Language of Movement for Building Assessment:
A Review of the Evaluation Methods of the Human Movement in the Built Space

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ABSTRACT: The purpose of this article is to provide a framework for the categorization of methods and techniques of human movement evaluation, measurement, and assessment in the built space. The reviewed methods have been put together in a framework by the consideration of the level of movement and the timescale. In doing so, the phenomenon of movement has been distinguished as a four-level of movement scale that are subject to eight timescales. These four levels are imbedded movement, dynamic posture, dynamic location, and dynamic agent. Finally, twenty selected techniques and methods are defined and the methodological procedures of each of them have been described. These methods are mainly derived from studies on daylighting and comfort.
KEYWORDS: Movement, Daylighting, Architecture, Comfort, Methodology

1. INTRODUCTION

A collection of choreographic postures has been employed to establish a distinctive movement vocabulary, governed by geometric rules specifically formulated for the human body. This codified grammar of movement, detailed in a set of rules, intricately shapes the dynamics of the human body, giving rise to a nuanced corporeal experience [1]. Consequently, the deliberate and coordinated movements originating from diverse parts and joints of the body can be meticulously observed and monitored, offering valuable insights into various variables associated with the psychophysiological conditions of individuals. This paper explores a selected set of architectural and urban studies to shape a comprehensive review of evaluation methods for human movement within built spaces, exploring the complex language of movement as a tool for building assessment.

The interdisciplinary nature of the research, drawing insights from neuroscience, biometrics, and psychology, further broadens the understanding of human movement. This expansion of scope highlights the multifaceted nature of movement and its profound impact on psychophysiological conditions. As a result, the research facilitates a structured approach to the analysis of human movement, enabling more informed, user-centric decisions in diverse contexts within the built environment.

2. METHODOLOGY

This paper reviews the diverse approaches employed for measuring, assessing, and evaluating movement within a selected group of studies in architecture and urbanism. The contexts of the studies selected to review are daylighting and comfort that evolved around the main keywords of ‘movement’, ‘daylight’, and ‘architecture’. It explores the intricacies of the methodologies applied in these studies, shedding light on the tools, instruments, and techniques utilized to capture and analyze movement data. For classification of these methods, movement could be distinguished into three main scales (Fig. 1).

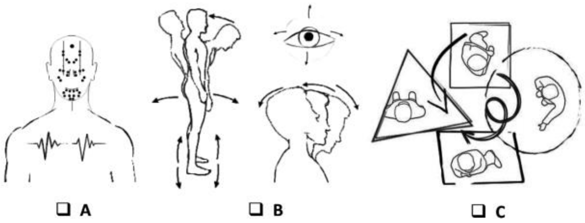

Figure 1: movement scales. Movement of the facial muscles and heart (A), Movement of the joints and eye (B), and Movement of the body through the space (C) (source: author).

By categorizing movement into distinct levels and timescales, the comprehensive framework provided here enriches the theoretical foundation of architectural and urban studies and empowers it with practical applications and examples for each movement level and timescale.

3. RESULTS

Based on the review on the selected studies a table could be created illustrating the methods of evaluating movement in the built space. The table provides a structured overview of movement levels categorized across various timescales, ranging from instant to annual intervals. It distinguishes movement in four scales of micro-scale (imbedded motion of organs), mid-scale (reposition, redirection, ocular movement, limb movement) (Table 1), macro-scale (relocation, movement through space), and mega-scale (occupation cycle, migration, walking rate) (Table 2).

Table 1: Methods of evaluation of movement in the built space based on the scale and time of the movement for micro and mid scales.

Movement level / **Timescale**	**Micro-scale:** Imbedded motion / movement of organs	**Mid-scale:** Reposition / redirection / ocular movement / movement of the joints
Instant (a range of seconds)	* Biometric analysis (EEG, SGR, EMG, PPG) * Affectiva iMotions video analysis	* Eye Tracking, Motion sensing * Adaptive zone * Time-of-Flight sensing * Vision-based pose estimation
Momentary (minutely or a range of minutes)	* Biometric analysis (EEG, SGR, EMG, PPG) * Affectiva iMotions video analysis	* Eye Tracking * Adaptive zone * Time-of-Flight sensing * Vision-based pose estimation
Temporary (hourly or a range of hours)	* Smart bracelet recording	* Eye Tracking * Adaptive zone * Time-of-Flight sensing
Diurnal (daily)	* Smart bracelet recording	* Actigraphy

Table 2: Methods of evaluation of movement in the built space based on the scale and time of the movement for macro and mega scales.

Movement level / **Timescale**	**Macro-scale:** Relocation / movement pattern	**Mega-scale:** Occupation cycle / migration / walking rate / trajectory
Instant (a range of seconds)	* Timelapse footage with short intervals * Video recording analysis * Direct Observation * Time-of-Flight sensing * Behavioral mapping	* Long Short-Term Memory (LSTM) trajectory prediction
Momentary (minutely or a range of minutes)	* Timelapse footage with short intervals * Video recording analysis * Space syntax * Direct Observation * Time-of-Flight sensing * Vision-based motion tracking * Behavioral mapping	* Datalogging * Monitoring * Long Short-Term Memory (LSTM) trajectory prediction * Space syntax * Behavioral mapping
Temporary (hourly or a range of hours)	* Timelapse footage with intervals * Space syntax * Direct Observation * Time-of-Flight sensing * Vision-based motion tracking * Behavioral mapping	* Datalogging * Monitoring * Space syntax * Behavioral mapping
Diurnal (daily)	* Timelapse footage with long intervals * Actigraphy * Space syntax * Time-of-Flight sensing	* Datalogging * Monitoring * Space syntax
Periodic (weekly)	* Actigraphy	* Actigraphy * Monitoring * Web-based observation
Cyclical (monthly)	* Actigraphy	* Actigraphy * Monitoring * Web-based observation
Quarterly (seasonally) / **Annual** (yearly)	-	* Observation * Web-based observation

4. DISCUSSION

The methods addressed in the tables (1, and 2) could be categorized in four movement types of imbedded motion, dynamic position, dynamic location, and dynamic agent each of which occur in different levels. Therefore, they require different approaches of analysis.

4.1. Small-scale Movement: Imbedded Motion

"The body expresses movement even when motionless" [2]. This notion stems from the physical and physiological facts that even in a static position, the same push and pull of the environmental and biological forces needed for motion occurs. This ongoing struggle is characterized by the constant interaction between the body and gravitational forces (refer to neutral body orientation as depicted by researchers [3]), as well as the dynamic interplay within the skeletal framework and musculature.

Heartbeat variability represents a form of motion generated by the cardiac muscle. This dynamic aspect was a pivotal factor in the mood-related analysis conducted by Peper et al. [4]. Consequently, in this study, posture, conceptualized as a distinct form of movement, was established as the independent variable, with heartbeat variability serving as the dependent variable (Fig. 3). In a separate investigation [5], the Photoplethysmogram (PPG) was employed to measure heartbeat variability, contributing to a deeper understanding of emotional responses and stress levels. Moreover, recognizing heartbeat variability resulting from physical activity, essentially movement within movement, presents an avenue for developing a thermal comfort model, as illustrated in the work by [6].

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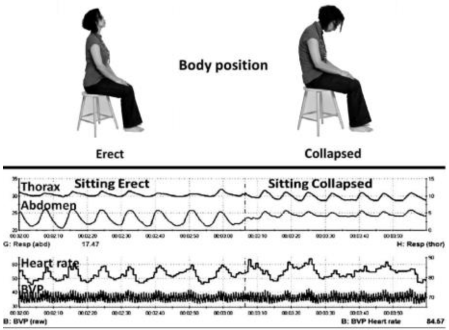

Figure 3: Effect of posture on respiratory breathing pattern and heart rate variability (source: [4]).

Beyond the motions orchestrated by the internal activities of human organs, studies investigating sleep have underscored the significance of readiness for movement and activity. Understanding this readiness holds particular importance in the realm of movement studies, as the body aligns its internal chronometer with environmental cues, leading to variations in activity-rest patterns across different environmental conditions [7]. These patterns can be intentionally manipulated to achieve specific timing for movement and activity. Consequently, in these scenarios, human activity patterns and schedules are established as independent variables, exerting influence on how the built space should be approached. Considering this, regression analysis has been employed to predict human movement [8].

Biometric tools to record and map human experience is one of the recent areas of research. Ergan et al. [5], in their research argue that to map the experience of human effected by the architectural design features, the use of body area sensor network concept proves to be useful. In doing so, they [5] integrated Electroencephalogram (EEG), facial- or vision-based Electromyography (EMG), Galvanic Skin Response (SGR), Photoplethysmogram (PPG), and Eye Tracking tools with virtual reality environment to analyze human experience in the virtual built space.

Elementary emotions	Muscles involved	Produced actions
Happiness	• Orbicularis oculi • Zygomaticus major	• Closing eyelids • Pulling mouth corners upward and laterally
Surprise	• Frontalis • Levator palpebrae superioris	• Raising eyebrows • Raising upper eyelid
Fear	• Frontalis • Corrugator supercilii • Levator palpebrae superioris	• Raising eyebrows • Lowering eyebrows • Raising upper eyelid
Anger	• Corrugator supercilii • Levator palpebrae superioris • Orbicularis oculi	• Lowering eyebrows • Raising upper eyelid • Closing eyelids
Sadness	• Frontalis • Corrugator supercilii • Depressor anguli oris	• Raising eyebrows • Lowering eyebrows • Depressing lip corners
Disgust	• Levator labii superioris • Levator labii superioris alaeque nasi	• Raising upper lip • Raising upper lip and wrinkling nasal skin

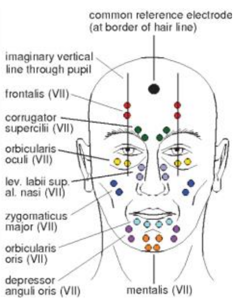

Figure 4: Connection of the emotional expressions with the produced facial actions (Source: [10]).

Deciphering the facial expressions would help to assess the affective impact of architectural features on the user. Each produced action is linked to an emotional state representing the condition of the built space (Fig. 4). Beside EMG tool, cutting edge software could have the ability of analyzing the affective impact of the architectural elements. For instance, Affectiva iMotions is a facial expression analysis software that evaluates the video recordings of the users to read the facial expressions [9]. This technology enhances the precision of evaluating the affective responses of individuals to various architectural features.

Eye tracking technologies play a pivotal role in advancing the assessment of dynamic visual attention, as demonstrated by the use of portable eye trackers [11]. These technologies excel not only in pinpointing areas of interest but also in generating insightful heatmaps [12]. Moreover, the analysis extends to factors such as the direction of gaze, the degree of eye opening, and pupil size, particularly valuable for investigations into daylighting [13].

4.2. Medium-scale Movement: Dynamic Posture and Position

Dynamic physical expressions and the activity of limbs and body parts shape the overall dynamic state of the human body in the space. The study of different postures and positions of the body in the space could determine valuable information for the researchers and designers collecting data on mood, sleep, and activity rates in the built space.

The dynamic portrayal of the body within an environment serves as a valuable tool for assessing human emotive states. Paterson's study [14] on the experiential aspects of architecture, focusing on vision and touch, demonstrates that user mood states can be discerned through the observation of postures and gestures. Building on this notion, researchers [4] conducted an experiment linking depression levels and emotional recall to varying postures, including both erect and collapsed conditions (refer to Fig. 3). Consequently, understanding the motivations and stimuli driving user movement within a building becomes feasible by gauging mood states, which can be deduced through posture and gesture observation.

The dynamic appearance of the body in space is not limited to visual observation; it extends to the use of motion sensors to monitor user activity, enabling strategic adaptations of the built environment to meet occupants' needs. Research in this realm includes the application of passive-infrared (PIR) motion sensors, notably enhancing adaptive lighting control through movement detection [15]. Additionally, ceiling-mounted Time-of-Flight sensors (ToF) provide opportunities for gesture recognition [16], extending their utility beyond mere recognition to applications like occupancy sensing, people counting, and activity monitoring. This multi-faceted approach facilitates comprehensive analysis of movement and interaction patterns within a space.

Limb activities could be considered as the main parameter of shaping the dynamic position and posture in the space. A tool to measure physical activity at this level is Actigraph. This tool could be used for different purposes ranging from physical activity assessment such as speed, activity counts, activity intensity, and steps per a given time [17] to rest/activity or sleep/wake cycle [18] [19]. Actigraphy with the use of actiwatches was a method to study the level of activity of participants in a long-term survey to study well-being and sleep quality [20].

Activity of the joints is also noteworthy specially for studies related to healthcare, safety, and sports. This activity defines the grammar of human skeleton motion while performing certain tasks. Motion could be captured through vision-based human motion sensing for ergonomic and biomechanical analysis [21]. The motion data in Liu et al.'s [21] research is consisted of the angles at body joints and could be depicted in a 3D or 2D illustration (Fig. 6A).

Dynamic direction or position of view is an output of the movement of head or the rotation of body. In daylighting studies, this behavior is attributed to the concept of 'adaptive zone' in which the visual comfort of the observer would be evaluated [22]. Although the method known as adaptive zone is initially to assess visual comfort and not movement, however, the view angles introduced to run the analysis imply the existence of movement of the body in a fixed location. Therefore, it could be possible to use this method for the evaluation of other environmental effects.

4.3. Large-scale Movement: Dynamic Location

The dynamic interplay of the body with the space between points has been used to study the successfulness of the spatial design. The most basic form of movement analysis on the surface is space syntax methodology. While space syntax is taking into account factors such as movement patterns, cognition, and behavior [23], it could not cover all aspects of human movement varying from different timescales and levels explained previously in this article. In this method movement is a part of analysis based on the analysis of the spatial configurations integrated with social structures other than tracking and sensing movement [24]. Connectivity and integration are the two closely related factors when it comes into the study of movement as a link between different spatial units. These factors find application in generating heatmaps [25].

More direct approaches could be implemented to have a more accurate track of movement. Autographical shading and dotting on the map to locate the spatial appraised points [26], phenomenological writings and modeling [27], and autoethnography of the experience of movement [28] were three techniques to assess the experience of the space. They [28] understood atmospheres emerging according to the levels of activity and movement. With this approach each location is given an identity. Emotional representation of the locations in the space has been introduced as a variable dependent on the affective state of people in different locations besides spatial navigation [26]. Here movement described as spatial navigation plays an extraneous role for the independent variable. Chun and Towse [29] express that with auto-ethnographical approach researchers will narrate their 'own spatial experiences' to guide further design decisions.

Mapping of perceived daylight boundaries and best locations through survey and based on participants' drawing was a method of perceptional representation of the locations in the space [30]. This research aimed to understand the perception of users. In urban, researchers [31] have used timelapse photography with 1.5 minutes intervals to capture the use of resting areas in a square over time scale to assess each location.

Mapping human behavior to examine independent variables has captured the interest of many researchers. For example, in a study on the impact of the daylighting condition, the users' movements in a café have been mapped to understand whether the daylit areas are busiest or not [32]. Hong et al. [33] conducted a behavioral mapping using virtual agents. They used Dassault Systèmes' 3DVia Virtools which is a visual programming platform to create anthropomorphic goal-oriented agents mimicking human activities with four defined parameters defining and limiting the range of behaviors. Their goal was to find an optimal match between human activity and built environment in architectural design. In another context, aiming to classify behavior pattern, researchers [34] were able to model manual lighting control behavior patterns based on daylight illuminance and interior layout. To categorize, occupancy detectors were used to understand the change of occupancy and interaction pattern with the change in the layout and daylight conditions. Based on the data, a fuzzy logic model through MATLAB FIS editor was constructed.

Observation is the first method of data collection in studies related to behavior of people in a space regarding the use of space or the elements in the space [35]. More convenient methods such as, time-lapse photography has proven to be a good method for the analysis of occupation cycle and pattern to study the energy use [35]. However, for the study of occupancy, the use of computer vision sensors and cameras is a good method for data collection is a more advanced methodology [36].

The rate of corporeal and sensory engagement with the environment as a dependent variable has been studied through observation and monitoring in different studies [37]. The higher the level of environmental affordances, the higher the rate of corporeal and sensory engagement. Or in better terms, the richness of quality environmental

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affordances directly contributes to an enhanced adaptive engagement experience.

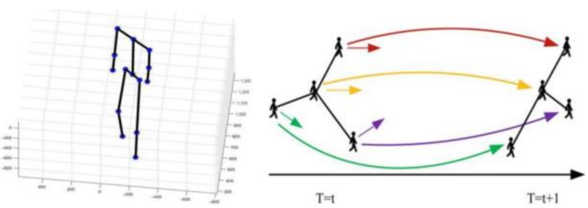
4.4. Mega-scale Movement: Dynamic Agents

Some certain studies such as post occupancy evaluation that involve long duration measurements or studies on urban components that involve higher intensities and volumes of movement patterns require other methods of evaluation. In other words, movement could also be interpreted and studied as the change in occupant counts or occupancy duration in each location. For instance, Jens and Khoudi [38] have grouped these two parameters with seats and tables to understand which place shows lesser change in occupants count and duration before and after a planned intervention. Based on this knowledge, the impact of different conditions on the occupancy patterns could be deciphered.

Pedestrian motion is the most analyzed parameters in the urban studies. For example, in an early study, Burse [39] simulated the movement and route decision of virtual individuals in an open space through an online multi-agent system called BOTworld to analyze human thermal comfort in different microclimatic condition.

On the urban scale, there have been many other studies considering user movement as a dependent variable on the environmental conditions or morphology. For example, researchers [40] have tried to simulate user movement through the analysis of the relationship of movement with the urban components. de Montigny et al. [41] have visually inspected the volumes of walking to establish its correlation with the locally felt weather.

One of the most important problems when dealing with volumes of movement is safety issues. For this reason, predicting models such as image processing have been used to predict trajectories of the pedestrians (Fig. 6B). However, the improved method of trajectory prediction has been recently introduced [42].



❑ A ❑ B

Figure 6: A 3D skeleton extraction for motion sensing and analysis (A) (Source: [21]). Prediction of the human movment (B) (Source: [42])

5. LIMITATIONS

While this research helps the understanding of human movement within built spaces, it is essential to acknowledge that the proposed framework is not comprehensive and can benefit from further refinement. The correlations between movement levels and timescales could be more robust, and to enhance the validity and generalizability of the framework, a systematic review encompassing a broader range of references beyond those primarily related to daylighting and comfort is recommended. The current review provides a valuable starting point, offering practical insights and applications, yet a more comprehensive analysis could strengthen the results and refine the framework.

6. CONCLUSION

Based on the framework presented in this article that classifies movement into 4 levels and 8 timescales, the diversity of movement evaluation has been shown. 20 methods have been introduced and explained here to measure, assess, or evaluate human movement inside the built space. These methods are: Biometric analysis (EEG, SGR, EMG, PPG), Affectiva iMotions video analysis, Eye Tracking, Motion sensing, Adaptive zone, Time-of-Flight sensing, Vision-based pose estimation, Timelapse footage with short intervals, Video recording analysis, Direct Observation, Long Short-Term Memory (LSTM) trajectory prediction, Space syntax, Vision-based motion tracking, Datalogging, Monitoring, Smart bracelet recording, Timelapse footage with intervals, Timelapse footage with long intervals, Actigraphy, and Web-based observation.

In addition, the classification introduced here does not consider methods as subject-specific. Therefore, depending on study they could be modified. It is important to note that this review is a contribution to the establishment of a framework to practically correlate human movement with architecture.

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