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Using human motion intensity as input for urban design

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Abstract. This paper presents a study investigating the potential use of human motion intensities as input for parametric urban design. Through a computer vision analysis of thermal images, motion intensity maps are generated and utilized as design drivers for urban design patterns; and, through a case study of a town square, human occupancy and motion intensities are used to generate situated flow topologies presenting new adaptive methods for urban design. These methods incorporate local flow as design drivers for canopy, pavement and furniture layout. The urban design solution may be configured due to various parameters such as security, comfort, navigation, efficiency, or aesthetics.

1 Introduction

For the first time in human history, more than half of the human population inhabits urban environments, and this now presents itself as 'second nature' to humans. The urban context is of a very complex nature and is composed by a multitude of different networks, infrastructures and volumes. The city has become the dominant 'scenery' for everyday life. As such it presents still greater design challenges for an improved urban spatial performance, and it creates more inspiring, efficient and stimulating public spaces. One must acknowledge that urban spaces are sites of movement and interaction that contain under-utilized potential [8, 10]. If we can understand when the 'stages' are used in terms of human movement and occupancy, we can generate site-specific flow maps, which present a basis for new understandings of the dynamics of the different flow systems that can create a foundation for better and more sensitive/adaptive approaches to urban movement [7, 9], to computer vision technologies and to new sensor technologies. It is an interdisciplinary design challenge to develop new analysis and design tools and methods that can improve urban performance and efficiency. By mapping everyday flow activities, it will be possible to generate site-specific representations, which present well functioning and unused regions

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of urban space. This knowledge can be used to quality new flow topologies such as furniture placement, lighting, navigation patterns, or just as creative ingredients.

This paper will present the use of thermal computer vision as a method for automated human activity analyses in public places. The flow is presented as quantities of occupancy, groupings, and motion. Furthermore, this paper will present urban design scenarios for data driven design patterns and response strategies for adaptive urban environments. The tools are tested in the experimental setup at the central public square of Gl. Torv, Aalborg, Denmark (figure 1).

Fig. 1. View from the camera position, Gl. Torv in Aalborg, Denmark

2 Material and Methods

To approach this interdisciplinary research and design challenge, we employ the following models from the two scientific areas: computer-vision and parametric design [16]. The idea is to use thermal camera observations for the quantification of human activity in public spaces and later use the information as design drivers for parametric design "machines" [18] for urban spaces as illustrated in figure 2.

Fig. 2. The processed maps from thermal camera observation, computer vision analysis, informed design system into urban design spaces.

2.1 Generating human motion intensity maps

Detecting and tracking people is a large research area in computer vision; there are approaches, such as ours, using thermal cameras [1, 5, 2]. Thermal cameras are still quite expensive, but because of information security and privacy, it is not legal to film public places in Denmark. This is the primary reason to utilize thermal cameras. In this paper, the video material obtained from the thermal camera is analyzed in order to detect people and their activity in the public square. The people are detected in each frame by performing a running background subtraction and thresholding the image based on temperature difference. The position of each person is found using a homography that maps the image coordinates into the position at the square in world coordinates. The square is divided into 280 × 240 small areas and represented by a matrix, in which the detected persons are added as gaussian distributions with radii of 1 metre.

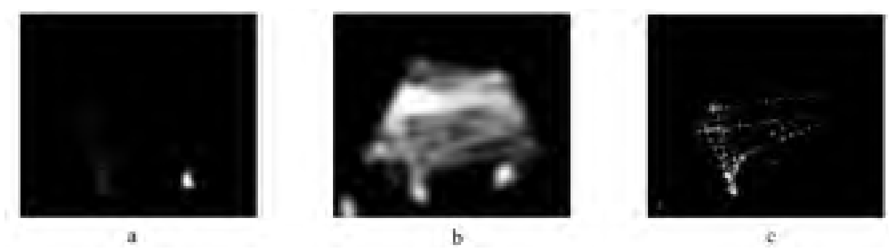

Fig. 3. Utilization of the square over a period of 30 minutes. a: Occupancy, b: Motion, c: Groupings.

Figure 3 illustrates the utilization of the square during 30 minutes of an ordinary Danish summer day. To calculate the occupancy map, each detected person is added to the corresponding area of the map. The intensity of each area of the map will therefore describe the total occupancy rate of the area during the observed time period. The motion map is found based on the difference between two successive frames. A gradient vector calculated for the position of each person gives a direction and magnitude describing the person's motion between the two frames. By summarizing the magnitude of these vectors, the motion map shown in figure 3 (a) is found. Groupings of people are found for each frame, by detecting areas where the gaussian distributions (representing people) overlap. These areas are added to the groupings map for the complete time period. Finally, the three maps are summed up to get a representation of the total utilization of the square as seen in figure 6.

2.2 Data driven urban design strategies

Because of the merger of technologies in the built environment [15], architecture has changed the scope from asking questions of what a building is to what a building does [11]. Today the very "face-expression" of the building can change to a wide range of success criteria. It is this process of adaptation, we need to qualify and articulate. If we can measure tendencies characterizing "good urban spaces", we are able to generate significant representations, which can afford better and more context-aware design solutions. In line with established theories in the field of urban design [3, 13, 4, 20], we will argue that the creation of 'good urban spaces' has to do with functional requirements (access, capacities, legibility etc.), social dimensions (meeting points between different cultures and social groups, vivid and playful experiences etc.) as well as aesthetic dimensions (materials, urban furniture, surfaces etc.). In short, good urban spaces are spaces where the basic functions of the city (living, producing, and consuming) are fulfilled in an environment of socially creative and stimulating experiences.

Situated design patterns. During the last 10 years, computation has become a significant part of the architect's sketchbook and vocabulary; algorithmic [19], parametric [17], morphogenetic [6], animated [14], interactive, generative, responsive, adaptive, and performative [11]. All ways to qualify the specific use of computation in architectural design environments. The techniques apply advanced control algorithms, simulations and self-organizing generative algorithms, which allow designers to handle more information in design models and optimize e.g. structural and environmental performance. The techniques have had a tendency to stay inside the virtual domain without utilizing dynamic phenomena on-"site" as active design drivers. It seems to be of great relevance to take a step back and explore the qualities of the situated data and discuss how we can structure data into meaningful information and inform adaptive urban design systems; such as the intensity of the light, the pattern on the pavement or the three dimensional structures which provide shelter from the rain and the sun.

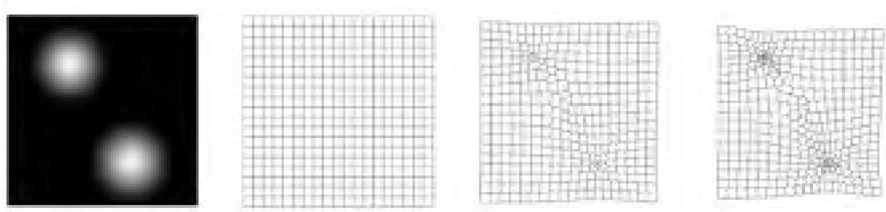

Fig. 4. Left weight image. The three right images, Voronoi variations of grid deformations with weight (0,4,8) of the weight image.

The computer vision data displays a differentiated high resolution bitmap of intensities of occupancy, groupings and motion in the urban space. This data is valuable information about its use and provides vital information for urban design. The different types of activities will afford different spatial requirement to the design, either for the static design of the place, e.g. pathways, furnishing, or for dynamic elements such as lighting, mediation etc.

3 A case study: "Gammel Torv" in Aalborg City

3.1 Experimental setup

From a window placed on the 4th floor, a thermal camera films 24 hours of the activity in the square, Gammel Torv, in the city of Aalborg in Denmark. The camera films a crop of 70 × 50 meters of the total 300 × 70m square. The square is located in the center of the city and functions as an open, free space typically used for gatherings such as concerts, carnival, Christmas market etc. On ordinary days, however, it serves as a passage and a resting place between the two shopping streets in the city. The camera used in this setup is an AXIS Q1921-E with the following specifications: 10mm lens, 55° horizontal view, a resolution of 384 × 288, and a frame rate of 30 fps. The images include a primary flow path, a bench and a parking lot in the distance. The video was processed on a desktop computer using OpenCV for C++ and Matlab; the design patterns were generated in the parametric programming software Grasshopper for Rhino.

3.2 From site analysis to urban design using intensity maps.

First we need to understand the relationship between recorded data and architectural qualities. In the following, we will describe the spatial demands for places with high occupancy, primary flow lines, groupings and non-flow spaces.

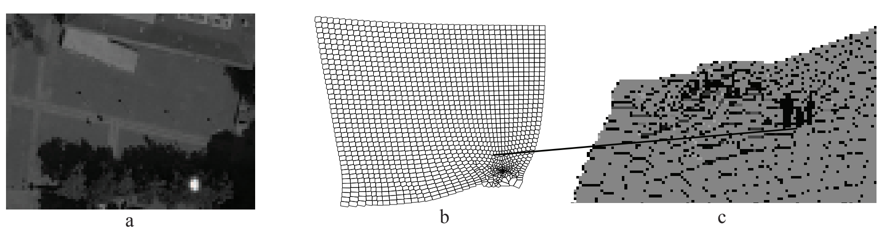

Fig. 5. a: Occupancy map. b: The tessellation in the Voronoi pattern is informed by the bitmap. c: The area of each Voronoi tile drives the high of the furniture structure, this gives many edges and height complexity in areas with long occupancy.

Occupancy. In places with high occupancy, there is often a need for places to stand, sit, lie or lean. Often, we do not occupy a space in the center of the square but seek towards the edges to cover our back. Our engagement is often directed towards other people, personal thoughts or fascination with the complex patterns of the tree crown or the dynamic patterns of the sky. It is a place for thoughtfulness. We prefer soft materials like grass, wood or plastic etc. Thus, we begin to have an idea of topologies and material properties for the region of occupancy. In figure 5, the occupancy map (30 min.) has informed a Voronoi tile. Intensity in the tessellation is controlled by the occupancy intensity on the map - places with high occupancy have a high amount of edges and complexity, whereas places with lower occupancy are less complex.

Primary flow. The primary flow lines demand a frictionless movement - too many obstacles can cause a bad experience, and, in the worst cases, cause you to find another, faster route. When moving on the flow path you are observed and observing other people directly. The short eye-to-eye contact, body checking, ignoring etc. - this is the urban catwalk. It is a retreat for the high heelers, the person texting on the phone while running to the train or the fast moving skater etc.; indeed this space is a showroom. You do not want to stumble on the pavement or spend too much energy on navigation. The flow space is also the place to go when you are lost in the small spawns. When finding a route, it will always take you to a larger infrastructure, and as such you are connected to someplace you know. At night, this is the place where you want to see the heads of fellow pedestrians; it makes you feel calm and safe, because you can see the intentions. The space has an entrance and an exit; it has a direction, and the surface is plain but not slippery on rainy days. In the night time, the illumination is important.

Groupings. Places with a high amount of groupings could indicate meeting places or places with high friction. The grouping can be voluntary or involuntary; e.g. when waiting for a buss, standing in line or meeting your family or friends. Meetings in the public space are of informal groupings, and un-grouping is a very common social dynamic. The places are typically known as special places with special characteristics that somehow differentiate and become a common reference; e.g. under the clock or on the stairs by the water etc. It is difficult to present a single topology for this spatial character, but we can apply the principle of variation and differentiation in patterns, thus creating identity or exclusivity.

Non-flow spaces. Regions with no or very little activity hold a potential for a new intervention that can improve the performance of the space. It is the first place to build a new design proposal, which facilitates new forms of occupancy; e.g. shelter from the sun, rain or wind, new facilities or maybe space for new architectural programs; such as kiosks, shops, restaurants etc. This presents potential places for new architectural footprints. In figure 6, one can see potential flow spaces; the red markings show the selected nodes. The placement can be more or less private (indicated by the amount of black in the circle). In figure 6, a column structure holds a potential canopy structure, which is raised towards the central flow paths and lowered around the more intimate sitting facilities. The pattern and the outline of the structure is informed by the intensities from the multilayered flow maps. As such, the pattern relates to one specific section of the square, underlining the novelty of that specific location.

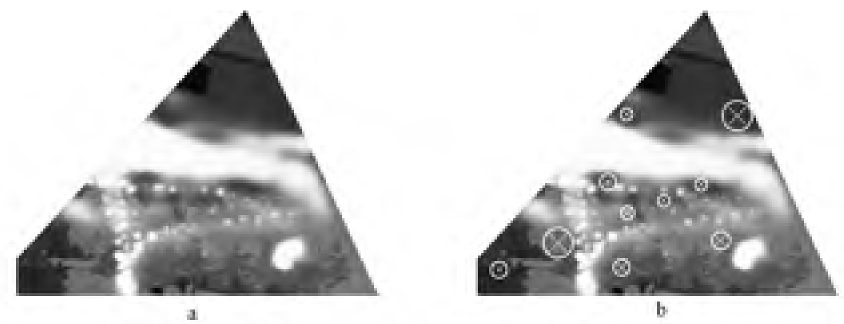

Fig. 6. a: Black shows the collected flow regions. b: Selected canopy footprints (marked with +).

Merging the four urban flow topologies presents a multilayered design matrix where different topologies and spatial qualities are separated by the analysis done from the existing site. Because of the nature of the data, it is possible to treat high-resolution data and create separations, not as lines but as gradient patterns. These are to be studied further together with the performative qualities of the urban flow topologies.

Fig. 7. Figure 5 & 6 are superimposed into a multilayered flow sketch.

4 Discussion and Conclusion

The case study demonstrates that data from a thermal camera can be used as input in an urban design system, and by using computer vision techniques, it is possible to separate at least four types of flow: occupancy, flow, groupings and non-flow activity. The flow data maps are basis for a design case study where corresponding flow topologies are studied and formalized. The design scenario is one out of many possible design solutions, but it illustrates the intended data flow from between context, analysis, translation, representation, and into formalization. The outlined design methodology is linear, but if the project were realized; shape, texture, proportions, acoustics etc. would change the public "scene" and thereby change the way interactions unfold in the square. This is an iterative process. This looping process has a potential to visualize place usage, and present a foundation for a more intelligent selection of future design scenarios. The thermal camera images present tendencies, not individual actions, and they do not present accurate activities. The tendencies show how people are using (or not using) the public space, and this flow selection process indicates significant special qualities; is it a place you just pass through or a place where you check-in? Each of these activities has their own look and their own topology. As such, the image material gives us a better understanding of the spatial potentials and use of the space and presents valuable information for the designer or planner.

In this small project, we have used 30 minutes of recordings from a sunny summer day in mid July. These conditions are present 1495 hours [12] a year, which equals 17 %. This would give a snapshot of the existing flow patterns, which are in constant change and can never be predicted. We can collect more data by raising the chance of a good predication of human behavior, but it would always merely establish guidelines and tendencies. The flow tendencies are interlinked to the architectural setting, and when the light changes, the furniture moves, or a new tent is established, it will mobilize significant change in flow systems. These are the changes we have to evaluate to build better places for people. As such, we should discuss how the data could be a significant driver for future design decisions, and thereby close the feedback loop between real-world data and evaluated design effects. This study would need more than 30 minutes worth of snapshots, and the data would spread across seasons, for better qualifying new design proposals.

Redesigning the place, however, is a complex affair, and we still cannot tell the difference between a concert and a demonstration just by looking at the occupancy map. We still need an analytical eye interpreting the data. And what looks like unused spaces on the flow maps, could have other aesthetic qualities, e.g. the water surface (that appears as unused space on the heat map), the emergent ripple patterns on the surface, or the many-colored reflection of the sunset, which is the very reason to spend time on the riverbank - the unused space holds significant qualities, which can not be revealed from the maps. Therefore, it becomes important to treat urban design with due care before adding new edges in the city, but, indeed, the flow maps do add a significant and valuable design to the pencil case of the analytical planner.

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