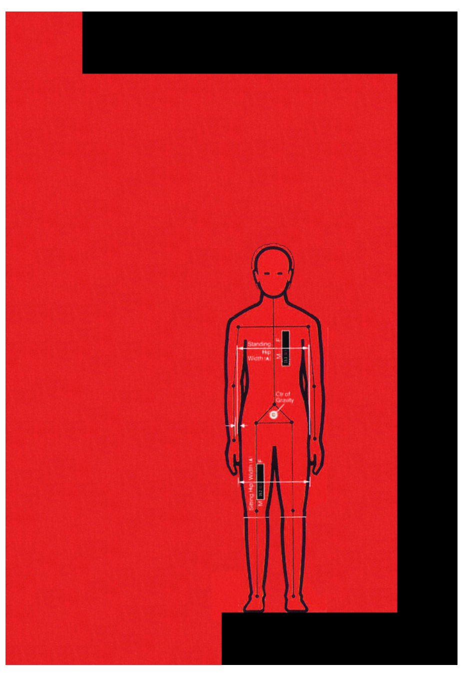
SPACE AND MOTION



data based rules of public space pedestrian motion

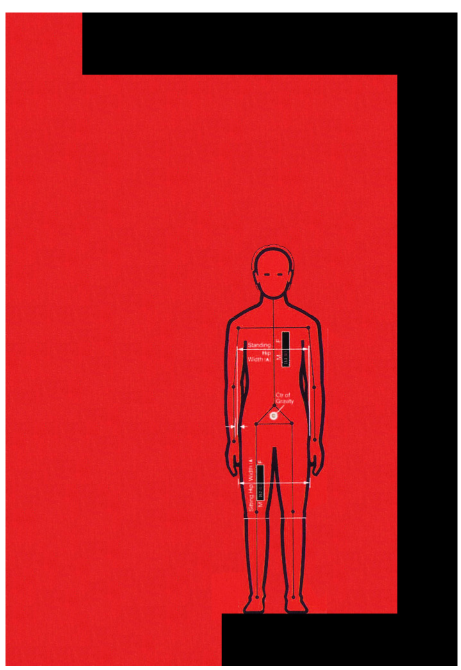
by Paloma Gonzalez Rojas.

TABLE OF CONTENTS



SPACE AND MOTION

[0.0]
INTRO



[0.1] Hypothesis/ Steps/ Intended Contributions

The understanding of space relies on motion as we experience space by crossing, is the hypothesis that forges this research. The thesis is an attempt to map, quantify, and analyze people's motion for purposes of understanding and creating space, and simulating motion in future research. The research follows the vision of incorporating people's motion into architecture design process in early stages, to connect space with its inhabitants.

Currently, motion is simulated for the utilitarian purposes of optimizing emergency exit or egress, and for films and other representational aims. Those simulations are governed by assumptions regarding people's behavior or by implementing analogous models as input, such as stochastic and particle systems or collision avoidance. In contrast, this research proposes grounding simulation on data from real people's motion, with the purpose of understanding their spatial behavior, and replicate it or explore probable scenarios.

The research produced a human metric for design, the Space-Motion Metrics, using as input people's motion, through observations on site, the analysis of the data, and architectural features. Data does not inform by itself, presenting the challenge of defining how to interpret it towards the spatial behavior of people. In this thesis I seek to demonstrate that it is possible to obtain quantified data of the impact that an architectural feature has over people's motion. The Metrics, embodies that challenge and measures the relation between both, people's motion and spatial features. The Metrics enable quantifying motion and pursuing empirical research about people's spatial behavior. Behavior is understood as a sequence of bodily movements. Sequences of movements are divided into parameter indicators, such as speed, time and gesture, that are possible to grasp and measure. The approach goes beyond efficiency in space use, to grasp foremost "spatial behavior" or "laws of use" following Cristian Valdes concept (2007) through measurable parameters. The "laws of use are explained in Background chapter, and refer roughly to the overall sense of how a space is occupied.

The Space-Motion Metric is framework of the collected data that lead to the formulation of the rules. Space-Motion Rule System correlates spatial features with people's motion statistical analysis. This advancement is a small step that grounds unprecedented research about people's motion interaction with space. Overall, the reflexion unfolds around a methodology designed as input for a simulation tool. Yet only part of the methodology is pursued due to the required depth of data development time constraints of the thesis. The developed sections are: collecting data, measuring and creating statistics from the data and finally formulating rules with people's motion indicators and spatial features.

From analyzing how people behave in space, the research develops new understanding of the phenomenon, by formally describing human behavior in space, through motion data analysis. Data collection implements depth sensor and video camera, recording data from people's motion in real world conditions, which means that people is not aware of being recorded and therefore behave naturally. For the analysis, pieces of software were developed in the context of this thesis for generating statistics. The statistics explore the parameters that integrate people's motion interaction with spatial features. The research questions how and why people move in space in time, in order to inform the design process. Enabled by technology, the research is a response to an historical disciplinary dispute, by proposing to design space through people's motion, it proposes the inclusion of time.

It becomes necessary to make explicit that the development of Space-Motion Metrics is likely to expose cultural differences in the data at macro-scale, while emphasizing the capability to project these local diversities to design. Furthermore, this conceptualization disrupts the idea of a standardizable design. Therefore, this thesis questions how data can be generalizable from one location to another or perhaps the impossibility to do so. In a sense, to analyze data from people's motion from different locations platform to discover our similarities and differences. To the best of my knowledge, such analysis that has not been systematically developed yet.

The thesis is divided in 5 chapters. The first chapter exposes the problem covered in Space-Motion proposal. Must highlight the importance of understanding the background of such proposal which is explained in the second chapter. In the third chapter the methodology for working with Space-Motion is explained and in the fourth chapter the methodology is tested with real data. Finally, in the fifth chapter the thesis go over the conclusions.

The intended contributions of this thesis are the following: Data Collection Methods, Data sets, as mentioned earlier, the Space-Motion Metrics for extracting indicators from the collected data, Space-Motion rules that correlate motion statics with spatial features. Proposing the study of space through motion, particularly its inhabitants motion, to test and enhance design.

Must highlight that the study does not intend to be definitive; the data is not enough to deliver generalizable conclusions regarding the connection between an architectural feature and people's motion. The aim of this research is producing a replicable methodology that translates dynamic data into generative rules, as a main to successfully investigate. The methodology is the main contribution of this research.. This line of questioning explores the role of data for design. Data visualization is for understanding existing space. Data simulation can be used for projecting how space will be.

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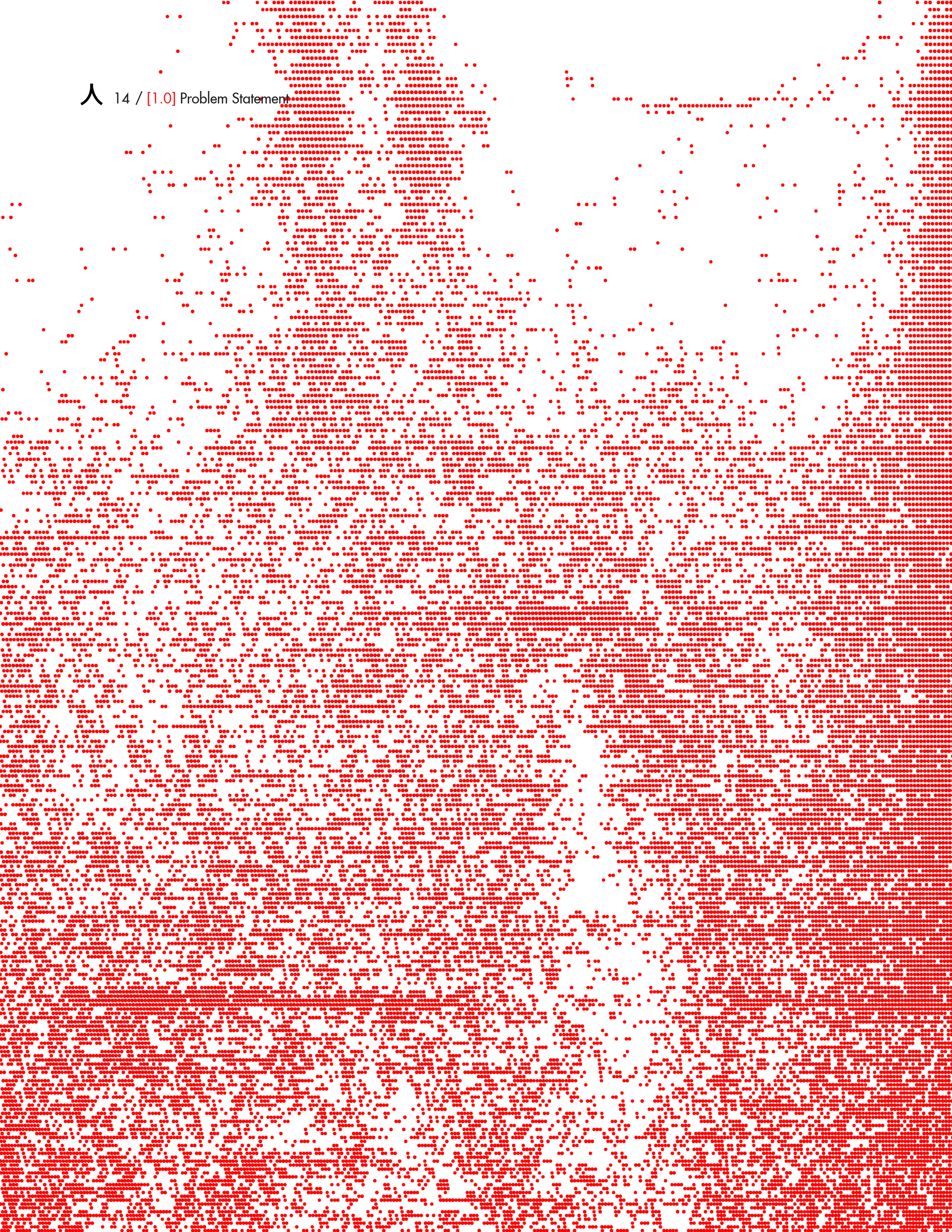


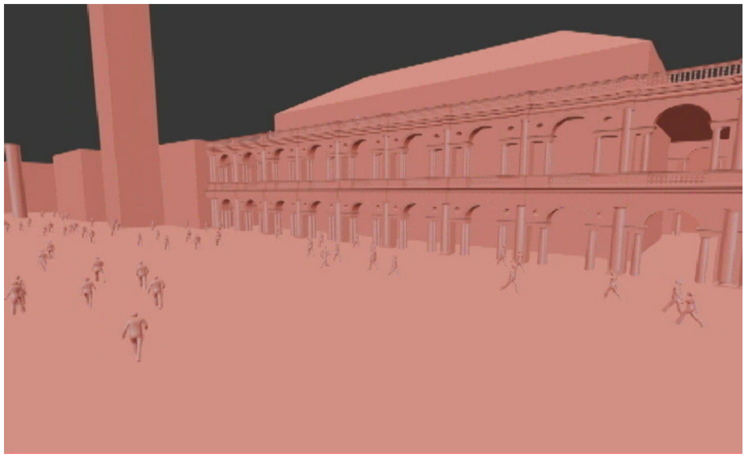
[1.0]
PROBLEM STATEMENT

Figure. 1. Thomas Eakins History of a Jump 1885. ("Chronophotographs from 'The Human Body in Action' -- Experiments In Motion," n.d.)

[1.1] People's motion in space

The book "The Songlines" about Australian natives writes, "because the Aboriginals were wanderers they… could not imagine territory as a block of land hemmed in by frontiers: but rather an interlocking network of 'lines' or 'ways to go through'" (1987). Perhaps how we move in space builds also our perception of space. Ann Pendleton-Jullian(1996) states: "The crossing is not intended as a means to arrive at another place but rather an experience that changes the perceived meaning of things." When we are still, we are not fully conscious about space surrounding us. While moving, however, we sense space, interacting with the environment and others. Furthermore, the problem that this thesis explores is developing the means to design space through motion. This line of questioning alludes to the prevailing conception in architecture of designing the static form of space, which is tangible and possible to grasp, over the changing dimension that holds problem, as Pa. Michelis(1949) and B. Latour(2005) confirm. This changing dimension, often explored in architecture as light transformations, is understood here as transformations in people's motion. By incorporating motion into the design process, time is introduced as well, as motion entails to think about the project in terms of a process, or more specifically, as a sequence of motion.

Simulation tools that introduce human motion into the design process in early stages are rare to nonexistent. Available tools are typically used for deterministically visualizing figures and simulating pedestrians with the goal of analyzing emergency exits or egress. Such simulations are built without consideration for non-goal oriented interaction with space; this presents a gap for design. As a result architects fail in connecting space with the motion of people that inhabits such space. Moreover, in the case of human behavior, additional degrees of complexity appear since the interaction between humans and with surroundings is unpredictable. However, human motion sequences could be translated to a set of parameters, that can be formulated into rules that would in turn generate a non-deterministic performance. The main challenge, is to define the parameter indicators and rules, which will be achieved by substantial data analysis.



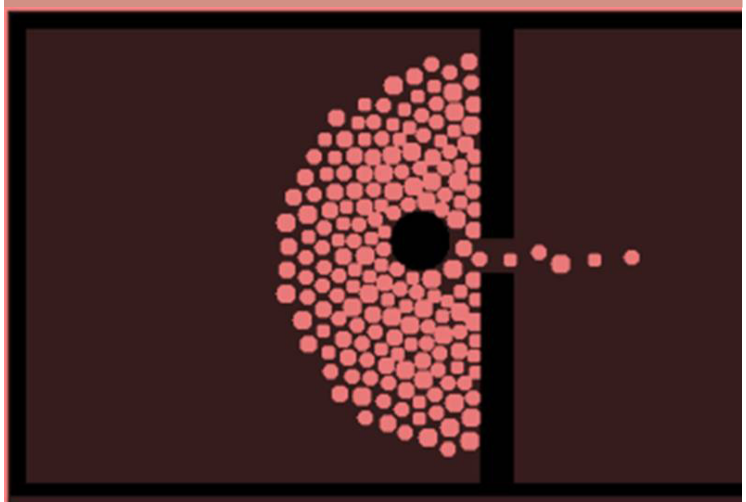


Figure. 2. Simulation of people walking in front of Basilica Palladiana.

Figure. 3. Emergency exit simulation. (“6.4. Escape Dynamics | Open Agent Based Modeling Consortium,” n.d.)

This thesis proposes two main ideas that have scarce precedents. Firstly, creating statistics from real people’s motion data for grounding simulations. Secondly proposes creating a Metrics to measure such motion in relation to space, as a set of indicators. The Metrics lead to developing rules as outcome of correlating both inputs. The thesis’s claim: by recording and analyzing people’s motion it is possible to extract indicators that affect people’s motion in space. This research maps, quantifies, and formulates pedestrian motion correlation with space and questions the role of data for projecting what space could be. One of the main problems regarding the study of people’s motion in space is the lack of empirical data, as Waldau et al. states (2007, p1.) In this thesis I seek to demonstrate that it is possible to obtain quantified data of the impact that an architectural feature has over some person’s motion.

The study focuses in people's motion, in order to produce empirical research. Precedent work regarding people's behavior in space has exposed the difficulty for people to verbalize spatio-temporal behavior and perhaps the impossibility of quantifying the phenomenon through verbal data collection as with surveys. Alexandra Milloniga, and Katja Schechtnerb stated in Environment and Planning Journal Paper about their research "...This is apparently especially true for spatio-temporal behavior,... is highly automated and humans are hardly fully aware of the factors influencing their decision (n.d, p.10.) Therefore motion data analysis is a reliable parameter to set the base of simulating spatio-temporal behavior to inform design. Consequently, it is require to develop a framework to measure motion data.

The Space-Motion Metrics were developed by observing on site the frequency of motion that could be correlated with space. The measurements take pedestrian motion and spatial features as input. Despite a thorough search in order to find existing metrics to gauge spatial behavior of people, or their motion towards space, no precedents were found, impulsing. Consequently the development of the Metrics is very valuable for the study of motion and space. The Metrics gauge actions composed by speed, time, gesture, direction, shape and scale towards spatial features. While speed and time are basic measurements, one of the most important advancements of the thesis is the conceptualization of the "spatial gesture." Gesture consists of a change or a combination of changes in bodily motion, such as change in gaze direction and an increase in walk speed. The spatial gesture correspond a series of movements of human interaction with space, as changing the gaze or the direction of the head pointing a spatial feature such as the upper floors of a multistory atrium. The development of the metrics of motion enables empirical research.

The Space-Motion Rules takes the results of the Metrics indicators to formulate rules based on statistics correlation with space features. The rules restrain considering the statistics as facts, but instead as a corpus of a behavior model. The rules are formulated by correlating the statistics with spatial features as breadth search, privileging collecting as many different samples of motion correlation with space as possible. For this thesis time frame, the main indicators applied in the rules are: speed, gesture and time.

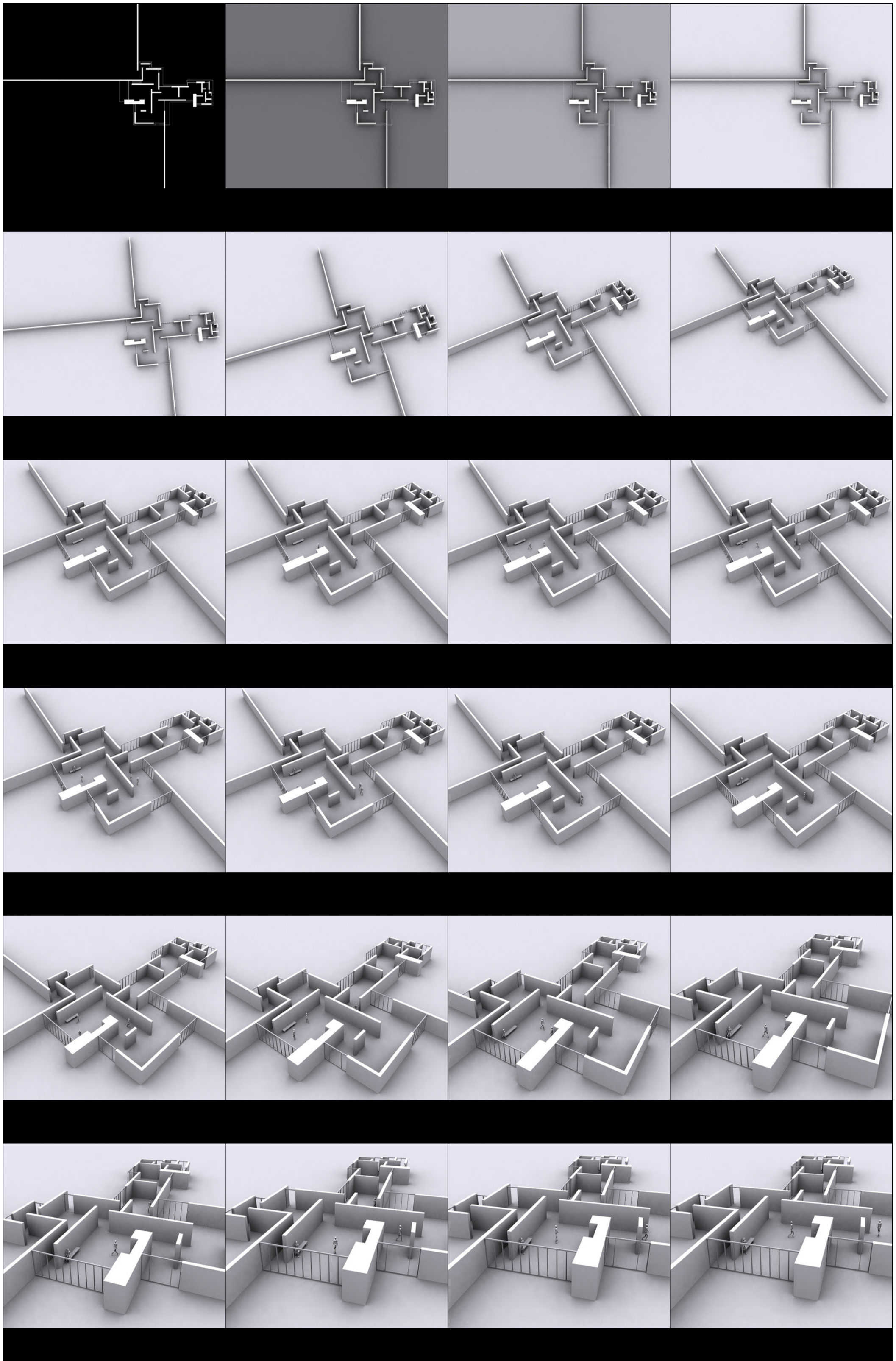


Figure. 4. Agent Based Simulation. Narahara, T. (2007). The Space Re-Actor : walking a synthetic man through architectural space (Thesis).

Different approaches to quantify people's behavior in space were developed within the architecture discipline. William H Whyte, measured the proportion of architecture elements such as benches in small public spaces in New York (2001.) Christian Valdes, developed a notation method to record the position of people inside of a house for a month, as argument for his final undergraduate project (2001.) Taro Narahara's a Master student of the MIT Design Computation group proposed incorporating people's reactions into the design process by simulating human response towards architecture elements (2007.) His analysis is similar to Whyte's seeking for the purpose of the behavior, and not how the motion is. Narahara developed the simulations by using stochastic methods to define how the agents act, this thesis proposes grounding the motion in data.

How: The proposed methodology to be developed into a tool latterly, consists of creating a tracking method to collect data. The second step is to quantify motion indicators applying the Space-Motion Metrics, and finally use those parameters to build rules. Consequently the thesis produces a methodology that translates dynamic data into a rule system.

The steps of the methodology are the following:

Step 1. Collect data: define a location, define position of devices, record with Kinect and video camera, observe the people on site. Collect data from people's motion in a public space from observer point of view with digital devices. The selected methods are Kinect sensor, which is a depth camera, that has built in software to recognize human skeleton and video camera, complemented with computer vision algorithms to extract the data. The data collections are performed in real world conditions, which means that people is recorded without them knowing. For this purpose I obtained a MIT COUHES Permission to perform research using human subjects.

Step 2. Analyze data: develop data visualizations, observe frequency of motion, develop the statistics from using the metrics. The indicators seek to describe the correlation between motion and space. The selected indicators are the following: Speed, Time, Gesture, Shape, Direction, Scale and Distance to elements.

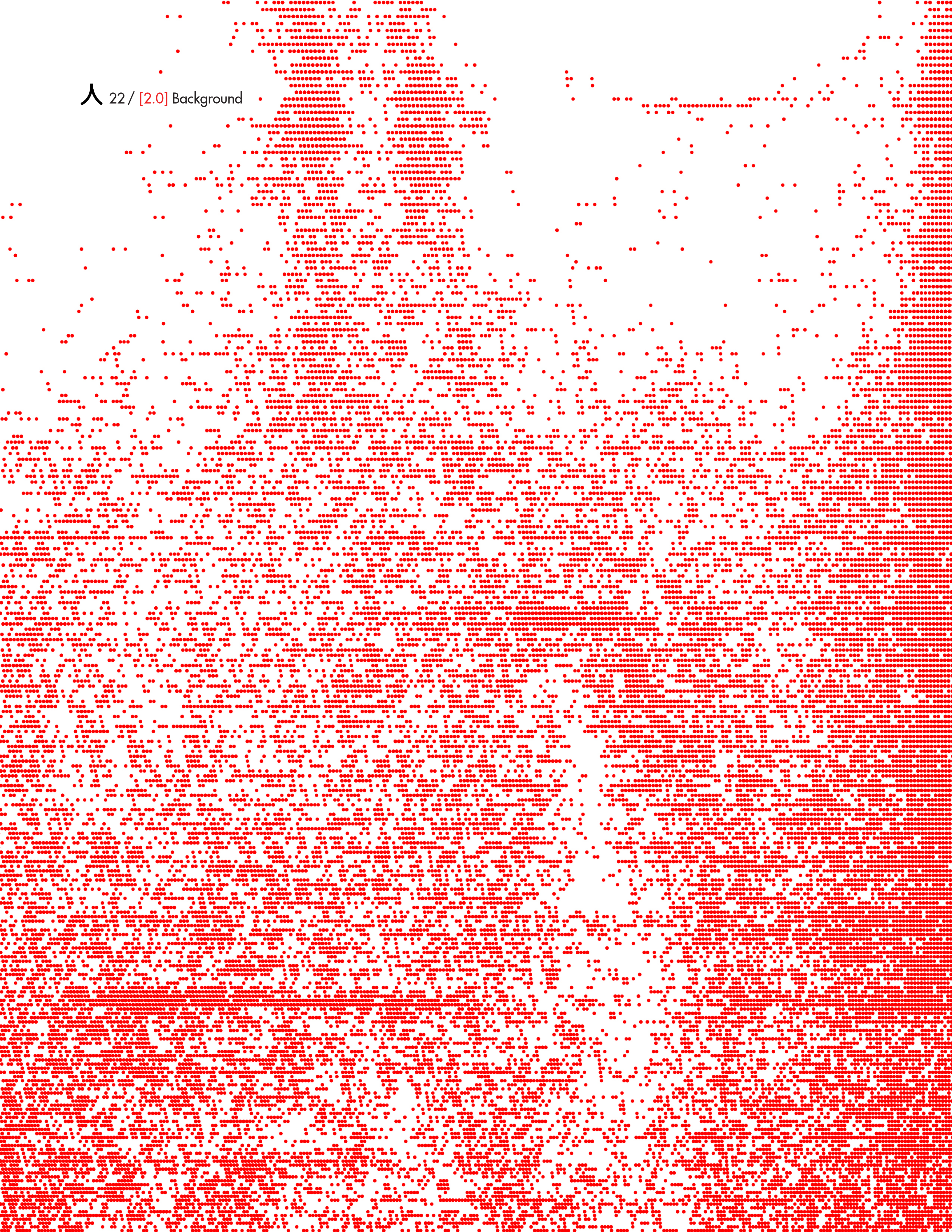
Step 3. Formulate rules from data, correlating statistics with spatial features, connecting form/spatial attributes with motion to create a rule-base system. The rules are formulated by correlating the statistics with spatial features as breadth search which seeks for amplitude but not depth, privileging collecting as many different sequences of motion as possible. The main indicators of the rules are: speed, gesture and time.

Step 4. Simulate people's motion behavior in space with an Artificial Intelligence Agent Based Model, defining the behavior with the rule-based system. The result of this model will be the setting for creating a new Agent based tool Non goal oriented Non deterministic, for testing early stages of the design process. This step is not included in the thesis.

[1.2] Methodology section developed in this thesis

Only the three firsts steps of the methodology presented earlier are developed; the data collection developed through computational scripts. The third step, rule formulation, formalize the main findings of the empirical process. The research is accompanied by a search for theoretical and practical means to convey meaning to the produced data. The simulation, which corresponds to step 4. is defined as part of the overall methodology, yet is not developed in the context of this thesis. As for the current development of this thesis the simulation has the role of making explicit the purposes and bounds of rest of the steps.

Must add that it is a research challenge to question the possibility of transposing the data. For example there is a study that states that Chinese capital walk 10% faster than those in Hong Kong, in the context of a subway station (Waldau et al.,2007, p175.) The study shows that it may or may not be possible to transpose data from one location to another. On the other hand, the development of space-motion research might highlight cultural motion differences in the data at macro-scale, while emphasizing the capability to project these local diversities to design. Furthermore, this conceptualization disrupts the idea of a standardizable design since motion indicators might correspond to their locations exclusively.



[2.0]
BACKGROUND

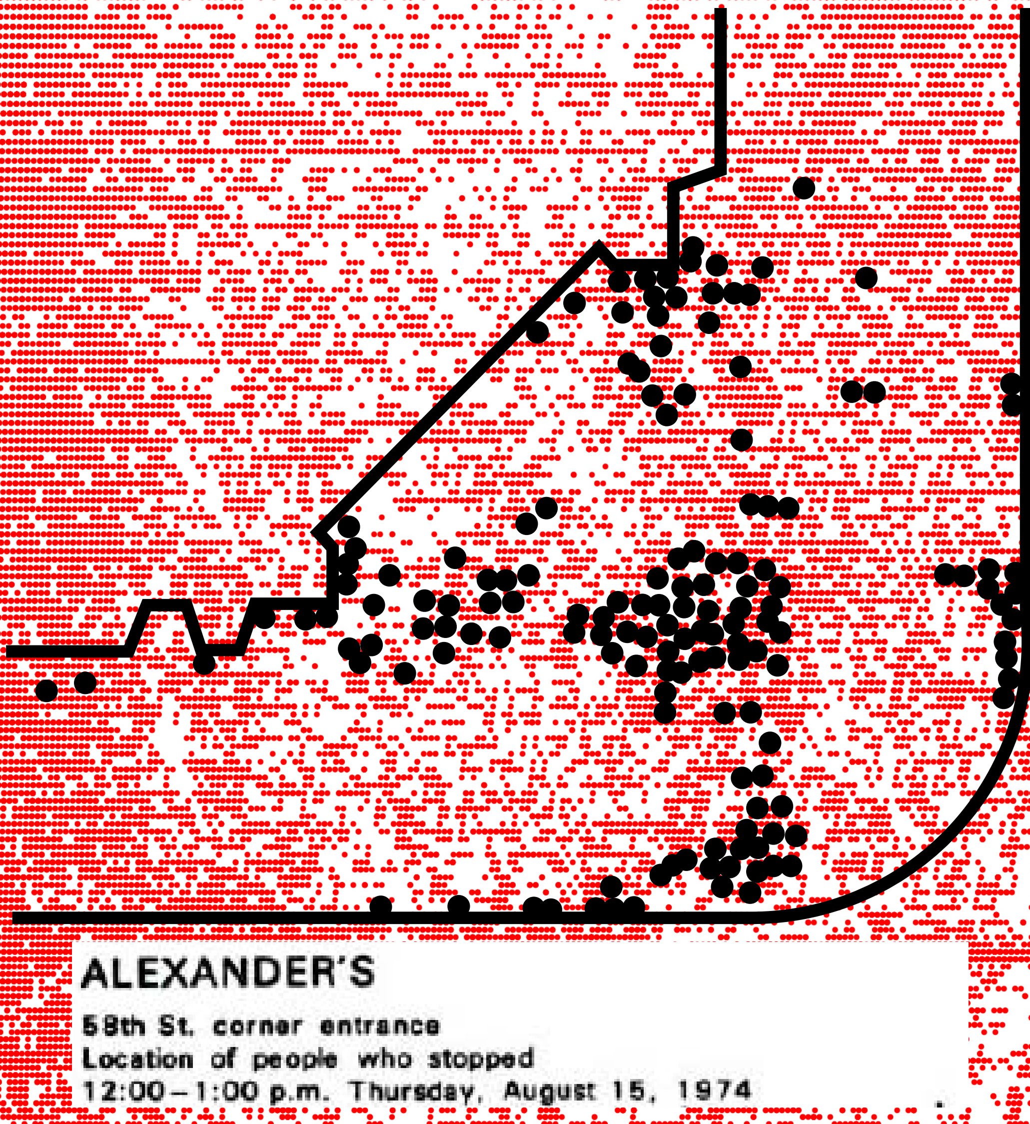


Figure. 5. Pedestrian Flow Diagram. Whyte, W.H. (2001). The Social Life of Small Urban Spaces.

The Background discusses the diverse tools and means used to simulate Human Motion. The thesis framework is defined to discuss the final simulation tool development. However the thesis is focused on the stage of mapping, quantifying and formulating rules from collected data, for creating the mentioned simulation tool for designing space. Therefore the literature review about simulation is limited to referencing its meaning and the two most common methods to simulate people's motion, Microsimulation and Agent Based Models.

From Design view, the urbanist William H. Whyte presented a pioneering study about how people behave in public spaces in the eighties. Using current video camera technology at the time, he captured several videos from plazas and parks and quantified the spatial gestures.
Regarding how to represent humans or human motion in space, in Architecture we can find the common use of silhouettes, that deliver scale and context. However, some architects have gone beyond that creating notation systems of pedestrian and automobile flows, as the Chilean Cristian Valdes.

Finally the chapter discusses the gap for architecture design. This gap consists of means to represent and simulate people's motion only in determinist and goal oriented manner, which is not entirely applicable to design. Emergency exit to evacuate people from a building that endangers their lives is a key issue in contemporary design. Yet, how the space would be the rest of the time? How it works as platform for different activities, and what are the spatial situations that generates? One of the main references for my work is Taro Narahara's Thesis, a SMARCHS student of the MIT Design computation group that proposes a tool for design purpose, without the use of data

[2.1] Simulation

Simulation tools that introduce human motion into the design process of space in early stages are rare to nonexistent. This sentence refers that there are not many simulation tools that hold the precepts of design. According to Ian Bogost (2006) A simulation is the gap between the rule base representation of a source system and a user's subjectivity… the gap constitutes the core representation of simulation, between the work's rules and its reception (what the system chooses to include and exclude) (p.105.) Our experiences construct mental models of the simulation that converge on an interpretation based on what the simulation includes and what it includes (p.104.) In the first quotes Bogost explains the partitive and representational nature of simulations, which is of interest of design, since the representation is a core element of design, and clearly a representation involves discriminating what to include in the representation. A simulation is always a reduction of reality and therefore should not understood as such. The second quote explains the functional aspect of a simulation "we construct a mental model" of the simulation in order to manipulate it, expressing the possibility to increase the understanding that we have of a model, appealing characteristic for the creative process.

As was introduced before, there are two main software to simulate moving figures in the context of Urban and Architecture Design, which are through "Micro-simulation" and "Agent Based Models" type of modeling. Both methods are mostly implemented in software tools to analyze Emergency Exit and Egress in Transport Engineering. Therefore the software functions with the goal of optimizing the emergency exit of the moving figures or calculating the average egress time in a certain spatial context, such as a music concert.

Microsimulation is a category of computer simulation for analysis that works at a small scale resolution of a problem. Microsimulation is a rule base simulation that performs through Transition Matrices. The scale of the simulation, regarding its applications in urban analysis of streets networks or the volumetric of a public building, to the detail of the corner of a wall. It is commonly used for traffic and pedestrian simulations. According to Nigel Gilbert (2008) Microsimulation starts with a large database describing a sample of individuals, households, or organizations and then uses rules to update the sample members as though time was advancing. (p.17) Microsimulations allow asking prediction about the future regarding the input data. Urban Planning the Micro-simulation method is also applied to create models of streets and urban contexts, yet the focus is goal oriented, for example in retail analysis, with the purpose of analyzing why humans move particularly towards certain locations. In such analysis, socioeconomic data is used to define the profile of the agents; in the case of emergency exit and egress data is recalled in general. Legion Software is used to calculate Emergency Exit and Egress Simulation, applying Micro-simulation very accurately. The company that owns the software has performed some studies that recognize the differences in walking between cultures.

Agent based models: Formally, agent-based modeling is a computational method that enables a researcher to create, analyze, and experiment with models composed of agents that interact within an environment. Agent based models are the category of simulations to implement when the outcome of a problem is unknown. Agent based models is also a rule base simulation that implements discrete elements, the "agents" to interact with each other and with the environment according to the rules. Agents can pass informational messages to each other and act on the basis of what they learn from these messages (Gilbert, 2008, p. 6) For example in the game "The game of Life" neighbor agents can communicate if they are dead of alive to one agent, so it can determine its own state. In the case of emergency exit simulations, agents can pass messages of alert. The possibility of modeling such agent-to-agent interactions is the main way in which agent- based modeling differs from other types of computational models (Gilbert, 2008, p.7)

The leverage that the Microsimulation method has over the Agent simulation models that will be explained later, is that the simulation uses real data as input, as a sample survey for example, Nigel explains. There are two main disadvantages Nigel states, the first is that the time iteration requires very detailed Transition Matrices, that specify the probability that an agent currently in some state will change to some other state in the following year (Gilbert, 2008, p. 17.) This requires large data estimates for every agent defined in the simulation. For example, there are many differences in the probability that all age groups of a populations would obtain jobs in a certain period of time. The second disadvantage is that in Microsimulation each agent is aged individually and treated as though it is isolated in the world. Microsimulation does not allow for any interaction between agents and typically has no notion of space or geography (Gilbert, 2008, p. 18.) In the case of Urban and Architecture Design it is required that the interaction of the agents with space is part of the analysis.

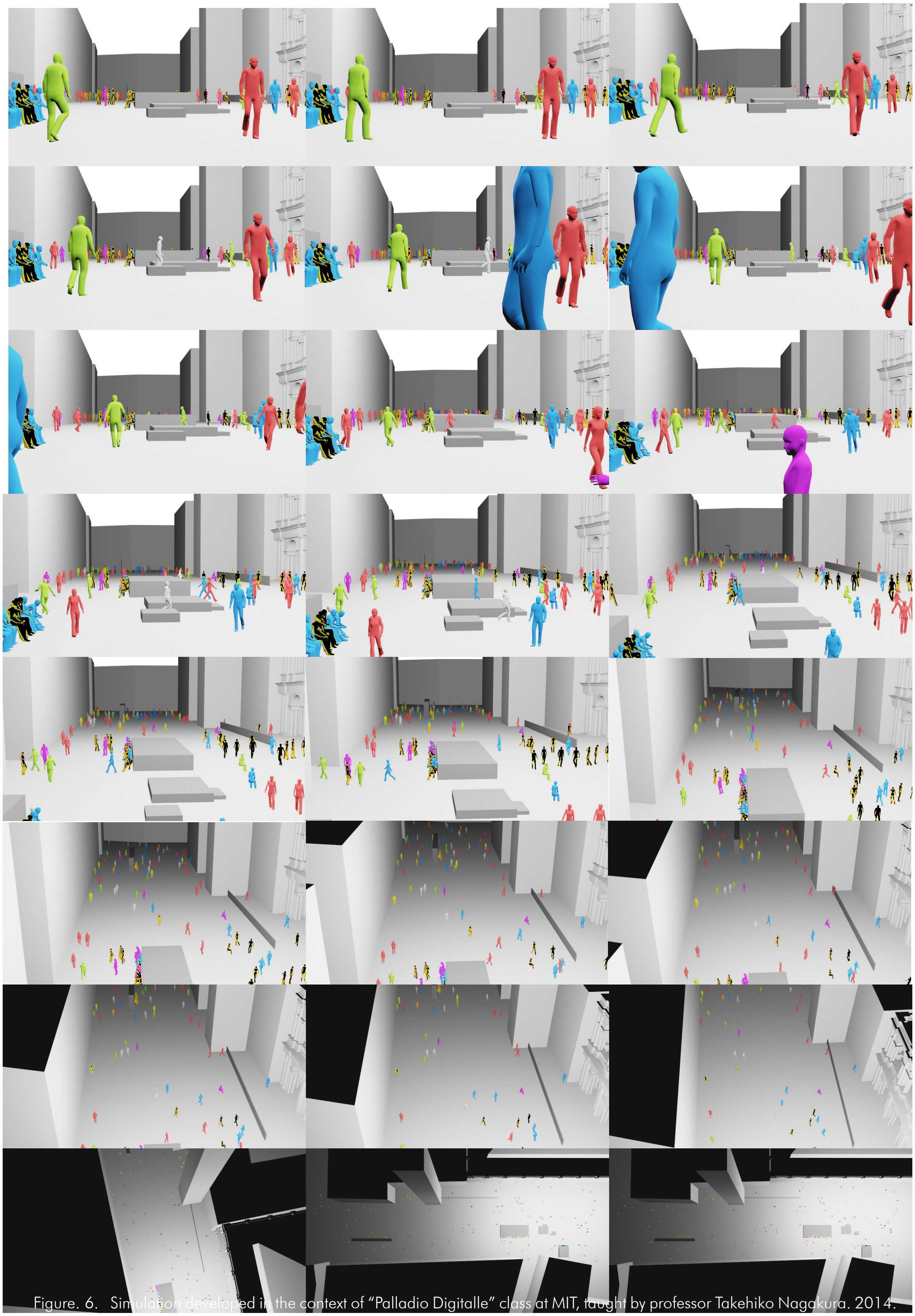


Figure. 6. Simulation developed in the context of "Palladio Digitalle" class at MIT, taught by professor Takehiko Nagakura. 2014.

The main advantages of agent based models are: direct correspondence between the computational agents in the model and real-world actors, the use of heterogeneous actors, the representation of the environment and the possibility of bounded rationality (Gilbert, 2008, p.8.) Agent based models are defined by stochastic methods. The thesis proposes to train them with data.

Unlike the examples of Urban Design, in Architecture the use of software for simulation people's motion as part of the virtual models is much less advanced since often, not even a simulation software is used but a motion representation software, just to illustrate the motion. In the context of representing design the software is mainly for deterministically visualizing figures, such as "Populate" plug in for Autodesk 3ds Max, which somehow replicates drawing the silhouette of the person in 3d, and not interacting with the model of the space.

[2.2] Architecture View

Within the architectural discipline some efforts were devoted to understand motion through drawings and other mediums. William H. Whyte, a renowned urbanist, in The Social Life of Small Urban Spaces (1980,) develops many statistics from video footage of small public places of New York in the late seventies, through a research developed with his group Street Life project. The study is focused on design elements to grasp if a public space is successful or not. The design elements such as benches, trees, water features, food accessibility and attractors such as musicians and other performative elements are analyzed to quantify their presence in a good design. Whyte's research is pioneer in the field of urbanism because it was probably the first to develop anthropological observation of the city inhabitants. The research is very insightful and exposes many important factors of public space design. The observation on people's behavior are general and not included in the statistical analysis. However this is a cardinal and insightful study for the aim of this thesis.

Architects have approached the problem of motion with several points of view. In the text "Figures, Doors and Passages" Robin Evans (1997)

Figure. 7. Pedestrian Flow Diagram. Whyte, W. H. (2001). The Social Life of Small Urban Spaces.

recounts the recent inclusion of the corridor in housing program, highlighting this process as one of the deepest typological changes to domestic architecture. The significance of this change severely modifies human relations; going from the Italian Villa of interconnected enclosures and interconnected to move inadvertently by endless corridors lives. In this study the author analyzes the effect that the housing layout could have over the interaction among the inhabitants of a house. The study is developed by comparing paintings from the XV century to analyze the presence of human body in relation to space and others. In the book the author also explains how the creation of the corridor could be intended to regulate such interactions. The importance of this study for this thesis is that it could be argued that an architectural element was used to regulate people's motion, and regulate interpersonal relations in space as a consequence. In that sense, the architects were, perhaps, observing people's motion and designing to generate an impact over it.

Louis Kahn developed many drawing studies to understand pedestrian and automobile traffic, some of them of a proposed urban project for Philadelphia in 1952. The drawing show the trajectories and how they become a network. (Matilda McQuaid, 2002, p. 112) The traffic studies are carefully drawn with an abstract notation system created by the architect in order to reconfigure the streets according to a hierarchical model. The abstract notational system was composed by dotted lines, which represented the movement of trucks and different rhythms of the traffic. The spirals represented parking lots and situations in which the cars were stopped. The arrows represented the fast flows of cars around the suburban areas. McQuaid explains, *To explain his movement study, Kahn invoked a historical analogy: for him, the girdle of expressways and parking towers circling the city center metaphorically recalled the walls and towers that protected the medieval cities of Europe. Kahn's specific comparison was to the largely medieval town of Carcassonne, in the South of France: just as Carcassonne was a city built for defense, Kahn envisioned the modern city center having to defend itself against the automobile* (2002, p. 112.) Although this study is dedicated to analyze and represent the motion vehicles within the city, it is an important reference for the thesis in that it seeks to represent the movement in relation with space.

[2.2.1] Cristian Valdes Interview

Cristian Valdez, a Chilean architect from the University of Valparaiso, measured and took notes of how a family occupied a house for a month, their motion trajectories to understand space (Iturriaga, 2008). Cristian Valdes was a student of Professor Alberto Cruz, one of the most important Chilean Theorists of Architecture. I would like to express the reflection of what it means for architecture to measure people's motion as presenting an excerpt of an interview to this great architect developed for this thesis:

PG: Please professor Cristian, tell me about the story that Sandra Iturriaga talks in her book "Cristián Valdes, La medida de la Arquitectura" about a logbook that you built about how a family lived in a house, for your final undergraduate Project (2008.)

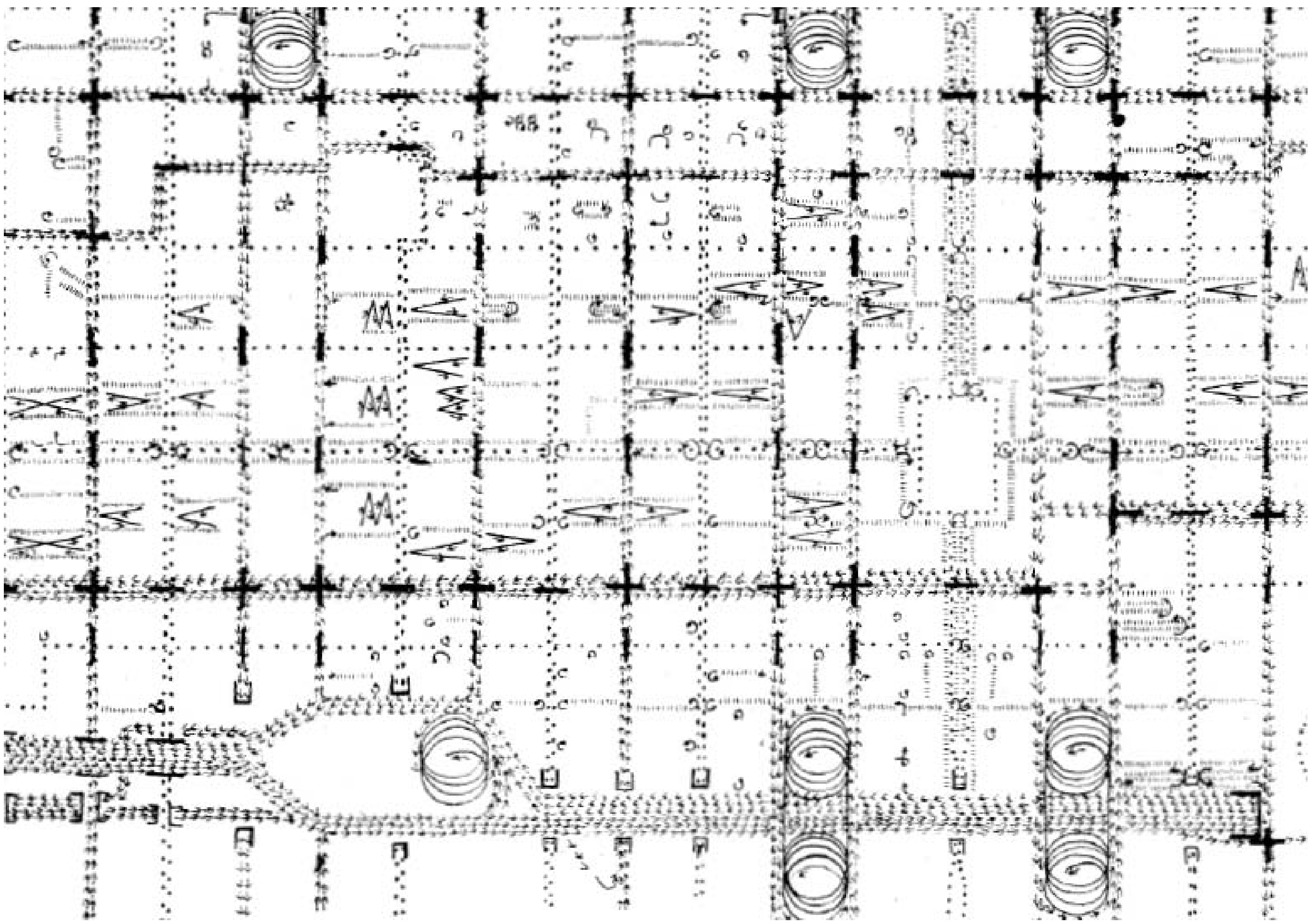


Figure. 8. Louis Kahn Drawing. Traffic Study for Philadelphia project. ("MoMA | The Collection | Louis I. Kahn. Traffic Study, project, Philadelphia, Pennsylvania, Plan of proposed traffic-movement pattern. 1952," n.d.)

CV: That was an exercise, assigned by Alberto Cruz C (2)., a very intelligent man, who doesn't stop in functional aspects, but in an aspect that links with life, because life comes with different, particular demands… He proposed, a very special task: let's add a requirement to your project, let define three different stages of life, first a young couple, could be single people, a couple of newlywed, and a coupe of about 40, he was then forty, old age. How do you embrace life in these three levels, or use the space at all three levels. Because in the first level, the person is single, then the person is married, and after that the person has children. What happens with intimacy, that was the fundamental question.

PG: How was the assignment that Alberto Cruz C. gave you… with drawings, or notes…I mean with what tools?

CV: Well people do things as they can… no really... Architecture is made with plans; plans, drawings, all. We can say, this is the structure, this is the space, now use what you are proposing with different rhythms, the rhythms of the 25's , the rhythms of 30's, the rhythms of the 40's. Now we can say the rhythms of 20's, the rhythms of 40's and the rhythms of the 80's. Things need to adapt to those rhythms and sometimes it doesn't work, that is a lesson.

For example everybody talks now about flexibility. What does flexibility is for? To adapt, to respond. Well this assignment that he gave me was to see how can I respond to this reality and to see if that flexibility exists or not, if the house works for one rhythm and if the house keeps working for the other. A simple assignment that was useful for the project.

When you talk about these relations that exists between the body and space, in reality is something that is not necessarily formulated. These (relations) are events, "acts" (3), that somehow demand something. Is not like, because if you want to gather more people, you make the space bigger, that could be a way to do it, but if the structure doesn't work for that, what else you can do, you have to find another way to do so….

PG: Yes, and one of my focus is how to turn these relations between people's motion and space into a tool for architects or designer. I have studied the Neufert too, and the idea is not to make it as functional as that, the idea is to understand the complexity of these relations, in order to use them perhaps, as alternate way as you said.

CV: Things, people are not unlimited, we are all different. As we are all different we will never do thing the same way if we do things from our own perception of things. You might say as the way each of us feel things, our emotions. From there we act. Everyone is particular. There are no formulas. Even though this has to be governed by your observant position, of yourself and others, in a state in which you could collect, apprehend, through trial and error, as a personal experience. Everybody walks different, everybody talk differently, we are similar but not the same. All gestures are different and are specific to each.

What happens with this? As an architect what you do is to imagine, the good moments of life, remembering, with your memories. For example I would like to receive people here in the winter, the sun in my back. I don't like to seat in furniture, I like to seat in the floor, why? because I have a widened view. This appreciating are like feelings, memories, associated with experiences that you have had. Then, what we do (as architects), what we must do is to imagine from our own. With this you build your dimensions, your measurements. People are different and have different appreciations of things, you can not demand the same from everybody. It is not a formula and there is no catalogue, it doesn't exist.

PG: I have been working also in the meaning of the memory of space. Since I have been observing people in different situations I starting reflecting about the fact that so many people have walked in the same pavements but the floor is not capable to show it and therefore we are not able to see it. I did an installation about this. Let me show you "WalkAcross". This installation integrates two depth sensors, that are similar to cameras, and follow people through the museum. Then this is translated into a plan view. And I thought of this as a painting, in the wall, but a painting in which everyone is part of.

CV: Painting or no painting they build a surface.

PG: That's right. So this follows people as they walk in the museum, for me we have a memory of space, the traces of people.

CV: At the end what matters about this, is that, if this are the traffic flows inside the museum, it is useful for seeing for how long people stop to see the paintings, this is one aspect. If you do the same exercise in a house, What it would be useful for? I did something similar when I did my Thesis project. It consisted of: in several plan drawings, of several floors of a house, I asked my wife, she was my girlfriend back then, to point out where were the people that day, stating who and where, and drew small dots, small painted squares, for each person. After several days I asked her again, where were you, where did you move through, where somebody else moved through and kept marking dots. I did this for five or six months as a curiosity.

I did this because I wanted to know about a thing that she said, that when she went through from one enclosure or room to the other, this was a house full of many rooms, there were areas in which there was a window, and there she stopped, looked and after kept doing whatever she was doing before that. She said that every time she passed by a certain window she stopped and looked outside. When I heard this I payed attention. It turns out that suddenly I grabbed this work and it resulted in a numerous drawings; many boards and I could see the squares. I placed this boards, (tracing paper that wasn't that transparent) against the light and I could see all the squares throughout the paper. It was a house that was a box, and what you saw (through light) it was a shape, a sort of amoeba that which "wandered" around the house, and the rest was unoccupied.

What was the importance? In that time what you graduate as an architect, what you could do was State Housing as DFL2 (143 square meters), for a family of seven and if it didn't fit seven beds, the project got rejected. There were limitations in material use, because it was social benefit, and the state was trying to optimize this benefit with austerity.

At the end the motion study that I did enable me to discover a "law," the "law of use," I named it as that. It works as for example, if I am going to design one of those 143 m2 houses,I can't have "dead" spaces, so you can have spaces only for sleeping, you shouldn't. And that was the maximum, could you image what happens in smaller houses… you get a "ship" or airplane situation. At the end it is about how you work with the minor spaces. What comes up from this is an issue of shape, form linked to use. This use was defined as the illuminated areas and the areas that the sun reaches occasionally. And yet another thing, it was also linked to a circulation. Therefore, for me the "law" was , the use, as live and conscious use, the light and the sun, these built the "being." I say "being" because I wanted the house to be a place for "being," because these were small area houses and I needed to make it big. How to turn big something small? extending the being through the whole house, and then the house became wide. Then the study helped me to understand this, and from these ideas all my projects come from.

PG: So in a sense you worked with time stretching space…

CV: Yes of course, time is what integrates space…

PG: And expand…

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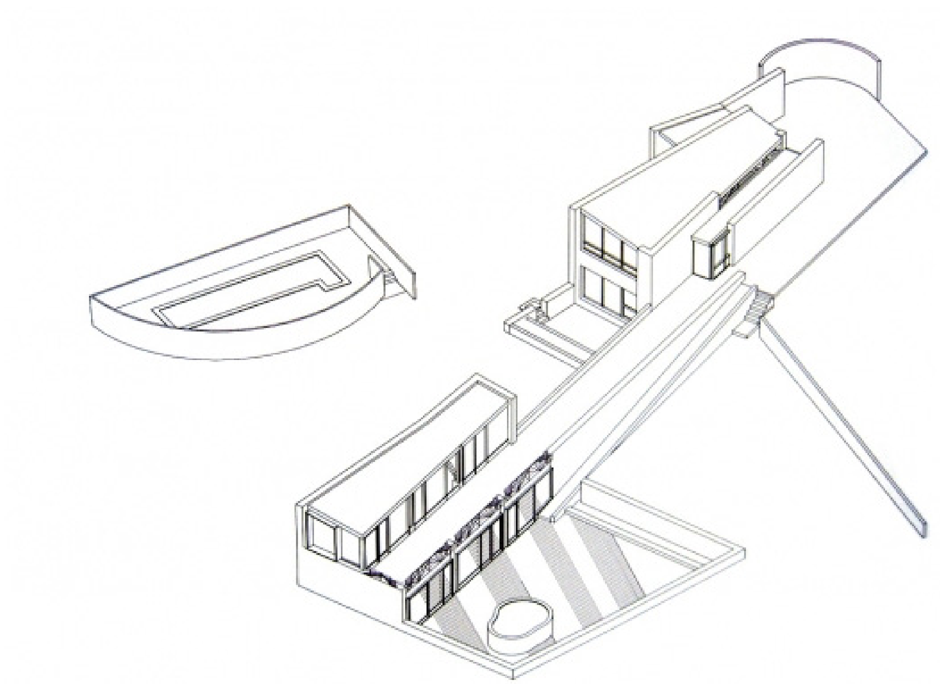


Figure. 9. Cristian Valdes drawing developed for his final undergraduate project. Iturriaga, S. (2008).

CV: And parallel times, are multiple, when many people share a space other conditions appear. So from these ideas my Thesis final project comes. When Alberto Cruz C. proposed this assignment of the rhythms, I was designing a studio, an open space, through the rhythms I understood the intimacy of different situations as a marriage cohabiting with their children and so on.

PG: As part of the cohabitation of people...

CV: Yes, and there is another thing that is important. I establish some principles, that could be idiotic, but the judgment is not important.... But another issue is what happens with the site situation. As Valparaiso has many hills, I went up in the hills and observed people, as people worked, and do things, and it has something to do with something that you said at the beginning, as I looked far, I saw the ocean horizon. So people was working, doing carpentry in front of the ocean horizon, hanging the cloth and walking in front of the ocean horizon. So in which framework this "acts" of life are? What is the difference between this acts, between doing carpentry in front of the ocean and being enclosed working inside of a studio with whatever light you have without seeing anything. That seems to me that this modest daily actions are dignified with the reference of space. Before, I was talking about looking through a window, looking towards an exterior, is not the same as being in an exterior and being part of that space, being integrated with that space in which you participate of an amplitude and have also this relations. So for me this has to do also with the floor, I realized that the floor, more than walls, is a fundamental relation to connect with the deepness of space.

PG: Talking about this floor, this surface...That you mentioned before, please tell what do you think about the memory of space.

CV: That is one observation but don't stop there, what can you do with that. As other have done other installations regarding that as for example someone placed sand inside of a museum and everybody walked there and you get the memory of that space. But what you want to know is how to grasp "conformation" or "configuration" or the process of giving shape to space. The example of sand works as an installation, there you can grasp motion, take photographs of it, measure it, similar to what you did in your installation.

Measure what you want to measure. Yet, you want to measure life regarding what? What do you want to see? For me it was not that important at the time you see, I did other stuff in the meanwhile, I did it as a curiosity, however, it gave me a lead for the project that I haven't thought about before. I wanted to see the use but I didn't knew what I was going to see, when this amoeba appear, it was a different house that I was seeing, that is the house that is used, and you could even cut the shape with scissors, there was the house, drawn as the house that is used.

So the study throws "the design law" and the shape of the law, and with that you can work with.

The research process developed by Cristián Valdes explains how people's motion could inform the design process. It is clear that for this architect motion is not sufficient to be the argument of an architectural project, which is a shared opinion in the context this research. Yet, people's motion has the potential of informing design and creating a different perspective for design.

Metrics are a core element of design disciplines. In that scope, there have some efforts to relate humans to space such as the so called "Neufert", "Architects' Data" First published in 1936 by Ernst Neufert, which has been a base book of architecture discipline since then. The work of the German architect a clear reference for the development of this research. The book seeks to rationalize the size and distribution of architecture typologies. Rather than giving a full description of the research presented in the book, I will refer to the linkage that has to the present research. The catalogue influences the research in the focus of rationalizing the components of architecture. In this research the quantification of people's motion, an intangible matter, is a similar idea to what Ernst Neufert did in his catalogue. Yet this thesis's research has no aim of stating absolute paradigms for design regarding the motion. On one hand, the study is very speculative. On the other hand the statistics from people's motion data are formulated as rules that could be combined in a non prescriptive manner.

Finally in "A Pattern Language: Towns, Buildings, Construction" (1997) is a book about architecture, urban design, and community livability. It was authored by Christopher Alexander, Sara Ishikawa and Murray Silverstein of the Center for Environmental Structure of Berkeley, California. Alexander presents a vast research on urban and architecture "patterns." The categorizations of the book are remarkable references for the formulation of the Space-Motion Rules and Metrics.

[2.3] The Design Gap

According to Ian Bogost in the book "Unit Operations" (2006) a simulation is: a subjective representation that communicate an ideology (p.103) Consequently simulation tools that are built for optimizing the emergency exit moment of a certain number of people from a building does not contemplate the situations that happen in the same building the rest of the time. There is also a main conceptual difference between a simulation built for Transport engineering and one built for design which is its non prescriptive nature.

[2.3.1] The Space Reactor

One of the main references of the research is Taro Narahara's Thesis, "Space Reactor" (2007) an MIT Master's student of the Design Computation group that proposed incorporating people's reactions into the design process by simulating human response towards architecture elements. His analysis is similar to Whyte's seeking for the purpose of the behavior, and not how the motion is. Narahara developed the simulations by using stochastic methods to define how the agents act, weather this thesis proposes grounding the motion in data.

In the context of this research I developed similar premises as the ones presented in the "Space Reactor," and therefore such study is considered a main antecedent for the research in terms of conceptualizing the incorporations of humans into the design process through simulation. Nevertheless, this thesis is focused on the step considered previous to simulation which is analyzing people's motion. Narahara's thesis is a great contribution for the study, and many of the premises are applicable to this research, therefore the main elements of the "Space Reactor" are explained below.

Narahara's thesis argues that architecture design should not be evaluated just by geometric or stylish criteria, yet it needs to include how inhabitants respond to the design. This is an original statement in a historical architectural dispute, this new perspective comes from the possibilities enabled by new digital analysis tools. Narahara's thesis is debatable because some architects may not agree and may argue that design can respond to many different criteria, and as long as it fulfills a certain functionality inhabitants are not relevant. The stand taken by the author is that architects should understand the importance of the inhabitants, which is explained clearly in thesis. They make the argument that being able to get feedback on spatial relationships based on the simplified agents is a useful metric for designers who have no other tools to address these concerns besides their imaginations. The author argues that their tool might introduce simplified simulation software as a common feedback based design tool into practice or as a way to analyze already built work. The discourse surrounding analytical solutions vs

stochastic simulations makes the point clearly that stochastic simulations are valid. There were not many precedents that discussed simulations of humans in architecture directly. The thesis methodology was to develop multiple pieces of software to perform a set of simulations that could then be analyzed to gauge their validity for interesting outcomes and also usability as a tool. Steps inferred from the thesis are as follows:
Develop random walk and pedestrian avoidance simulations
Develop 2d attractor / interaction simulation based on random walk
Develop software to generate animations from simulation runs
Run multiple simulations on Mies designs and analyze results.

The author tests the tool with a real design. The Barcelona Pavilion designed by Mies Van der Rohe, and two version of it modifying the spatial conditions and argues that the response of the tool changes. Along with that process the author tests the digital tool with two other designs. The problem in this is that the tool is not unveiling a new fact about the design. However it aids the designers with a new way of visualizing the design. The original idea for an agent based visualization tool for architects is novel and provocative, and the development of the tool and agents seems rigorous and interesting, but the final experiments and their results are too general and little quantitative data is presented on them.

As was mentioned earlier the Space-Motion thesis research is very similar in terms of the general goal presented by Taro Narahara. The features that differentiate the approach defined for the research consist of proposing to use data from people's motion collected on site as described earlier, to obtain motion that is closer to the manner that people behave in space.

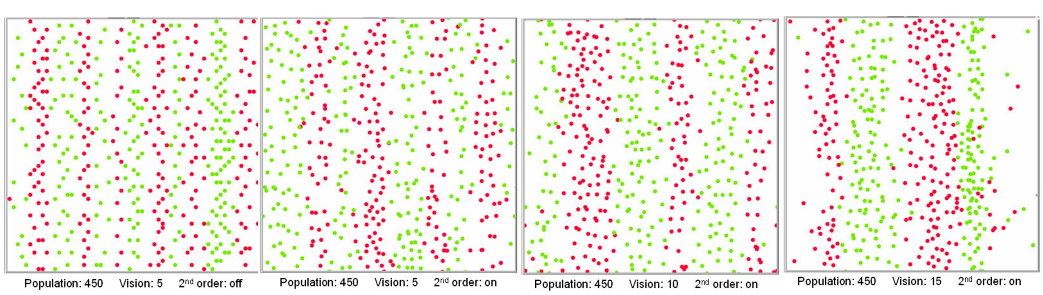
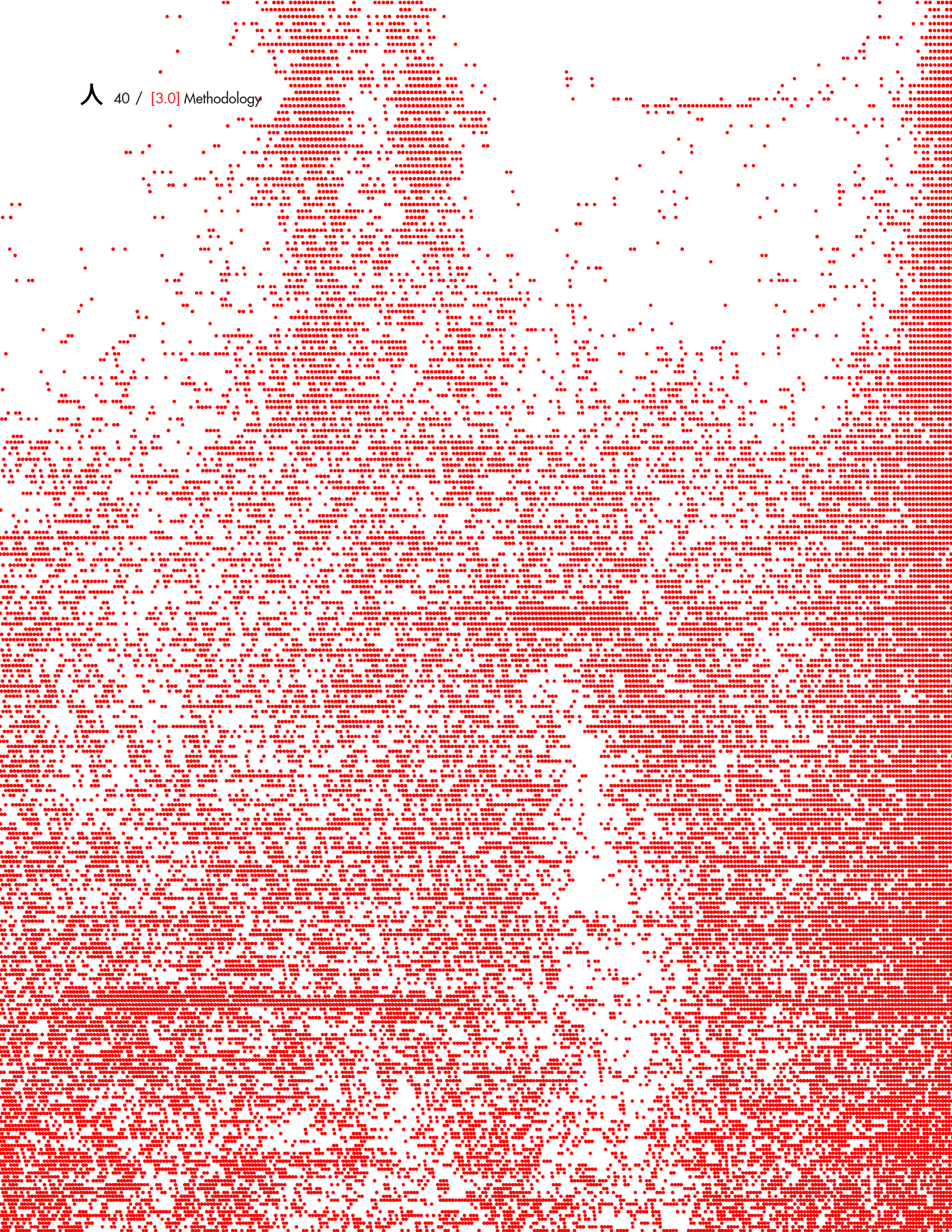


Figure. 10. Agent Based Simulation. Narahara, T. (2007). The Space Re-Actor : walking a synthetic man through architectural space (Thesis).



[3.0]

METHODOLOGY

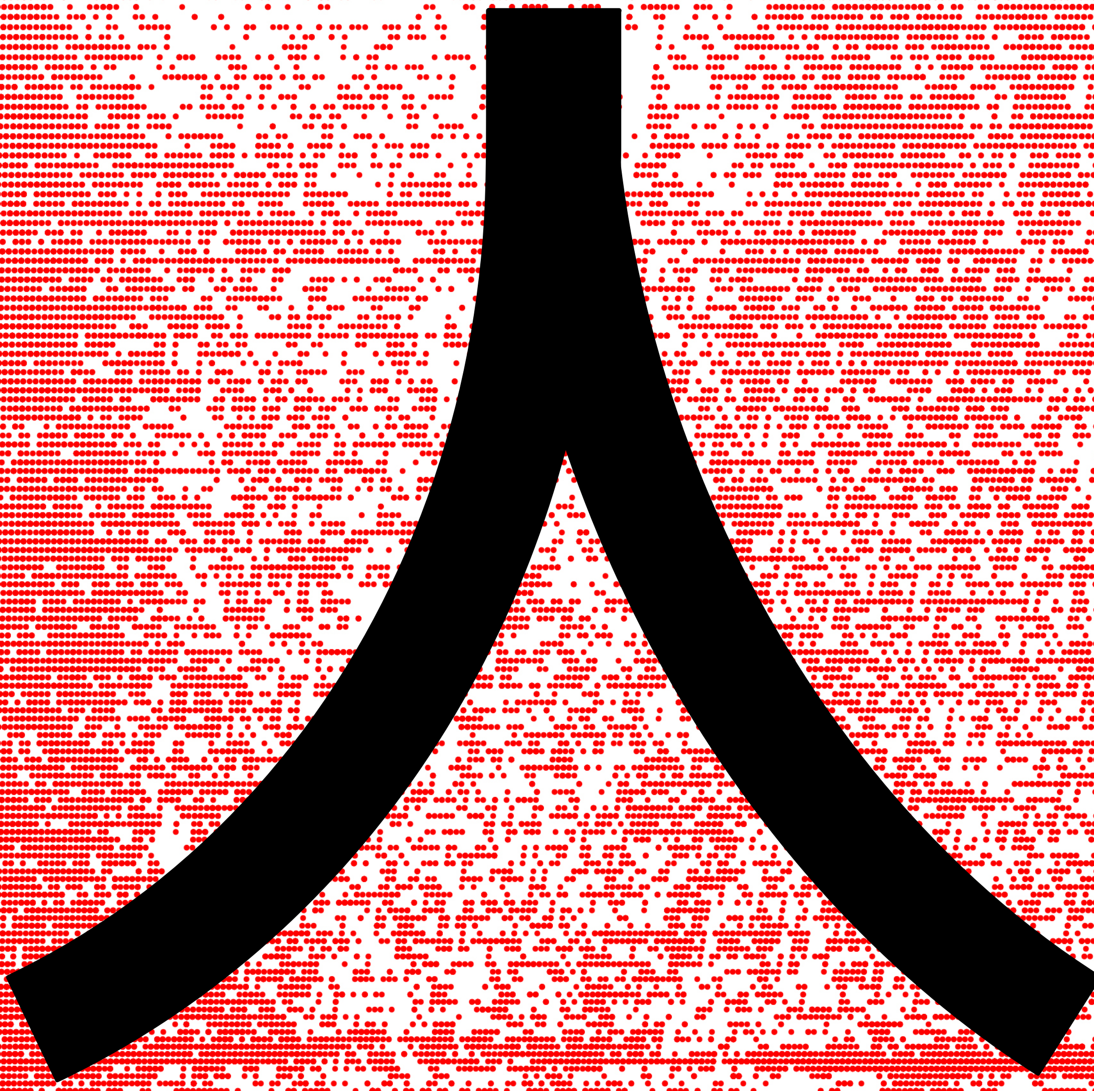


Figure. 11. Chinese character "REN" which means person.

[3.1.] The Methodology

One might argue that the answer about how buildings interact with people relies on people's motion. Motion is understood here as a reaction to a stimulus, a symptom of a process that we can not still grasp. For centuries medicine was based on studying human body's reaction to diseases as symptoms. Doctors lacked the necessary tools to be able observe bacteria or virus directly. It wasn't until the invention of the microscope that medicine finally shifted to look directly to its subject of study. While symptoms are perceived, "signs" are perceived by "others." Similarly, in this study I am seeking for the "signs" produced by the correlation between architecture and people's motion in time.

In response to such complexity a Methodology was developed to grasp people's motion phenomenon. The main question that the methodology seeks to respond is how to translate people's motion in a manner that is meaningful for designing space and for people that will inhabit space. If we understand people's motion as a sequence of actions, then the actions could expose parameters that define them. A system of measurements is required to define what to measure from this actions, how to quantify them and how they correspond with space

The thesis proposes that the Methodology starts with field work; gathering data from people in space. Yet, how to gather data from people? How is it possible to capture their movement? Technological advancements such as Microsoft Depth Camera, the Kinect Sensor, is implemented for this purpose. The Kinect is one of the newest advancements in technology that recognizes the human skeleton and human gesture. In addition video camera is implemented due to the small range of the Kinect. The video camera captures large spaces, yet presents more difficulty in terms of the identification of humans. The second step is to analyze the data. For that purpose a list of parameters that compose motion are defined, as the Space-Motion Metrics. The Metrics attempts to answer the task of defining what to search for when analyzing space through motion. The Metrics allow to build statistics that are pertinent for design purposes. Finally the formulation of the Space-Motion Rules correlate the a group of indicators with an spatial feature. The spatial feature is defined as an architectural element such as an entrance, or a portion of a space such as a corridor. The indicator of space is understood as its volumetric configuration.

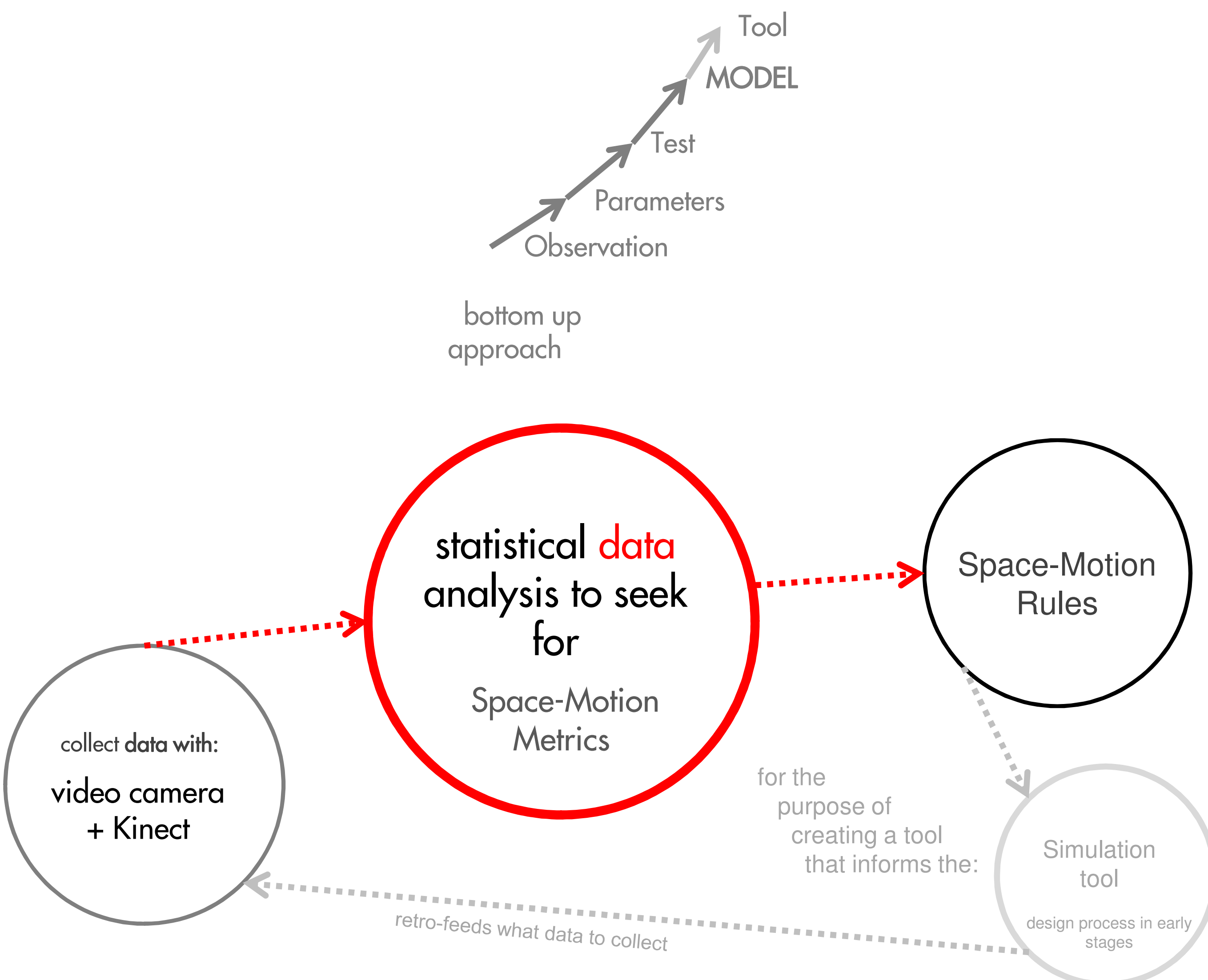


Figure. 12. Thesis Methodology.

[3.2] Steps

Step 1. Data Collection from people's motion in a public place from with the observer point of view. Step 2. Data Analysis to identify the design variables that affect people's motion; as main research question. Step 3. Process variables connecting form/spatial attributes with motion into a Shape Grammars rules set; to ensure nondeterminism. Finally, (Not included in this thesis) Step 4. Simulate people's motion behavior with an Artificial Intelligence agent based model. Development of simulations tools through Neural Nets and Fuzzy logic.

[3.2.1]Data Collection

Plans, architecture traditional means, are static information that refer to the static elements in architecture. Until the development of 3D models, generated in software with a recording platform, the human body was seemingly a device to inform the scale of the drawing. However, motion, or more precisely, the kinetics of human body is an advancement of media technologies. However, with the Kinect, Leap Motion, Occulus Rift and other devices now the body is entering representational space in new and more informative manners.

The purpose of tracking people's motion, is to obtain trajectories that show the periodicity of usage of a building and develop new information for the architecture design process, and retrieve the possibility of its representation. Architects have tried to "map" human motion by several means in the past and failed, mainly with observations and survey, in order to enable its analysis the design process. The data collection is performed in a real world location. The goal of recording in a location is to capture people moving in space as they naturally do.

Currently, technology has brought several pedestrian tracking methods. However, most of them are based on the use of video camera.[4] In Urban Planning the advent of GPS (Geo-referenced system) to track human trajectories is at large scale is becoming extensive. Kinects, a depth camera sensor tracks humans trajectories at a smaller scale, holding a quote of unforeseen advancements in architecture. Therefore Kinect was selected for this project.

Kinect

When people move inside a space they leave an unseen trace that has not been possible to accurately record and reproduce until very recently. In 2010, a gaming depth camera, the Kinect, was first released, and in 2011 Microsoft released the SDK (Software Development Kit) generating interest in research areas that had had troublesome development in tracking people's moves and walking-paths. The Kinects track people inside a space. Since Kinects are depth cameras it is possible to get the three dimensional model of the space and of the human. It works as sonar, emitting a pattern of infrared laser light. The original purpose of the Kinects was to replace the gaming controller for the XBox One, therefore the platform for recognizing humans is remarkably stable. Kinects recognize up to six users and can track in detail only two of these. Still, it retrieves the trajectories of six people at the same time. This is a major difference in comparison with video cameras since with the video footage the recognition is made through background subtraction. This makes Kinects especially appealing for tracking human trajectories. The sensing range of the depth sensor is a triangle of 3.5 m depth and 3.0 m wide. This is a relatively small area in terms of studying how a space works when tracking people motion. It retrieves position data of skeletons and video recording located in that range. The advantages of using Kinects over observation and survey methods are tremendous; the data collection is highly reliable as the trajectories correspond with real time streaming, and the location data is precise to the millimeter.

How people interact with architecture is a considerable complex phenomenon and even though the Kinects retrieve 3D skeleton information, I developed a code that focuses on plan trajectories in order to constrain the analytical process track six users at the same time. The work-flow consists of developing the capturing code using Processing Simple OpenNi Library. This is relatively simple since this library has most of the basic methods of recognizing a user and translating them to a skeleton already built in..

This is remarkable simple tool, yet few have used it for analyzing people's motion. In 2012 Stefan Seer, Norbert Brandle, Carlo Ratti, proposed using Kinects with purpose of analyzing people's motion in space, installing the sensors at the MIT infinite corridor. [5] Currently is much easier to collect data for analysis since the algorithms developed in OpenNi are methods of the Simple OpenNi and in OpenCV libraries. Another important factor of the Kinect is that it records people from an exterior point of view. In this study it is purposely chosen to use recording methods that have the "observer point of view".

Video Camera

The purpose of using video camera is being able to reach a larger space than the Kinect. The Kinect is very effective, yet its range is quite small, 4 by 4 meters approximately. The video camera has the advantage of size, and also retrieving the full image of the situation recorded, giving context to the data collected by the Kinect. The two disadvantages is that the space is distorted by the point of view, so the data must be unwarped, and the extraction of the paths must be done with Computer Vision Algorithms such as Opencv, which is not that advanced, or algorithms developed for MatLab, which involves the use of Machine Learning algorithms.

Figure. 13. Balloon Mapping Project. Photograph taken in Vicenza, Italy by Onur Yuce Gun, 2014.

Figure. 14. Balloon Mapping Project. Photograph taken in Vicenza, Italy by Onur Yuce Gun, 2014.

Due to the scope of the Thesis I have employed Opencv algorithms to extract the trajectories of people in space from the video footage. In future developments I foresee to obtain better results with MatLab Machine Learning algorithms for Computer Vision.

Balloon Mapping

In the context of the Palladio Digitale course I developed: a experiment of using a balloon filled with helium to get footage from the Piazza dei Signore in front of the Palladian Basilica. The use of algorithms for extracting paths traces from pedestrian traffic of the Piazza and the Building, generating the data for a model that uses the data as a starting point for visualizing such paths. First I am going to show the balloon mapping experiment that done in Vicenza. Currently there is a considerable development of balloon mapping mostly for taking aerial photograph with more detail than Google Earth.. The balloon was purchased from the "Public Lab", a community which develops and applies open-source tools to environmental exploration and investigation.

To do this experiment there a considerable logistics tasks such as, purchasing the helium locally which was a difficult. In addition I obtained permission from the Vicenza City Council, involving several meetings with the person in charge of cultural projects. We inflated the balloon in public space and moved towards the square. With the balloon ready to be launched, we attached a lightweight camera, the GOPRO HERO 3 with a protection cage. The camera was set to take pictures every 5 seconds In order to make a time lapse of the square. We used two strings to control the balloon and flew over the Piazza for almost four hours.

The balloon must fly in good weather conditions with winds less than 10 km per hour. That day the wind was 6 km per hour and the balloon was very stable. The balloon reached 60m height approximately due to the amount of helium, which in this case was a little less than recommended. The balloon experiment was a success in terms of solving many logistics problems and getting the raw data from the square. The best way of recording people moving for extracting the paths is to capture from the top because the occlusion, when people walks in from of each other. Yet the main problem is that the footage is unstable and therefore is very difficult to extract the paths for now.

In terms of logistics, technical and theoretical developments for next steps it is necessary to consider: In terms of logistics a. This system costs roughly 500 dollars, to fly the balloon for a entire day. With that amount of helium the balloon can fly for two days. b. It requires to get permission from the city and the helium must be purchased locally. Also transporting the filled balloon must be taken into account.

Technical issues a. Stability : The balloon mapping still has some stability problems and the algorithm for stabilizing the images is in early stage. b. Interval of photos: it is better to set the time lapse framing at 1 picture per second c. Height : in this case the balloon went up 60 m height approximately due to using 2.2 m3 of helium instead of recommended 2.5 m3.. The balloon deflates in time losing height, and need to be re-filled in constant periods. e. The wind is an important factor it has to be less than 10 km per hour g. To post process the data more development of surf algorithm is needed h. As I said before there is a large community of people developing this open source techniques which will produce further developments on the areas that need improvements such as stabilizing the images. i. Balloon attracting people, One theoretical issue to take into account is that balloon changes the pattern of behavior of the piazza by attracting people to it. This must be studied with scientific observer theories to resolute the best performance of the experiment.

Defining the Location

Public space is the civic place by excellence. Public space is where people gather and exchange experiences. This research is focused in spaces of exchange, considering public buildings to outdoor plazas. The possible actions or events that can happen inside of a space are a reflection of the size of the space. Usually a public or semi public space is what could be defined as large space for public reunion. In this case the size should be big enough to be considered a public space. Corridors are studied in order to obtain data from spaces that are strictly for transit.

The main parameter to define the location to perform the experiment is the abstract concept presenting “generalizable spatial situations.” This research is currently in early stages and therefore is focus on covering the basic variables of space. The generalizable spatial situations representative of an spectra of other spaces, exposing an elemental condition.

Architectural typology definition also represents a parameter to follow, as if the typology of a space such as a multi story atrium in two different buildings the results of the analysis will be analogous. Consequently, the data collections are done in similar typological spaces.
Indoor Public Spaces are isolated from environmental and cultural conditions that exceed this study, therefore the defined locations in this case are indoor spaces. The indoor semi public space cancels out environmental conditions such as weather, and traffic. It also narrows down the public to capture. In

[3.2.2] Space-Motion Metrics

What is the data retrieving? How to measure the data? The range of parameters that can be obtained from the data from people's motion in spaces is extensive and undefined for design purposes. The only premise that is certain is the purpose is to produce meaningful results to inform the design process of space.
In general, the data can retrieve many valuable information for designers as it is without any processing: the first valuable information are the flows in plan based in data. Transit zones of space, and more importantly a public space, separate the surface in two: traffic and stationary areas. Traffic flows are one of the basic components of designing space, the recording devices provide the exact routes, including the ones that escape to professionals observation. The video camera retrieves information in 3 dimensions as for instance a spatial gestures regarding a spatial configuration. The skeleton data recorded with the Kinect works in 3 dimensions as well over a smaller area that can be understood as a micro-situation.
As a reference, other disciplines that analyze people's motion such as Transport Engineer have three basic parameters to study pedestrian flows: density, speed and direction, among with the factor of interaction between pedestrians and the presence of obstacles (Daamen & Hoogendoorn, 2003.) In the context of this thesis the main goal is to understand how space features affect people's motion and therefore the interaction with others will not explored, and is considered a further step in the research. Density is not a factor to describe yet.
On the other hand, speed is by essence the prime parameter that combines space and object transformations on its position coordinates.

Figure. 15. Spatial Gesture example: change of gaze direction. Media Lab Lobby. 2015.

Yet speed is considered a parameter of efficiency or optimal performance in emergency exit for example. In Transport Engineering context speed is implemented to optimize the performance of pedestrians. Nevertheless, in this research, speed is part of how we approach space in motion. *Consequently the geometry of space may have an effect of its value.*

The main question to answer regarding speed and space is: when does the speed changes in relation to spatial configuration. Speed exposes different states of people's motion, the period when a person starts walking or approaches an objective are slower, for example. Speed may also expose the effort that a person does while moving over a terrain. An interesting evaluation about speed is to observe if people change the speed value while walking from one spatial configuration to another, such as from walking from a wide space to a narrow space.

While speed is a basic measurement, gesture is one of the most important advancements of the thesis conceptualized as "spatial gesture." Gesture consists of a change or a combination of changes in bodily motion, such as change in gaze direction and an increase in walk speed. The spatial gesture correspond a series of movements of human interaction with space, as changing the gaze or the direction of the head pointing a spatial feature such as the upper floors of a multistory atrium.

Gesture may expose people's interaction with space. People perform a variety of gestures while crossing a space that may not be related to the space, therefore evaluating spatial gestures is a task that presents a challenge. After observing people's behavior for extended periods of time it is evident that the head and legs are the body components that participate in the interaction with space, while in motion. According to this the gesture recognition is defined as identifying bodily movements from the head or the legs in interaction with spatial features.

The data also retrieve traffic flows in time, showing periodicity of the space, following Cristian Valdes words, the rhythms of space (2015.) If the motion are recorded for a long period, the data can retrieve how much time a person stays in one position and where people spend more time. With this information designers would know how to coordinate different not programmed events in a space or space areas. Timing people's motion in space can also expose the areas where materials suffer intense use. More importantly, timing space introduces periodicity to static objects of architecture.

Speed and Time are highly interconnected. When the speed is low, the time spent is longer. By defining several ranges of speed, people can be sorted out as standing, wondering or strictly moving. This category might show the program that the space has. For example people stand or wander around an exhibition. The timing also tells for how long that spatial feature affected a person's motion.

The shape of the path in plan could inform the route that people decide to take in a specific space configuration. For example, in the case of the elevator at the MIT Media Lab Building in the first floor, people takes a curve to avoid the exterior corner of the elevator. A experiment could be done by introducing a curved element to the exterior corner and test how people react. The route of people in two dimensions display the spatial elements that attract people towards them and divide the areas that are for circulation and the areas that are for stationary activities.

The direction of the path, towards a goal, motion approaching the goal, defined by the programmatic elements of the space. In the context of this research, the direction of the path becomes important for determining which spatial features are affecting a person motion. Humans have a direction defined by the eye's field of view. For instance, when measuring the change of gaze direction, the direction of the path narrows down the possible interactions in half as the person can only see what is in front of them.

Scale refers to size of the analyzed situation in relation to human scale. For example the scale of an entrance is considered a micro scale situation, a public space of a hypothetical size of 100 by 100 meters would be large scale situation. In terms of scale, for example a complete route is a gesture in a large scale public space, yet a change of height in the center of mass is a gesture in a micro-situation.

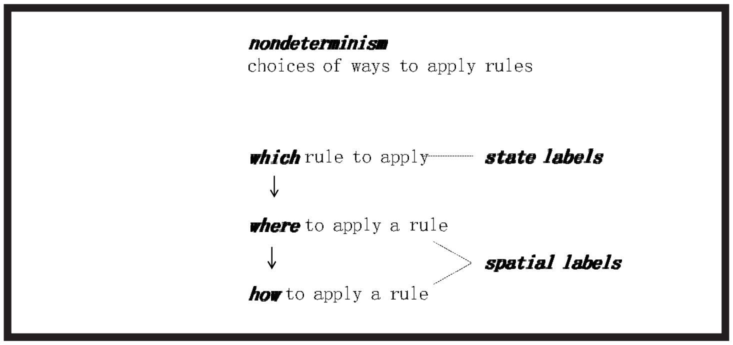


Figure. 16. Shape Grammars non determinism. "Visual Computing" class at MIT, taught by Professor Terry Knight. Material developed by the professor for the class.2014.

In addition is important to state that human motion is deeply embedded in each particular culture, implying that motion is conditioned by this fact. Currently it is possible to track human motion, yet it is essential to assess such motion in terms of the cultural model from which the data comes from. Therefore, this type of analysis must be generated taking into account that it might be applicable only for the specific context in which it was performed. Architecture is always linked to the place in which it is built.

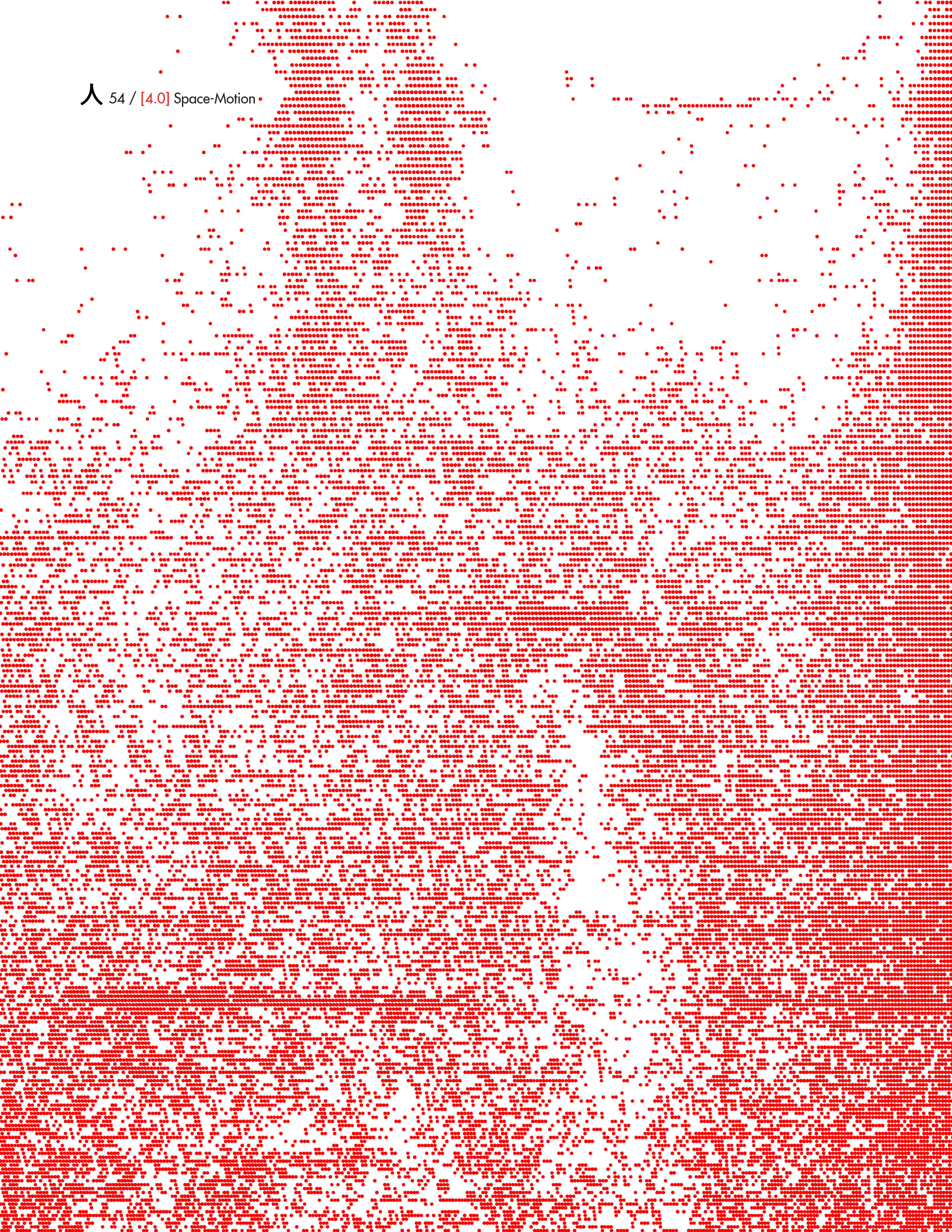
[3.2.3] Space Motion Rules

Rule based systems can be used as methodology for design process, Shape Grammars is one of the most important rule-based systems for design. One of the most powerful aspects about Shape Grammars is that it implies nondeterminism. In Shape Grammars there are two types of rules, the ones that are a property of the drawing , that have a correlation with arithmetics basic operations, rule addition, rule deletion and rule change, and the ones defined by the designer. The rules that use shape properties are defined as transformations. " A nondeterministic basic grammar is a basic grammar with a limited kind of nondeterminism added to it. It is a partially ordered set of addition rules. The rule format restrictions for an ND basic grammar are the same as those for a basic grammar. The rule ordering restrictions are relaxed. Rules may be partially ordered allowing for a choice of rules to apply in any step of a derivation of a design" (Knight, 1998, p. 504.) Shape Grammars methodology guides the generation of the Space-Motion Rules.
The Space-Motion Rules correlate spatial features with people's motion indicators. The rules are basic pieces of a larger model. Motion is divided

into rules to produce a generative system. The rules express a before and after responding their conception as a sequence. According to Ian Bogost regarding rule-based systems such as cellular automata writes: "The complexity of these systems is generated by the cooperative effect of many simple identical components... offer a way to understand complex systems by breaking down large scale behavior into simple generative rules." (2008, p.94) The complexity generated by the rules as a model of behavior will exceed the complexity of each independent element. When people's motion interaction with architectural configuration is broke down in smaller pieces, as rules composed by a gesture towards a window, similar contexts can be homologated. The smaller pieces seek to be elemental situations of space. The rule becomes prototypical of a certain spatial morphology if the elements that compose the rule are basic and generalizable. For example the "boundary" of a traffic space, as the walls of several corridors can be analyzed as homologable boundaries, yet the width, the space in between, can vary. Overall a space can be considered a corridor if the width is small enough and the main use of the space is transit. Consequently, a rule correlating motion with a corridor could be applicable to different corridors as the architectural features are defined as parametric.

One of the aims of the research is building a platform for upgrading visualization and goal oriented simulations as functional simulation that returns spatial feedback at public space scale. The main purpose is to inform, enhance and test the design process, for incorporating people's motion in the design process. The main reason to have the simulation step present in the development of this thesis, which is focused in the metrics and the rules for motion, is to create a data based rules that are indeed useful for a simulation.

In order to assess the types of rules that are useful for simulating motion of pedestrians I reviewed software that simulate human behavior with the Agent Based Model rule system. The software review included testing Massive Prime, an ABM software in which the behavior of the agents is set by a system of Neural Nets and Fuzzy Logic, Legion a software very similar to Massive Prime, that implements Microsimulation to model pedestrians instead. Finally the software selected to develop the proof of concept of modeling a Pedestrian to evaluate spatial configuration of a defined space, in this case a public space such as MIT Lobby 7 was MAYA MIARMY software plug in. This software "imitates" the development achieved in Massive Prime, yet the interface is less complicated and is free of charge with some limitations. MAYA MIARMY also defines the behavior of the agents via Neural Nets. This analysis grounds for further steps of the research.



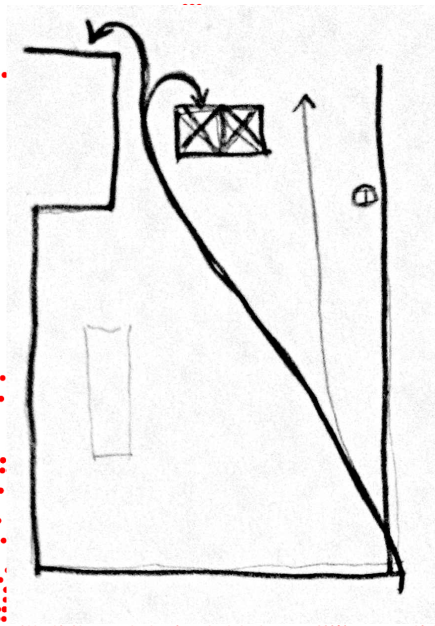


Figure. 17. Plan drawing done by memory, of the MIT Media Lab Lobby. It shows the main traffic flows. Drawing developed in collaboration with MIT Professor Lorena Bello.

[4.0] SPACE AND MOTION

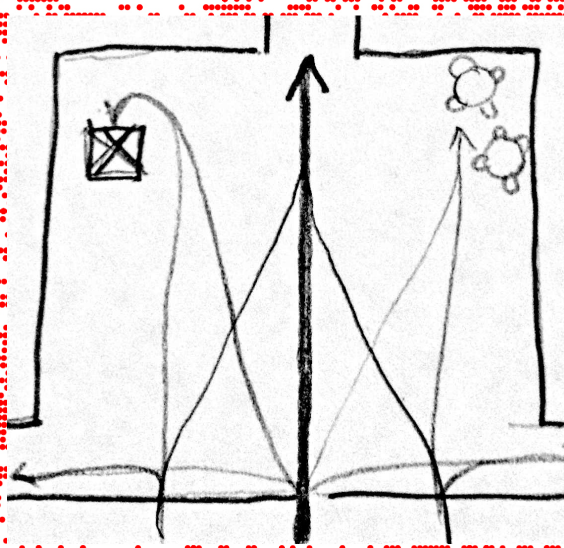


Figure. 18. Plan drawing done by memory, of the MIT Lobby 7. It shows the main traffic flows. Drawing developed in collaboration with MIT Professor Lorena Bello.

[4.1] Proof of Concept

For instance, architects can easily state the main motion patterns of a space, as we can see in the drawing made by memory, yet this study provides evidence of people's of such motion flows, and retrieves indicators such as time spent in a route. Time spent is an important factor of a space. The time spent demonstrates the different events that can be celebrated in the same area in different times, expressing the usage of the building.

People's motion is modified by space, hence, studying how people move in a space might elucidate spatial behavior. Human behavior is one of the most complex phenomenons that exist. Humans are complex because they not always act according to reasons that are possible to grasp. Therefore this study is not focused on the purpose of motion, the research centers instead in how people move. The empirical approach towards investigating people's motion represents a difficult task even more due to the qualitative complexity of the phenomenon. To tackle this problem it is required to rigorously define how to investigate, understanding its implications to the study. The empirical approach of the research is determined for producing meaningful results for incorporating people's motion into the architecture design process. This research can retrieve for example that some of the routes that connect architectural elements such as entrances are actually not as busy as they were considered to be.

While the Methodology Chapter explored the conceptual implications and background of the defined processes, the Proof of Concept Chapter displays the empirical research. The Proof of Concept consists of generating an experiment applying the three first steps of the Methodology: by recording people's motion for Data Sampling, quantifying the data by the Space-Motion Metrics, and finally formulating the Space-Motion Rules. The goal of the experiment presented in this thesis is to test if it is possible to perform empirical research about people's motion in space, and obtaining meaningful results. To explore this premises I developed an experiment with the following steps:

1 Data Sampling: by define a location, define position of devices, record with Kinect and video camera, observe the people on site. The data collections were performed in several locations, defining two of them as the main spaces to be analyzed. The difference with the rest of the sampling is that in those two spaces video camera was used, complementing Kinect sensor. In the rest of the locations the data collections were performed only with Kinect.

2 Data Analysis: Space-Motion Metrics. The steps of the analysis are: develop data visualizations, observe frequency of motion, develop the statistics using the metrics. All the processes are performed with several algorithms developed in the context of this thesis. The data visualizations were developed using Processing Language. The data visualizations purpose is to be able to inspect the data mainly from the Kinects and observe the frequency of motion. Through the data visualizations and the measuring the data with Space and Motion Metrics, patterns can be observed, measuring also how often they happen in time. Finally the measured parameters are summarized in averages, percentages and other statistical means.

3. Rule Formulation: Space-Motion Rules. The third step is developing the Space-Motion Rules by formulating the rules correlating statistics with spatial features. The rules privilege breadth, than depth meaning that a variety of motion behavior were selected to build a rule, yet the study almost does not include comparisons among the same spatial features.

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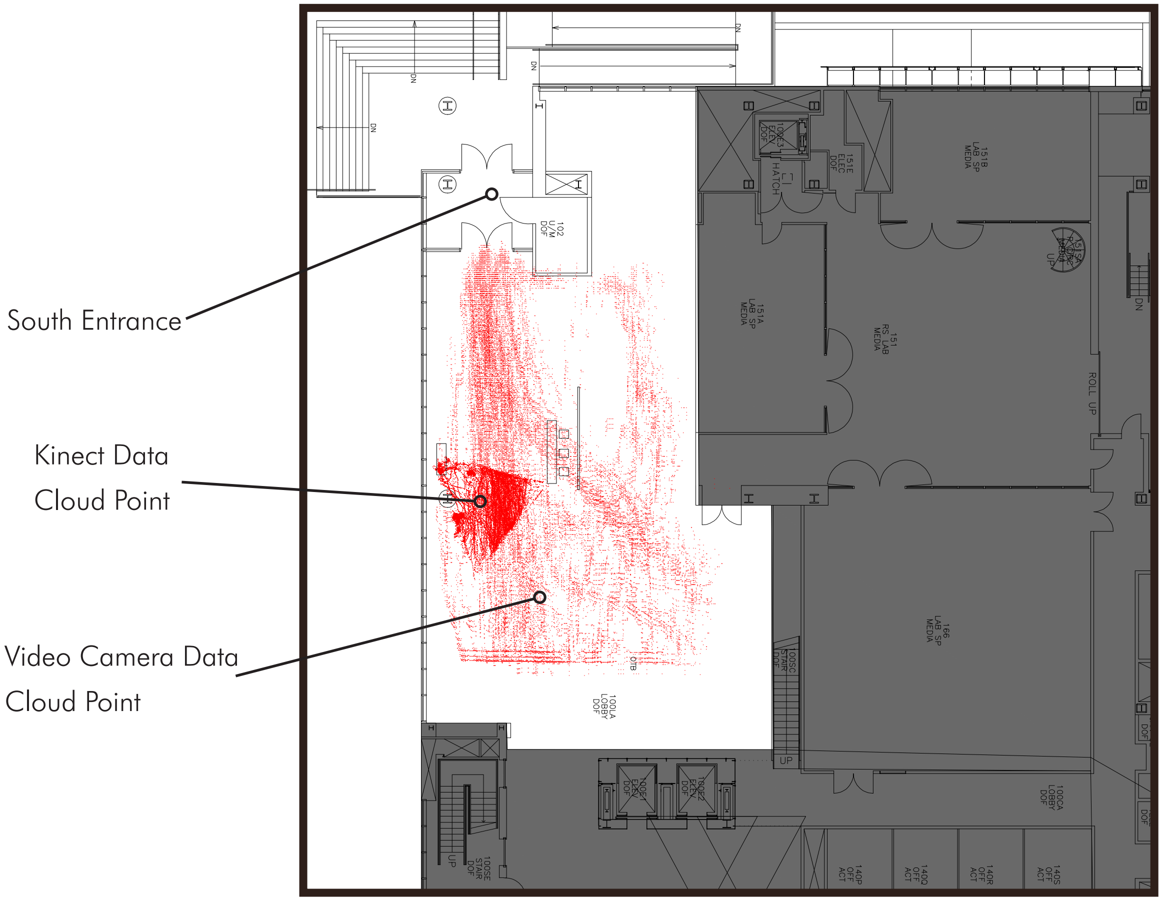


Figure. 19. MIT Media Lab Lobby plan diagram.

1. South Entrance
2. Bench
3. Window
4. Circulation from the entrance
5. Free flow in the Multi-story atrium
6. Exhibition

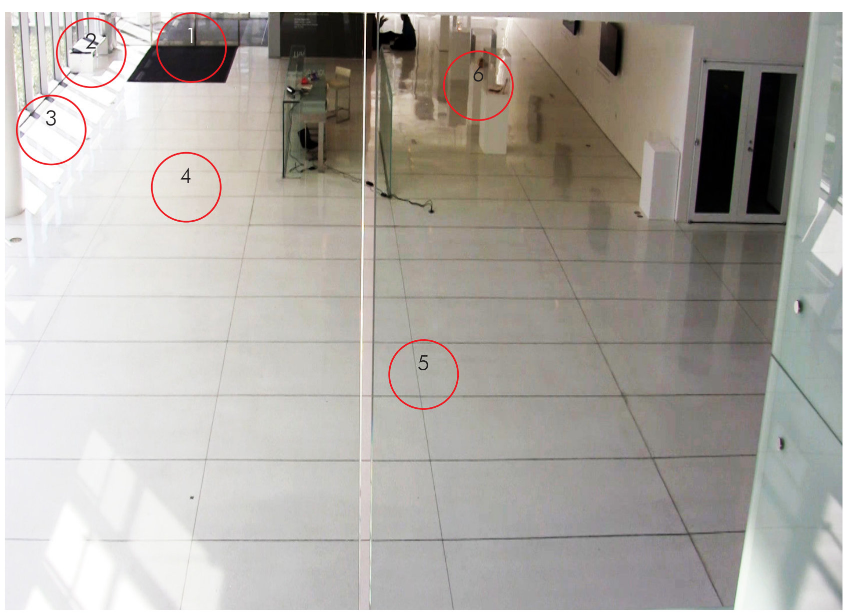


Figure. 20. MIT Media Lab spatial features to analyze. The circles show where spatial gestures can happen.

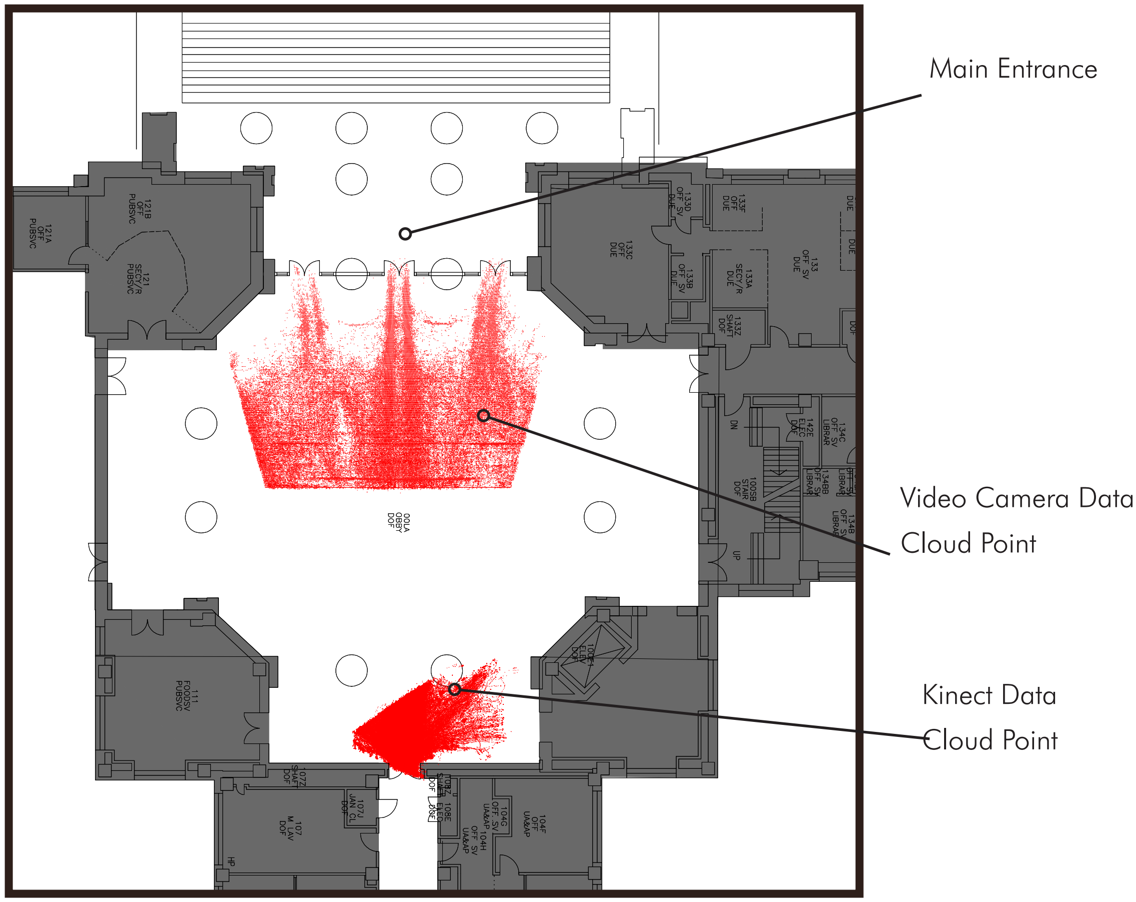


Figure. 21. MIT Lobby 7 plan diagram.

1. Entrance
2. Look up gesture zone

Figure. 22. Screen shot of the video footage recorded at the MIT Lobby 7. The circles show where spatial gestures can happen.

[4.1.1] Data Sampling

The data collection is executed with external sensors, the Microsoft Kinect Sensor and Video Camera, in coherence with the selected criteria of observing people's motion from an outside point of view.

The data collections were developed only in educational semi public indoor spaces, as to use analogue contexts. The analysis unfolds over two main locations, MIT Media Lab Lobby and MIT Lobby 7. Both spaces are multi story space that connects with a change in ceiling height. The condition of being indoor benefits the study in the sense that it cancels out many environmental variables such as climatic conditions and it is accessed by an homogeneous public. In a public space that is inside of a building two factors are the ones that determine how the space is used, one is the volumetric form of the space and the second factor is the events that are happening there.

The selected spaces, MIT Media Lab Lobby and MIT Lobby 7, are public indoor spaces, of an Educational Institution. The Typology is a multi story space that connects with a change in ceiling height. Other complementary data collections locations were gathered in: Catholic University of Chile Main Building Vestibule, in Santiago of Chile; National University of Colombia Cafeteria, in Medellin Colombia; and Pisa University Corridor, from the city of Pisa, Italy. The data was collected mainly with Kinect sensor. The locations allow to compare data from different countries.

Figure. 23. School cafe of the Universidad Nacional de Medellin, (UNAL) Colombia. It shows the area in which the Kinect data was collected.

Figure. 24. Lobby of the Catholic University of Chile (UC) main building. It shows the area in which the Kinect data was collected.

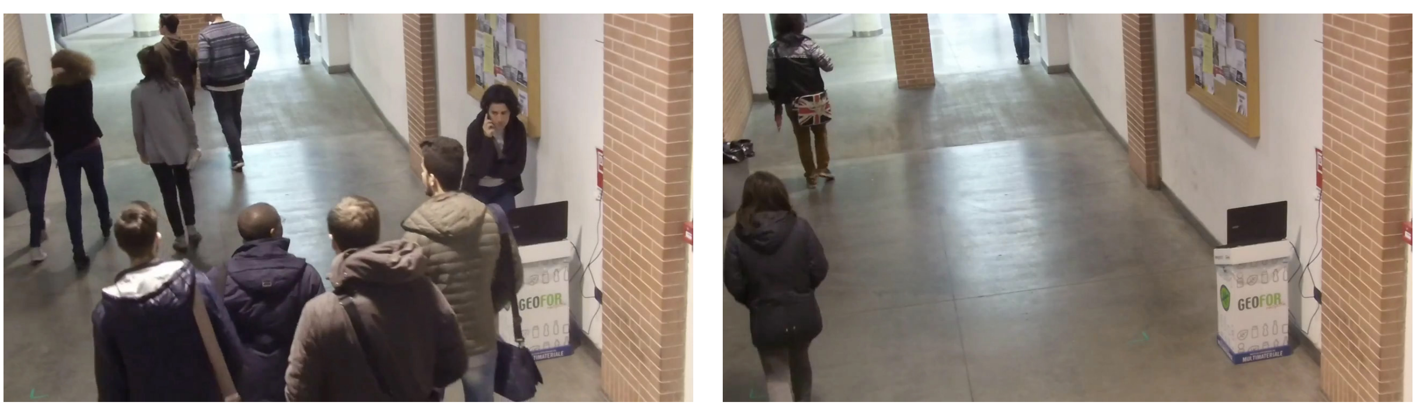


Figure. 25. Corridor at the University of Pisa (UNIPI) Italy. It shows the area in which the Kinect data was collected.

The criteria for locating the recording devices responds to the goal of finding generalizable spatial situations more than characterizing the location. The Kinect are located in key positions and the cameras on upper floors to get an advantage point of view of the space

- Microsoft Kinect Sensor
- Collects:
- Coordinates of the Center of Mass + timestamp (of a maximum of 10 people the Kinect v1 and up to 6 people, with the Kinect v2.)
- Coordinates of the “skeleton”, which is defined by 25 joints of the body, retrieving the coordinates in space for each of them, plus the timestamp.

Define Position.

In all the recordings developed with Kinect the sensor was placed frontally to the motion of people except in the recording done in Pisa Italy. As was stated before the Kinect has a range of view with the shape of a cone. In some occasions the Kinects fails to recognize the skeleton of some of people due to several reasons such as, the body of the person does not fit in the sensor range, the person is above the limit number of people that the Kinect can record, or the lighting is sending some reflection that the sensor identifies as an object. The same could happen with ladder or other linear objects. Therefore it is better to record in situation in which the number of people is not too large, as the Kinect v1 can record 10 people at the same time, recognizing only the Center of Mass of these people, and the Kinect v2 can recognize only 6 in the same manner.

Define Key Location.

Another factor to take into account is that the Kinects have a small range and therefore must be located in Key positions that will capture representative data of the architectural feature. This aspect requires analysis and planning. The official range of the Kinect is a cone of 4 meters approximately, yet I have data collections performed with Kinect v1 that show data of 7.5 meters, as it is easy to see in data collected at the MIT Lobby 7. The reason this is possible might be that the SDK, with the middleware OpenNI, did not had range restrictions for the device. This does work the same way with the Kinect v2. However, the Kinect range might be enlarged in the future releases.

The definition of a Key location gravitates over the "generalizable" or more "prototypical" spatial situations of the selected space. For example the exchange zones as the transition between a corridor and a wider space, a change of ceiling height, the entrance of an elevator, etc.

Data sets with Kinect:

MIT Lobby 7, Year 2015, 1 Kinect, 8 hours.
The Kinect v1 used at the data collection at the MIT Lobby 7, was located in a tripod at the entrance of the infinite corridor. The sensor captured flows in both directions, for eight continuous hours. The height was 90 cm. The data collection was performed on a Wednesday, on the April 8th of 2015. April is a period in which MIT receives many tours and groups of people that come to visit for Open House and admissions. This involves recording an heterogeneous group composed by parents and students, and external public. On the day of the recording, there were two tours after 1.00 pm. The main student traffic occurred between 9.30 and 10.00 am.

MIT Media Lab Building, Year 2015. 1 Kinects, 8 hours for 3 days.
The Kinect v2 used at the three days data collections at the MIT Media Lab Lobby was placed as it appears in the map location, at a height of 120 cm. It recorded for 8 continuous hours for each of the three days. The recording were performed on three different days, February 25th, Wednesday, March 11th Wednesday and March 13th Friday, busiest day, all in the current 2015 year. On the last recording day, the situation was similar to Lobby 7 in which many tours were visiting the building, composed by people from companies, parents and students. The other two days were mostly a public of students, faculty and MIT staff.

MIT Infinite Corridor, Year 2015, 1 Kinect, 4 hours.
The recording at the "MIT Infinite Corridor", abbreviated as IC, was performed on the third of February of 2014. The Kinect v1 was placed at 1.2 meters height. The recording was performed during the afternoon, around 5.30 pm, time in which most of students leave Campus. The people recorded is mainly students that attend the MIT Campus during the Independent Activities Period, during January, that finalize at the

beginning of February. The area of the“MIT Infinite Corridor” that is close to MIT Building 10 Lobby connects with a hub of flows.

Pisa University, Year 2015, 1 Kinect, 1 hr.
The data collection performed in Pisa University, UNIPI, located in Pisa, Italy, at the Engineering and Medicine Pavilion was developed in a special setting. The Kinect v2 was placed at 4 meters height, looking down, therefore the data visualization of this recording does not show the conical range of the Kinect. The data collection was done on the 24th of March of 2015, in a “corridor” spatial situation, which could be comparable to the “MIT Infinite Corridor” spatial setting but wider. The data collection was performed for one continuous hour. The Kinect captured mostly students of Engineering and Medicine. The pick of the traffic flow happened during lunch time while recording.

Catholic University, Building Vestibule, Year 2015, 1 Kinect, 8 hours.
The recording performed at the Catholic University of Chile, UC, located in Santiago of Chile occurred on January 12th, 2015. The Kinect v1 was placed on top of a table at 75 cm height. The Kinect captured the main traffic coming from outside the building, which leads directly to the sidewalk of the Alameda Avenue, to the interior facilities of the Campus. That day it was “Registration day” in which all the students come to school, many with their parents to register into a program. This as a special use of the space. In addition to the students, two guards were patrolling the space, which were recorded too.

National University, Cafeteria, Year 2015, 1 Kinect, 1 hour.
The recording performed at the National University of Colombia, UNAL, located in Medellin occurred on January 25th, 2015. The Kinect v1 was placed on top of a table at 75 cm height. The Kinect captured the main traffic in the cafeteria corridor. The data was collected on a regular class day during lunch time. Must add that the cafeteria has a semi-outdoor condition as the weather in Colombia allows to leave building open without vertical enclosures.

MIT Media Lab Building, Year 2013. 8 Kinects, 1 year.
A research group of the MIT Media Lab "Responsive Environments" decided to explore the use of Kinects for gutturally controlling 25 screens around their building, recording every path of a person walking in front of the sensors across a space at the same time. These data constitute the only database of anonymized tracked people inside a building, perhaps in the entire world. This group kindly share a data set with me, from 2013 January 1st until December 31st of 2013

- Video Camera:
- Collects:
- Continuous video footage from an advantage point of view, as in a high position. It is possible to extract Spatial gestures measurements.
- Coordinates of the trajectories of people in plan view, which are extracted post-capture.

Define Location:
The location of the camera devices is defined as to find for an advantage point of view over the space that will be analyzed. The advantage point of view is a higher point such as upper floors or on top of the space. The trajectories extracted from the video footage required to be mapped to an orthogonal space and therefore it is very useful to direct the device symmetrically in the horizontal axis. When recording from a frontal point of view with the camera, people block each other, therefore it is needed to place the camera as high as possible.

Data sets with Video Camera:

MIT Lobby 7, Year 2015, 1 Video Camera, 8 hours. MAIN
The video Camera was located on the third floor of the Lobby 7 looking down. It recorded for 8 continuous hours. The advantage of this position is that it was not easy for people to realize that the camera was there.

MIT Media Lab Building, Year 2015. 1 Video Camera, 8 hours each for 3 days. MAIN
The video Camera was located on the second floor of the MIT Media Lab Lobby looking down. It recorded for 8 continuous hours, for each of the three days. The camera was mounted in a tripod and in a location that it wasn't easily discovered.

[4.1.2] Space-Motion Metrics: speed, gestures and time

Data Processing

The Kinect data needs to be cleaned before it could be used, through several processed developed with Java Language. This consist of eliminating the coordinates that are closer to zero, since the range of the sensor works at a distance of 40 cm of the object. When the Kinect is recording more that one people it jumps from one to the other as it is identifying both of their motion. Because of that the recorded data is not sequentially ordered, and the point could not be assigned to the same user. To avoid this problem an algorithm that redistributes the points to their users is applied to the data, calculating the distance and time threshold to define a user trajectory. Finally a data visualization is created, drawing each of the points of each of the trajectories. The stroke of the points correspond to the time spent in each of the locations, the size adjusts according to the person's motion.

The video footage recorded with the camera is analyzed using OpenCV Background Subtraction algorithm in order to extract the trajectories of people in Space. After this process is finished, the coordinates are undistorted from the perspective of the video and are ready to be analyzed. The equations used to undistort the points were found on the paper "A Vision Based Top-View Transformation Model for a Vehicle Parking Assistant." (Lin & Wang, 2012)

$$x^* = H x \sin \phi + f \cos \phi - y \cos \phi + f \sin \phi$$

$$y^* = H y \sin \phi + f \cos \phi - y \cos \phi + f \sin \phi$$

"where (x, y) are the original image coordinates, and (x*, y*) are the destination image coordinates, H is the distance between the camera and ground, f is the focal length of the camera, and ϕ is the camera tilt angle." (Lin & Wang, 2012)

In terms of the "Spatial Gestures", is more complex to do this through the Computer Vision algorithms. There is the possibility of using Matlab routines, yet due to the scope of the thesis, this task was performed manually.

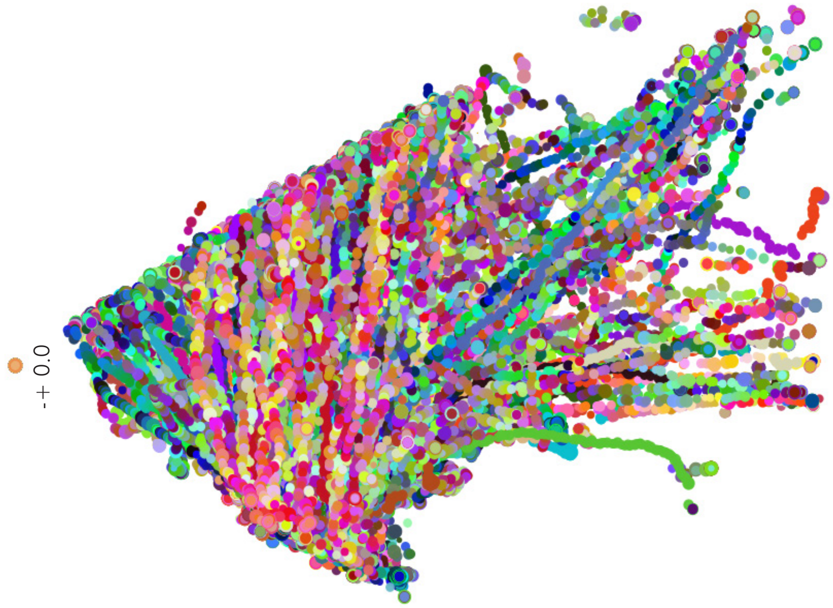


Figure. 26. Data visualization using Kinect data from UC Lobby. It illustrates how the data is not distributed by user, therefore the colors do not follow teach trajectories. It also shows that the tracked motion goes beyond the Kinect official range. The lines that go outside the main triangle are 7 meters long. The official range of the Kinect is 4 meters long. The longer lines were verified and validated.

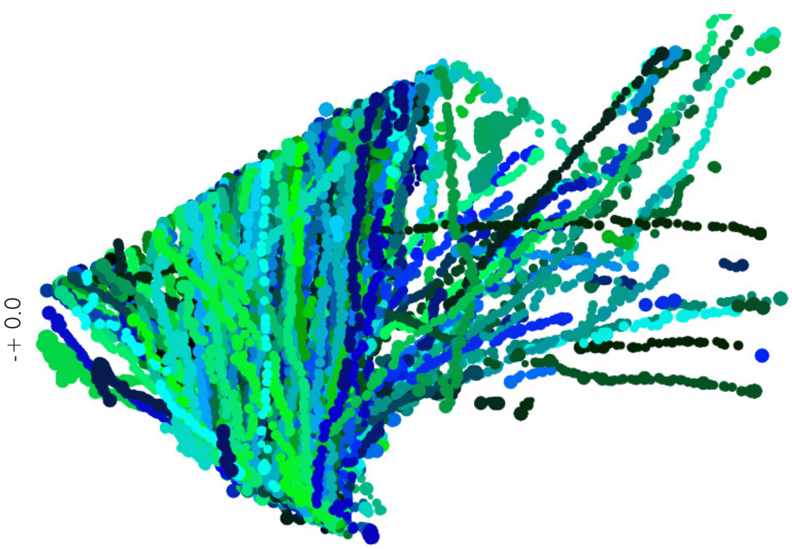


Figure. 27. Data visualization using Kinect data from UC Lobby. It illustrates how the data is distributed by user, after processed by the code created for the thesis. Each line is just one color, and corresponds to one user. The +- 0.0 is the position of the Kinect.

This research analyzes people's spatial behavior towards architectures features, and therefore is a research that treat humans as research subjects. MIT Regulations regarding the use of Human Subjects in research is very strict, and is regulated by COUHES, "Committee on the Use of Humans as Experimental Subjects." As a result a training is required in which the ethics and principles for treating with humans are exposed. In addition a permission to record with the Video Camera is required. Hence no face of people can be shown in this document. As a result all the photographs from the data collection locations will be displayed without people and if people is included their faces will be erased.

METRICS

The main three metrics analyzed in the thesis are speed, gesture and time. Speed is the main indicator of space-time relations, and it is part of every spatial gesture.

1- Speed: The average speed is calculated, as well as the speed approaching several architectural features. Once the trajectories of people's motion are extracted from the video footage it is also possible to calculate the speed in a larger range.

The speed baseline of preferred walking speed is 1.4 m/s, according to many published studies (Waldau et al., 2007.) The baseline was tested by myself and one more subject. The Kinect successfully retrieved the expected speeds, validating the published standards. As reference this is equivalent to 4.5 feet per second.

At 0.8 meters per second a person starts moving. If the speed is greater than 1.4 meters per second is considered high speed and in some cases extreme higher speed. The speed is calculated dividing the distance of the location points by the time spent between the points. Therefore the measurements are scaled to real world conditions. The speed is measured in relation to spatial configuration or spatial features. For example the speed in a corridor, or the speed approaching an entrance. Calculating the speed allows to sort the people that is recorded differentiating the ones that are moving from the ones standing or wondering. This aspect of the speed improves data processing because after the data is recorded becomes a black box.

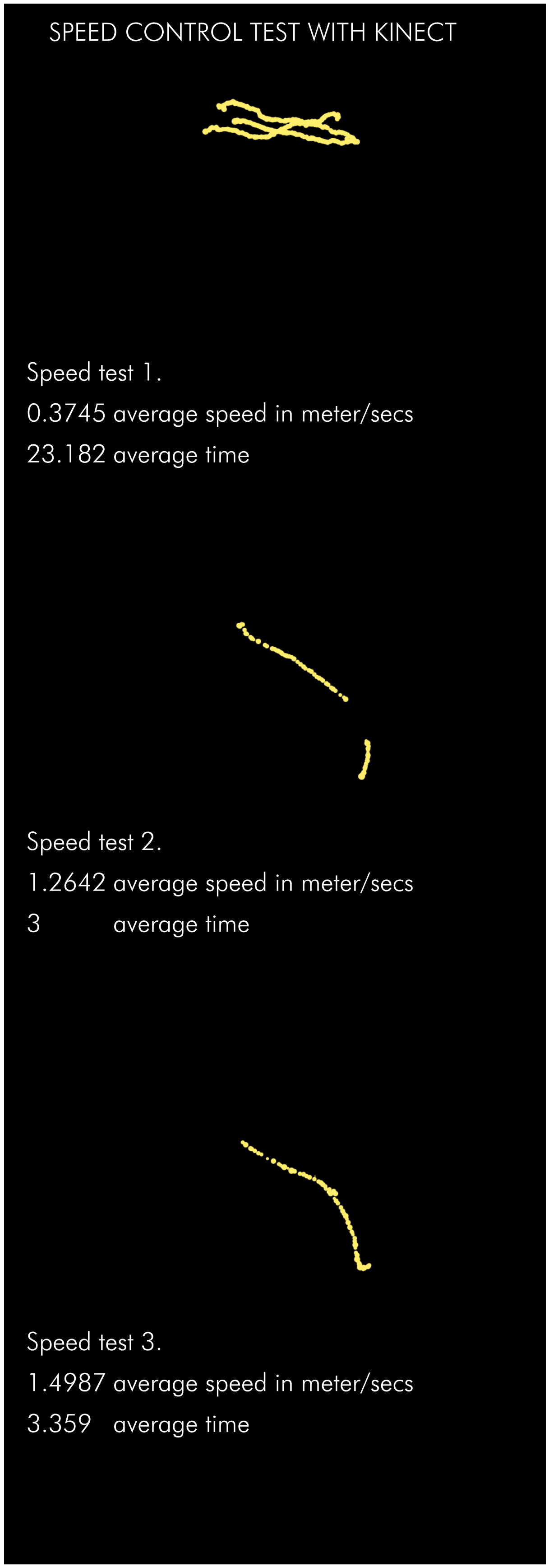


Figure. 28. Speed baseline control test. The Test was performed by myself and another human subject. We walk in an indoor space and recorded our motion in three different speeds, increasing velocity. The test was performed with Kinect v1. According to the test the speed of 1.4 m/s proved to be comfortable as walking speed.

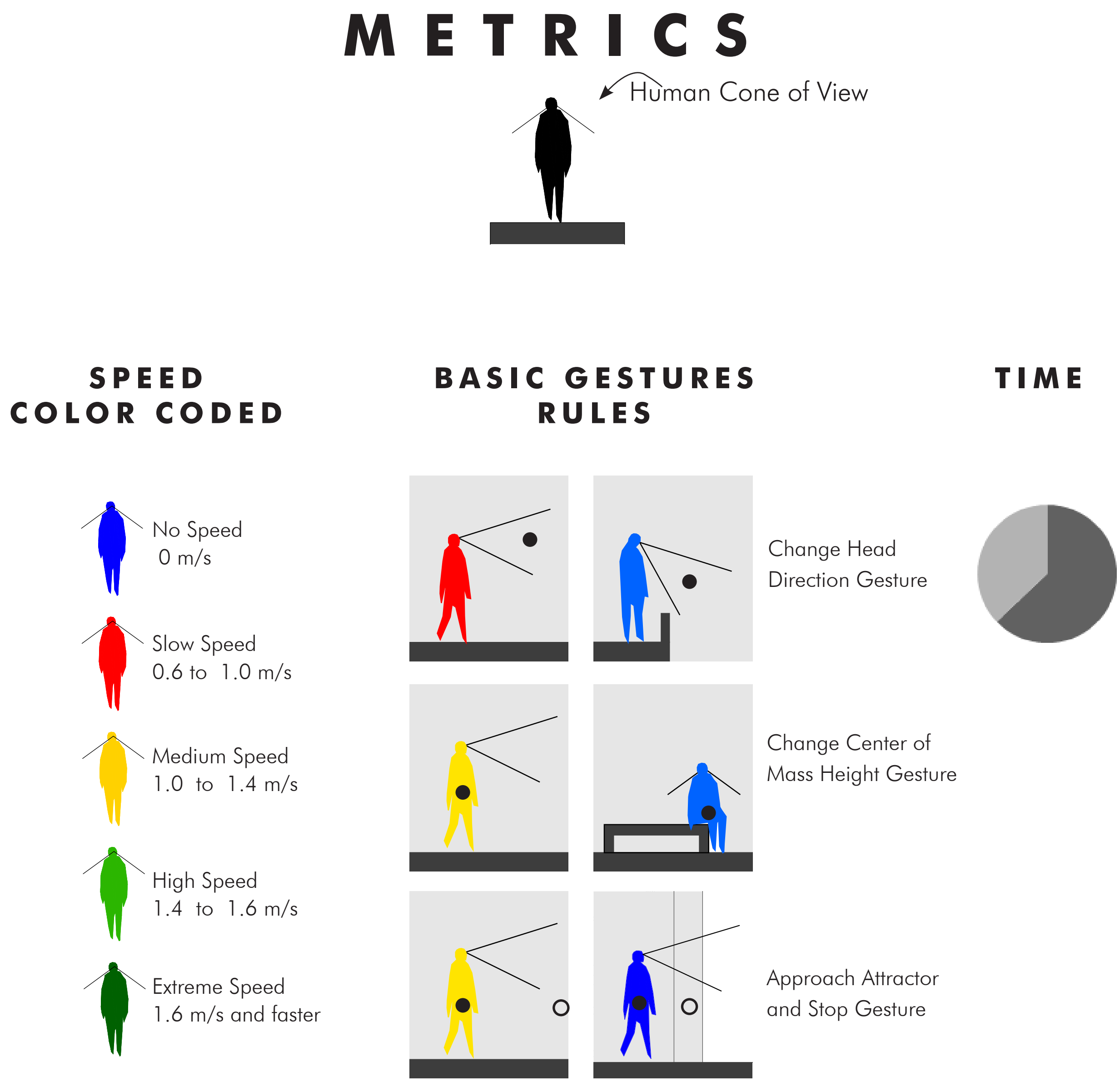


Figure. 29. Metric Indicators.

2-Gestures: The gestures are defined as a group of body movements such as walking-turning-the-head-up, or walking-seating that refer to a spatial condition. The gestures must be identified among a large number of gestures that people do behaving regularly in public space. When a gesture is positively identified regarding a spatial feature of the selected space, it is added to general count. The gestures are extracted from the Video Footage manually and some of them are obtained from the Kinect data..

3- Time: period spent calculation, is retrieved by the Kinect Data. Time is used to the speed calculation, however it retrieves information by itself as exposing the time spent in a certain location. The time is calculated for people standing and for people in motion.

4- Shape: is retrieved by the data visualization of the Kinect Data. A visual inspection is performed. In future developments it is possible to analyze the curvature and the angle in relation to the architectural feature, as for example in the entrance of the Media Lab Data from the elevator at Class Room 140. The shape also demonstrates the consistency of the pattern of motion in time as it is possible to trace the routes of several days with the data of the Media Lab Building. However, in further steps the shape of the trajectory could be analyzed in terms of its geometry.

5- Direction: The data is divided by direction of route, from Kinect and Video Footage. The direction of the route retrieve where the person is heading. The direction is determined by the sequence of position points as was described before.

6- Scale: The Kinect range, retrieves a micro situation. However sometimes it retrieves a fragment of a larger situation. The difference is made explicit in the data visualizations. The video footage retrieves the scale of the public space.

DATA VISUALIZATIONS

In order to study the datasets, I developed several trajectory visualizations, contextualizing the trajectories to their locations. The visualizations have a triangular shape making explicit the sensing range of the Kinect and are overlapped with a plan of the location. In some of the visualizations the time spent is calculated and sized the stroke of the points according to how much time a person stayed in that specific position. This process makes explicit the speed of people. The large stains show that a person was wandering around a certain location for a prolonged period of time. The data retrieves the coordinates and user ID. The color of the points is changed every time the trajectory of a new person starts. The 0.0 coordinates are on top of each images and represent the position of the Kinect. The locations are diverse, from a first floor entrance, to a staircase with slow pace.

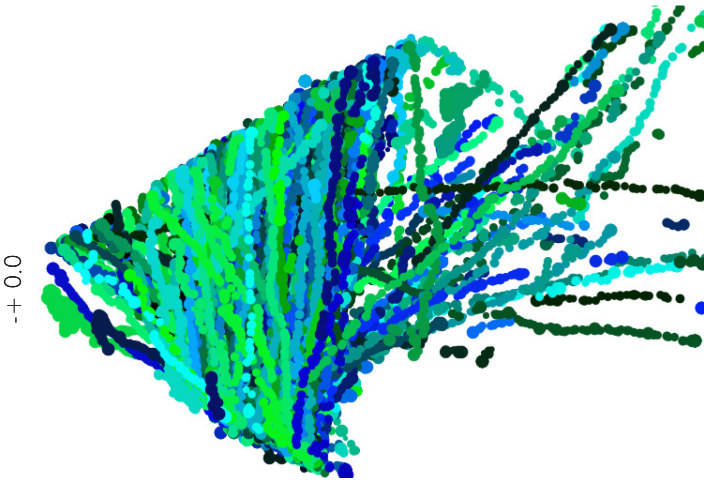


Figure. 30. MIT Lobby 7 Data Visualization.

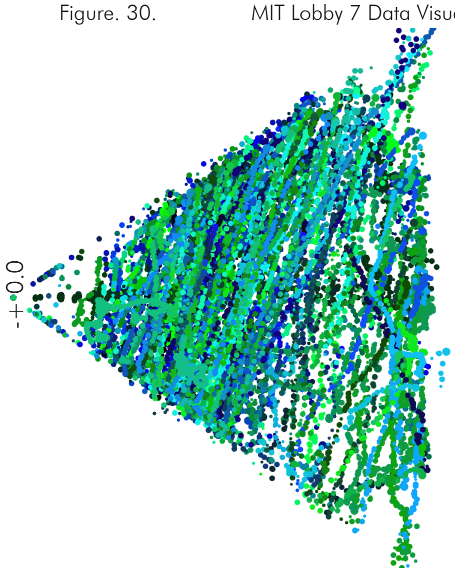


Figure. 31. MIT Media Lab Lobby Data Visualization.

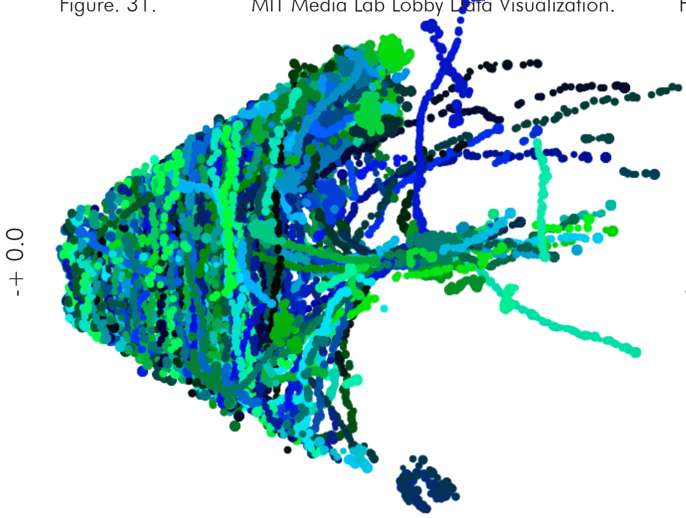


Figure. 32. MIT Infinite Corridor Data Visualization.

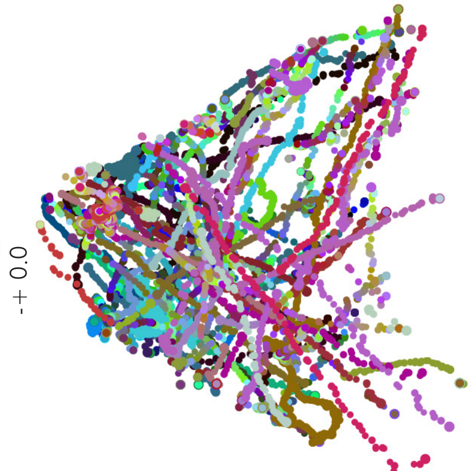


Figure. 35. UNAL Cafeteria Data Visualization.

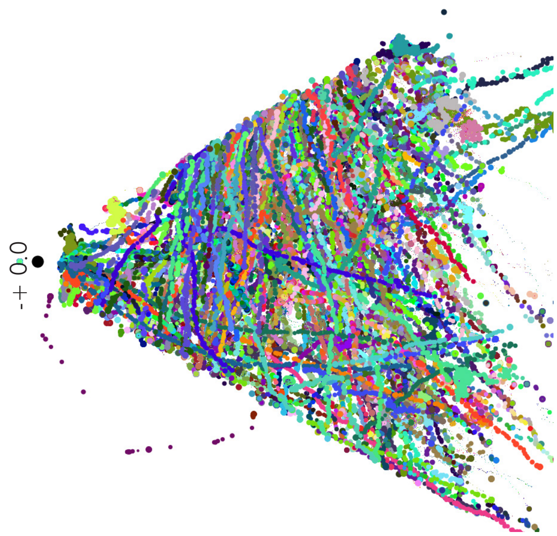


Figure. 34. UC Vestibule Data Visualization.

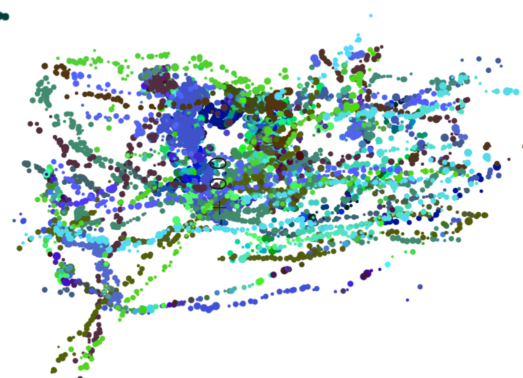


Figure. 33. UNIPI Corridor Data Visualization.

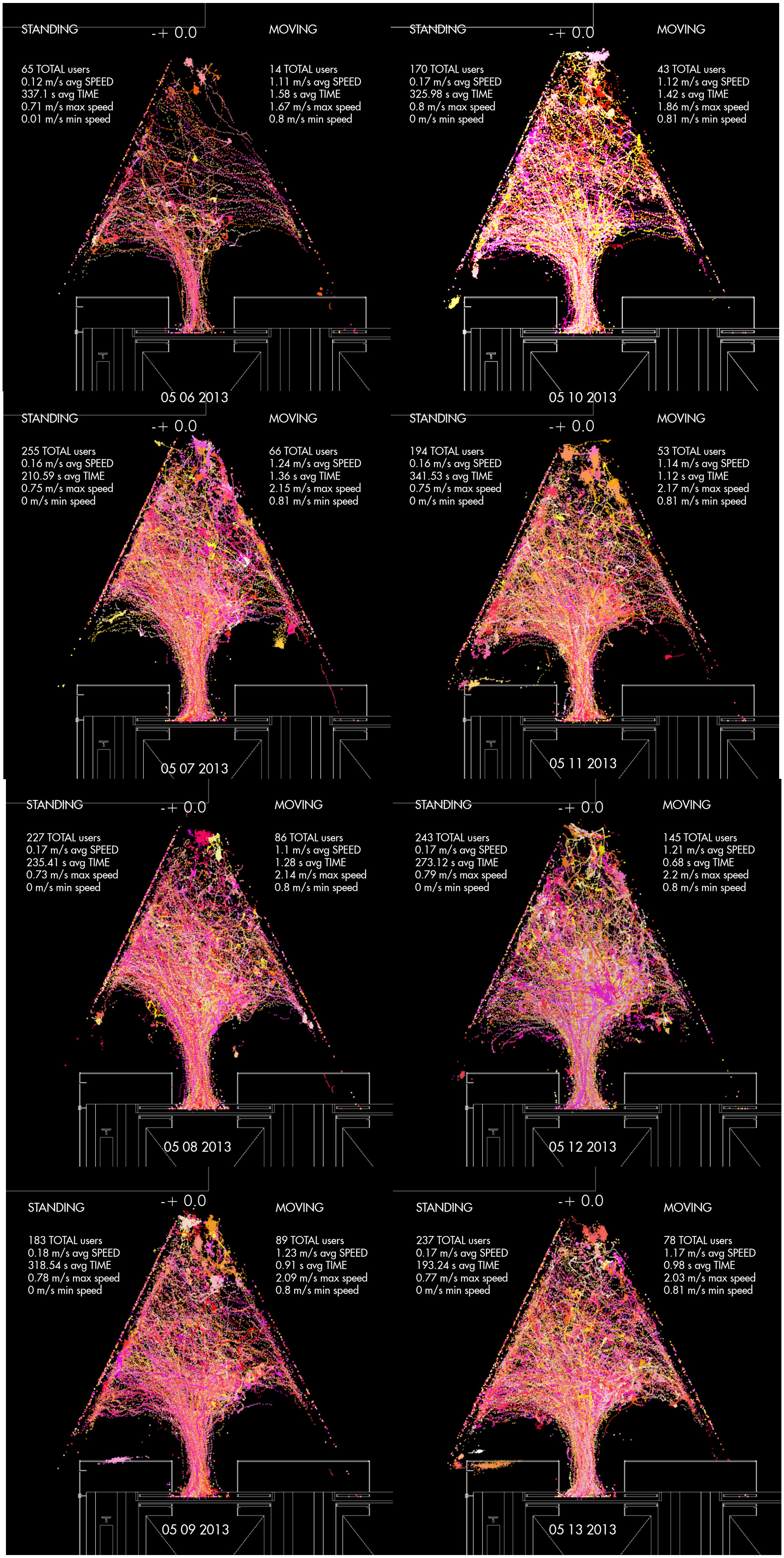
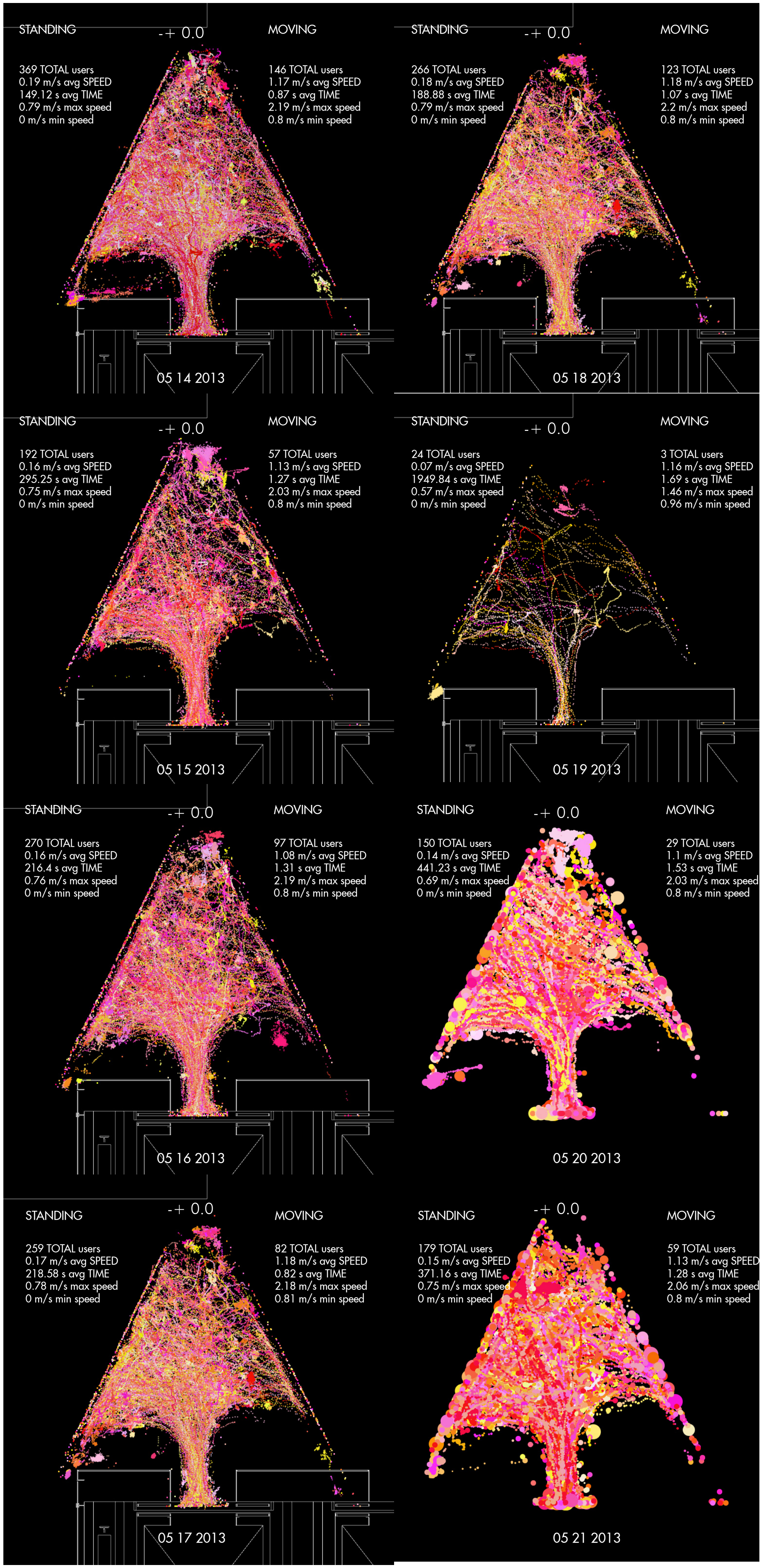


Figure. 36. 1
Elevator entrance in front of Media Lab Classroom 140 Entrance. Data visualizations from 16 days of May 2013, recorded with Kinect sensor at the MIT Media Lab Lobby. The sequence of visualizations shows the consistency of the pattern of people's trajectories. Over time, validating the data from the Kinect sensor.


STANDING
-+ 0.0
MOVING
369 TOTAL users
0.19 m/s avg SPEED
149.12 s avg TIME
0.79 m/s max speed
0 m/s min speed
146 TOTAL users
1.17 m/s avg SPEED
0.87 s avg TIME
2.19 m/s max speed
0.8 m/s min speed
05 14 2013
STANDING
-+ 0.0
MOVING
266 TOTAL users
0.18 m/s avg SPEED
188.88 s avg TIME
0.79 m/s max speed
0 m/s min speed
123 TOTAL users
1.18 m/s avg SPEED
1.07 s avg TIME
2.2 m/s max speed
0.8 m/s min speed
05 18 2013
STANDING
-+ 0.0
MOVING
192 TOTAL users
0.16 m/s avg SPEED
295.25 s avg TIME
0.75 m/s max speed
0 m/s min speed
57 TOTAL users
1.13 m/s avg SPEED
1.27 s avg TIME
2.03 m/s max speed
0.8 m/s min speed
05 15 2013
STANDING
-+ 0.0
MOVING
24 TOTAL users
0.07 m/s avg SPEED
1949.84 s avg TIME
0.57 m/s max speed
0 m/s min speed
3 TOTAL users
1.16 m/s avg SPEED
1.69 s avg TIME
1.46 m/s max speed
0.96 m/s min speed
05 19 2013
STANDING
-+ 0.0
MOVING
270 TOTAL users
0.16 m/s avg SPEED
216.4 s avg TIME
0.76 m/s max speed
0 m/s min speed
97 TOTAL users
1.08 m/s avg SPEED
1.31 s avg TIME
2.19 m/s max speed
0.8 m/s min speed
05 16 2013
STANDING
-+ 0.0
MOVING
150 TOTAL users
0.14 m/s avg SPEED
441.23 s avg TIME
0.69 m/s max speed
0 m/s min speed
29 TOTAL users
1.1 m/s avg SPEED
1.53 s avg TIME
2.03 m/s max speed
0.8 m/s min speed
05 20 2013
STANDING
-+ 0.0
MOVING
259 TOTAL users
0.17 m/s avg SPEED
218.58 s avg TIME
0.78 m/s max speed
0 m/s min speed
82 TOTAL users
1.18 m/s avg SPEED
0.82 s avg TIME
2.18 m/s max speed
0.81 m/s min speed
05 17 2013
STANDING
-+ 0.0
MOVING
179 TOTAL users
0.15 m/s avg SPEED
371.16 s avg TIME
0.75 m/s max speed
0 m/s min speed
59 TOTAL users
1.13 m/s avg SPEED
1.28 s avg TIME
2.06 m/s max speed
0.8 m/s min speed
05 21 2013

人

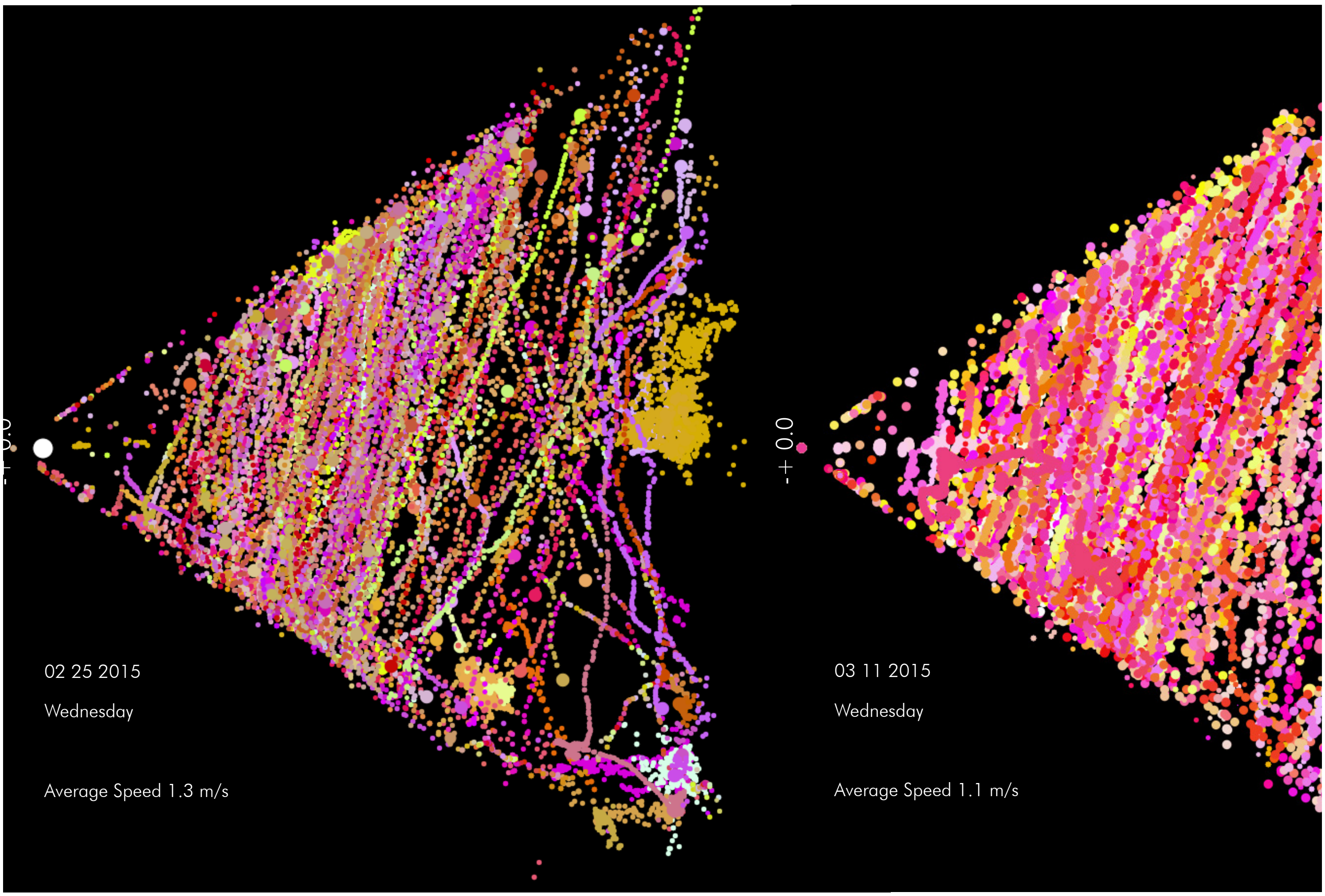
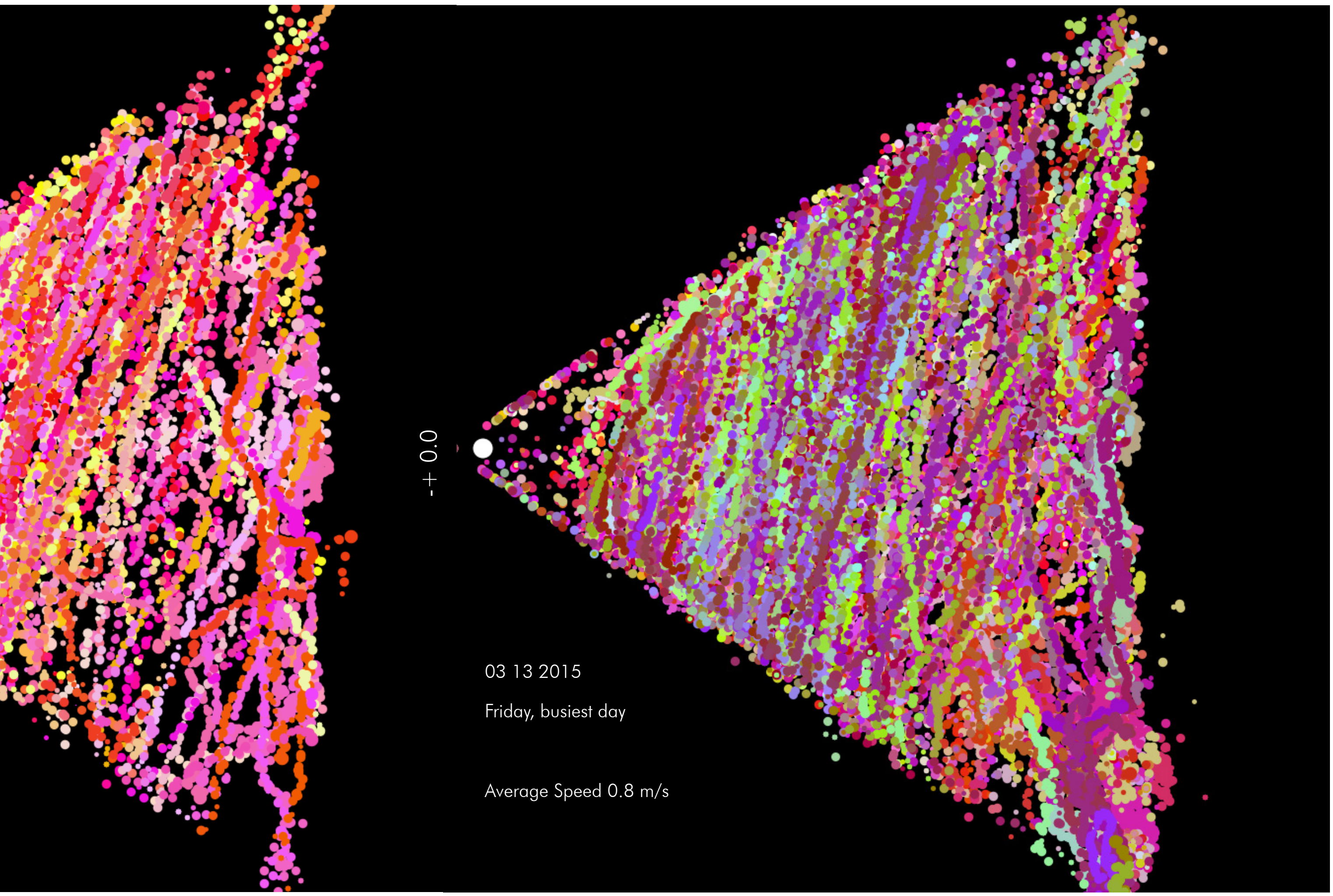
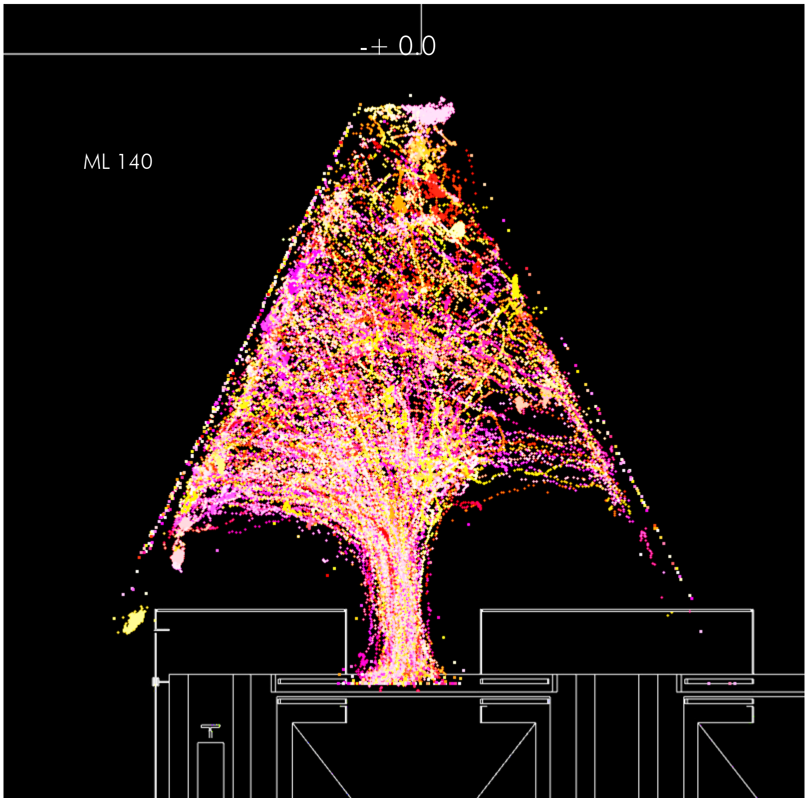


Figure. 37. Data visualization sequence from Kinect data recorded at the MIT Media Lab Lobby, in the are shown in the building plan at page 50. The visualization shows the main traffic flow coming from the South Entrance.

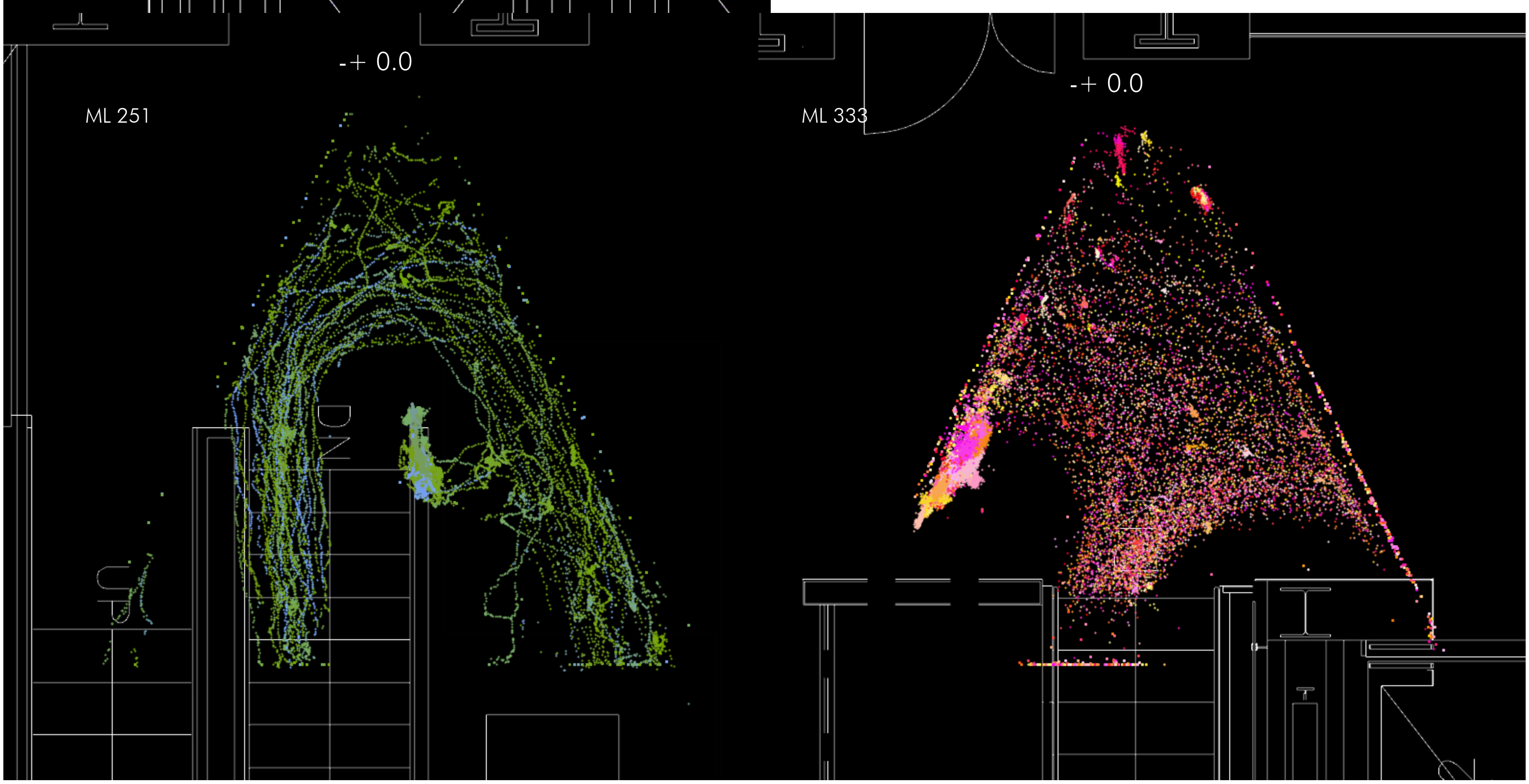


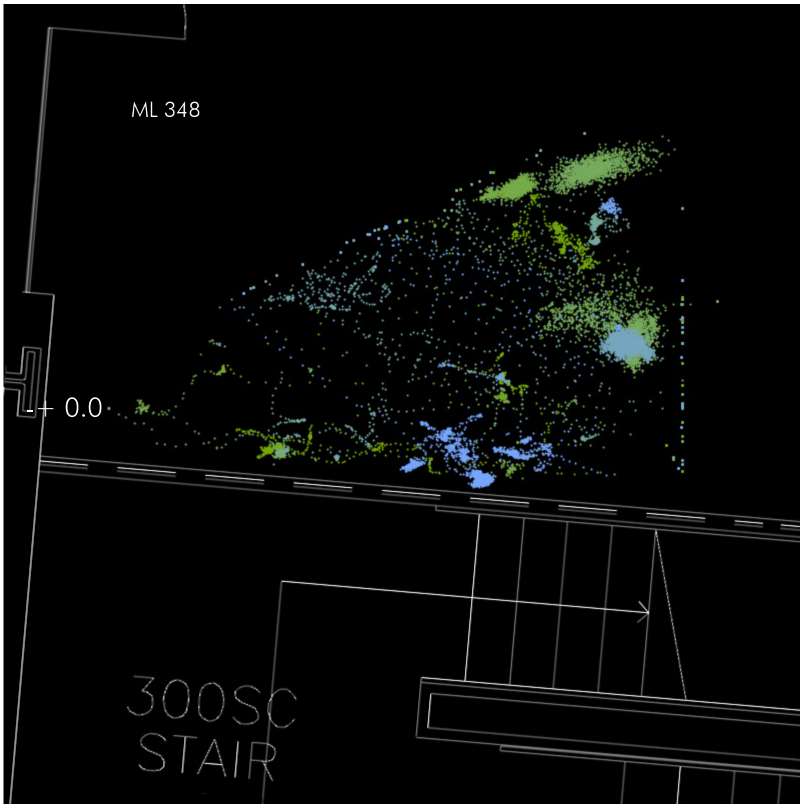
The three visualizations from the MIT Media Lab data presented show 8 hours of recording over three days. The Kinect was located in order to reach the main traffic flow of the area, after the south entrance of the building. The Kinect range also reached the bench and people that performs the lookup gesture before entering the void. In the three day datasets I have determined the average speed. It is also possible to observe how busy was the space in the day that the data was collecting by evaluating the accumulative paths of people and the count of the users.



Six of these data visualizations are presented together, developed with the datasets from the Media Lab Building. In addition, I could observe some spatial constants that were proven such as the importance of the large voids that connect several stories of the Media Lab Building, as we can see in the "Classroom 348" and "Classroom 474" figures. In both of these visualizations large stains appear reflecting longer periods of time spent in the areas that are closer to the voids banisters. This discovery may seem obvious, - the building is working as the architect's intention set it to be-. Nevertheless it was not until now that this could be finally proven with real data, which constitute a contribution of this research.

“ML” means Media Lab, and the number is the classroom number close to the Kinect recording.





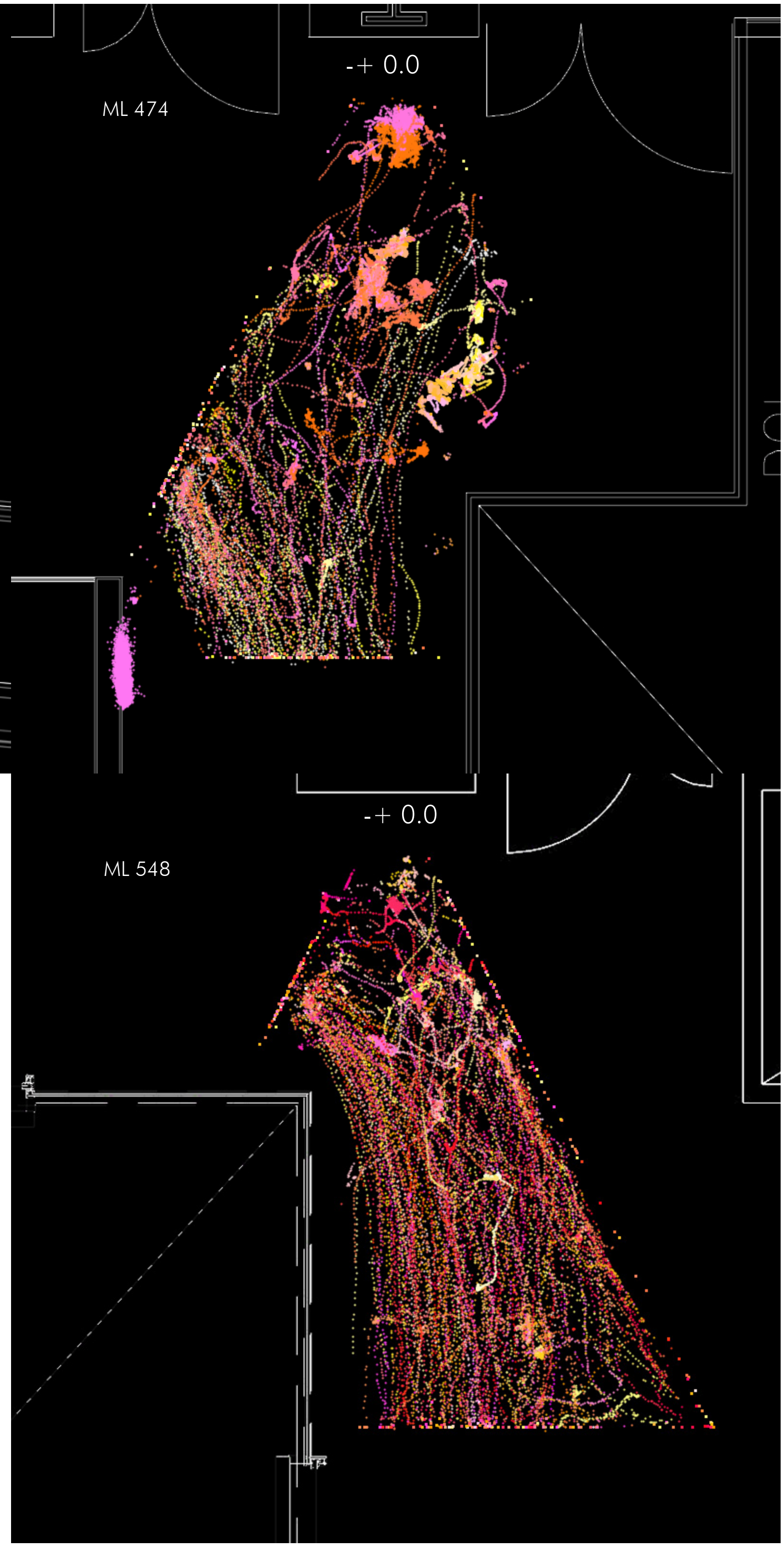


Figure. 38. Data visualization sequence from Kinect data recorded at the MIT Media Lab Lobby. It shows six different locations from the building. The data comes from the data set generated by the MIT Responsive Group.

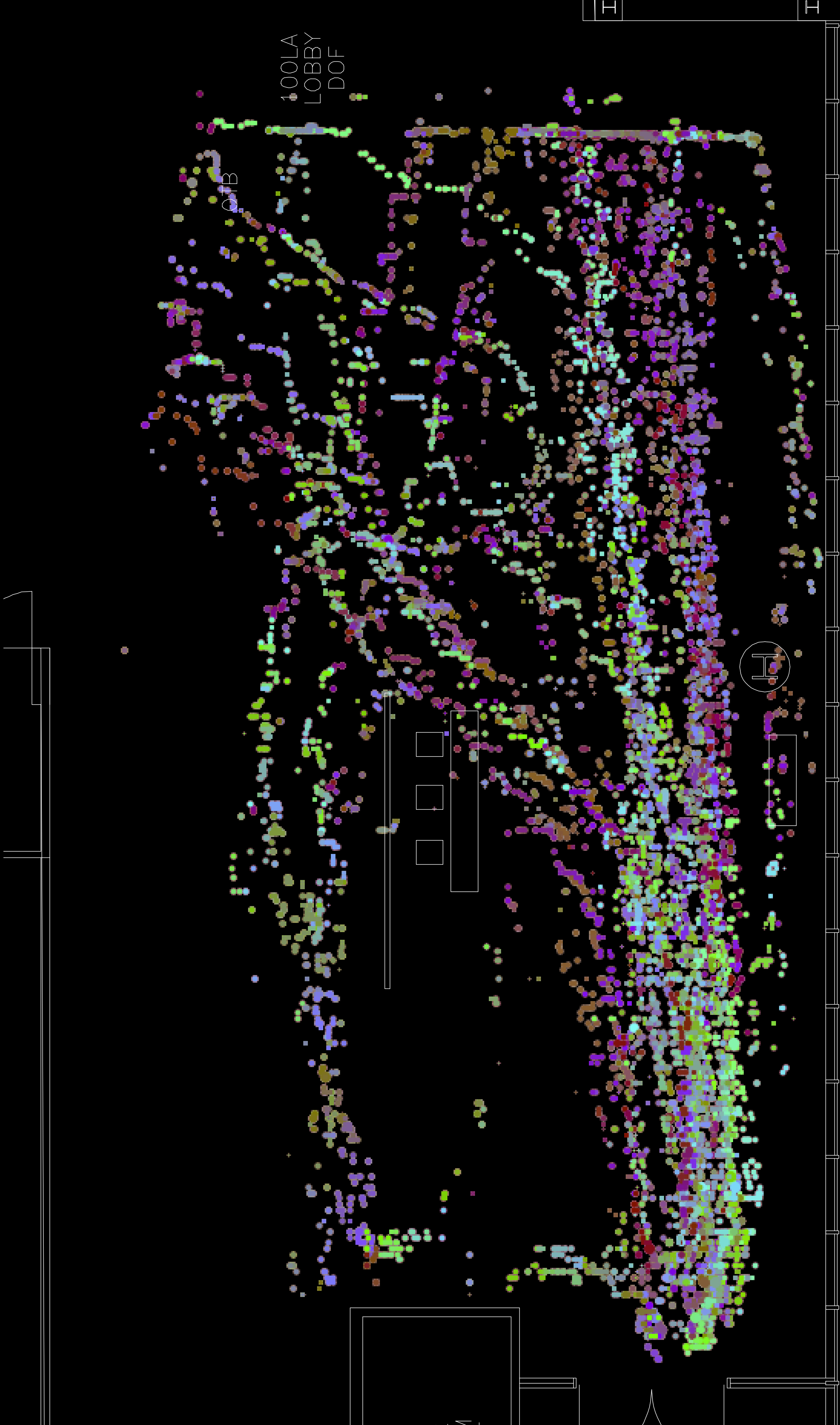


Figure. 39. Data visualization developed with the position coordinates extracted from video footage. Shows the MIT Media Lab Lobby main traffic flows.

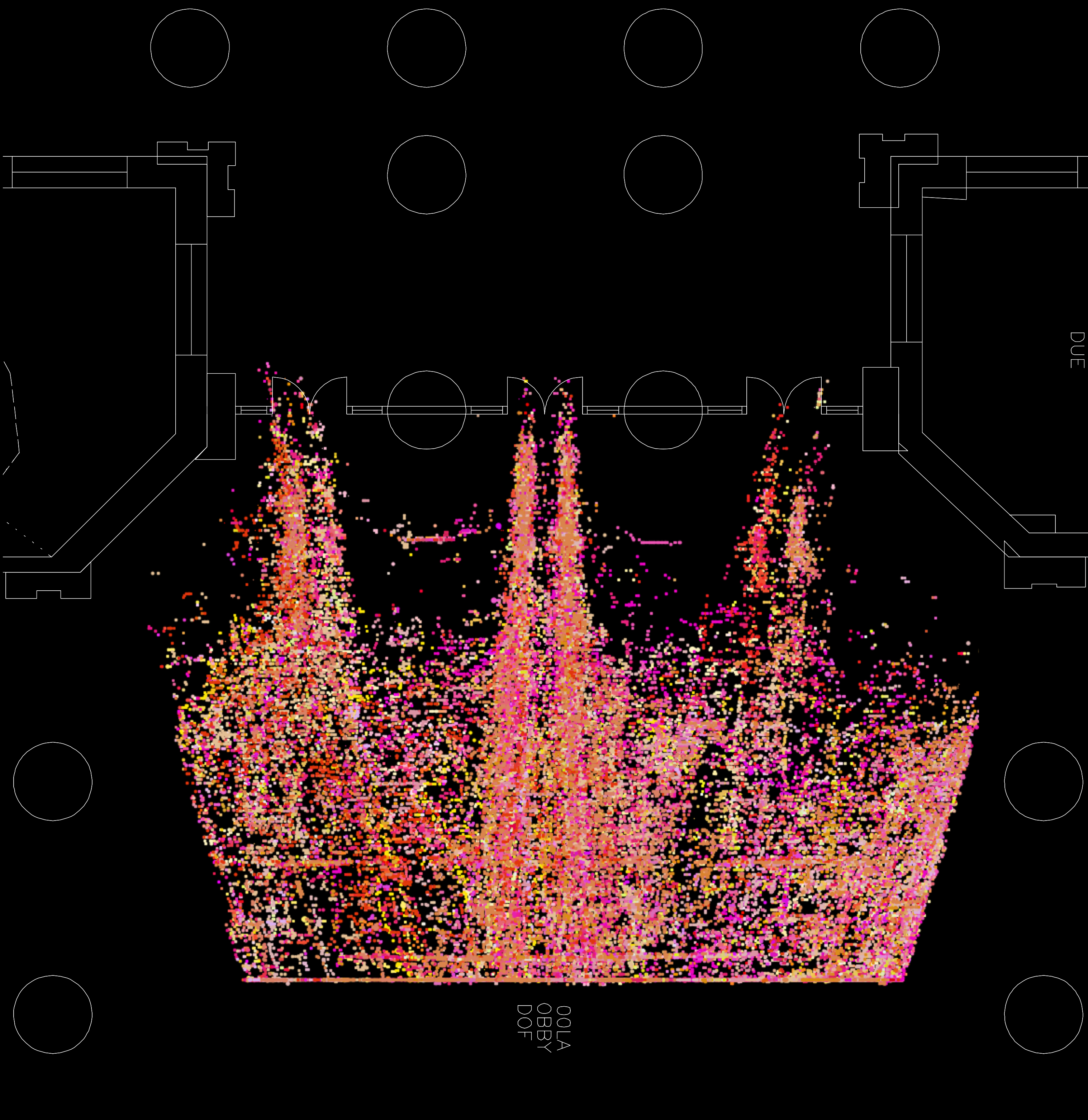


Figure. 40. Data visualization developed with the position coordinates extracted from video footage. Shows the MIT Lobby 7 main traffic flows.

	UC VESTIBULE
300	TOTAL USERS
1.28	AVG SPEED
1.77	MAX AVG SPEED
1.03	MIN AVG SPEED
1.43	AVG TIME

	UNIPI CORRIDOR
67	TOTAL USERS
1.61	AVG SPEED
2.28	MAX AVG SPEED
1.11	MIN AVG SPEED
3.12	AVG TIME

	MIT CORRIDOR
498	TOTAL USERS
1.49	AVG SPEED
2.22	MAX AVG SPEED
1.03	MIN AVG SPEED
0.90	AVG TIME

	UC VESTIBULE
646	TOTAL USERS
0.92	AVG SPEED
1.77	MAX AVG SPEED
0.20	MIN AVG SPEED
4.77	AVG TIME

	UNIPI CORRIDOR
113	TOTAL USERS
1.24	AVG SPEED
2.28	MAX AVG SPEED
0.32	MIN AVG SPEED
5.15	AVG TIME

	MIT CORRIDOR
1021	TOTAL USERS
0.99	AVG SPEED
2.22	MAX AVG SPEED
0.10	MIN AVG SPEED
3.47	AVG TIME

	UC VESTIBULE
346	TOTAL USERS
0.62	AVG SPEED
0.99	MAX AVG SPEED
0.20	MIN AVG SPEED
7.48	AVG TIME

	UNIPI CORRIDOR
46	TOTAL USERS
0.55	AVG SPEED
0.80	MAX AVG SPEED
0.32	MIN AVG SPEED
9.13	AVG TIME

	MIT CORRIDOR
523	TOTAL USERS
0.52	AVG SPEED
0.98	MAX AVG SPEED
0.10	MIN AVG SPEED
5.88	AVG TIME

	MIT LOBBY 7
6126	TOTAL USERS
1.44	AVG SPEED
2.42	MAX AVG SPEED
1.00	MIN AVG SPEED
1.23	AVG TIME

	MIT ML LOBBY
375	TOTAL USERS
1.46	AVG SPEED
2.29	MAX AVG SPEED
1.01	MIN AVG SPEED
1.99	AVG TIME

ML 140	ENTRANCE
11	TOTAL USERS
1.06	AVG SPEED
1.08	MAX AVG SPEED
1.03	MIN AVG SPEED
3.91	AVG TIME

	MIT LOBBY 7
7723	TOTAL USERS
1.29	AVG SPEED
2.42	MAX AVG SPEED
0.10	MIN AVG SPEED
1.64	AVG TIME

	MIT ML LOBBY
505	TOTAL USERS
1.24	AVG SPEED
2.29	MAX AVG SPEED
0.13	MIN AVG SPEED
4.06	AVG TIME

ML 140	ENTRANCE
4253	TOTAL USERS
0.43	AVG SPEED
1.03	MAX AVG SPEED
0.06	MIN AVG SPEED
17.11	AVG TIME

	MIT LOBBY 7
1597	TOTAL USERS
0.70	AVG SPEED
1.00	MAX AVG SPEED
0.10	MIN AVG SPEED
3.13	AVG TIME

	MIT ML LOBBY
130	TOTAL USERS
0.60	AVG SPEED
0.99	MAX AVG SPEED
0.13	MIN AVG SPEED
9.60	AVG TIME

ML 140	ENTRANCE
4242	TOTAL USERS
0.43	AVG SPEED
0.96	MAX AVG SPEED
0.06	MIN AVG SPEED
17.15	AVG TIME

ML 251	STAIRS
506	TOTAL USERS
1.17	AVG SPEED
1.82	MAX AVG SPEED
1.01	MIN AVG SPEED
1.07	AVG TIME

MOV	UNAL
66	TOTAL USERS
1.26	AVG SPEED
1.49	MAX AVG SPEED
1.08	MIN AVG SPEED
1.31	AVG TIME

Figure. 41. Statistics from each of the locations where data was collected with Kinect Sensor.

ML 251	STAIRS
7047	TOTAL USERS
0.65	AVG SPEED
1.82	MAX AVG SPEED
0.03	MIN AVG SPEED
3.06	AVG TIME

ALL	UNAL
126	TOTAL USERS
0.75	AVG SPEED
1.26	MAX AVG SPEED
0.21	MIN AVG SPEED
12.76	AVG TIME

ML 251	STAIRS
6541	TOTAL USERS
0.61	AVG SPEED
1.00	MAX AVG SPEED
0.03	MIN AVG SPEED
3.22	AVG TIME

ML 348	BALCONY
2648	TOTAL USERS
0.08	AVG SPEED
0.18	MAX AVG SPEED
0.02	MIN AVG SPEED
34.98	AVG TIME

ALL	UNAL
79	TOTAL USERS
0.53	AVG SPEED
0.80	MAX AVG SPEED
0.21	MIN AVG SPEED
15.01	AVG TIME

STATISTICS

SPEED | TIME

MOVING	TOTAL PEOPLE	AVG SPEED	MAX AVG SPEED	MIN AVG SPEED	AVG TIME
UNIPI CORRIDOR	67	1.61	2.28	1.11	3.12
MIT CORRIDOR	498	1.49	2.22	1.03	0.90
MIT ML LOBBY	375	1.46	2.29	1.01	1.99
MIT LOBBY 7	6126	1.44	2.42	1.00	1.23
UC VESTIBULE	300	1.28	1.77	1.03	1.43
UNAL CAFETERIA	66	1.26	1.48	1.08	1.31

ALL	TOTAL PEOPLE	AVG SPEED	MAX AVG SPEED	MIN AVG SPEED	AVG TIME
UNIPI CORRIDOR	113	1.24	2.28	0.32	5.15
MIT CORRIDOR	1021	0.99	2.22	0.10	3.47
MIT ML LOBBY	505	1.24	2.29	0.13	4.06
MIT LOBBY 7	7723	1.29	2.42	0.10	1.64
UC VESTIBULE	646	0.92	1.77	0.20	4.77
UNAL CAFETERIA	126	0.74	1.25	0.21	12.75

STANDING	TOTAL PEOPLE	AVG SPEED	MAX AVG SPEED	MIN AVG SPEED	AVG TIME
UNIPI CORRIDOR	46	0.55	0.80	0.32	9.13
MIT CORRIDOR	523	0.52	0.98	0.10	5.88
MIT ML LOBBY	130	0.60	0.99	0.13	9.60
MIT LOBBY 7	1597	0.70	1.00	0.10	3.13
UC VESTIBULE	346	0.62	0.99	0.20	7.48
UNAL CAFETERIA	79	0.53	0.80	0.21	15.01

MONTH	TOTAL PEOPLE	AVG SPEED	MAX AVG SPEED	MIN AVG SPEED	AVG TIME
ML 251 STAIRS	7047	0.65	1.82	0.03	3.06
ML 140 ENTRANCE	11	1.06	1.08	1.03	3.91
ML 348 BALCONY	2648	0.08	0.18	0.02	34.98

Figure. 42. Summary of the Statistics of Speed and Time.

GESTURE

SPEED CURVES

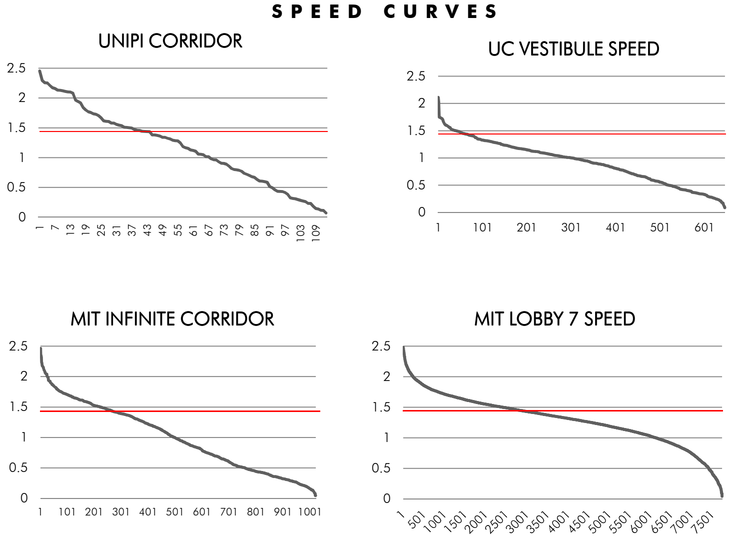


Figure. 43. Speed curves in four locations.

MEDIA LAB LOBBY	South Entrance	North Entrance
TOTAL PEOPLE	755	796
LOOK UP	70%	15%
LOOK THROUGH WINDOWS	27%	13%
WALK AROUND EXHIBITION	19%	9%
SAT ON BENCHES	3%	3%

Figure. 44. Gesture results.

[4.1.3] SPACE AND MOTION RULES

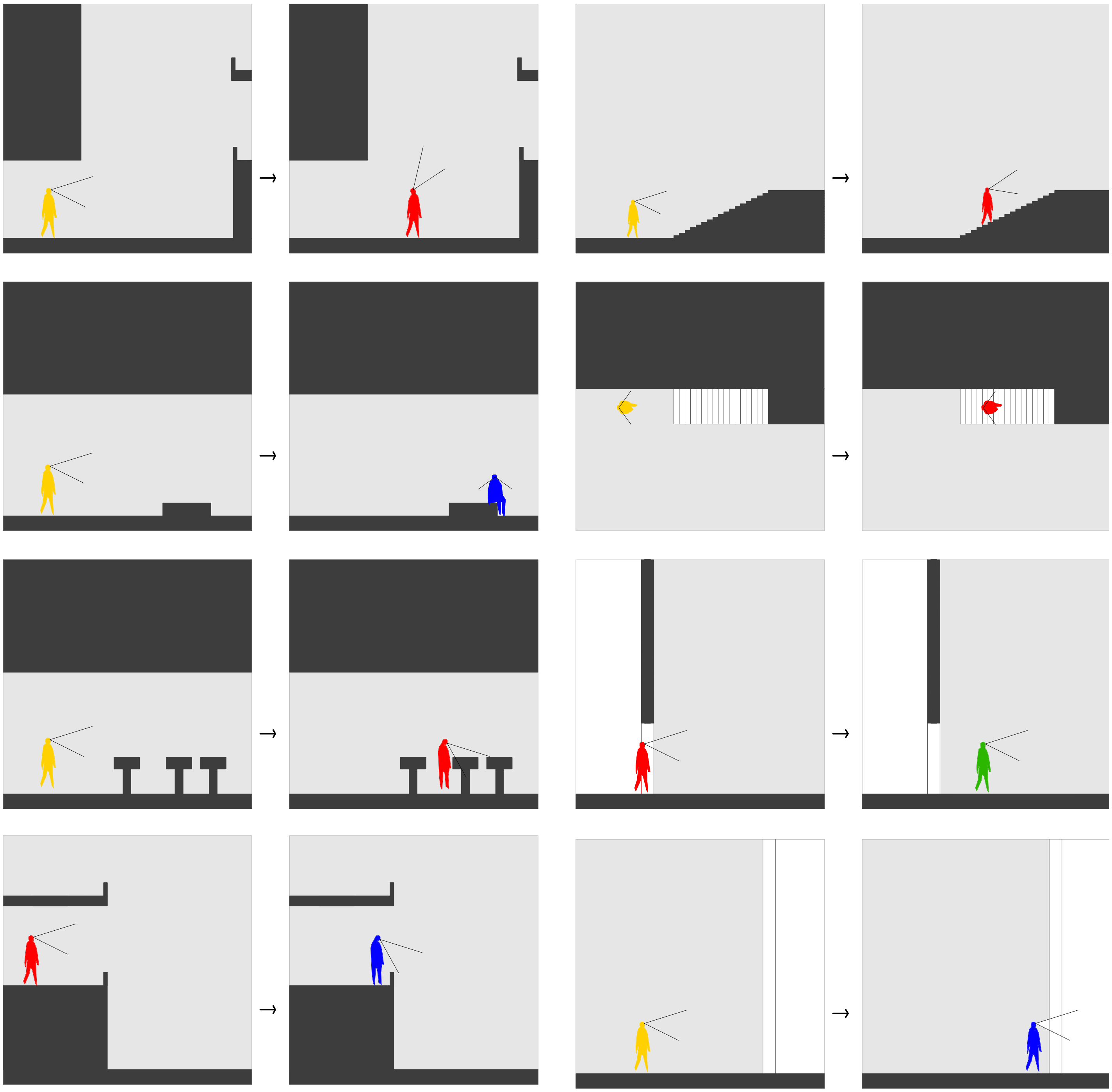
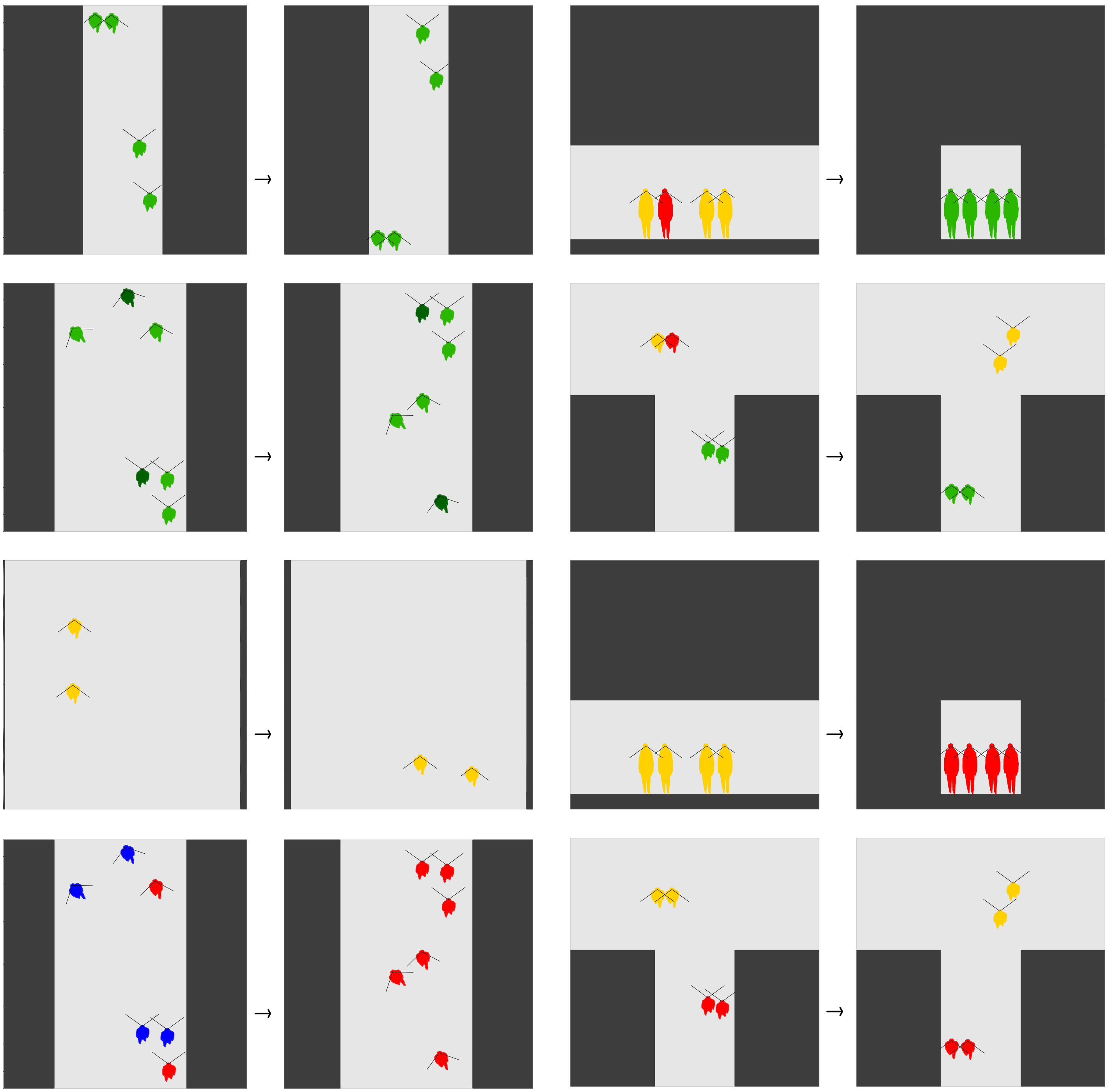


Figure. 45. All the *Space-Motion* rules.



RULES

The first and most important issue to state is that the result of the analysis is not by any means definitive or absolute. The results of the study are presented as rules or “laws of use” in terms of percentages, averages and other mathematical definitions generating a body of spatial movements that are highly speculative at this point. The rules show mainly spatial gesture rules and speed rules. The data used for each of the rules comes mostly from MIT Media Lab and Lobby 7, and sometimes from data samples from other countries. The locations where the data was collected are analogous; similar spatial typology in an educational building. It is not the intent either to create a characterization of each of the locations or to define a body of rules that correspond to a specific locations. Consequently, this rules are not expected to be applied to create new motion yet. The architectural features selected for the rules are presented in section and in plan view, depending if the feature is better represented in either of the drawing tools. The definition of these features is developed identifying the key and generalizable features of the space.

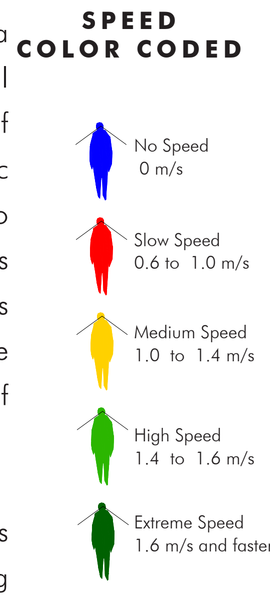
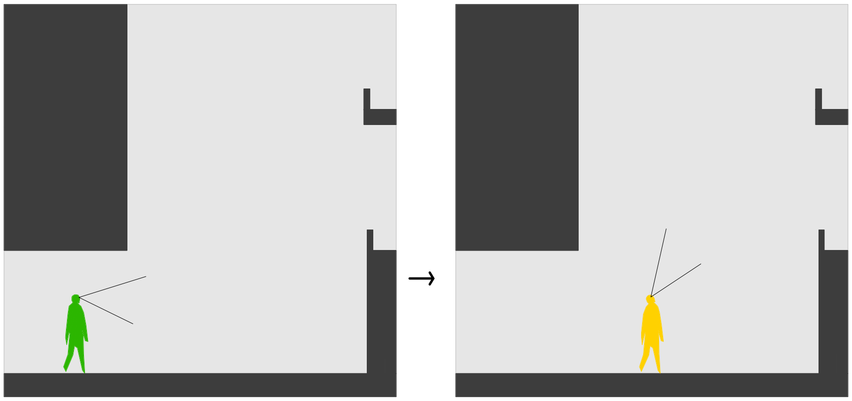


Figure. 46. Speed color code.

The rules are formulated by correlating the statistics with spatial features as breadth search which seeks for amplitude but not depth, privileging collecting as many different sequences of motion as possible. The main indicators of the rules are: speed, gesture and time. Speed is color coded as to understand the way people approach space. Gestures are divided in three basic rules: change of gaze, change of center of mass height, and the gesture of purposely approaching and spatial attractor. For example seating is translated into a change of the center of mass height. This translation allows for the Kinect to be to recognize the movement. Finally , time reflects the periodicity of the rule. The rules are very obvious yet, the research provides evidence of them and the parameters for measuring and simulating latterly, which currently is very scarce. The thirteen rules as a whole constitute a behavior model.

SECTION VIEW

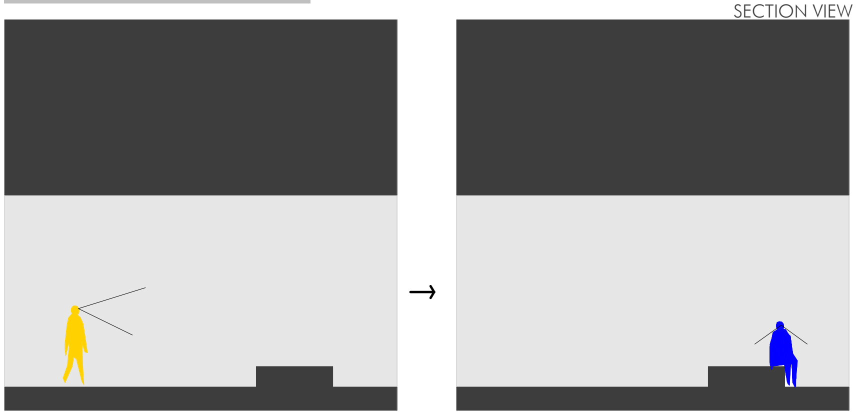


RULE 1. DECREASE SPEED _ LOOK UP / MULTI STORY ATRIUM

	MIT ML LOBBY
375	TOTAL USERS
1.46	AVG SPEED
2.29	MAX AVG SPEED
1.01	MIN AVG SPEED
1.99	AVG TIME

MEDIA LAB LOBBY	South Entrance	North Entrance	%
TOTAL USERS	755	796	
LOOK UP	528	15	70.00

SECTION VIEW

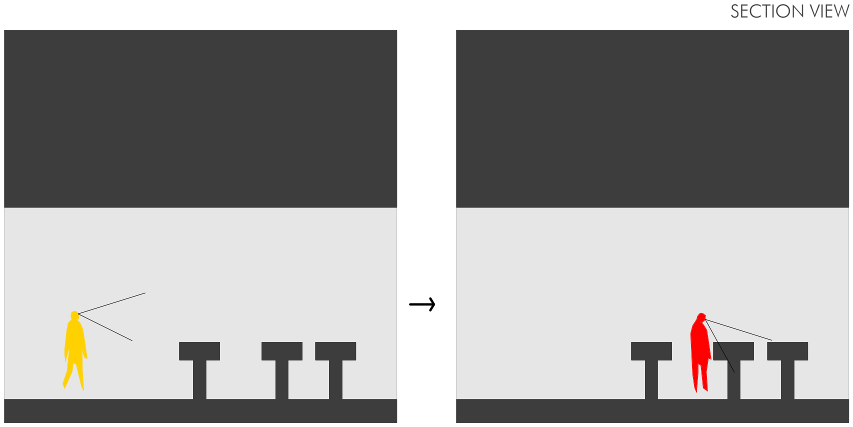


RULE 2 SEAT GESTURE / BENCH ATTRACTOR

	MIT ML LOBBY
505	TOTAL USERS
1.24	AVG SPEED
2.29	MAX AVG SPEED
0.13	MIN AVG SPEED
4.06	AVG TIME

MEDIA LAB LOBBY	South Entrance		%
TOTAL USERS	755	796	
SAT ON BENCHES	24	16	2.58

SECTION VIEW



RULE 3. WONDER AROUND / EXHIBITION ATTRACTOR

	MIT ML LOBBY
505	TOTAL USERS
1.24	AVG SPEED
2.29	MAX AVG SPEED
0.13	MIN AVG SPEED
4.06	AVG TIME

MEDIA LAB LOBBY	South Entrance		%
TOTAL USERS	755	796	
WALK AROUND EXHIBITION	143	72	14.00

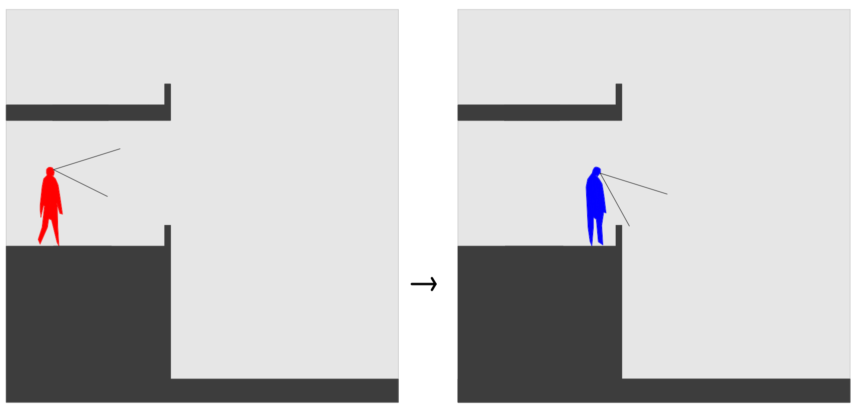
SECTION VIEW

RULE 4. LOOK THROUGH / TRANSPARENT ATTRACTOR

	MIT ML LOBBY
505	TOTAL USERS
1.24	AVG SPEED
2.29	MAX AVG SPEED
0.13	MIN AVG SPEED
4.06	AVG TIME

MEDIA LAB LOBBY	South Entrance	North Entrance	%
TOTAL USERS	755	796	
LOOK THROUGH WINDOWS	204	103	20.00

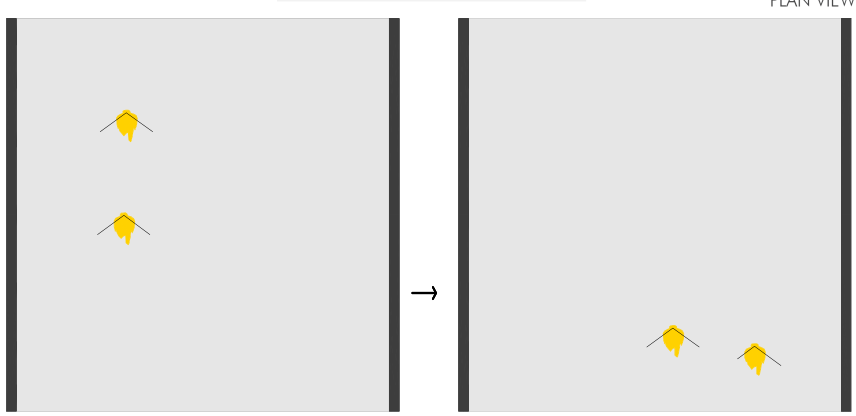
SECTION VIEW



RULE 5. LOOK DOWN / BALCONY ATTRACTOR

ML 348	BALCONY
2648	TOTAL USERS
0.08	AVG SPEED
0.18	MAX AVG SPEED
0.02	MIN AVG SPEED
34.98	AVG TIME

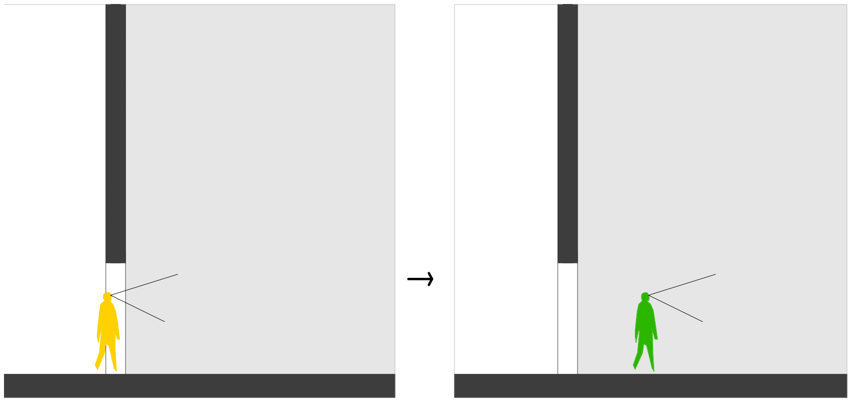
PLAN VIEW



RULE 6. MAINTAIN LOW SPEED / WIDE SPACE

	UC VESTIBULE
646	TOTAL USERS
0.92	AVG SPEED
1.77	MAX AVG SPEED
0.20	MIN AVG SPEED
4.77	AVG TIME

SECTION VIEW

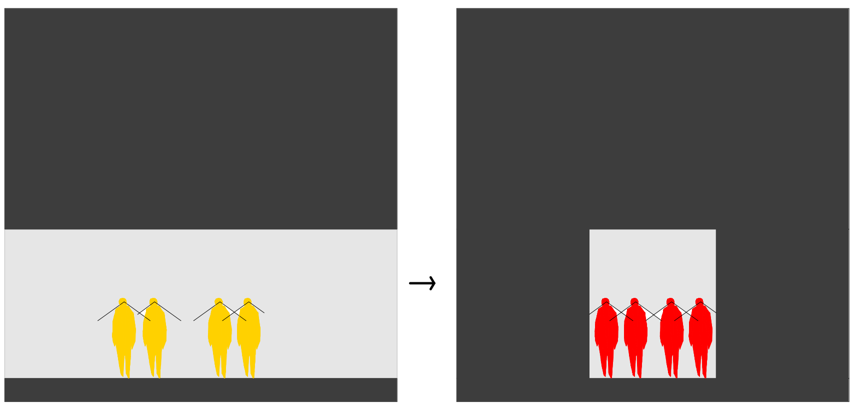


RULE 7. PASS THROUGH / ENTRANCE

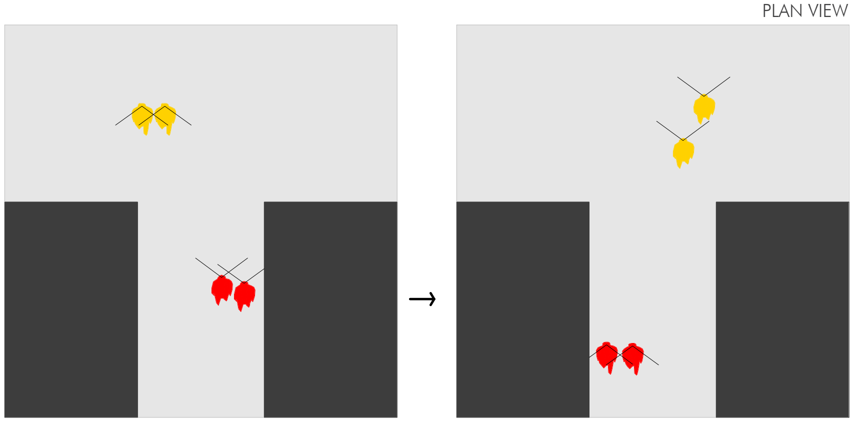
ML 140	ENTRANCE
11	TOTAL USERS
1.06	AVG SPEED
1.08	MAX AVG SPEED
1.03	MIN AVG SPEED
3.91	AVG TIME

	MIT ML LOBBY
375	TOTAL USERS
1.46	AVG SPEED
2.29	MAX AVG SPEED
1.01	MIN AVG SPEED
1.99	AVG TIME

SECTION VIEW



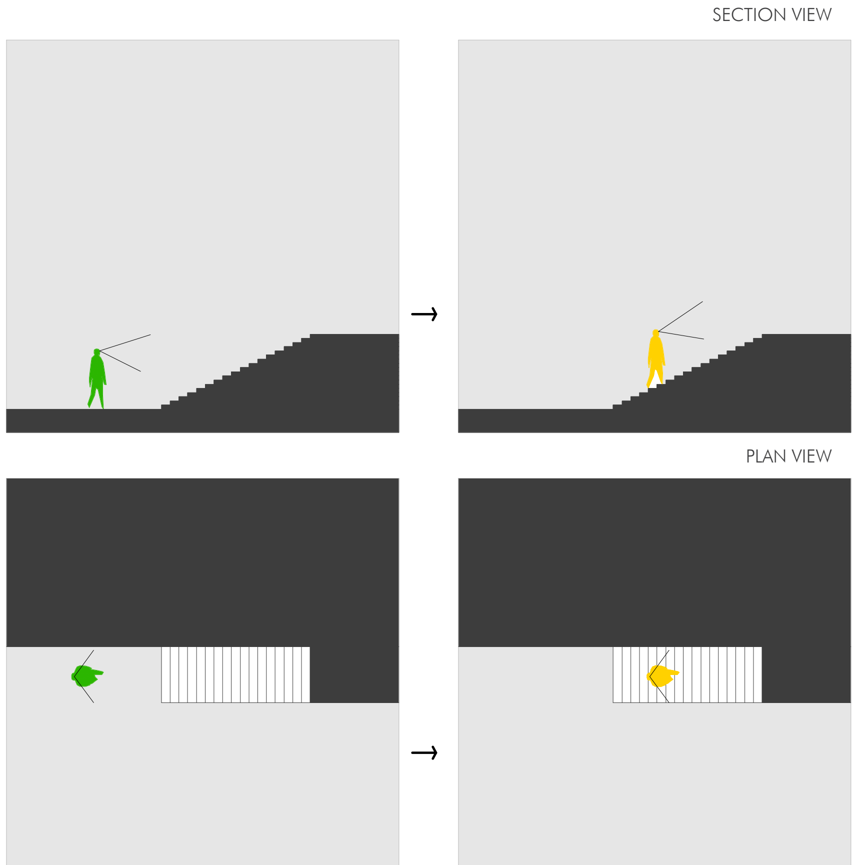
PLAN VIEW



RULE 12. DECREASE SPEED / WIDE LOBBY_ NARROW CORRIDOR

	MIT LOBBY 7
7723	TOTAL USERS
1.29	AVG SPEED
2.42	MAX AVG SPEED
0.10	MIN AVG SPEED
1.64	AVG TIME

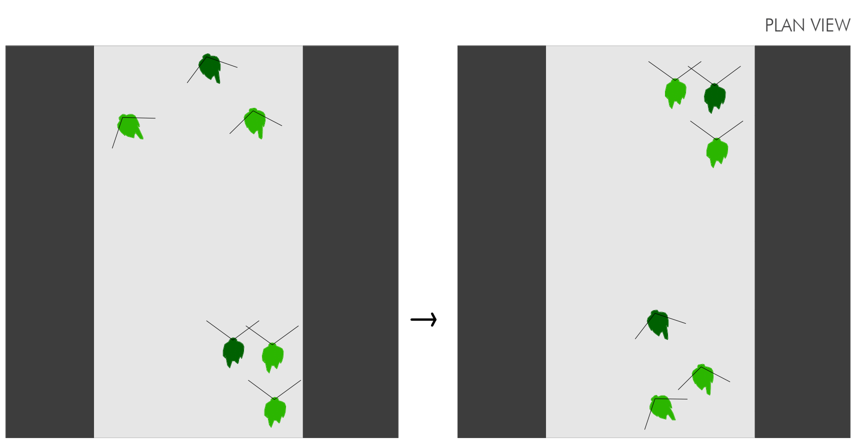
	MIT CORRIDOR
1021	TOTAL USERS
0.99	AVG SPEED
2.22	MAX AVG SPEED
0.10	MIN AVG SPEED
3.47	AVG TIME



RULE 8. UP - DOWN/ STAIRS

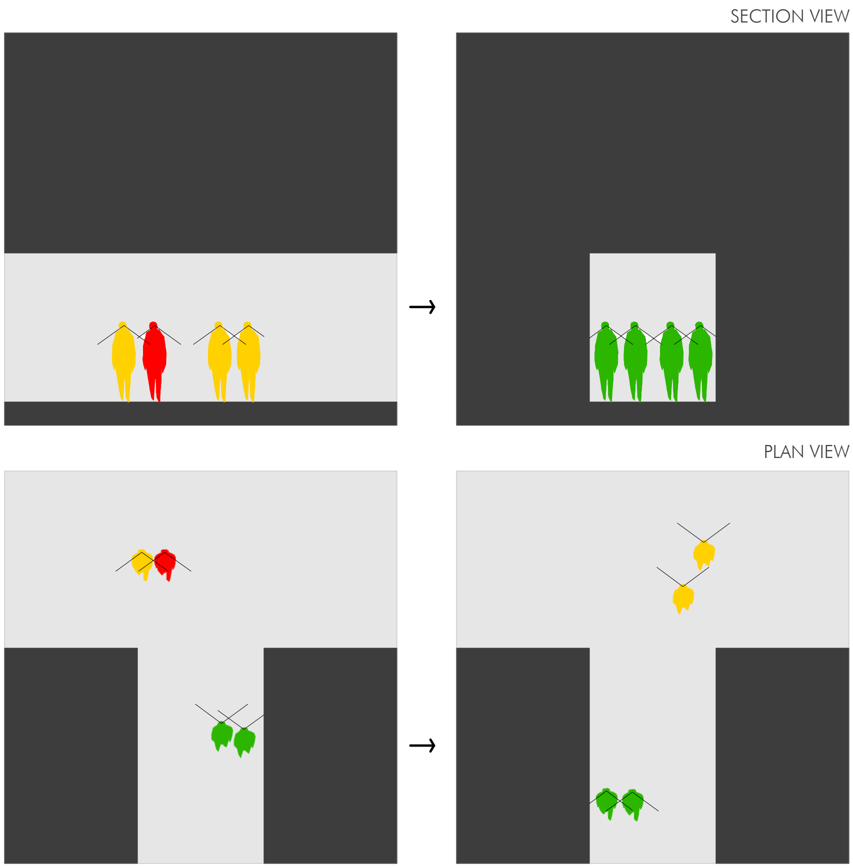
	MIT ML LOBBY
375	TOTAL USERS
1.46	AVG SPEED
2.29	MAX AVG SPEED
1.01	MIN AVG SPEED
1.99	AVG TIME

ML 251	STAIRS
7047	TOTAL USERS
0.65	AVG SPEED
1.82	MAX AVG SPEED
0.03	MIN AVG SPEED
3.06	AVG TIME



RULE 11. MAINTAIN HIGH SPEED / WIDE CORRIDOR

	UNIPI CORRIDOR
67	TOTAL USERS
1.61	AVG SPEED
2.28	MAX AVG SPEED
1.11	MIN AVG SPEED
3.12	AVG TIME



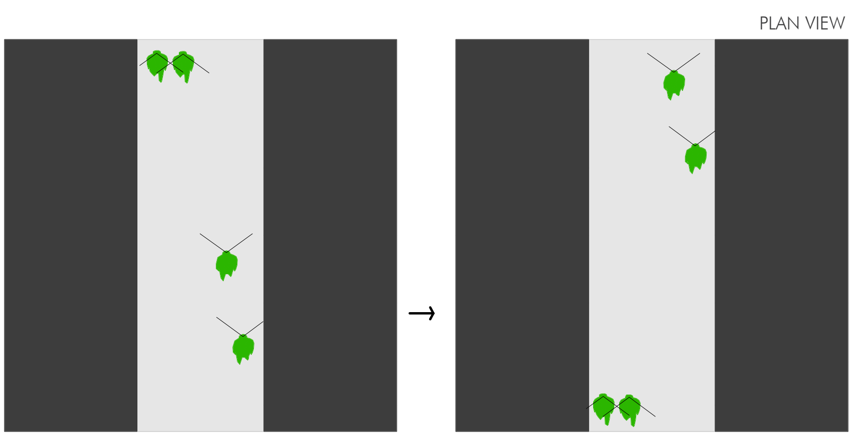
RULE 9. INCREASE SPEED / WIDE LOBBY_NARROW CORRIDOR

MIT LOBBY 7

7723	TOTAL USERS
1.29	AVG SPEED
2.42	MAX AVG SPEED
0.10	MIN AVG SPEED
1.64	AVG TIME

MIT CORRIDOR

498	TOTAL USERS
1.49	AVG SPEED
2.22	MAX AVG SPEED
1.03	MIN AVG SPEED
0.90	AVG TIME



RULE 10. MAINTAIN MEDIUM SPEED NARROW CORRIDOR

MIT CORRIDOR

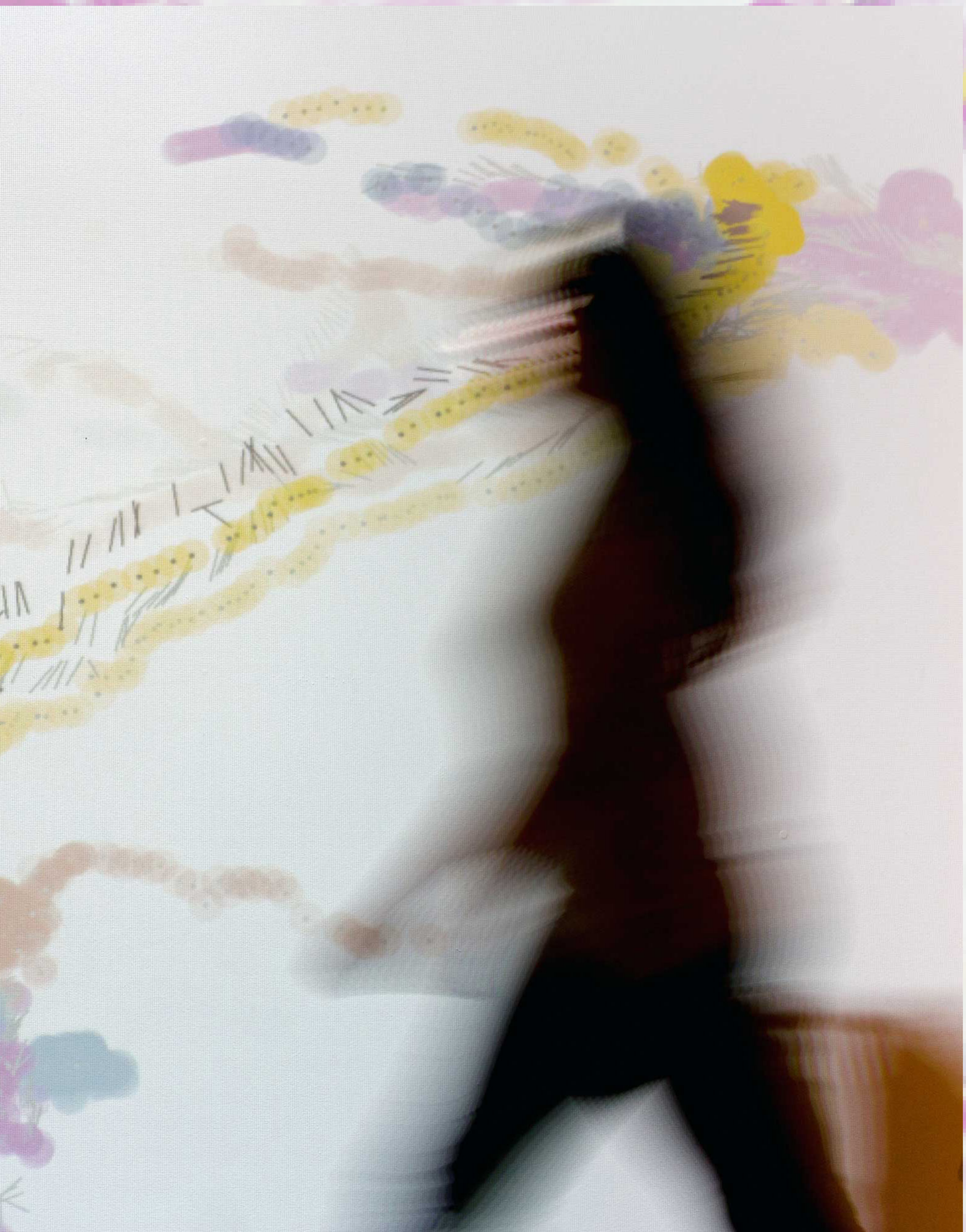
498	TOTAL USERS
1.49	AVG SPEED
2.22	MAX AVG SPEED
1.03	MIN AVG SPEED
0.90	AVG TIME

W A L K   A C R O S S

Award: **"MIT - UNIPI Funding"** , UNIPI, consisting of traveling expenses, for funding research Collaboration between MIT and Pisa University. (2015-2016)

Award: **"Director's Grant",** from CAMIT, Council of the Arts of MIT, for funding "WalkAcross" installation at MIT Museum (2014)

INSTALLATIONS



4.3. Installations

The second procedure of testing Kinects capabilities for analyzing people's motions was developed through Museum Installation. I have authored two exhibitions named "Walk Across" as the result of an independent research for Prof. Takehiko Nagakura; one at The MIT Museum and one at the Harvard Graduate School of Design Kirkland Gallery. The first exhibition at the MIT Museum was presented to the public on May 2014, until the present, and the second at Kirkland Gallery from November 22th to November 26th of 2014. The data visualizations that I developed from Media Lab Building Kinect data inspired "Walk Across." The interactive installation consists of integrating Kinect sensor with my algorithm that displays real time visitor trajectory data in aerial view. Moreover, "Walk Across" encompasses the concepts of my ongoing work. From the memory of space displayed in the visualization to the awareness of the body while moving. Making explicit the interaction between people, between present and past data, and with space, to collectively drawing with your own body. Finally, seeing motion and seeing disappear the re-creation of motion almost as a simulation. Resulting in profound insight for my research, the work proved to be valuable even outside the discipline.

WALKACROSS Spatial Setting at the MIT Museum

Figure. 50. "Traces" MIT MUSEUM Photograph Credits: David Schialliol, 2014.

Figure. 47. Microsoft Kinect 2013.

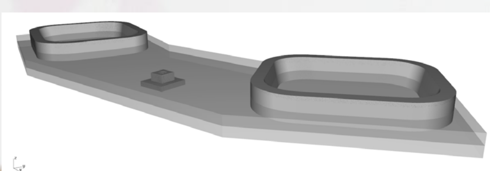


Figure. 49. Rig designed for the MIT MUSEUM Exhibition.

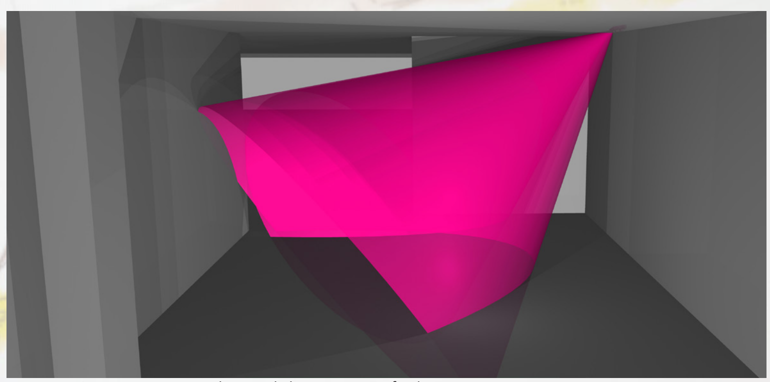


Figure. 48. 3d model Range of the Kinect Sensor.

The installations is composed by: two Microsoft Kinects Sensors placed in a rig designed specially for the exhibition, one projector 6.000 lumen, and one processor 2.2 GH, plus my algorithm developed in Processing and Java..

Discussion at HARVARD GSD Kirkland Gallery

Figure. 51. Harvard Graduate School of Design Kirkland Gallery exhibition.

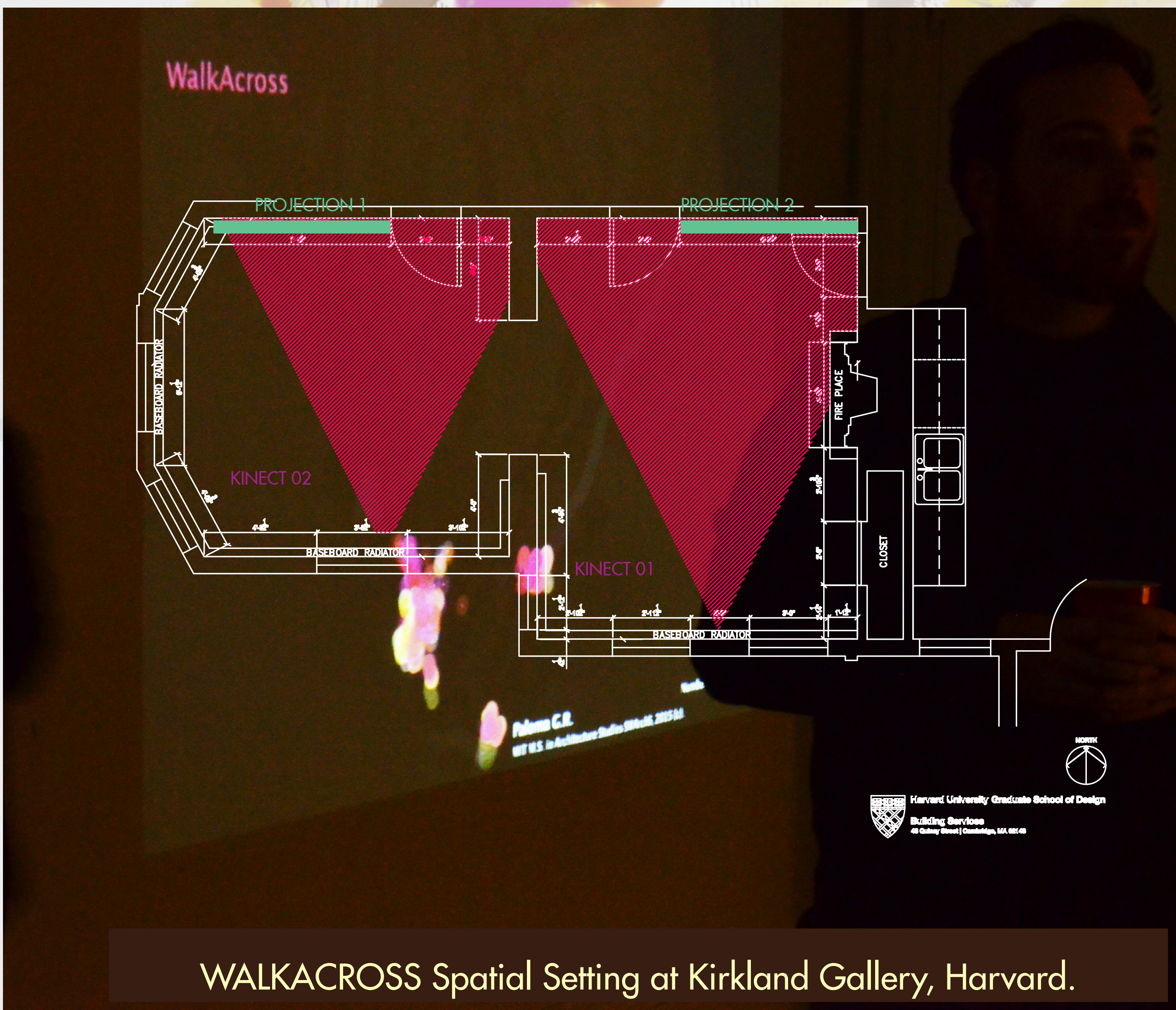
Dimitris: What is your motivation to build this installation?
Paloma: My main motivation to develop this installation is my ongoing research about people's motion in space. Architecture discipline lacks resources to measure how people behave in space. In addition the installation revolves around the idea of revealing an abstract beauty of motion traces in space, specifically the trajectories in aerial view, for the visitors to interact with. Data visualization is for understanding existing space. Data simulation can be used for projecting how space will be.

Dimitris: What is the general theoretical framework in which the installation is based?
Paloma: As designers, simulations are the path for testing space with human behavior. For this purpose it is necessary to track real motion to input data into such models, and use artificial intelligence to introduce complexity in the virtual representation of humans interactions.

Dimitris: Why did you choose this setting for the installation, as to work with external sensor and projection on the wall?
Paloma: I decided this setting for two reasons, the first one is the claim that I am exploring on my research which is to study human motion from the "Observer" point of view. This means to not use wearable sensors to track human motion but to set a static point of view in space to analyze motion from the exterior as bottom-up perspective.
The second reason is to question the condition of an "Ever-changing" painting hanging in the wall. Paintings are still, yet as the data generation is continuous the projection is continuous as well creating the illusion of a changing painting that never actually exists.

Dimitris: How this relates to architecture discipline?
Paloma: This might be a progress in terms of expanding architect's set of tools with AI, for designing better cities and buildings, and perhaps be able to test how a new space would shape people's reactions towards architectural elements.

Excerpt of the discussion with Dimitris Papanikolaou to whom I sincerely thank for performing a wonderful conversation counterpart and for his theoretical contributions to the subject.
Dimitris Papanikolaou: Harvard Graduate School of Design, Doctor of Design Candidate (2015).

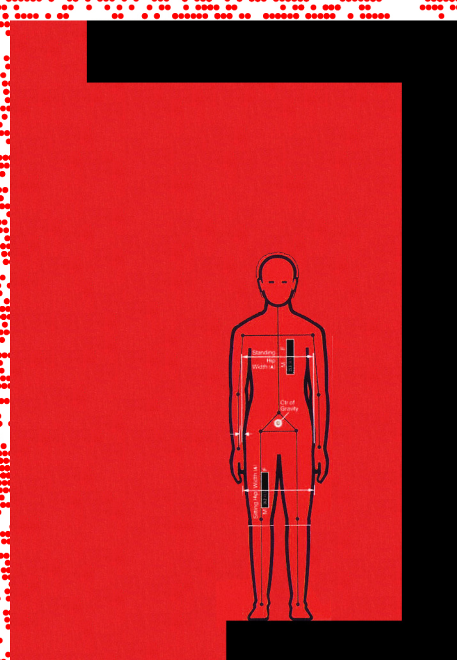


WALKACROSS Spatial Setting at Kirkland Gallery, Harvard.

Figure. 52. Harvard Graduate School of Design Kirkland Gallery exhibition.

Figure. 53. Harvard Graduate School of Design Kirkland Gallery exhibition.

[5.0] CONCLUSIONS



[5.1] Discussion and conclusions

In 1970, Nicholas Negroponte and the Architecture Machine Group (MIT) developed an early and famous example of a Responsive Environment for the project “Seek,” included in “Software” exhibition at the Jewish Museum in New York. The project consisted of a small environment for a gerbil colony to inhabit composed of metal blocks inside of a glass box. The gerbils were constantly observed dynamically in real time to develop motion probabilities inside the environment, and a robotic arm rearranged the configuration of the blocks according to the gerbils’ likely future actions. Even though this experiment failed to recognize gerbil “spatial needs”, and it is not an applicable model for architecture, it encompasses the basic concepts of Responsive Architecture and, more importantly, gives clues about the need of quantitative data about the occupants’ behavior and the search for reliable rules to modify the environment properly. Probably, the miscue was that observation was a deficient input for deciding how to rearrange the environment; a tracking system could have been a better choice. In addition, probabilities were set to be deterministic, “programmed to either correct or amplify (not both) the dislocations caused by the gerbils” (“RUDY/GODINEZ,” n.d.)

My analysis suggested that a method for analyzing people’s motion in space is needed, for including space-human motion interaction in the design process and in real time architecture performance, as in other practices. We as humans shape our buildings, and after, buildings shape how humans behave in them. The same happens with public space. Yet, how can we clarify such phenomenon, for design improvements?

As was mentioned earlier Robin Evans’s research in “Figures Doors and Passages” (1997) explains how the invention of the corridor is a clear example in which an architectural element is used to modify human behavior. That discovery was made by studying how humans inhabited their houses in the past, through history and documentation, without observing or tracking humans. Nowadays, several sensors could be used to simplify the task and make progress on observing how walls, for example, are currently modifying our behavior, dynamically in real time. On the other hand sensors could be used to collect the data for further developments in testing new designs in virtual environments.

The correlation between people’s motion and space, enabled by technology, is a study that has almost no precedents. The exploration developed for this thesis through data collection and analysis represents a first step in the architecture field and in the ambit of human motion research. The research is an attempt to advance in generating knowledge about the impact of space over how people move in such space, based on evidence.

In the same line of questioning, the Space-Motion research could improve the understanding and visualization that designers have over their projects. The research allows discovering, through evidence, how a new design or a modification of an existing space could impact people's motion. Currently the design process lacks the means to grasp how a space configuration or architectural feature will generate different motion behavior from its users, leaving architects in a infirm position. On the other hand, sometimes the space created does not correspond with the intentions meant for the space.

Consequently, one of the major contribution of this research is to provide evidence of people's motion patterns in space, enabled by Microsoft Kinect technology and video cameras. By correlating the trajectories with the architecture of the selected place as it was developed with the different selected locations, this research retrieved reliable data statistics regarding an architectural setting which may verify or deny our assumptions over space as designers. It also produced the Space-Motion Metrics for further research and the Space-Motion Rules for the use of simulation and design. Being able to get feedback on spatial relationships based on data collection methods is a useful metric for designers. Space-Motion research is also a first step to regaining an understanding of the impact of a space feature over people's motion. Similar to Negroponte's intention with the gerbils' responsive environment experiment, the research can retrieve data from people's motion in space and bring new information for determining how to respond to humans through design, enabled by technology.

[5.1.1] Data collection

The research generated the following questions regarding the use of data: Is data from one space to another generalizable? What is a generalizable spatial feature? Because data from humans is linked to the specific time and place in which it was collected, the transposing of that data to another location is problematic. People belong to a certain culture rooted in the location, or at least are immersed in a context that sets some behavioral rules. Such a culture could have specific parameters for how to behave in space, such as walking at a fast pace or moving with a certain rhythm.

However, the data shows very similar speed patterns from three different continents' samples. The data samples were collected in four different countries, including the United States of North America, Chile and Colombia of South America, and Italy of Europe. One could expect that there would be differences in the speed patterns of each location. As explained before, the data was collected only in high level educational semi public indoor spaces, belonging to three major schools. The data samples from the three lobbies, and the data from the two corridors are correspondent and comparable. The data suggests that the average speeds are very close, exposing no significant differences between contexts. However, this observation requires further research. The data collections are too limited to define accurate similitudes. It would also be important to collect data from locations that have extreme cultural differences from one another. Nevertheless, I would not agree on stating that the statistics produced by this research, such as the averages of speeds of different locations are universal or representative of a certain culture. There are even differences from MIT Lobby 7 to the MIT Infinite Corridor statistics, making explicit that space affects people's motion as this thesis proposes.

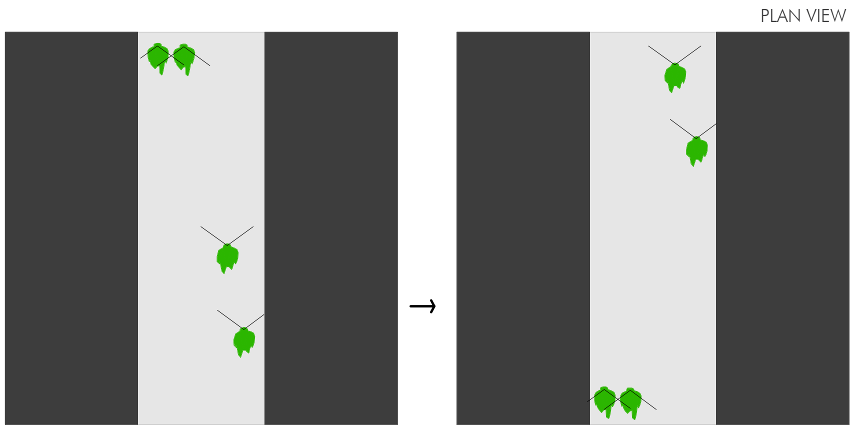
On the other hand, similar spatial conditions could be correspondent, such as transposing the data from an educational campus corridor to an airport corridor. In both situations people either aim to move fast if they need to get to a distribution hub soon or move slow if they have time to spare. Of course, the spatial conditions would have been similar in terms of the width and height of the corridor. These factors may affect people's motion behavior as we can see in the comparison from the two corridors. However if the two spatial configurations are similar, the data might possibly be transposable.

In the Problem Statement I affirmed that the development of Space-Motion data analysis may highlight cultural motion differences in the data at the macro-scale, while emphasizing the capability to project these local diversities to design. The analyzed data comes from the center of mass of people since the trajectories retrieve the speed indicator. By no means is the intention to standardize people's motion metrics in order to willingly transpose the statistical data.

Finally, the data collection methods are very robust and the pieces of software generated to perform the analysis represent a platform for further research and are applicable to other purposes. The thesis produced valuable information generated about how to apply the devices and about the advantages and constraints of using video cameras and Kinect sensors, as detailed in chapter four. The video camera, complemented by OpenCV algorithms retrieves effectively the trajectory data from video footage and the possibility to manually count spatial gesture. The Kinect is one of the most reliable human tracking sensors with which is possible to faithfully track people's trajectories, and is surprisingly effortless with a very robust system. The only disadvantage is that the sensor's range is considerably small, approximately 9m2. The disadvantage of the sensing range is resolved in my installation "WalkAcross" at the MIT Museum by using multiple Kinects for generating the expected data set.

COMPARISON

WIDER =FASTER?



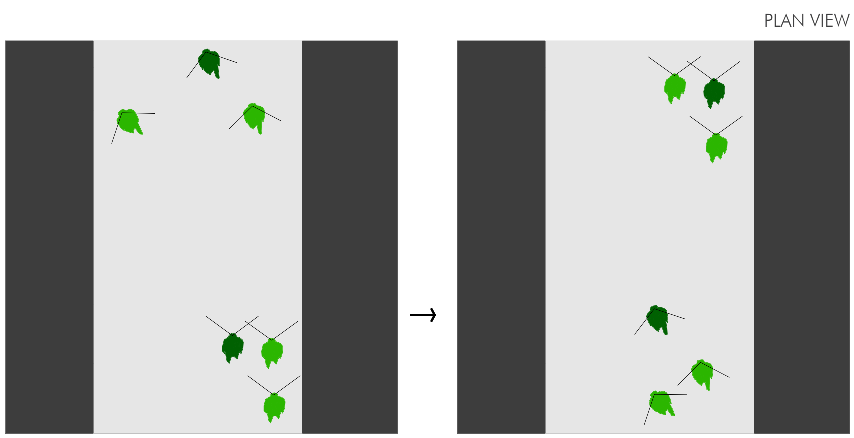
MIT (EU)

1.48 m/s

RULE 10. MAINTAIN MEDIUM SPEED NARROW CORRIDOR

MIT CORRIDOR

498	TOTAL USERS
1.49	AVG SPEED
2.22	MAX AVG SPEED
1.03	MIN AVG SPEED
0.90	AVG TIME



UNIPI (ITALY)

1.60 m/s

RULE 11. MAINTAIN HIGH SPEED / WIDE CORRIDOR

UNIPI CORRIDOR

67	TOTAL USERS
1.61	AVG SPEED
2.28	MAX AVG SPEED
1.11	MIN AVG SPEED
3.12	AVG TIME

[5.1.2] Space-Motion Metrics

Currently it is possible to track people's motion with different data collection methods such as a video camera, depth sensor, and global positioning system via satellite. The possibility to store gigantic volumes of data is also possible, and the interest in exploring such data for several purposes as design and urban planning is increasing. However, a difficult task is to define what to search for when analyzing the data to retrieve meaningful statistics or indicators for linking space with people's motion.

The development of the Space-Motion Metrics is an advancement for analyzing people's spatial behavior. The definition of the six motion indicators: speed, time, gesture, shape, direction and scale, are useful metrics to enable such research, as explained in the Methodology chapter. The definition of the indicators required a considerable amount of data analysis and observation. While speed and time are basic measurements, one of the most important advancements of the thesis is the conceptualization of the "spatial gesture." Its importance remains in the fact that currently there are no means to define or measure this type of action. Gesture consists of a change or a combination of changes in bodily motion, such as change in gaze direction and change in the center of mass height. These indicators were developed entirely in the context of this thesis, in order to define a framework for measuring the interactions between people's motion and space.

The metrics were tested in all the locations. Speed of course is the most basic computation regarding position and time, yet when correlated with a spatial feature acquires a different meaning. The speed that people show when freely walking in a corridor seems to be affected by the configuration of the space. One could speculate that the width of the corridor can define the activities that are possible to do; a wider corridor allows standing in groups while a narrower corridor acquires the category of transit space, as a result of applying this metric. From the statistics, it is possible to observe that the amount of people seems to affect the distribution of the higher and lower speeds, Lobby 7 curve is smooth and continuous built over a sample of 7.500 people.

In this research speed in not understood as an efficiency measure or optimization indicator, speed is part of how we approach space in motion. Consequently the geometry of space may have an effect of its value. For example, does wider means faster? An interesting finding regarding the rules is the increase in speed if a space for transit gets wider as shown in the rule analysis. Comparing the speed from the MIT Infinite Corridor, and the UNIPI Corridor one could speculate that when the width of a transit space is widened, people walk faster.

5.1.3] Space-Motion Rules

Taro Narahara's thesis "The Space Reactor" (2007) has a spatial analysis that is similar to the analysis of urbanist William H. Whyte regarding the small public spaces. Both researchers analyze the impact of elements present in space such as the attraction of water, the materials used, and the presence of urban furniture as benches. In the case of Whyte he adds trees to the equation. This analysis refers to the "load" that the spatial feature has, relating how people move to the program of the space. The schema is more similar to an origin-destination survey. It analyses space in terms of purpose.

Unlike the above, this thesis proposes to analyze the "spatial features" of a location, understood as the volumetric elements that compose an architectural setting. The Space-Motion Metrics measure "how" people interact with that feature, as modifying their speed, or changing their bodily posture, generating a spatial gesture. For example, the definition of the spatial features considers a corridor as spatial element, or an entire space depending on the scale of the analysis. Following that definition, motion is measured regarding such spatial features, for example at what distance people change their speed when walking towards an entrance. The analysis is radically different from the analysis of Narahara or Whyte. In general it refers to the volumes that conform a space, as an attempt to work with the physical components of architecture design.

The Space-Motion rules formalize the correlation between the motion statistics and spatial features. Space works as the framework and the changing variable is people's motion. The relevance of the rules formulation process is to identify and illustrate the possible relation between both inputs. It is important to generate a system of statistics that are not prescriptive for design purposes. The statistics should not be understood as absolute facts, because of the limitations of the study. The rules are meaningful for projecting what space could be, based on motion data.

As for implementing artificial intelligence simulation tools, as Agent Based Models, one of the most difficult parts of the task is to define the initial behavior. For that reason the behavior of the agents is defined by stochastic methods. In contrast the rules generated by this research are based in statistical data analysis, collected from people's motion. Space-Motion Rules provide a framework for the definition of the spatial behavior of the agents. On the other hand, speed, time and gesture are fundamental indicators to generate simulations of people's motion over a certain space, as rules. In this regards, if the agents are defined with a spatial behavior, the simulation becomes useful for informing the design process in the early stages, to generate better cities.

The rules developed constitute a model of motion behavior, as a first step for incorporating people's motion into the architecture design process in its early stages. For further research, the generative capability of the rules could be used as input for simulating motion, as part of my PhD research. The Space-Motion rules formalize the correlation between the motion statistics and spatial features. The relevance of the rules formulation process is to identify and illustrate the possible relation between both inputs. The rules are meaningful for projecting what space could be, based on motion data.

[5.2] General Contributions

- Data Collection Method: The data collection method was defined to work as the observer point of view, therefore camera type sensors, like the Microsoft Kinect or a Video Camera will be used to collect the data.
- Data sets: currently reliable data sets of human motion are scarce to nonexistent, therefore the data sets created for this research are a contribution by itself.
- The theoretical proposal to architecture relating the design process with motion, particularly its inhabitants motion, to test and enhance design, using data as input.
- Space-Motion Metrics: as a framework to measure motion indicators towards space from data.
- Space-Motion Rules: as the rule system formalizes the correlation between people's motion and space.

For further steps, developing the simulations will be the priority of the research. As a complementary development would be to Test in depth the same indicators parameters in different spatial settings, as for example to compare many corridors, analyzing only the boundary of the space.

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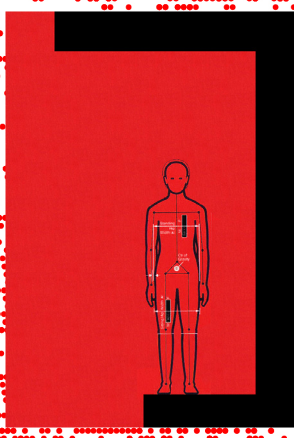
[6.0] REFERENCES



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