Master's thesis

NTNU
Norwegian University of Science and Technology

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Stressed in the City

How Different Urban Environments Affect Stress

Master's thesis in Fysisk planlegging
Supervisor: Helge Hillnhütter
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Preface

This master's thesis is written for the course FP4400 master's thesis in physical planning. This semester has been dedicated in its entirety to the study of stress understood through the use of biosensors which have provided objective physiological data, and subjective qualitative and quantitative data. While I believe the subject I have chosen to be extremely interesting, it is very much a complex topic which has not been widely studied, leaving it a large research field gap. This gap should be filled because of the objective results biosensors produce, providing new dimensions and insights. Walkability, architecture and stress is to a large degree fields of study which have traditionally been qualitative, but biosensors have the possibility of researching such fields with new methods. Because of the limited research available on studies such as this, and the limited sample size of participants in this study, I consider it as a pilot study.

To avoid accusations of plagiarism, it should be known that many parts of chapters 1 and 2 are more or less directly copied from my assignment which was prepared for this thesis. Most of chapter 1, and about half of subchapters 2.2-2.6 were written November 2022, though substantial parts of these texts have been rewritten. The text referred to is Lem (2022).

I would like to thank my supervisors PhD candidate Lisa Marie Brunner and associate professor Helge Hillnhütter for providing help, feedback and discussion for my results. Additionally, I would like to thank PhD candidate Henrikke Dybvik for help with HRV analysis programs.

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Jørgen Valheim Lem

Abstract

This master's thesis presents a study that utilizes biosensors to assess heart rate variability (HRV) and stress levels among participants in various urban environments. The goal of the study is to investigate the relationship between different urban environments and physiological and psychological responses and view such data in conjuncture with participant self-reports. The study adopts a mixed-methods approach combining physiological measurements with subjective feedback to gain a comprehensive understanding of the relationship between urban environments, HRV, and perceived stress.

The research employs a wearable biosensor to collect real-time HRV data from participants while they navigate distinct urban contexts. These environments include parks, industrial estates, and residential areas. The biosensor data captures HRV parameters such as time-domain and frequency domain.

Furthermore, participant self-reports are collected partly through structured questionnaires and partly through a semi-structured interview, capturing subjective affect and perceptions of the built environment. By comparing objective physiological data with self-reported data, a comprehensive assessment of stress and its relation to urban environments is achieved.

Findings from this thesis indicates that there is a correlation between objective physiological data and subjective self-reports. Participant-expressed dissatisfaction with urban qualities overlapped to a quite large degree with areas of heightened indicated stress levels. The built elements which were negatively perceived, included areas largely designed for car accessibility, areas with industrial architecture, and a pedestrian underpass which was particularly dim-lit and claustrophobic.

Keywords: **Heart rate variability, stress, biosensors, urban environments, self-reports, physiological measurements, walkability.**

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Aim of the thesis

Our understanding of how the built environment affects our mental health and emotions is not well documented nor understood (Eberhard, 2009; Nanda et al. 2013, as cited by Bowen et al. 2019). Nonetheless, it is well-known that the built environment and its degree of attractiveness does have effects on our subjective well-being (Mouratidis & Hassan, 2020). The street design, the architecture, the greenery, the traffic, and many other factors that make up the city and its experience, should be designed as socially and environmentally sustainable as possible. To create guidelines for urban design in the future, it needs to be based on good research. However, many articles related to biosensors, which will be discussed in this thesis, states that they are pilot projects, or that more participants are needed in the future for more accurate results. This is also the case for this thesis. Therefore, this field of measuring affect with the help of biosensors can be considered one with a research gap. Mouratidis and Hassan (2020) also believe that the research field about affect and its relation to the built environment is lacking, and that it should be more deeply understood.

This thesis will take a mixed methodological approach in trying to discover if certain built environments are responsible for increasing stress levels in participants. Biosensors which gather heart rate variability data (time-domain and frequency-domain) are used to assess increased mental arousal, which is subsequently analysed in conjunction with self-reported affective states and rankings of the built environment by participants. Data was gathered on an approximately 20-minute-long walk traversing through physically distinct environments.

Research question

The master’s thesis will try to answer this proposed main research question:

Is there a measurable difference in stress in different urban environments?

In addition to the main research question, I will try to answer two sub-questions:

1. *Is there a match between quantitative measured data and self-reported stress levels?*
2. *Which urban qualities increase stress, and which decrease stress?*

1. Introduction

It is an established fact that the urban environment has a quite significant effect on well-being (Mouratidis & Hassan, 2020). This includes common elements found within a city, such as architecture, landscape architecture and general structure of the urban fabrics. These characteristics influence how we perceive and value our city and local environment, in addition to feeling happier when we think of a place as beautiful or serene (Ellard, C. 2020). Investigating which environments causes possible mental distress, is important for reaching the goal of the liveable city, in which citizens thrive.

In the last few years, new and better biosensors and accompanying software have become easily commercially available. Subsequently, research utilising biosensors is more accurate compared to a decade ago. Thus, studies may reveal information that can be used for shaping urban planning policies.

Not only is measuring affect/emotions with sensors very interesting, but important as well, in an age where there are strong debates surrounding the quality of cities, and how they are currently being expanded or redeveloped (Lundgaard, 2021; Thiis-Evensen, 2022). Therefore, this thesis aims for a greater understanding of the built environment's effect on people's stress levels, trying to identify whether certain physical components of the city have clear negative associations for participants in this study.

1.1 Short history of urban planning

Modernism arose from the ruins of WW1, when several dynasties collapsed after centuries in power and people saw a significant change in attitude starting in the 1920s with liberalism, the rise of communism and individualism (Cheng, 2022). During the 1800s industrial revolution, workers moved en masse to the cities to find work in factories. The growth of cities at an immense rate caused many cities to expand rapidly, while sanitary conditions still staying poor for a large share of the population. Additionally, the population density was very high, and the apartments were overcrowded (Library of congress, n.d).

In 1854, John Snow studied causes and hypothesis of the outbreak of Cholera on Broad Street in London, in which 616 people died. His findings helped draw attention to public health issues, which led to construction of better sanitary facilities from the mid-19th century and onwards (Eyeler, 2001). From this point onwards, good sanitary conditions were of the utmost importance to urban planners, especially in the western world. Lighting conditions, air and greenery were other hugely important tasks to solve for urban planners and sprung up because of the poor quality of the aforementioned factors in the very dense cities of the industrial age. The focus on such factors shaped both modern architecture and planning and influenced greatly 20th century planners such as Le Corbusier who favoured towers in the city and the dissolution of the dense city, which allowed for lots of light and open green space.

From the inception of Bauhaus in 1919 and the stronger emergence of modernism during the 1930s architecture took a sharp turn from the flamboyant decorations of pre-WW1. This was partly due to shifting social trends and the introduction of new building materials such as concrete and steel frames. In the same period, urban planning embraced principles emphasising light, fresh air, and greenery to a large degree. Although some cities were already in the 1800s being redesigned for traffic and accessibility, such as in Paris, the scale of such building did not emerge to a large extent before the 1950s, when car ownership was increasing, especially in the western world (Walsh, n.d). Subsequently, older quarters of many cities were razed to build new housing, especially in the U.S., where often previously black neighbourhoods were demolished to build highways for increased mobility and suburbanization (Beyer, 2020).

In many parts of the world by the 1960/70s, the dense, urban streetscapes were being replaced by scattered townscapes which neglected pedestrians and favoured automobiles. While single detached housing was quite prevalent in Norway before roughly 1960, expansion of suburbs and hinterland exploded after cars ceased to be rationed in 1960, and the number of cars doubled between 1960 and 1964 (Monsrud, 1999). This enabled construction of large suburbs and spread townscapes because of ease of movement. Groruddalen in Oslo was constructed from the 1960s and onward and this development was possible because of the car. Its planning is clearly shaped from contemporary car-based principles, in which traditional streets are non-existent. Instead, monotonous apartment blocks stand tall in a centreless, streetless landscape, in which walking is tedious and the distances large, designed for motorized vehicles.

Since then, however, cities in at least many parts of Europe, have stopped favouring the development of car-friendly infrastructure or tried to make the pedestrian's role more prominent. Examples include shutting off town centra or thoroughfares for cars, or rerouting traffic. New Urbanism, a branch of urban planning that grew from the 1980s as a reaction to car-based, "inhuman" modernist planning, emphasized walkability and proximity to city centra as a socially, environmentally, and healthily sustainable way of planning future cities (CNU, n.d). Density and transformation were principles from the New Urbanism that gained especially much traction, and which are commonplace nowadays, when previously industrial areas cease to function as such and are transformed into residential or commercial neighbourhoods which are often designed with pedestrians in mind. Examples of such are Solsiden in Trondheim, Aker Brygge in Oslo and Canary Wharf in London.

1.2 Criticisms of modernist planning

In 1961, activist Jane Jacobs released the landmark book *The Death and Life of Great American Cities*. Here she recognized and criticized the errors of modernist planning which included neglection of human scale in planning, urban renewal and land use separation. She advocated for walkable streets and mixed-use, vibrant neighbourhoods. Similarly, writers like Gordon Cullen, Jan Gehl, Aldo Rossi, Robert Venturi, Allan Jacobs, and Leon Krier have all published books criticizing urban planning of their time (1950s through 1980s) as being monotonous and hostile to the pedestrian and that it ignored the complexity of human nature in an urban setting (Flack, 2016).

A lot of the criticism regarded modern urban planning's lack of creating *spaces*. One would create buildings, but the buildings have no connection to its surroundings, ceasing to create meaningful areas of being. Urban fabric stops being fabric when the buildings are not woven into the existing tapestry that is the city. This is exactly the problem with the modernist streetscape: they have dissolved too much, too patchy, too much space in-between (Flack, 2016). Siu and Huang (2015) criticize modernist planning as alienating and neglecting human needs and scale and having destroyed public spaces in favour of infrastructural purposes.

From the 1970s, and especially since the U.N. Brundtland commission report, *Our Common Future* in 1987, negative impacts stemming from the car have been shed light on. The most widely associated problem with cars is its greenhouse emissions. Cars are relatively energy inefficient, especially when many cars are driven with only one passenger. Additionally, there are many ripple effects from car use. Other consequences of cars are microplastics, noise pollution and land use. These pose the largest environmental problems and affect nature and health on local and global scale. Furthermore, road infrastructure and its upkeep cost a fortune, and space required to store parked cars consume land which otherwise could have been used for recreation or living (Shoup, 2011). The car has been a main primer for suburbanization, which have created low-density housing that consumes far more green space than apartment housing does. Public health has suffered extensively from excessive car usage, causing reduced natural activity, and has caused higher levels of cardiovascular diseases, stress levels and obesity because of inactiveness and reduced levels of walking and bicycling (Douglas et al., 2011).

Debates are still raging in Norwegian media about what good and bad planning is, and that contemporary architecture and newbuilt streetscape are severely lacking (Lundgaard, 2021). Contemporary planning in Norway might be considered lacking because of various reasons. One is that there is rarely a holistically planned area, because many new developments are somewhat detached from the city elsewhere. This means that the streetscape is not as connected as in the traditional city: each new area is often built on smaller plots of land and infrastructure is already established, making it difficult to change the streetscape, especially if it is located next to a highly congested road (Juven, 2017).

Another possible reason for the weakened sense of streetscape is building requirements. Lighting level requirements and other technical aspects of buildings have an impact on building design and placement, and deviating from “standard design” might be costly because of new designs and additional planning time needed. For example, many apartment buildings and their subsequent street layout in popular historical districts in Oslo would be illegal to build today because they do not fulfil technical requirements of modern building codes (Sørgjerd and Dons, 2020). Additionally, despite trying to reduce car dependency, Norway is still building in such a manner which fosters such a dependency (Elldér, Haugen and Vilhelmson, 2022).

1.3 The aspect of stress and its relevance

What exactly is psychological stress? Stress understood after Russel (1980) defines stress as "on a spectrum in which high levels of arousal and displeasure are combined". A different researcher defined it as "an adaptative response to an identified stimulus that leads to changes in an individual's psychological and physiological equilibrium" (Rodriguez-Valencia et al., 2022).

Stress is a big factor in life. High levels of stress reduce quality of life. Prolonged periods of stress have shown to decrease both mental and physical health. Problems which may arise because of stress, is insomnia, fatigue, depression, high blood pressure, higher risk of cardiovascular disease, muscle pains and more (Racine, 2020).

Stress can arise from many different reasons, but for this assignment it will have to be directly associated with the urban city. Examples include streetscape, the built environment, architecture, and elements connected to those things, such as noise, pollution, and traffic, which are all inter-connected (de Vries et al. 2013.) Most would probably say that they would be more stressed when walking alongside a noisy and polluted motorway, or in an industrial area, than on a small road in a single detached housing neighbourhood (LaJeunesse, 2022).

Measuring stress from a pedestrian's perspective in the street has only been studied in very limited regards as pilot studies, with primarily wristbands being used as measuring device for physiological data, such as electrodermal activity or heart rate variation. Combining accuracy in measurement and ease of use has made biosensors an exciting new piece of technology which can be used to assess stress based on relevant variables. Heart rate variability (HRV) and electrodermal activity (EDA) have become commonly used types of data for assessing stress. HRV measures inter-heartbeat intervals, while EDA measures skin conductance levels as a result of bodily sweating.

It is important to keep in mind that simply assessing psychological stress by looking at data is not possible, because of the variety of factors involved in causing a spike in what we believe to be stress. For example, a high degree of affective arousal might stem from something positive, such as bearings of good news, just as how it can be "bad" arousal in the form of heightened alertness or stress. Thus, context is the key to further assess when one is stressed. This is one of the important reasons for incorporating a subjective method for assessing stress, because it provides greater context, which makes it easier to assess stress.

1.4 Walkability and its relevance

Walkability can be defined as how neighbourhoods embody three central environmental characteristics: densities of buildings and people, set of attractions and functions, and the quality of accessing these (Dovey and Pavka, 2020). How we perceive the built environment in terms of physical barriers and how “stressful” it seems to walk somewhere, plays a part in how willing we are to walk and bicycle somewhere, and how far as well. One study found that general urban design, particularly streetscape, has a significant influence of pedestrian activity (Ewing et al., 2016). For example, sidewalk coverage and ease of crossings impacted walkability quite a lot. A high degree of walkability has become an important part of the idea of developing the liveable city in the past 30 years.

Norway’s planning and building act from 2008’s opening paragraph emphasizes sustainability (Plan- og bygningsloven, 2008). The state planning guidelines for coordinated housing, area and transport planning were introduced in 2014, and their functions are to increase the efficiency of resource utilization, especially land use. Sustainable development of cities is prioritized, which includes stronger restrictions on wasteful land use, such as with low-density housing, otherwise known as *sprawl*, which was prevalent in times described in chapter 1.1. Instead, densification, infills, improved public transport and friendlier environments for pedestrians and bicyclists should encourage a more environmentally friendly way of living and managing our cities (Hanssen et al., 2015, p.13-14).

Other aims of the guidelines are ones related to boosting public health for example, which has suffered under car-dominated planning. An obvious way which reduces the need for cars in everyday life is making the city more walkable. Shortening walking distances to everyday needs such as grocery stores decreases car use (Elldér, Haugen and Vilhelmson, 2022). Building densely and developing brownfields are common building paradigms, are this increases walkability. However, short distances to amenities is only one aspect of walkability. Ease of movement, visual aesthetics, safety and several other factors are just as important as proximity.

The whole issue of measuring stress in these different urban areas, is based on the idea of finding out whether we react differently to pedestrian-friendly and more traditional streetscape and architecture, compared to the modern planning, in which streets do not exist in the same way as in older districts. This is not to indicate that modern areas are necessarily bad for walking, but rather that older areas were built at a time when walking was the primary means of transportation. A reason why this topic is interesting and why I believe it to be important, is because it is essential to shape our future cities into places which are better suited for human well-being, compared to what has been done the past 70-80 years. With climate change and "the green shift", politicians and citizens alike find it important to decrease car use and increase environmentally friendly travel alternatives, such as walking, to combat greenhouse emissions (Regjeringen, 2021). To encourage walking through other actions than penalizing ones such as high costs of car ownership and restrictive car accessibility, creating lively streetscapes are important. A myriad of studies confirms the hypothesis that the built environment is an important factor when one is considering walking as a means of travel (Dörrzapf et al., 2019; Silvennoinen et al., 2022; Rodriguez-Valencia et al., 2022).

As a part of the streetscape, architecture too plays a role. Height of buildings, quality of façade and transparentness are design factors which impact walkability, which in turn have consequence for how we perceive an urban environment and how willing we are to walk (Capolongo, 2014). Architecture varies strongly throughout the world, with skyscrapers and modernism being more widespread outside Europe. One study from Singapore, found that quality of façade and building height were important factors in walkability, and that one area with lower buildings was more popular with participants for walking than another area with taller buildings (Silvennoinen et al., 2022). Similar claims were made by Mouratidis and Hassan (2020), who found that traditional architecture (which is short compared to modernism) received significantly higher praise than modern architecture. Using data extracted and analysed from experiments which may uncover human reactions to different urban streetscapes, which should be used as learning for future building. The problem of life in the city and all the factors that play a part in its success, is inherently a democratic problem. If urban morphology and architecture should play a part in its success, then I believe we should shape our cities in a way that reflects findings in this thesis.

Data gathered in this thesis is strongly connected to walkability, as overall quality of the streetscape and conditions for walking affects well-being and stress. This thesis delves deeper into walkability and tries to identify areas which reduce the overall quality of walkability. The aspects of aesthetics and safety regarding walkability are especially emphasised in this thesis.

2. Summary of theory on central topics

2.1 General

The term aesthetics covers a wide area in our society. It stems from the Greek word *aisthanesthai* and means the branch of philosophy that deals with the subject of beauty and taste (Cold et al., 1998). Aesthetics is a word often used in connection to architecture and can be applied to the quality of streetscapes as well. Quality of aesthetics affects human psyche: perceived beauty strengthens feelings of well-being, while ugliness can diminish it (Guha & Channon, 2020). Measuring effects of environment on affect is tricky, but there are studies discerning human reactions to certain physical environments (Chen et al., 2019; Palmberg et al., 2021; LaJeunsesse et al., 2022; Birenboim et al., 2019). The physical environment is always existing, and one cannot simply ignore its presence. Because the fact that emotional responses are triggered from how we perceive the built environment and that we act and live in such environments every day of our lives (Mouratidis & Hassan, 2020), then it is highly important to know the effects of visual stimuli from the built environment on people's psyche to create successful urban developments.

However, of the few studies attempting to understand the built environment's effect on people, fewer have used biosensors. Biosensors provide objective data because measured numbers are "real" representations of unbiased physiological data. This thesis is strongly dependent on such unbiased data for assessing stress. Even though physiological data is unbiased as therefore good for analysis, it still needs to be addressed within a context. Therefore, this study is one of few studies to my knowledge that employs quantitative physiological data together with quantitative *and* qualitative subjective data for assessing stress.

This chapter presents summaries of theory relevant to the scope of the study. This includes general information about well-being of people in the context of urban environments, the effects of architecture on affect, what walkability is and why it is important, a brief look at affect itself, and finally a deeper look at biosensors.

2.2 On well-being

2.2.1 Defining well-being

Well-being is a frequently mentioned term within studies of urban planning, as one of the goals of urban planning is creating liveable cities in which citizens thrive. However, defining well-being has been debated due to its general meaning, its application to many study fields, and the numerous factors involved in measuring it. Krefis et al. (2018) states that "[well-being] has a multi-faceted nature, which can be defined as and measured in a variety of ways". Depending on the context, its meaning varies. In an everyday manner, one can likely understand it at face value alongside terms such as life satisfaction and general happiness.

However, when discussing well-being and its relation to urban environments and public health, it becomes more ambiguous and needs clarification. Szombathely et al. (2017) developed a conceptual model for approaching and defining the subject of health-related urban well-being. Here, four different "sectors" are identified:

- Individual
- Society
- Morphology
- Stressors

The *individual* sector is about factors that affect well-being on a subjective basis. Physical and mental health are essential for determining well-being. Additionally, socio-economic and demographic background plays a significant part.

The *society* sector overlaps somewhat with the individual sector. Variables related to geographical and social sciences are central. Security, or safety, is central, and affects other factors, such as physical and mental health and social interactions. Safety and sociality affect how the city's environment is used and the adaptive capacity of people.

The *morphology* sector unites infrastructural variables. Means of transportation and the ease of movement affect movement behaviour and environmental stressors.

The *stressor* sector encompasses stressors modified by the environment. This could be related to city design, like presence/absence of greenery, conditions for walking, or human-influenced stressors, like crowding or pollution.

Their interrelations and associated factors which may pose risks to health-related urban well-being are analysed, and the arena they impact, which include physical (objective), mental (subjective) and emotional (affective well-being) health, along with those that are not connected directly to human health, such as climate, political systems, social functioning, and social context in which people live (von Szombathely et al. 2017).

In this thesis, well-being will be mostly limited to individual health, particularly emotional affective state and understood as how Birgit Cold roughly defines it (1998): people's preferences for certain places generally, and which elements cause happy or pleasant feelings that make people avoid or seek certain places.

2.2.2 Influences on well-being

A problem with well-being and subjective well-being (SWB), is finding out exactly what influences it and the mechanisms behind understanding the factors that influence it (Mouratidis, 2019). The difference between well-being and SWB is that SWB denotes how interviewees see their well-being from self-reports, while well-being is more objective. As stated previously, urban form does impact well-being, but it is harder to determine exactly how. Some studies have indicated that quality of life, or happiness, decreases in large metropolitan areas compared to smaller metropolitan areas (Mouratidis, 2019), but which urban forms has been up for debate.

Table 1
Descriptive statistics of all variables.

Variables	N	Min/max	Mean	s.d.
SWB				
Life satisfaction	1340	0/10	7.88	(1.71)
Eudaimonia	1329	0/10	7.85	(1.70)
Happiness (hedonic)	1318	1/5	3.67	(0.84)
Anxiety (hedonic)	1324	1/5	2.02	(1.01)
SWB determinants				
Personal relationships satisfaction	1315	0/10	7.57	(1.91)
Leisure satisfaction	1309	0/10	7.15	(2.09)
Health	1338	0/10	7.72	(1.82)
Emotional response to neighborhood	1322	1/5	4.11	(0.75)
Neighborhood characteristics				
Compact (low-density suburban = 0, compact = 1)	1039	0/1	0.51	(0.50)
Distance to city center (km)	1344	0.7/46.2	10.22	(10.84)
Neighborhood density (persons/ha)	1341	14/306	112.93	(88.04)
Perceived safety	1330	1/5	4.22	(0.82)
Perceived noise	1341	1/5	2.46	(1.14)
Perceived cleanliness	1325	1/5	3.81	(0.91)
Sociodemographic variables				
Age	1344	19/94	50.16	(15.71)
Unemployed	1339	0/1	0.03	(0.16)
Living with partner/spouse	1329	0/1	0.61	(0.49)
Non-Norwegian	1342	0/1	0.09	(0.28)
Adjusted household income (1000s NOK)[a]	1259	35/4330	642.2	(321.08)
Respondent is female	1331	0/1	0.53	(0.50)
Respondent has college degree or higher	1341	0/1	0.79	(0.41)
Household with children	1334	0/1	0.32	(0.47)

Figure 1 Statistics in variables. Mouratidis, 2019

Mouratidis (2019) investigated the impacts of compact cities on SWB. Data was collected through self-reports (N=1330 roughly), and factors related to SWB were compared to neighbourhood characteristics and sociodemographic data, as can be seen on Figure 1. In general, there was an indication that compact urban forms showed people to have significantly higher relationship satisfaction and perceived better health when compared to those who lived in low-density neighbourhoods. However, emotional response to own neighbourhood was much more negative in dense neighbourhoods, but short distances to city centres had positive impacts, however outweighed by dense neighbourhood dissatisfaction. It should be noted that the average distance to the city centre from the respondents was 10 kilometers, which can be considered far, and might skew the results, meaning that there might be a negative bias towards living in dense neighbourhoods and few respondents lived in true dense areas.

Problems associated with compact urban forms, such as littering, crowding, noise and air pollution obviously negatively affect city life. Mouratidis (2019) found that when such problems are under control, then compactness becomes more attractive again. Personal relationship and health satisfaction were regarded as the two most important influences in determining SWB, and compact urban form had positive effects on the influences. It is likely that compact urban form shape travel mode of transport, as shorter distances to fulfil everyday needs make people prefer to walk or bicycle rather than taking the car, impacting self-reported health (Ewing et al, 2003; Stevenson et al., 2016, as cited by Mouratidis, 2019).

However, feelings of safety are also important for well-being, as part of the emotional health aspect. High density is often associated with higher levels of crime, or at least the fear of crime, influencing levels of stress (Mouratidis, 2019). Levels of anxiety were also higher in compact urban areas than low-density suburbs, which might be explained through higher levels of noise and little green space (Mouratidis, 2019).

2.2.3 Urban health and morphology

Urban health builds upon many factors like well-being. Figure 2 shows a detailed illustration of factors which may influence urban health. Morphology and urban planning are of particular interest to me, given its close relevance to my thesis. Krefis et al. (2018) review literature about urban health and well-being, and among other things, morphology. The studies reviewed deal primarily with urban blue- and greenspace, but also a little with the built environment.

Generally, as one could imagine, proximity to blue and green qualities improved urban health. For example, one study (Ward-Thompson et al. 2016) from Scotland showed a correlation between positive associations of access to green space and stress and general health. The amount of green space near four selected communities were objectively measured, along with the subjective ratings of green space use, social wellbeing, physical activity, and stress of the locals. White et al. (2013) found correlations between urban green space and mental distress, noting lower stress levels and better general health, like Ward-Thompson et al. McCracken et al. (2016) investigated associations between urban greenspace and health-related quality of life in children, and found that high levels of greenspace use significantly improved children's general health. Völker et al. (2013, 2015) found that rivers and bluespace enhanced health and urban wellbeing.

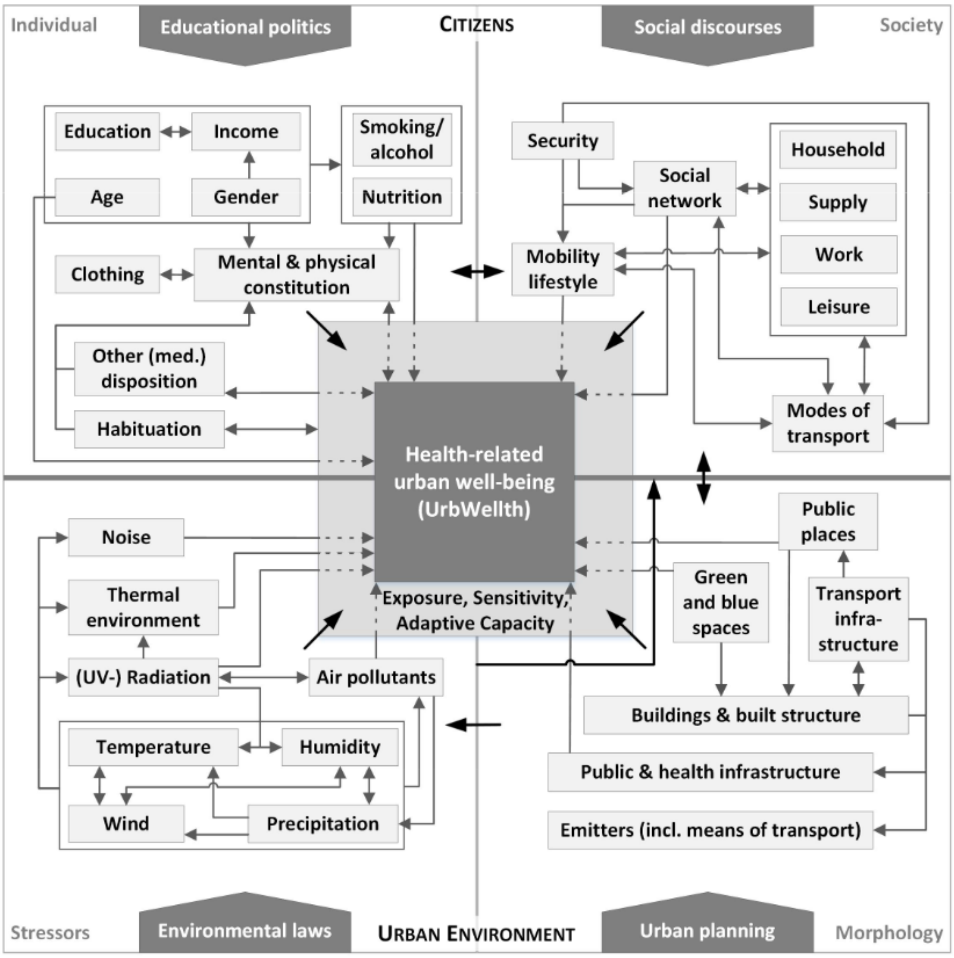

Figure 2 Conceptual model of health-related urban well-being (UrbWellth) Image source: Von Szombathely et al., 2017

Some studies reviewed dealt with the built environment. One such study (Brown et al., 2008) found that architecture which facilitates visual and social contact, improved senior citizens' physical functioning directly, and their psychological distress and social support indirectly. Garvin et al. (2012) found that vacant land (often associated with decay), attracted crime and reduced urban wellbeing through stigma and anxiety, among other negative effects.

2.3 On architecture

On the topic of behaviour and architecture, we know that it does impact well-being, however, studies on the preferences of ordinary people surrounding architecture are still lacking. Since the soft return of traditional elements in post-modernism in the 1980s, contemporary/international architecture is the dominant architectural style, overshadowing traditional (McNeill, 2009). Globalism and urbanism have for a period of close to one hundred years led to international architecture, applied throughout the world because of its ease of construction and low construction costs compared to more ornate and complex traditional architecture. Subsequently, it has become the leading style, but being heavily criticised for disrupting local building traditions, creating aesthetic disharmony, and driving cities to lose identity (Mouratidis & Hassan, 2020). Why design is important is that it is not purely a moot point. Aesthetics affect SWB, and pleasing environments contribute positively to it (Negami et al., 2019; Seresinhe et al., 2019, as cited by Mouratidis & Hassan, 2020). Being happy with one's environment is good for SWB, and knowledge about perceptions of architecture should therefore be regarded as great value for democratic urban planning.

Dynamic and complex facades create positive effects and leave good impressions on people, while monotonous and simple facades impact people negatively (Talen et al., 2022). People are also more likely to feel depressed in areas commonly regarded as depressing (likely grey and dull places) (Guha & Channon, 2020), and this should be taken into serious consideration when designing urban spaces. Modern architecture very often tends to be monotonous, with few objects standing out. Hass-Klau et al. studied the street as a "living space" and concluded that interesting features and having things to look at in the street was essential for social activity. Jacobs and Gehl et al. found that in streets that were regarded as attractive for pedestrians, head movement rates were strongly increased. This was apparent in places with detailed facades and strong entrances, compared to monotonous facades. It was concluded that frequent head turning was a good indicator for pleasing visual stimuli in urban environments (Gehl et al., 2004; Jacobs, 1994; Hass-Klau et al., 1999, as cited by Hillnhütter, 2016).

Mouraditis and Hassan (2020) conducted a study in Oslo in which virtual reality headsets were employed to show participants environments of very different qualities immersively, which were categorized as A (traditional architecture) and B (contemporary). 28 students from the Norwegian University of Life Sciences participated, with a mean age of 21,5 years. The students answered questionnaires about the participant's evaluation of the selected areas. Variables that were individually judged were among others architecture, interest, and the feelings of pleasantness, safety, and relaxation. Results from the study show how traditional architecture scores significantly higher in overall appreciation than contemporary architecture.

There can be several reasons for this. First, the characterizations of traditional architecture could indicate what we perceive as pretty and pleasant. Traditional architecture is often based on principles of symmetry, order, and richness of ornamentations, compared to the industrial look and lack of symmetry and ornamentation in contemporary architecture. Second, it is possible that traditional architecture complements and interacts more holistic with its environment, creating more lively streets, in contrast to contemporary architecture which might be perceived to do less so. It should be noted that the participants are quite few and have a similar cultural background, so biases can be present. Despite this, it should be given considerations in urban planning and architecture to design places more in harmony with people's preferences, as architecture does impact psychological well-being and walkability (Mouratidis & Hassan).

There is substantial evidence that certain types of housing and characteristics of it induce negative effects on well-being compared to others. For example, high residential density is found to disrupt development of supportive relationships within the household, increasing risks of psychological distress (Evans, 2003). On the contrary, cluster housing has been found to increase mean values for social interaction and perceived safety (Krefis et al., 2018).

From the perspective on the outside, high-rise buildings have been subject of criticism for overloading existing nearby social infrastructure, congesting local traffic, and destroying neighbourhood characteristics and aesthetics (Broyer, 2002). One study found that high-rise buildings, especially when combined with narrow streets, stimulated negative reactions from a pedestrian point of view (Chen et al., 2018). This was self-reported as well, indicating that high-rises are actively being negatively perceived by many members of the general populace.

2.4 On walkability

2.4.1 Defining walkability

Figure 3 Example of nine categories and interrelation in determining walkability. Zuniga-Teran et al., 2017

Walkability, like other terms used in this paper (and on this general topic as well), needs to be defined because of its ambivalent meaning. Lo (2009) emphasized that the meaning of walkability depends on who is asking because of the wide range of actors in the discourse of the subject. Walkability has been described as essentially how convenient travelling by foot is and is determined by physical factors such as distances to amenities and quality of infrastructure for pedestrians (Dovey and Pafka, 2020).

The most common factors in measuring walkability are as follows, and can be seen on Figure 3 (Lo, 2009):

- Presence of continuous and well-maintained sidewalks
- Universal access characteristics
- Path directness/street connectivity
- Safety of at-grade crossing treatments
- Absence of heavy and high-speed traffic
- Land-use density
- Building and land use diversity
- Landscaping
- Visually interesting scenery/buildings
- Safety/perceived safety

High or positive evaluations of these factors indicates a city with high walkability, an inherently good thing.

2.4.2 Walkability and its importance

The concept of walkability has become ever more popular over the past decades, with it being lauded as a more environmentally and socially sustainable, and healthier mode of transport than driving (Silvennoinen et al., 2022). High levels of walking have been viewed as positive outcomes on population health (Stevenson et al., 2016), and of course how climate emissions are lowered as a result of people preferring walking or environmentally friendly alternatives over cars. (Ewing and Cervero, 2010; Newman et al., 2009, as cited by Arellana et al., 2020).

Many governments around the world have shifted their focus from achieving increased efficiency and safety for motorized, private vehicular travel, to improving public transport and walkability. The Norwegian government advocate for their version of the 15-minute city, called the *ten-minute city*, or *the proximity city* (Regjeringen, 2016). The 15-minute city is an urban planning concept stemming from the New Urbanism movement of the 1980s, in which citizens can reach most everyday services within 15 minutes by walking or cycling from one's home. Such design is favourable for many reasons, but especially for the climate and health reasons, such as the green shift mentioned in chapter 1.4. However, good walkability is required to make the proximity city a fruitful future urban planning principle, as willingness to walk and walkability is determined by factors seen in figure 3.

Emphasis on developing cities on the car's terms have resulted in increased sprawl, noise and greenhouse gas emissions and worse public health (Ewing et al., 2016). Silvennoinen et al. (2022) recognizes four needs that are decisive for walking: convenience, safety, comfort, and attractiveness. The safety aspect can be connected to feelings of stress, because feeling unsafe makes one stressful. Popular ways to lower levels of stress in traffic, is widening sidewalks and lowering driving speed limits (Zuniga-Teran et al., 2017).

It should also be noted that factors involved in walkability go beyond the built environment. Walkability is a multi-dimensional concept, and outside aforementioned factors, topography, climate, and crime play roles as well in determining walkability (Dovey & Pafka, 2020).

However, such factors are hard or even impossible to improve upon and will be left out of the discussion, except for crime.

Jane Jacobs defined three important factors in creating lively and walkable cities: the need for concentration (density), mixed primary uses, and small blocks (Jacobs, 1961). Such thinking has since become very popular within urban design, who believe exactly that such design lead to safer and more walkable streets (Dovey & Pafka, 2020).

2.4.3 The built environment's effect on walkability

Hillnhütter (2016) writes about pedestrians' walking habits in different walking environments. It is uncovered that pedestrians most often seek out environments that are rich in sensory experience, and the positive emotions that come with such experiences affect observable walking habits (Borson Fich et al., 2011, as cited by Hillnhütter, 2016).

Walking speed is one such observable habit. In high sensory activity zones, such as shopping streets with active facades, people tend to move slower. Normal walking speed is about 90 meters per minute, but pedestrians slow down to 60 metres per minute, or perhaps briefly halting, before continuing (Whyte, 1988, as cited by Hillnhütter, 2016). However, such speeds are contextualized, and depends on destination. For example, work commute walking speeds were not impacted by environment, as getting to work in time is more important. Boring surroundings, meaning where facades are considered boring, make people move faster. Several researchers found that walking speeds in big American cities were significantly higher than in smaller towns, possibly indicating that people walk faster in stressful environments (Levine et al., 2007; Whyte, 1988, as cited by Hillnhütter).

The environment's effect on *perception of time* is also examined. In short, walks in environments with high cognitive loads, such as places with interesting facades, will in real time seem short compared to boring environments, but remembered duration of the walk will make it seem longer (Bosselmann, 1998, as cited by Hillnhütter, 2016). This is an obvious contradiction but is explained through a logic: when walking in high cognitive load areas, there are things to look at which keeps you preoccupied with assessing the environment rather than time passed, but in retrospect, you remember the walk as longer because the elements in the environment made impressions which you remember better than if you walked in a low cognitive environment. If the impressions are pleasant then time pass quickly. Stimulations can also be overwhelming, resulting in stress, making time pass slower (Hillnhütter, 2016).

As described in 1.4, *Architecture and building typology* also play a quite significant part in encouraging/discouraging walking. One study which employed virtual reality headsets to experience a streetscape, displayed three different urban environments in Singapore (Silvennoinen et al., 2022). They had all different design qualities, such as height, façade, façade length, colour, and liveliness, important urban design qualities as listed by architect Jan Gehl. There were 48 participants, significantly more than in other similar studies which use biometric sensors to measure affect. The study has three hypothesises: that higher façade quality, higher liveliness and lower buildings together increase the measured walking activities (H1); that each of these features individually increases walking activities (walkability) (H2); with liveliness having the largest positive effect (H3) (Silvennoinen et al., 2022). While H1 was confirmed, H3 was contradicted, and it was determined that the quality of façade was the most important factor in increasing walkability. Regarding building height, it was discovered that environments with lower buildings scored higher, but that the effect size was small to medium, and was deemed inconclusive to be influential on walkability. It can be argued that the significance of building height varies around the world, and that Singaporeans in a country with primarily very tall housing react differently to building height than a Norwegian would.

2.5 On stress and affect

Knowing your own body and how you feel can be difficult. Psychological stress which rises from certain types of stimuli, leads to changes in a person's psychological and physiological equilibrium, and inhibits or changes one's decision making and task performance (Marois et al., 2018, as cited by Rodriguez-Valencia et al., 2022). Psychologists, clinicians, and researchers have noted for some time that people have trouble identifying, assessing, and describing their own emotions (Saarni, 1999). This can suggest that many people do not experience emotions as individually felt entities, but rather as a complex set of sensations that cannot be dissected easily, like with a spectrum (Russel & Fehr, 1994). This is one thing that makes this kind of research prone to faults, because the data retrieved can be interpreted differently from one participant to another, as people can wrongly report their own stress levels because they understand the questions and their body differently.

2.5.1 Affect

Affect, or emotions, are a set of variables that might moderate behaviour (Balters and Steinert, 2015). In psychology, there are primarily two different schools of thought on describing affect. One discerns affect as discrete categories at two levels (medium and high intensity) and categories include interest-excitement, enjoyment-joy, anger-rage, and contempt-disgust. The second considers affect to be a combination of multiple dimensions (Wulvik et al. 2020).

On the topic of travel behaviour and well-being, psychological strain influences the choices we take in method of transport, routes, etc., in addition to generally having a negative effect on emotional well-being (Rodriguez-Valencia et al., 2022). Certain studies have found that anxiety and stress levels are higher in cities, which cite noise and crowds as the cause (Mouratidis, 2019). Another major reason for stress is traffic congestion, which cause a domino effect of negative effects, such as noise and air pollution, microplastics, and fear of street crossings. City morphology, if sprawling and based on car principles, therefore could continue creating stressful situations for pedestrians. The stress from such situations causes "learned helplessness", which makes pedestrians avoid certain places or activities (Rodriguez-Valencia et al., 2022). Therefore, to create sustainable cities, improving built environment is a must. By improving built environment, especially in ways that facilitate walking and bicycling and making it safer, encouraging commuters to use sustainable transport mode becomes easier, in addition to decreasing pedestrian stress levels (Rodriguez-Valencia et al., 2022). Rodriguez-Valencia et al. (2022) emphasizes the importance of identifying characteristics of different street segments, or the built environment, to see how they influence stress levels, and subsequently basing policy for design of sidewalks that are good for pedestrians.

2.5.2 Measuring affect

Measuring affect can be done in several ways, depending on what type of affect one is looking for. Truly knowing someone's emotions cannot be directly measured by one test alone, rather one can triangulate results from different measurements.

Evaluations of subjective affect is usually done through self-report surveys (Dybvik et al., 2018). However, assessing personal feelings can be tough, as described previously. To help guide an affective evaluation survey participant, one can provide “guidelines” which makes defining own emotions easier. One such example can be shown on Figure 4, the circumplex model of affect. The circumplex model of affect proposes the fact that all affective states arise from two neurophysiological systems: one related to *valence*, which is the subjective evaluation of affect on a positive-negative spectrum, and the other is related to *arousal*, which is the alertness of the body and mind (Russell, 1980, as cited by Posner et al., 2005). Determining affective state from these the two axes shown on Figure 4 is used within subjective self-report surveys, as measuring valence with biosensors or “technical” tests is difficult, and one cannot determine valence from activation because high/low arousal can encompass both good and bad subjective well-being. Measuring objective arousal through biosensors will be discussed more in detail in the next subchapter.

The circumplex model of affect will be used as the basis for evaluating subjective affect during the post-walk interviews.

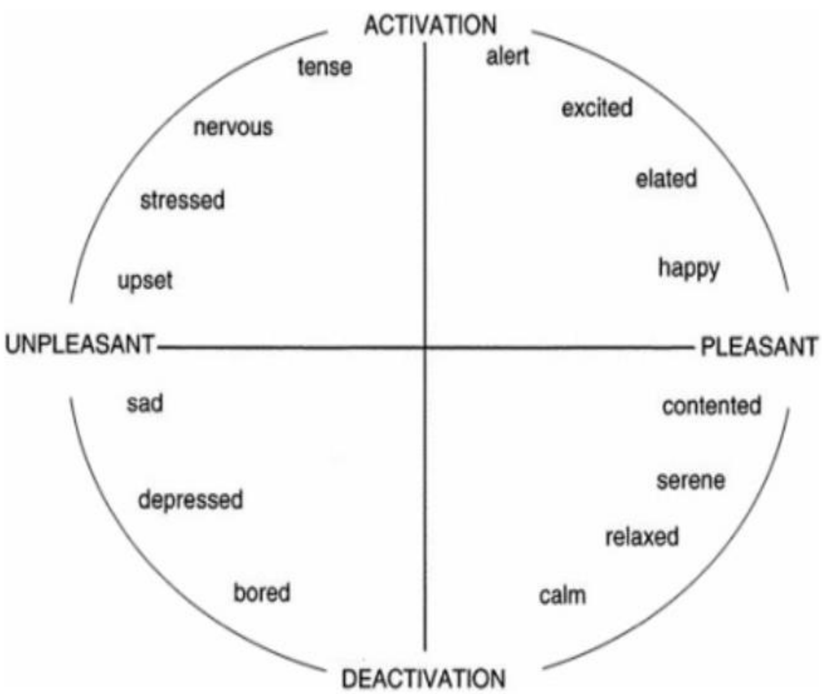

Figure 4 The circumplex model of affection. Source: Posner et al. 2005

2.6 On biosensory research

The use of sensors to record biosensory data for use in research is still somewhat in its early stages. There have been a few articles which have utilized conventional, store-bought wristbands to measure stress, or at least factors associated with stress, such as heart rate, heart rate variations and electrodermal activity (Birenboim et al. 2019; Chen et al. 2018; Palmberg et al. 2021). However, a common characteristic for these studies is that they are emphasizing that the research is prone to faults due to low number of participants and calling the projects pilot projects. Most of the studies up until now which have studied stress from physiological data, have used certain types of digital watches such as the MS band or E4 Empathica. These devices have mostly rendered somewhat shallow results, because of limited sensitivity. Additionally, there are certain issues with utilizing solely biosensors when measuring stress in the built environment. In the same way stress can be understood in a broad sense, it is also multifaceted in what causes it. Therefore, it is sometimes difficult to ascertain what elements cause a rise in stress levels, because of busy nature of the city and the sheer number of possible factors (Birenboim et al., 2019).

2.6.1 Indicators of mental state

Directly assessing "stress" with biosensors is not possible. There is lack of a comprehensive framework for assessing stress that is universally used (Kim et al., 2018), which means one can try different methods. One method adopts sensors to measure individual indicators, which are then triangulated with different data measures and interpreted as stress (Chen et al. 2018). In most studies that concern measuring physiological and psychological reactions to the built environment, the stress indicators are the combination of *photoplethysmography* (PPG) related data, that is cardiac-related functions, such as heart rate and heart rate variation, together with *electrodermal activity* (EDA), sometimes known as galvanic skin response (GSR), which is a measure reflecting *sympathetic nervous system* (SNS) responses that are driven by cognitive and emotional arousal. Other possible indicators are breathing rate, oxygen saturation, muscle tension, blood pressure and body temperature (Dybvik et al., 2018).

One of the most important aspects of measured data is revealing the positive and negative emotional arousal experienced by the environment. Because of the objective nature of physiological data, sensors can uncover information humans might not recollect themselves.

For example, in environments one is familiar, physiological reactions connected to distress is masked because the negative feelings once experienced are now subconsciously supressed (LaJeunesse et al. 2021). Crossing a busy road increases EDA levels which is measurable, but a person who frequents such a road might not know they are distressed. Additionally, the objective data collected from biosensors have an advantage over subjective measuring, which is that biosensors can collect data without interruption, such as when surveys are conducted during an experiment (Dybvik et al., 2018). Surveys can be done post-walk, but participants might find it difficult to recall feelings depending on how impactful they were and how much time has passed.

Stress is a complex bodily reaction involving multiple physiological and psychological factors. Therefore, it is common to interpret HRV data in concurrence with other subjective measures, contextual information, and individual assessments to gain a more holistic understanding of stress levels in different environments. Below, the main stress indicators will be shed light on.

2.6.2 Heart rate variability

Heart rate variability (HRV) is a measure of the variation of time between each heartbeat and is often used as an indicator for different aspects of psychology and physiology (Appelhans & Luecken, 2006). Figure 5 illustrates the variance in time.

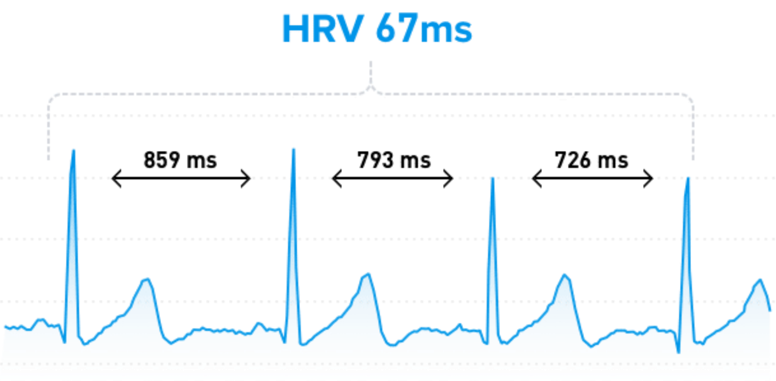

Figure 5 Heart rate variability. Normally, a healthy person has high variaty in time in-between heart beats. Source: Hyperice (2021/2022)

HRV has been proven to be an indicator of impact on SNS and the *parasympathetic nervous system* (PSNS), which is the opposite of SNS and regulates the body after feeling stressed or in danger, and tries to decrease heart rate (Birenboim et al., 2019). HRV therefore influences the balance between SNS and PSNS. For instance, high HRV indicates a healthy state of mind where a person generally possesses better decision making, regulation of emotions and attention, while low HRV mirrors the opposite (Thayer & Lane, 2009). High HRV therefore indicates that the body is better prepared to deal with situations that are stressful, and act accordingly. This is often reflected in how fast the heart rate will increase or decrease after a stressful situation.

HRV's reliability has been tested by meta-analysis studies. Kim et al. (2018) concluded that there is substantial evidence that back up HRV's reliability when used as an objective assessment criterion of both mental and physical health. Most articles reviewed by Kim et al. found that HRV variables changed with induced stress factors.

From a physiological perspective, HRV also has clinical significance. Deviant HRV, that is HRV which is significantly lower/higher than the population average, has shown to be a possible indicator of risks and symptoms of a range of health problems, especially surrounding cardiac functions (Escorihuela et al., 2020). This is especially the case with low HRV. Such health problems are congestive heart failure, diabetic neuropathy, and post-cardiac-transplant depression, among others (Escorihuela et al., 2020). There has also been a discussion whether HRV can be used to assess mental illness. Many studies have found connections between HRV and mental health, but mental health is notoriously difficult to diagnose, as the cause of it can stem from numerous factors which may be overlooked (Kim et al., 2018). Kim et al. (2018) argues that in order to look at HRV's impact on mental health, medical history and physiological data should be considered parallelly to give a more nuanced assessment. In any case, the article authors believe HRV should be used as a tool for evaluating general autonomic health, rather than specific diagnoses.

2.6.3 Heart rate

Heart rate (HR) and HRV are two common indicators of physical and mental state. HR is simply the number of heart beats per minute, as is used in many medical state assessments. In mental state assessment, a high number of heart beats per minute is associated with high physical or mental load, such as when one is experiencing feelings of fear, excitement, anger etc., or physical activities like running. A high HR is also associated with stress (Taelman et al. 2009, as cited by Birenboim et al. 2019). A low HR is associated with relaxation, contentment, serenity and similar feelings. Despite HR being an indicator of stress, it is rarely used as a scientific measure in determining stress. HR can be considered crude data in that sense: it tells the state of your body in a very inconsistent way. For example, a high HR is most often simply because of physical activity, and not necessarily because of mental anguish (EliteHRV, 2021).

2.6.4 The parasympathetic and sympathetic nervous system

The *parasympathetic* (PSNS) and *sympathetic nervous systems* (SNS) are two divisions of the autonomic nervous system (ANS) responsible for regulating various bodily functions, maintaining homeostasis, and orchestrating physiological responses to different situations (Deuchars et al., 2018). PSNS is often referred to as the "rest and digest" or "feed and breed" system. It is active during periods of relaxation, rest, and recovery. PSNS slows down heart rate, constricts pupils, stimulates digestion, and promotes relaxation. It helps conserve energy, promotes digestion and nutrient absorption, and supports overall recovery and healing processes in the body (Tindle and Tadi, 2022).

On the other hand, SNS is known as the "fight or flight" system. It prepares the body for action, especially during stressful or threatening situations. The sympathetic system accelerates heart rate, dilates pupils, increases blood pressure, redirects blood flow to essential organs and muscles, and triggers the release of stress hormones like adrenaline. It provides the body with the necessary resources and energy to respond to challenges, danger, or stressors (Birenboim et al., 2019).

When analysing HRV data, one looks at variables of HRV such as those below, in order to look for the prevalence of PSNS or SNS. Variables indicating a higher dominance of SNS activity over PSNS in one area is the basis for assessing stress there, though it must be contextualised.

2.6.5 Low frequency power, High frequency power and Low Frequency/High Frequency ratios

Low frequency (LF) power (ms^2) and *high frequency* (HF) power (ms^2) are variables used in frequency-domain heart rate variability (HRV) analysis to assess ANS activity and balance (Pham et al., 2021). LF power represents the power within the low-frequency range (0.04 to 0.15 Hz) of the HRV spectrum. It mirrors the merged influence of both sympathetic and parasympathetic branches of the ANS. LF power is associated with sympathetic activity, although it also includes some parasympathetic influence. Higher LF power values indicate increased sympathetic modulation or sympathetic dominance in the autonomic control of heart rate (von Rosenberg et al., 2017).

HF power, on the other hand, represents the power within the high-frequency range (0.15 to 0.4 Hz) of the HRV spectrum. It primarily reflects parasympathetic (vagal) activity and is considered a marker of respiratory sinus arrhythmia. *Vagal activity* is the baseline activity of the vagus nerve, which is a key component of PSNS (Grote et al., 2019). HF power is associated with respiratory and baroreflex mechanisms, indicating parasympathetic dominance or vagal modulation. Higher HF power values indicate increased parasympathetic influence on heart rate variability (von Rosenberg et al., 2017).

The LF/HF ratio is the ratio of LF power to HF power. It provides a relative measure of sympathetic and parasympathetic activity. A higher LF/HF ratio suggests a predominance of sympathetic activity or sympathovagal imbalance, whereas a lower LF/HF ratio indicates a shift towards parasympathetic dominance. However, it is important to note that the LF/HF ratio does not provide an absolute measure of sympathetic or parasympathetic activity but rather indicates their relative contributions. Despite its common use as an indicator of stress, it has been the source of scrutiny among academics (von Rosenberg et al., 2017).

2.6.6 RMSSD and SDNN

RMSSD (Root mean square of successive differences) and SDNN (standard deviation of NN intervals) are two important parameters used in heart rate variability (HRV) analysis. RMSSD quantifies the variability between adjacent RR intervals, representing beat-to-beat differences in heart rate. It reflects parasympathetic (vagal) modulation and is particularly sensitive to short-term changes in HRV. Higher RMSSD values indicate greater beat-to-beat variability and increased parasympathetic influence, suggesting a healthier autonomic nervous system functioning (Pham et al., 2021).

SDNN measures the overall variability of the heart rate by calculating the standard deviation of the NN intervals. It reflects the combined influences of both sympathetic and parasympathetic branches of the autonomic nervous system. Higher SDNN values indicate greater overall HRV, representing a more flexible autonomic regulation and a healthier cardiac system (Pham et al., 2021).

2.6.7 Problems of using biosensors for assessing stress

While using biosensors is an objective and interesting way of assessing mental state, its reliability has been questioned. A problem with researching stress with biosensory readers in an uncontrolled environment (or research in general) is that the experiments are subject to external influences such as noise, traffic, pollution, and unwanted occurrences, which are naturally occurring in an outside environment (Birenboim et al., 2019). Another problem is that data quality is reduced when HRV data is collected when one is active, because movement increases errors in measurements from the sensor's side. This is one of the reasons why many studies which have measured physiological data have been restricted to sedentary activities, such as when driving a car (Birenboim et al., 2019). Additionally, as mentioned previously, physical and social contexts matter. Having additional information about participants like their health, or knowing the setting in which data was measured, is important for correctly interpreting data (Bakker, Pechenizkiy, and Sidorova 2011; Osborne and Jones 2017, as cited by Birenboim et al., 2019). For example, HRV data indicating high arousal, can be both the results of something good or bad, and one cannot say that high arousal is automatically a bad thing. This is an example of perhaps the biggest challenge of HRV, which is its ambiguity in interpretation. Ambiguity in interpretation can also be made more difficult because of individual variability in HRV, since all people differ in baseline HRV. There is simply no clear answer as to which numbers are standard, but instead being within a broad range of an HRV index is considered "normal" (Seow, 2022).

2.6.8 Overview of some studies which have utilized biosensors to measure mental state

One study from Utrecht, Netherlands (Birenboim et al. 2019), utilized two different wristbands which are capable of streaming biosensory data to a phone or computer. A walk through a predetermined route in Utrecht centre, which included areas of different architecture, greenspace, traffic intensity, among other things. The cheap wristband's readings on some statistics such as EDA showed barely any difference, and consequently its data was omitted from the report. The other wristband showed increased activity during the walk, but it was argued that it was likely an increase in temperature that caused this, except for the traffic-heavy areas which caused a spike in EDA levels, presumably because of increased feelings of stress. For recorded heart rate and heart rate variations, both wristbands showed little to no difference during the walk, even when crossing the traffic-heavy areas. Despite this, the authors argued that they gave insight to changes in mental state during the stressful crossings. Holistically, the authors still believed the wristbands to be useful when enriched by contextualization, geospatial data, and subjective assessment.

Another study which utilized biosensory readers was one from China, which measured perceived positive and negative reactions in four participants from an on-site walk, coupled with phenomenological interviews directly afterwards, to shed light on the participants' own reflections on the walk (Chen et al., 2018). During the interview, participants were asked to label the different areas in which they walked with what emotion they felt at that place. The walk was repeated three times consecutively, in order to strengthen the recollection ability of the participants. The experiment's goal was to find out which environment the participants found the worst and best, so that areas which scored poorly can be used to exemplify how urban designers can improve blighted areas. Not surprisingly, the areas with the most traffic and parked cars scored the lowest, in addition to tall buildings, which seems like typical findings from these types of studies (Silvennoineen et al., 2022).

However, the findings from this study need to be taken with a pinch of salt, as the scope of the study is very limited, and as such is prone to bias. The article itself says that it is partly about testing the methodology of using biometric readers and concludes similarly to the study from Utrecht that using sensors as such is a promising method to measure emotional responses towards environmental stimulators (Chen et al., 2018).

A third study conducted in Stockholm, Sweden, used biosensors as well (Palmberg et al., 2021). In this study, five participants were given a smartwatch which measured heart rate with GPS tracker to pinpoint where heart rates deviated from the baseline over a period of three months.

Initially, all the participants were given the same smartwatch with identical firmware, however, results varied quite a bit because of faults during information gathering, as some participants forgot about data collection and others had updated the smartwatch's firmware which disrupted data collection. In the end, only one participant's data was used, but the authors deemed it suitable for use, but admitted that for future studies, more participants were needed. This is quite like studies mentioned earlier, which also had very limited data from few participants to analyse. The heart rate readings coupled with GPS location, gave insight into which places had fluctuating heart rates, and where it was more or less the same. This was considered interesting especially in the context of urban planning, because the heart rates give insight into well-being in different areas, which can be interesting for planners and urban designers to create better areas (Palmberg et al., 2021).

A study conducted in Chapel Hill, North Carolina employed an Empatica E4 wristwatch which recorded data related to cardiovascular functions and an electrodermal activity (EDA) sensor to track pedestrian stress levels in different urban environments (LaJeunesse, 2021). The watch was the same one used in the Birenboim study from 2019. Additionally, as with all the other studies, recorded data was attached to geographical coordinates from a GPS tracker, which allowed for analysis of the most and least stressful places. The methodology and findings were similar to those of the previously mentioned articles. Walks were taken along roads in different environments ranging from pedestrian dominated ones to major traffic arteries. Unsurprisingly, stress levels were found to be low in redsidential areas and high alongside major roads and mixed-used areas. A major assumption of why the participants were most stressed near major roads is because background noise from cars is associated with psychological stress and reduces pedestrians' cognitive resources (LaJeunesse, 2021). Additionally, the study found that participants were calmer in natural environments, which the study by Chen et al. (2019) also found.

One can see that in the articles discussed, they concluded with that while the sample sizes were small, biosensors provided interesting information which could be used in creating framework for future urban design and planning, but that future studies should have more participants. They all agreed that biosensors had big potential in the future for research, as they believed its convenient and passive data collection was a unique selling point for sensors. One big problem of biosensors in research is identifying stress factors. Stress is multifaceted and can arise from very many sources and in different ways for people. Therefore, one needs to be careful to draw comparisons between measured stress and the source for it. However, given a context, like in my case, source of stress is easier to identify.

3. Methodology

3.1 Experiment design

The point of the study was to view the effects on stress and affective state in different city environments, so one can try to identify the elements that cause the possible changes in mental stress. To do so, I have chosen a route in Trondheim that encompasses a variety of environmental characteristics. These include contemporary architecture, a modern park, older industrial areas, short segments of car-dominated areas, and pedestrian-friendly neighbourhoods with mostly traditional architecture. The unalike morphologies sprung out at different times in history, making a relatively small area very diverse in design.

Researching stress using such an area with such extreme characteristic differences is done very much so on purpose, because of troubles around identifying stress factors and the possibility that the sensors might not show much, if any, differences in mental nor physiological state if areas used in the research are too generic or similar. Conditions for walking and diverse architecture between the areas make it easier to isolate possible stress factors, and which elements participants react to, either subconsciously or actively. The areas and their physical characteristics will be discussed further below.

3.2 Data collection

The data collection method used in this thesis is characterised by using both quantitative and qualitative methods. Assessing stress is usually done by self-reports/questionnaires, while in other studies, objective physiological data is used instead. I strive to make results nuanced and accurate, and therefore both quantitative and qualitative methods have been employed to triangulate and assess stress from sensor data and post-walk interviews.

3.2.1 Physiological data from sensors

Data collected from sensors measuring physiological data were used to assess stress objectively. Originally, EDA was to be used together with HRV to assess objective stress, but this was later abandoned because of two reasons. Firstly, the EmotiBit, a sensor which captures physiological, emotional and movement data that I was going to use, never arrived as was subsequently replaced by the Polar H10. The EmotiBit could measure EDA, while the new sensor could not. Secondly, Professor Martin Steinert and Pasi Aalto of NTNU Wood argued against EDA because of its unreliability as a source of stress indication. Thirdly, with my experiment taking place in an uncontrolled environment, EDA would be very prone to errors, such as humidity level, temperature, natural sweat intensity, and physical load. Rather, HRV is considered a reliable stress indicator, and is the only physiological data used in the analysis. Figure 6 shows HRV variables. A LF/HF ratio definition is missing but is used prominently in analysis.

	Variable	Description
Heart rate variability	Mean RR (ms)	Average RR interval
	SDNN (ms)	Standard deviation of RR interval
	Mean HR (bpm)	Average heart rate
	SD HR (bpm)	Standard deviation of heart rate
	RMSSD (ms)	Root mean square of successive differences. Measure of short-term variability
	NN50 (n.u.)	Number of successive intervals that differ more than 50 ms
	pNN50 (%)	Relative number of successive intervals that differ more than 50 ms
	LFpeak, HFpeak (Hz)	Peak frequencies for LF and HF bands
	LFpow, HFpow (ms^2)	Absolute power in LF and HF bands
	LFpow, HFpow (n.u.)	Powers of LF and HF bands in normalized units $LF[n.u.] = \frac{LF[ms^2]}{LF[ms^2]+HF[ms^2]}$ $HF[n.u.] = \frac{HF[ms^2]}{LF[ms^2]+HF[ms^2]}$

Figure 6 Physiology variables, Wulvik et al., 2020

3.2.2 Subjective self-assessment interview

A post-walk questionnaire was prepared for obtaining data about participants' own evaluations of affect during the walk, the built environment, the importance of architecture and walkability. The questionnaire was written in English, and subsequently asked in English as well. Any confusion regarding the meaning of the questions were instantly cleared up. The experiment design was approved by NSD without any objections. Data collection was confidential, and none of the participants' names were revealed to anyone.

Of 13 questions, ten were closed, of which five were designed after the theories of affective quality by Russel and Pratt (1980), meaning that emotions evaluated were bipolar. Examples include pleasant/unpleasant, exciting/boring, and relaxed/stressed. These emotions were presented on a scale, in which (1) was “very”, (2) “a little”, (3) “neutral”, (4) “a little”, and (5) “very”. (1) would be the most positive, like “very pleasant” and (5) the most negative “very unpleasant”. The numerical value of these alternatives meant that they are inverted compared to the Likert scale, and the values were subsequently flipped during analysis, so that (5) would be the most positive alternative. Affective appraisal questions were asked first as to reduce possible bias from the questions assessing quality of the built environment, inspired by Mouratidis and Hassan (2020).

The next five questions were about participants’ evaluations of the built environment and their own feelings towards its importance. One question would for example be “accessibility/ease of movement affects my willingness to walk”. All questions used a Likert scale rating, meaning the participants were to answer how much they agreed with an assertion, with the scale ranging from strongly disagree (1) to strongly agree (5).

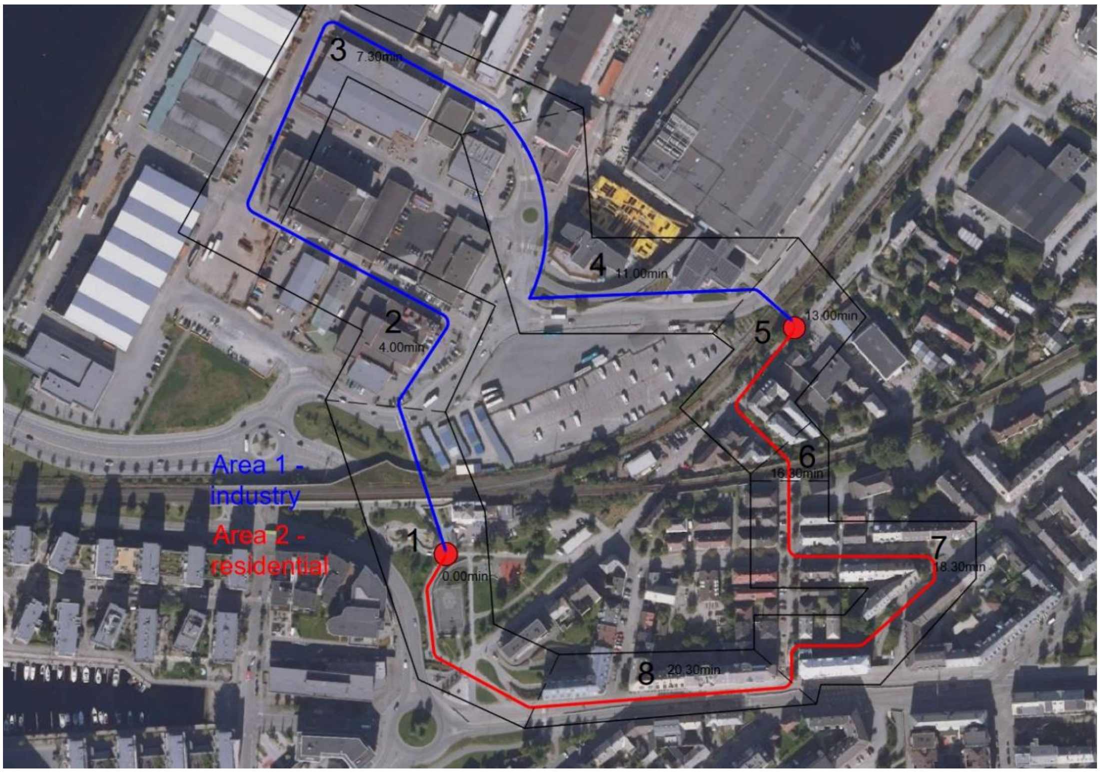

Figure 7 The walk dividied into area one and two, and split into eight distinct segments

Description

1. Modern Park around sporting grounds with train station nearby.
2. Somewhat intimate industrial area with a couple of new building.
3. Heavy industry area. Partly characterised by large WW2 bunker
4. Industry area with a few new office buildings and a busy road.
5. Baseline pause, few cars and old, wooden buildings in unique “anarchist” neighbourhood.
6. Narrow and heavily graffitied underpass.
7. Normal, if a tad run-down residential area mostly dating from around 1900.
8. Somewhat busy road with open city feel, lined with new and old buildings.

The last three questions were open-ended so the participants could elaborate on personal reflections on the environment and affect. These were:

- "Tell me about the walk: was there anything that you experienced as positive/negative? If so, what?"
- "Were there elements in the built environment on the walk that you thought were nice or not nice? Why?"
- "Were there any areas you felt more stressed than others?"

The route of the walk and its characteristics are shown in Figure 7.

3.3 Data analysis

Kubios Premium 3.5 (Kubios, 2022) was used for pre-processing of data. Kubios Premium is the discontinued branch of Kubios software (the main program is now Kubios Scientific) used for mostly scientific research of HRV and its analysis. It is a device-independent software, supporting many HR monitors, ECG devices and PPG monitors (Kubios, 2023). IBM SPSS statistics (SPSS, 2022) were used as a means for prosessing of data.

3.4 Data collection equipment

A commercial off-the-shelf piece of equipment called Polar H10 (Figure 8) was used for collecting physiological data instead of the EmotiBit. The H10 polar was chosen because of its ease of use, affordability and its reputable measurement precision. Its easy implementation, comfort and lack of invasiveness made it a good choice for outside use as well. It is popularly used as a way for athletes to track health and progress. Additionally, it is open source, which makes it possible to extract data needed for analysis, unlike many other commercial heart rate monitors. It is connected via Bluetooth to a phone for syncing data continuously, or internal memory storage if a phone is not available. The sampling rate of the Polar H10 is 130 Hz. See Table 1.

Figure 8 Polar H10. Source Polar (n.d)

A Polar Ignite wristwatch was used for GPS location tracking (Figure 9). The Polar H10 does support GPS tracking, but only with sessions from inside the Polar Beat/Flow application. Because the H10 could only be connected to and record from one application at a time, and I used a different one than the Polar ones (described further below), then an independent device like the Polar Ignite wristwatch was utilized as GPS tracker. The GPS tracker was activated simultaneously as the H10, so that recorded HRV data could be time-stamped quite accurately for analysis. This made it possible to backtrack and compare HRV data to specific places in time during the walk. This was essential in order to figure out possible elements in the environment that caused a significant change in HRV.

Figure 9 The route which was walked. Screenshot from Polar Beat application

The applications which are released by Polar, Polar Flow and Polar Beat, do not by default measure HRV, but can provide this, given a tool which can measure and extract HRV data. Fortunately, the Polar H10 is compatible with third party software. EliteHRV, a free health and fitness app with additional in-app purchases, was employed for HRV data extraction. This app, in addition to open HRV readings, can also do HRV snapshot readings, which were used for a one-minute test of the participant before the full walk. Unfortunately, there were participants in which the data turned out partially broken, with heavy signal noise, rendering segments unusable.

Table 1 Polar H10 technical and performance overview

	Criteria	**Polar H10**
Specifications	Sensors	Physiological sensors: measures HR by default, can measure HRV with third-party software. Sample rate: 130 Hz. Spatial: Tri-axial accelerometer
	User experience	No interface. All interaction through smartphone apps. A bit confusing to navigate two different Polar apps. Live-streaming of data through

		Bluetooth functions on phone or local memory if phone is unavailable during the session.
	Misc. tech. specifications	Battery duration (when active) ~ 400 hours Single use battery, non-rechargeable
	Other features	Waterproof (up to 30m depth)
	Price	Low price ~ 899 NOK
Performance	HR/HRV	High quality RR-interval data, high sampling rate. CPU speed: 64 MHz

3.5 Study area (Nyhavna/Buran)

This area was chosen due to its diverse built environment. The entirety of the walk, including a two-minute break about halfway in, took on average around 22 minutes. For the purposes of the readers of this thesis and myself for analysis, I sectioned the walk into eight segments (figure 7), which I would consider to be areas of distinguishable qualities. The two main areas were to be very diverse so that participants would more easily remember the walk because of the contrasts. The locations also varied a lot in building materials, ranging from heavy bunker concrete, steel sheeting, and glass in area one, to brick and wood in area two. As a whole and for participants, I sectioned the walk into two main segments: area one, characterised by industry and having no inhabitants, and area 2, characterised by being mostly residential with a few shops on ground floors. Figure 10 and Figure 11 show the walk in pictures in a chronological order.

The element of walkability was also evaluated in choosing this area. There is a mix of pedestrian-friendliness, with in general areas being friendly to pedestrians, but mostly because of the lack of traffic, rather than pedestrian-only zones.

Figure 10 Images from area one

Figure 11 Images from area two

Feature	Condition 1	Condition 2	Condition 3	Condition 4
Car restrictions	Car-dominated, fast and many cars	Traffic calmed, compromised pedestrian priority	Very few or no cars, pedestrian priority	As condition 3 but more intense and dominant
Shops and services	Shops, shop windows and services < 3 doors per 100m	Shops, shop windows and services 3 - 7 doors per 100m	Shops, shop windows and services > 7 doors per 100m	As condition 3 but more intense and dominant
Social activity	Walking, no stationary activities	More walking, necessary activities	Much walking, stationary and optional activities	As condition 3 but more intense and dominant
Enclosure	Street width/building height 3:1 and >3:1	Street width/building height 2:1	Street width/building height 1:1 and <1:1	As condition 3 but more intense and dominant
Edges, facades	Closed, passive, boring, horizontally structured	Somewhat closed, some variation	Transparent ground floor, varied, vertically structured	As condition 3 but more intense and dominant
Streetscape appearance	Technical, compromised maintenance, no identity	Clean, fairly well maintained, somewhat boring	Designed, high quality materials, varied, strong identity	As condition 3 but more intense and dominant
Green	No green	Three-dimensional green, trees	Well-designed greening with trees, scenic view, park	As condition 3 but more intense and dominant
Quantified value	*1*	*2*	*3*	*4*

Figure 12 Environment matrix. Hillnhütter, 2022

Table 2 Walkability scores after Hillnhütter's model

Segment	Car restriction	Shops/Services	Social activity	Enclosure	Edges/Facades	Streetscape Appearance	Green	Sum	Score/avg.
1	4	1	2	1	n/a	2	3	13	2,2
2	2	1	2	2	2	2	1	12	1,7
3	2	1	1	2	1	2	1	10	1,4
4	2	1	1	2	2	2	1	11	1,55
5	3	2	2	3	3	2	2	17	2,4
6	4	1	1	4	1	1	1	13	1,85
7	3	1	2	3	3	2	2	17	2,4
8	2	3	2	2	3	2	1	15	2,14

Table 2 shows scores which individual segments of the walk got after some indexes of walkability designed after Figure 12. Scores were calculated based on a subjective and approximate assessment of the walk's environments. Figure 13 illustrates a simplified map of walkability after the quantified walkability scores from table 2. Roughly speaking, it is clear in which areas walkability is highest. However, it must be mentioned that scores are reliant upon factors such as commercial activity and social activity (which overall scored low), which may not necessarily be the most critical factors determining walkability. By this, I mean that most people are not necessarily out shopping most of the time, and instead, quality of sidewalks, connectivity, attractiveness are more critical factors in measuring walkability.

Figure 13 Illustration of walkability on the walk

3.6 Participants

To have an unbiased selection of participants, I recruited people who are part of the general public, and not professionals within the field of urban planning or architecture. All participants in this study were students (N=12), with most having an engineering background. The age of participants ranged from 21 to 27 (24.0 ± 1.73). Of 12 participants, ten were male and two were female. Some participants' physiological data were partly omitted from analysis after the data was found to be plagued with significant noise in certain areas, rendering it prone to error. Participants were asked through social media if they wanted to participate in my master's thesis, and very briefly told them what the experiment was for in general terms. All participants were friends of mine.

3.7 Repeated trials

Because the trials are performed on a pre-determined route, then it is partially possible to replicate results. However, given the fact that people can react differently, there will be some deviations from study to study. Similarly, the qualitative data is likely to vary in some degree because participants' ability to remember or reflect differs. Despite this, the methodological design means that repeated trials are possible. If errors occur that causes parts of the field work to be re-done, then it should be easy to do so, though it is possible that participants would react less to the same environment, given their familiarity with the route on the second run.

3.8 Stating the hypotheses

The analysis of results collected in the experimental phase concern participants' reaction to the different built environments of the walk. Below are testable hypotheses which I have operationalised from the main research question:

Is there a measurable difference in stress in different urban environments?

H1: *participants experience higher levels of stress in car-friendlier environments than pedestrian-based environments*

H2: *modern architecture produces greater stress than traditional architecture*

H3: *indicated stress from sensors matches self-reports*

3.9 Experiment execution

Participants were greeted around the Lade train station near Solsiden in Trondheim. They were briefly introduced to what the experiment would encompass, and what data would be collected. I was careful not to explain too much, so to keep the participants from thinking in a way they normally would not. For example, stress was not mentioned by me at any point, and rarely pointed out or discussed the built environment. Instead, I wanted the participants to be their natural self so they would only notice things they normally would.

Before the walk, I had participants sign a consent form, ensuring the data collection was legal. I also asked them questions from a pre-walk questionnaire about things that could possibly influence the physiological response, such as if they had consumed caffeine or took medications altering heart or the nervous system functions. This data was not kept.

Then, physiology sensors, in this case the H10 Polar chest strap, was attached by me. I would douse the strap with water as the H10 instructs, as to reduce signal noise and artifacts. As we will see later in this thesis, this was not successful in all trials. Before heading out for the walk, I would wait for the EliteHRV app to stabilize and show "normal" data. From here, the participants walked beside me at a comfortable speed.

During the walk, I would try to avoid traffic and being a hinderance to car, so that the participants were not spooked by sudden interactions. This included for example staying at one side of the road, especially in places without clear pedestrian boundaries. About halfway into the walk, usually around the 13-minute mark, we would take a two-minute break to create a baseline before exploring the next segment of the walk, which, as stated, is visually very different. Subsequently, for the sake of the interview, I divided the walk into two parts, one before the baseline pause, and one for after. After the baseline pause, the walk continued essentially as it did before the pause.

The walk ended at the same place as we started. There I would end the HRV-reading session and save the data on my phone. The H10 Polar chest strap would be removed, and I would sit down with the participant, and have them answer a total of 13 questions from a questionnaire, of which ten were closed questions. After each participant, I would clean the equipment used.

4. Results

In this section, results gathered from data collection will be presented. One important aspect of the results is noting the small sample size, which should make one more cautious to interpret and draw conclusions from results, given the possibility of skewed results. Therefore, one must assume that participants in this thesis are normalised in the population. Because of the small sample sizes, determining a useful significance is difficult, therefore, normal statistical values such as significance numbers are not included in this thesis.

4.1 Physiological data results

Table 3 Physiological variable results overall for area one (industry) and area two (residential)

Paired Samples Statistics (N=12)

		Mean	Std. Deviation	Std. Error Mean
Mean RR (ms)	Area 1	599.363	57.887	16.710
	Area 2	595.073	49.181	14.197
Mean HR (bpm)	Area 1	100.921	9.227	2.663
	Area 2	101.445	8.165	2.357
SDHR (bpm)	Area 1	3.539	.933	.269
	Area 2	3.362	.922	.266
SDNN (ms)	Area 1	22.231	9.388	2.710
	Area 2	20.516	8.037	2.320
RMSSD (ms)	Area 1	15.210	7.407	2.138
	Area 2	13.930	6.194	1.788
NN50 (n.u.)	Area 1	10.166	11.400	3.291
	Area 2	8.083	10.058	2.903
pNN50 (%)	Area 1	1.423	2.379	.686
	Area 2	1.071	1.480	.427
LFPeak (Hz)	Area 1	.084	.017	.005
	Area 2	.086	.020	.005
HFPeak (Hz)	Area 1	.166	.016	.005
	Area 2	.173	.017	.005
LFPOW (Ms2)	Area 1	393.709	290.198	83.773
	Area 2	346.631	276.962	79.952
HFPOW (Ms2)	Area 1	85.107	83.181	24.012
	Area 2	79.160	78.673	22.711
HF/LF ratio	Area 1	6.170	2.932	.846
	Area 2	5.002	1.895	.547

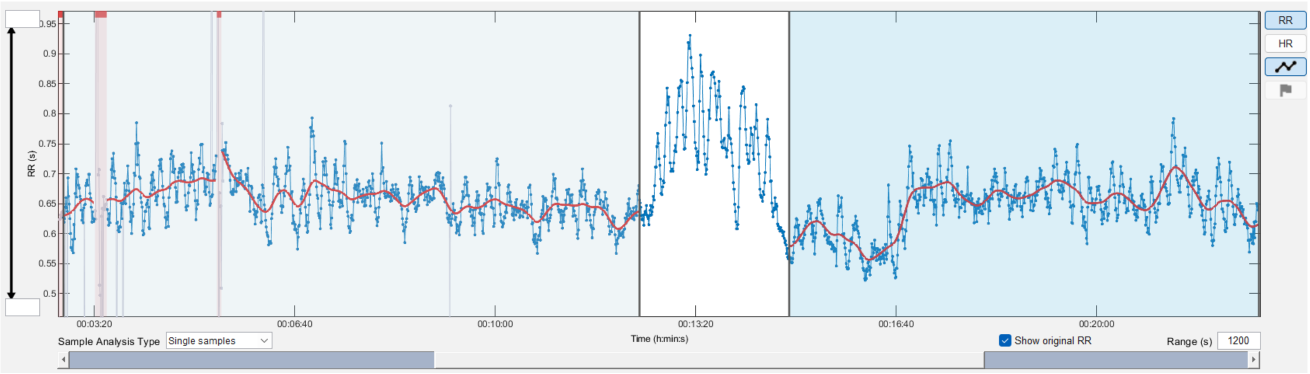

Figure 14 RR-interval graph from one participant. Area one is in light blue, and area two in darker blue. The middle is the baseline.

When physiological data is compared between only the two different main areas (Table 3), one can see that most variables have very little observable changes. Two common variables for HRV measurement, SDNN and RMSSD, both have minimal change. Same applies to mean HR and and RR-interval, which exhibit virtually no difference between the two areas of the walk. A view of RR-data in Kubios can be seen on Figure 14. However, smaller differences can be found in the frequency-domain. Normalised powers for low frequency exhibit a big change, while high frequency does not. LF/HF ratio, which is variable used that can indicate psychological stress. A higher LF/HF ratio indicates low vagal activation, which happens when vagus nerve activity is supressed due to several factors, like stress, among other things. The change between area one and two show a positive change, indicating that on a general basis, participants had greater sympathetic activity (increased stress) than in area two. However, LF power and HF power (ms2) both show little difference, so when these numbers are looked at together with the LF/HF ratio, which is commonly done, it is hard to say concretely if area one is more stressful than area two. Generally, from the results, area two can perhaps be slightly less stressful, because numbers suggest a little bit higher parasympathetic activity in area two compared to area one.

4.2 Comparisons of different segments

Comparing the entire walk of around 22-23 minutes can be generalising environments, which is unfortunate because there are many variances in urban qualities on the walk. In order to try to understand which particular elements might cause stress, I segmented the route into eight characteristic areas, and investigated if there were more significant differences when comparing segments from areas one and two against each other.

4.2.1 The underpass

From data in pre-processing and interviews, the underpass from segment 6 stood out in a negative sense. Participants noted feeling claustrophobic and disliking the shady nature of the underpass, and physiological data showed results indicating that participants felt worse here than in other places. For that reason, I compared physiological data between two segments, one from area 1 (heavy industry, Table 4) and one from area 2 (residential streets, Table 5). Comparing the underpass with two very different areas could uncover more nuanced differences in results than comparing the average of area 1 and area 2. Additionally, numbers indicating a higher sympathetic activity will be in this chapter be regarded as “stress”, because of the context participants put the areas in.

4.2.2 Underpass vs. heavy industry

Time-domain related data differed quite a lot from the two segments. Compared to the entirety of the walk from table 3, MeanRR, SDNN, and RMSSD show a greater change from the underpass segment to the heavy industry segment. One explanation is the climbing of around six steps in the underpass, which may have temporarily increased HR, subsequently impacting data for this segment. However, these steps were climbed slowly in order to reduce the increase in HR. Still, it is possible that given the large difference in these numbers, the underpass could be perceived to be slightly more stressful than heavy industry. Frequency-related data showed a great difference. The LF/HF ratio, in which a greater ratio indicates higher sympathetic activity, was found to be comparable between the two, with 0,7 separating the two. This could mean that the underpass was slightly more stressful than heavy industry.

Paired Samples Statistics (N=12)

Table 4 Physiological results comparing segment 6 and segment 3 of the walk. See figure 7 for walk description

		Mean	Std. Deviation	Std. Error Mean
MeanRR (ms)	Underpass	543.468	39.412	11.377
	Heavy industry	603.353	61.772	17.832
SDNN (ms)	Underpass	17.325	7.075	2.042
	Heavy industry	23.701	13.354	3.855
MeanHR (bpm)	Underpass	110.912	7.698	2.222
	Heavy industry	100.343	9.605	2.772
SDHR (bpm)	Underpass	3.41	1.011	.292
	Heavy industry	3.659	1.262	.364
RMSSD (ms)	Underpass	10.296	4.689	1.353
	Heavy industry	15.954	10.086	2.911
NN50 (n.u.)	Underpass	.250	.621	.179
	Heavy industry	2.750	3.250	.938
pNN50 (%)	Underpass	.295	.729	.210
	Heavy industry	2.717	7.072	2.041
LFPeak (Hz)	Underpass	.055	.015	.004
	Heavy industry	.087	.020	.005
HFPeak (Hz)	Underpass	.228	.089	.025
	Heavy industry	.171	.025	.007
LFPow (ms2)	Underpass	202.061	295.542	85.315
	Heavy industry	482.070	514.133	148.417
HFPow (ms2)	Underpass	39.684	63.721	18.394
	Heavy industry	104.444	170.116	49.108
LF/HF ratio	Underpass	7.941	5.499	1.587
	Heavy industry	7.271	3.362	.970

4.2.3 Underpass vs. residential street

When comparing the underpass segment with the residential streets segment (table 5), which follows directly after the underpass, time-domain data show almost identical result differences as it did when the underpass segment was compared with the heavy industry segment. However, frequency-domain show a significant difference. The most crucial difference is found in the LF/HF ratio, which show a three-point difference, meaning sympathetic activity was significantly lower in the residential streets segment compared to the underpass segment. An interesting point is that time-domain data are nearly identical in the two comparisons, meaning that physical activity could not have impacted the results of the LF/HF ratio. This could mean that the heavy industry and underpass areas are more stressful objectively.

Paired Samples Statistics (N=12)

Table 5 Physiological results comparing segment 6 and 7 of the walk. See figure 7 for walk description

		Mean	Std. Deviation	Std. Error Mean
MeanRR (ms)	Underpass	543.468	39.412	11.377
	Residential streets	603.286	55.670	16.070
SDNN (ms)	Underpass	17.325	7.075	2.042
	Residential streets	20.916	9.285	2.680
MeanHR (bpm)	Underpass	110.912	7.698	2.222
	Residential streets	100.214	8.994	2.596
SDHR (bpm)	Underpass	3.41	1.011	.292
	Residential streets	3.286	.950	.274
RMSSD (ms)	Underpass	10.296	4.689	1.353
	Residential streets	14.670	6.838	1.974
NN50 (n.u.)	Underpass	.250	.621	.179
	Residential streets	3.833	6.042	1.744
pNN50 (%)	Underpass	.295	.729	.210
	Residential streets	1.354	2.330	.672
LFPeak (Hz)	Underpass	.055	.015	.004
	Residential streets	.093	.021	.006
HFPeak (Hz)	Underpass	.228	.089	.025
	Residential streets	.165	.013	.003
LFPow (ms2)	Underpass	202.061	295.542	85.315
	Residential streets	349.301	362.2807	104.581
HFPow (ms2)	Underpass	39.684	63.7219	18.394
	Residential streets	87.803	116.956	33.762
LF/HF ratio	Underpass	7.941	5.499	1.587
	Residential streets	5.096	2.186	.631

4.3 Self-reports

Table 6 shows results from the post-walk questionnaire presented pairwise, while Table 7 shows participants' ranking of some basic city elements' effect on their walking behaviour, or at least perceived importance. Differences in affective state between the two areas are for the most part similar for both areas. Only strong differences in ratings were found in questions regarding pleasantness of the built environment, in which area one scored worse.

4.3.1 Area one and two

Table 6 suggests that perception of the areas' affective appraisal and environmental characteristics are generally similar. Regarding affective appraisal, the two areas are very similar. The first two questions asked about perhaps the most important aspects of the city, which is about feeling safe and at ease, scored highly. This indicates that morphology and architecture in general might not directly affect safety but can likely be attributed to crime and acute danger to a person. Both questions one and two scored around 4, meaning participants were "a little relaxed" and "a little safe". Question 3 assessing feelings of pleasantness during the walk were significantly different. Area one was rated "a little unpleasant", while participants were mostly neutral to area two. Similarly, question 6 assessing architecture alone garnered nearly identical scores, despite being told to differ between architecture (Q6) and general appearance (Q3). This is likely because participants believe architecture to be the dominant factor in assessing street pleasantness. Q4 was the only question in which area one got a more positive rating than area two. However, the standard deviation is higher for area one. Safe and efficient walking was rated 4,25 with the most agreeance between participants.

Paired Samples Statistics

Comparison of means between area one (industry) and area two (residential) **(N=12)**

Table 6 Overview of participant's ranking of the walk's two areas.

		Mean	Std. Deviation
Q1	Stressed (1) - Relaxed (5) Area one	3.75	.754
	Stressed (1) - Relaxed (5) Area two	3.92	.515
Q2	Fearful (1) - Safe (5) Area one	4.08	.793
	Fearful (1) - Safe (5) Area two	4.17	.718
Q3	Unpleasant (1) - Pleasant (5) Area one	2.08	.669
	Unpleasant (1) - Pleasant (5) Area two	3.33	.651
Q4	Visually uninteresting (1) - Visually interesting (5) Area one	3.67	1.073
	Visually uninteresting (1) - Visually interesting (5) Area two	3.33	.778
Q5	Boring environment (1) - Exciting environment (5) Area one	3.08	1.311
	Boring environment (1) - Exciting environment (5) Area two	3.08	.515
Q6	Pleasant architecture (1-5) Area one	2.00	1.044
	Pleasant architecture (1-5) Area two	3.33	.651
Q7	Safe/efficient walking (1-5) Area one	3.08	.793
	Safe/efficient walking (1-5) Area two	4.25	.452

Table 7 shows three assertions in which participants rated their agreeance on a scale from 1 (strongly disagree) to 5 (strongly agree). The question about accessibility scored nearly a perfect score with a low standard deviation. Participants were made to understand the question as how many barriers existed, large roads impeding walkability, etc. Unsurprisingly, all questions had scores indicating such elements are important for walkability, though efficiency of movement ranks slightly higher, meaning it could be overall more important for many people.

Table 7 Participants' agreement of assertions

N=12	Mean	Std. Deviation
Q8 Architecture affects my willingness to walk	4.17	1.193
Q9 Accessibility/ease of movement affects my willingness to walk	4.67	.492
Q10 The number of cars affect my willingness to walk	4.17	1.193

4.4 Open-ended questions

The open-ended questions allowed participants to share their own extended thoughts of the walk if they had such. Despite general agreeance that area one was unpleasant, there were still several participants that expressed admiration for area one. The main driver of fondness for area one stemmed from the fact that it is a type of place one infrequently visits, and thus is experienced as "new" and "exciting". On the other hand, parts of area two, like Buran, looks mostly like other residential areas in Trondheim, which participants seemed to perceive as standard or familiar, which in turn caused them to be more bored in area two compared to area one. One landmark that stood out for several participants was the Dora 2 bunker in the third segment of the walk (area one), which despite its rugged and "ugly" appearance, was seen as a positive contribution to the environment given its historical roots and iconic look. Railroad tracks which are partially buried by asphalt, were both positively and negatively assessed by three participants, of which two found it a positive boon because of the historical aspect, while one disliked it because he found it "ugly" and generally strongly disliked traces of industry. Some also mentioned their strong distaste for the general grey appearance of area one. Larging parking lots coupled with glass buildings and/or buildings with no paint caused a perceived strong boredom factor in area one. On the other hand, Buran, which employs a wide variety of façade colours, received praise for such.

Some participants commented on height of buildings and width of streets. While two participants complained about area one being too open and diffuse, one participant thought it was good, because of good lightning conditions. One participant thought that the ratio of building height to street width around Buran in area two was very good. One participant commented that lower buildings generally reduce feelings of stress. However, they said that tall buildings can be fine, if design is good and can be considered "pretty".

One thing that was noted as positive for the entire duration of the walk by several participants, was the general friendliness of environment towards pedestrians. In the industrial area, this was generally because of the lack of traffic, while in area two, partly lack of traffic but also because of a clearer separation of pedestrians and cars. This was a regular occurrence, with many participants stressing the importance of “designated walking zones”, unless there was clearly established a street hierarchy where pedestrians are prioritised. This is because it keeps people from looking over their shoulder in case a car should come. Thus, car-free areas were perceived in higher regard than car-dominated ones. Many participants noted that the somewhat run-down appearance of streets in area two, could be renovated in order to make it a much nicer area, emphasizing the connection between street and building quality to make a place pleasant, and not the two elements individually.

Spontaneity and chaos were treated very differently by participants. Some thought quick changes in the built environment, for example very contrasting architecture, was a negative thing. Svartlamoen (segment 5), which is famed in Trondheim for being alternative and spontaneous, was polarizing, with certain participants expressing admiration for the run-down appearance because of the gritty impression it left, while others simply thought it looked shabby. “Spontaneous” elements, such as graffiti and otherwise unusual elements not normally found widespread in the city, was generally positively received, as participants felt it livened up a given place.

The question of perceived stress saw participants agreeing on two things in particular. Firstly, the presence of cars, e.g., along the main road dividing area one and two, and secondly, the underpass (segment 6). Five participants noted they felt stressed in the underpass, with some noting its claustrophobic characteristic, being only about 2,5 meters in width and height. One participant commented that they liked graffiti in and around the underpass, while most disliked this, because they thought it reinforced the “shady” impression of the underpass, which contributed to feelings of stress. Six participants noted car traffic, especially noise, as stressors. Some of these complained about road crossings, while others who disliked traffic did not cite crossings as a stressor.

5. Discussion

Because of the small number of participants, getting certain statistical measures like *p*-values, t-values and correlation was difficult, I opted for a “dumber” method of simply comparing results, which is less scientific and harder to scrutinize by readers. A linear regression which would normally be used to show the relationship between the variables, has not been produced.

5.1 Relation between physiological and subjective results

From the results section, one can see there are some connections between physiological data and self-reports. When analysing physiological data from specific segments like the underpass, with other segments, together with participant self-report, I found a tendency that the segment that “scored the worst”, e.g., the underpass, was the built element that most participants noted as a stressful or unpleasant.

An important aspect of this thesis is seeing if there is a correlation between physiological data possibly indicating stress in certain areas of the walk, and the responses participants gave me in the post-walk interview. Stress understood after Russel (1980), defines stress as on a spectrum in which high levels of arousal and displeasure are combined. Arousal and displeasure are contextualised after participants’ feedback in this section. For example, physiological data indicating arousal experienced in one area is understood in relation to what participants said about that certain area. Same applies for displeasure. In general, participants were very sparingly in highlighting the positives of the walk, finding it easier to criticize. Given the fact that participants and I were passively experiencing the streetscapes and that I find it unlikely that most people would actively feel displeasure from strolling, my understanding of stress is determined from arousal from physiological data.

Questions in the questionnaire about perceived feelings of stress and safety scored very similarly, with minimal differences in score in both questions and within the areas themselves. When reviewing physiological data for area one and two, there are few significant factors which makes it possible to draw conclusions. However, when reviewing it considering specific segments, it is easier to see possible connections. For example, results from the heavy industry area indicated more negative results compared to segments in area two (except the underpass), which makes sense given the fact that participants found parts of the walk, like around the industrial area significantly less attractive than its traditional counterpart. This was evident in both the questionnaire and from the open-ended questions.

However, what is interesting is that participants felt as safe and relaxed in area one as they did in area two. If they answered they felt equally as safe, then it could be possible that less emotionally acute factors like pleasantness can have an impact on the sympathetic nervous system, given the lower LF/HF ratio found in the residential streets area. Nevertheless, it is possible that the street layout in area two, which separates cars from pedestrians in a clearer way than most of area one, increased parasympathetic nervous system activity, reducing the LF/HF ratio. This would be in line with what many participants stated about liking being physically more separated from cars compared to segment 2, 3 and 4 in area one, and how area one ranks worse than area two in safeness and efficiency of walking (table 6).

Controversially, I did not find strong results indicating that stress (or lack thereof) experienced in segment 4 along the busy road was any greater than in segment 7 (residential street), despite a few participants stated they disliked noise from cars. Despite this, scores found in table 6 ranks safe/efficient walking in area one as “neutral” and good score for question one and two, indicating that they might not have felt very stressed, but rather having searched for something to answer for the open-ended questions. However, this is speculation.

There seems to be certain evidence indicating that there might be a connection between physiological data and self-reported data. These connections are primarily regarding the “least popular” built elements like cramped and dark spaces such as the underpass, and the grey and asphalted segments of area one, because of their relatively higher significance in stress indicators and because of participants’ highlighting of the negative elements. Lower LF/HF ratio/lower sympathetic nervous system activity experienced in segment 7 might stem from more “neutral” architecture compared to previous segments, but also because of the safe streets for pedestrians. Because of such, drawing conclusions as to what exactly causes the increases and decreases of stress in physiological data is notoriously difficult, and one should be cautious about concluding anything too confidently. However, when viewed in conjunction with participant self-reports, it seems possible to see certain patterns in which elements participants react negatively to. Assessing what elements cause an increase in parasympathetic nervous system activity (indicating a relaxing body) seems to be harder to detect. Nevertheless, I would argue that there are results possibly indicating that certain urban design qualities increase psychological stress, and that subjective results can help support such claims.

5.2 Measurable differences in indicated stress in different environments

Physiological results suggest that there is a measurable difference in indicated stress from environment to environment. Time-domain analyses comparisons between area one and two showed little significant differences. This is perhaps because spikes in time-domain analysis data can be harder to detect when obtained through physical demanding means, such as walking, instead of through psychologically stimulated means, such as experiencing the walk in a sedentary position through video captures. Frequency-domain data, however, did show some small differences, albeit small ones.

When comparing specific characteristic areas (segments), differences were easier to spot. The underpass (segment 6) stood out negatively. Frequency-domain data here showed a quite significant deviation from the average mean of both area one and two holistically, being almost three points higher than the rest of area two, and almost two points higher than the average for area one. This is not necessarily due to slightly increased physical activity, as at least study found that LF/HF ratio did not increase with physical activity (Tanoue et al., 2022). The heavy industry area (segment 3) also stood out negatively compared to the average for area one. Findings such as this, in which areas of predominantly modernistic characteristics were perceived more negatively than more traditional areas, was expected in accordance with my hypotheses. However, it is important to note that such areas cannot be representative of modern architecture, given that they are of industrial character.

For certain environments, such as street crossings, my study did not find strong indicators in physiological data, while studies such as Birenboim et al. (2019) (using EDA data) found that a significant increase in indicated stress levels only occurred around street crossings. Of my 12 participants, only one mentioned feeling stressed around street crossings. This could indicate that the hypothesis of a correlation between objective and physiological data is not necessarily weakened. Nevertheless, I find that there are different indicated stress levels in different environments, but drawing conclusions as to what the reasons are for such differences cannot be said as of now with certainty.

5.3 Urban quality perception

Findings indicating the negative perception of areas described above are somewhat in line with a study conducted by LaJeunesse et al. (2021), in which EDA was used to determine stress, and mixed-use areas and industrial areas were found to be elevators of stress levels when located along collector and arterial roads. On the other side, low-density residential areas showed relatively lower stress levels. The study indicates that being prone to vehicular interactions was the main reason for increased stress levels in higher density areas, even if sub-consciously. This could make sense in my study as well, since in the industrial segment which people experienced relatively high stress levels, the separation between pedestrians and vehicles was indiscrete compared to the residential segments of area two. Despite the article noting that such an increase likely is sub-conscious (LaJeunesse et al., 2022), this may contradict my findings, in which many participants actively remembered being somewhat uneasy when traffic and walking happened on the same road area. The article, however, does not mention any association with architecture or morphology, but rather find correlations primarily between stress and car traffic and noise.

The quality of architecture is important for many (table 7). Table 6 and open-ended questions revealed participants' unfavourable views on the built environment in area one, except for one built element (Dora 2 bunker) which was considered visually interesting, but not pleasant. Mouratidis & Hassan (2020) found significant results suggesting traditional architecture was favoured to facades with modernist traits. Modernist facades were characterised as "by asymmetry, lack of ornamentation, and industrial appearance", which would describe all buildings found within area one. The similarities of results in which traditionalism is favoured to modernism was expected, despite area two scoring worse than I had anticipated.

Additionally, polls conducted on Norwegians revealed people in general favour traditional architecture (Lundgaard, 2023). Findings such as these, in addition to mine, could indicate that indeed industrial architecture is perceived to be unpleasant, and might cause an increase in stress levels and are subsequently examples of poor urban qualities.

Hillnhütter (2022) found that underpass' effect on head movement and time looked down to be the worst of all built elements in his study and concluded that "underpasses are clearly unattractive walking environments". This too could strengthen the finding that stress is elevated in the underpass. Underpasses are seen as undesirable because of several factors.

The biggest is its association with crime. Underpasses are often dimly lit, not in public view, prone to maintenance negligence, which leads to them either being used for crime, or people become fearful of possible crime taking place in such environments (Mushtaha et al., 2022). Incidentally, the first walk with a participant saw us experiencing people loitering around the entrance to the underpass, which both of us found to be uncomfortable. Additionally, the underpass encountered in this study is of low quality, failing to meet standard which should be quite basic (Mushtaha et al., 2022). It does not have universal access (one end has stairs), one cannot see any light from the outside on either entrance and the walls are covered in graffiti and the floor is littered with refuse.

Jan Gehl in his book "Life Between Cities" emphasizes that «people come where people are", and that many modern areas are poorly designed to foster spontaneous interactions or places to sit down (Gehl, 2011). The walk passed through districts with very few other people, especially in area one. A couple of participants remarked feeling less safe on the walk because of the lack of people. Obviously, people would not gather at places such as an underpass anyway, but the principle should be to generally avoid building dark and secluded places like underpasses because of their association with crime and their suggested increase in stress levels. The underpass is a prime example of what Gehl describes as "people unfriendly architecture".

5.4 Implications of the study on walkability

Results from the study have implications for the perceived friendliness of the environments for walking. There was a certain disagreement between participant rankings of walkability-related questions and free thoughts. Overall, feelings of safety ranked high, meaning participants were not afraid during the most mentally demanding parts of walk, which should have been around crossings, according to findings from LaJeunesse et al. (2022). Thus, walking conditions were satisfactory for most participants. However, open-ended questions revealed negative factors for walking which must be considered minor if they did not significantly impact the scores of walkability nor affect. The underpass was conceived to strengthen walkability, by allowing pedestrians to avoid unsafe crossing entirely, thereby increasing walkability from a technical standpoint. Factors such as connectivity, absence from traffic and buffer space from traffic are quite central to having a high degree of walkability (Lo, 2009). Despite underpasses meeting such criteria, this particular underpass does not meet the others, which include universal access, being visually interesting and having perceived safety. Hillnhüttter (2022) too is critical of them. However, priorities exist. Even though it scores poorly on such factors, it still does technically improve walkability, providing an opportunity to cross the train tracks above. Nevertheless, underpasses do not have to automatically score poorly on many factors. Keeping them well-lit, free of litter, universally designed, transparent and more generous in spatial dimensions can probably majorly improve the quality and perceived safety of underpasses for pedestrians (Mushtaha et al., 2022). It should be mentioned that women on average emphasized the importance of lighting when assessing feelings of perceived safety, while men were largely unaffected by this, when answering a questionnaire. Additionally, dim-lit areas were the primary locations of graffiti (Mushtaha et al., 2022), which may decrease perceived safety, as some participants expressing negative sentiments about graffiti. Generally, however, underpasses should be avoided.

Interestingly, industrial architecture which was regarded as “ugly” by almost all participants, was characterised as more visually interesting than the traditional architecture. This seems like a contradiction. Lo (2009) mentions visual interest as one of the key factors of walkability, yet the “ugly” architecture was apparently more visually interesting, even though participants disliked that architecture anyway. With such logic, coupled with the similar scores of perceived walkability and safety, then area one should be partly more walkable than area two. This would contradict participant open-ended question feedback which seemingly favour area two.

Traditional architecture, which according to Mouratidis and Hassan (2020) is more popular than contemporary, did not have observable effects on walkability in this study. However, most participants said they were willing to walk longer distances if surroundings were very pleasant. Drawing strong conclusions from this, however, is difficult, as areas differ in aesthetics, and if different built environments were studied, then perhaps effect of architecture on walkability could have differed. This could make sense because of the lack of praise area two received from participants, despite it being a more traditional-looking area compared to area one. Therefore, for this study, architecture seemingly had not an impact on perceived walkability.

Rather, actual safety, such as separation from cars, was important for participants and therefore perceived walkability. This is in line with Lo’s (2009) criteria for good walkability, who listed buffer zones from cars as a good measure for achieving good walkability. What is interesting, is that in the last few years, alternative urbanism design such as shared space street design, which minimises separation of modes of road users, have become more popular (Hammond and Musselwhite, 2013). This concept would lower walkability if following Lo's walkability criteria. The industrial segment in area one has an almost shared space aesthetic, which participants did not like. Hammond and Musselwhite (2013) found that while most participants enjoyed the visual aesthetics of shared space, many had problems with the usability of the street, and many would give way to vehicles, and people were wary of conflicts with cars. This is similar to LaJeunesse's (2022) results, who found increased stress in areas in which conflicts with cars were more prevalent. Walkability should therefore be considered better in area two, which is greener, less trafficked, architecturally more attractive, clear buffer zones between vehicles and pedestrians. If then the conclusion that area two is more walkable, then it corresponds with stress results, which were lower in area two in general, but especially compared to the industrial segments. Likewise, if the underpass should be considered a negative element for walkability, then it would correspond with stress levels, which were the highest for any segments. The increased stress in the underpass is possibly because of perceived crime and claustrophobia, which was reported by participants.

5.5 Answering the hypotheses

My analyses left H1 (*participants experience higher levels of stress in car-friendlier environments than pedestrian-based environments)* a somewhat strengthened hypothesis: participants did on average experience higher levels of stress in car-friendly environments compared to pedestrian-based environments from physiological data. On a general basis, areas which provided easier access for cars and on car's premises, seemed to indicate increased stress in such areas, although it is hard to determine exactly the reason. Participant self-reports were contradicting in this sense, because participants ranked the entirety of area one and two equally safe, despite many complaining about the lack of designated walking zones in area one. Several studies (LaJeunesse et al., 2021; Chen et al., 2018; Birenboim et al., 2019) found that usually increased stress was associated with places of traffic like near crossings, which I did not find substantial findings for. Usually, it was in areas without sidewalks and where roads still were shared by vehicles and pedestrians alike, that an increase in stress was found. This was like what LaJeunesse concluded with, that stress increased when there was a higher chance of accidents between pedestrian and vehicles. However, given the on average higher stress levels in car-friendlier areas compared to pedestrian-friendly ones, coupled with participants' thoughts and other studies, H1 is more likely to be true than false.

H2 (*modern architecture produces greater stress than traditional architecture)* resulted in being a somewhat strengthened hypothesis. Area one and especially segment 3 did on average have higher stress levels than its counterpart, and questions from the questionnaire showed participants disliking modern architecture. However, such a hypothesis is controversial, and one should be cautious about drawing conclusions to *all* modern architecture. The architecture featured in area one is not good examples of modernism, even if their characteristics are similar to general modern architecture. Very few studies have tried to "rank" architecture quantitatively nor qualitatively, so there is little evidence to back such a claim. Qualitative methods like used in Mouratidis and Hassan (2020) are prone to population bias, and the study has a relatively small sample (N=28). Even though H2 seems to be true, I am still careful in drawing conclusions, therefore H2 is left as a somewhat strengthened hypothesis.

H3 (*indicated stress from sensors matches self-reports*) resulted in a somewhat strengthened hypothesis. For the most part, physiological data had quite strong similarities to participant feedback. Areas of increased indicated stress were often mentioned in a negative light by participants. The residential segments of area two, which was less stressful than other places, was similarly talked about in a neutral or somewhat positive light. Such associations between self-reports and physiological data are in line with Wulvik et al. (2020), who found a correlation between self-reported stress and workload, and EDA and peak HF band of HRV, in addition to other positive correlations.

6. Limitations

As a master's thesis which delves into a research field with very limited existing research and lack of well-developed frameworks for analysing such a complex issue, understanding and analysing data collected was a very difficult task. As I consider this a pilot study, and because of lack of time resources given major delays in the deliverance of technological equipment, there are few participants in this thesis. Originally, I had planned for around 20 participants, but data collection was first started towards the end of April, giving little time for larger data quantities to be gathered. The EmotiBit, a small biosensor which was originally going to be used because of its totally open-source properties and its specific use for research, ended up being replaced by the Polar H10 because of delivery delays (it never arrived), which resulted in long periods of little progress.

Conclusions reached in this study should be taken with a pinch of salt, but an experienced researcher could take some inspiration from this thesis and strengthen the method used with additional participants, more accurate questions and a deeper understanding of statistics and its analysis. A regression analysis and solid *p*-values would make this study more scientifically valid. Unfortunately, as previously mentioned, a small sample size made it difficult to get valuable statistical results.

7. Conclusion

7.1 General

As far as I am aware, this thesis is one of few studies in which physiological, subjective questionnaires and open-ended questions have been used to evaluate stress in pedestrians in different urban environments. The study captured physiological data from participants on an on-site walk in Trondheim's inner city, and then a questionnaire followed by a semi-structured interview, obtaining both qualitative and quantitative evaluations of environmental and affective appraisal. Data have been analysed pairwise trying to uncover whether humans feel objectively more stress in certain environments, then compared data indicating stress up against participant feedback and ratings.

To answer the main research question presented in this thesis: yes, I would make the claim that there is indeed a difference in stress between urban environments investigated in this study. Additionally, the first research sub-question which was "*is there a match between quantitative measured data and self-reported stress levels?"* showed a positive match, at least when analysed in the way this study was conducted. The second research sub-question "*Which urban qualities increase stress and which decrease stress*" resulted in certain urban qualities being singled out for criticism, while it was difficult to assess which urban qualities decreased stress.

Results from this pilot study show a few discernible implications about the built environment's effect on stress, and the relation between sub-conscious physiological data and active reflections of participants. Firstly, results suggest certain environments like underpasses and industrial architecture increase feelings of stress, compared to other environments. Secondly, there seemed to be a connection between the perceived quality of areas by participants, and the objective stress which was measured at a given place. This was not reflected strongly from questionnaire scores, but rather from open-ended questions. Stress was generally lower in non-industrial/residential areas. Further studies which can strengthen or confirm findings from this study, which can be translated into policymaking for reducing the building of stress-increasing areas.

Another important momentum from this study is the methodology, which can be adapted and refined by future studies. It would be interesting to see whether findings in this study could be verified, with a larger sample size and more advanced analysis methods. Additionally, conducting a study like this in a controlled environment could be interesting, as physical activity produces different numbers than if data was collected from a sedentary position. Data collection from a sedentary position would make it easier to assert that data was reliable and stemmed from changes in mental state alone.

Indicators used in this thesis have been somewhat difficult to work with. In research, there is a disagreement of the certainty of reliability of LF and HF variables used, as some researchers claim one cannot tell for certain whether those variables say too much about stress levels. RSDNN and SDNN were very hard to work with, as they are influenced by physical activity, and baselines vary greatly between participants. Therefore, I believe that variables more closely related to strictly cardiovascular functions are better to use in a sedentary position, as previously mentioned. Because EDA is similarly tricky to use in uncontrolled environments, then EDA could be used in conjunction with cardiovascular dependent variables to perhaps gather more reliable results.

In addition to findings related to stress, this study contributes to the growing number of studies utilising biosensors for researching stress. Electrocardiogram devices have become better, cheaper and easier to use, especially coupled with conventional synchronizing options to other devices. The Polar H10 is a good example of a widely used piece of such technology which have become increasingly accurate with newer models, and which can be used for further clinical research. This thesis has utilised biosensors to demonstrate its value for obtaining objective data and monitoring mental states in various built environments. Despite promising results, additional research is needed, especially regarding standardised frameworks for less varying results from study to study. Efforts in reducing artifacts and signal noise such as moisturising the chest strap did not have any particular effect in reducing such signal noise. Future technological advancements can help minimise signal noise and improve reliability of data, making results more solid.

7.2 Future research

Future studies with similar methods should measure HRV data in residential areas with modern character instead of industrial areas, given people in general rarely visit industrial areas. Translating results from a study such as this into planning policy would be easier if the study was conducted in a place more frequented by people. This is especially the case for area one, which is an industrial estate with almost no visitors. Almost the entirety of area one is going to be redeveloped in the next few years.

Integrated GPS trackers should be strongly considered for further similar studies. Because of the technology used for this thesis did not allow for GPS and physiological data to be collected with the same device, an external GPS smartwatch was used together with the Polar H10 to determine physiological data in the correct physical environment. This could have resulted in minor errors in analysis, but time-stamped data and time-stamped GPS coordinates ensured I tried to my very best at being accurate in determining indicated stress in the right spot. Additionally, an integrated GPS tracker could be used for making HRV heatmaps, such as certain studies did with EDA-data (Birenboim et al., 2019; Dörrzapf et al., 2019).

Finally, more participants should be used for further studies. 12 participants are not able to produce statistically reliable data, which is exactly why I have not used significance numbers.

7.3 Personal reflections

I was quite surprised by the results of this thesis, however, this is possibly due to the small number of participants. As an urban planning student, I have come to realise that my views on cities are different and perhaps more thorough than those who are not of the urban planning/architecture profession, with myself emphasising elements in the built environment others do not. For example, area two scored worse than I had expected. This area is typical of what Jan Gehl denotes as human scale architecture with natural building materials and decent street quality. However, participants saw area two in general as worn-down, to a larger degree than I would have expected. Personally, I believe it is possible that the reputation of the area could have lowered pleasantness in that area, because of its association with municipal housing. Additionally, a syringe was found in this area with several participants, saying in post-walk interviews it made them uncomfortable.

Participant feedback for area one was mostly in line with my expectations. It is a visually unpleasant area, but at the same time interesting because of its gritty qualities, and the bunker is an example of very unusual architecture not found many places around Norway. I agreed with most participants about this. I did, however, find myself surprised that quite few participants commented on feeling stressed around street crossings, because I find myself to be so, and that studies cited in this thesis found elevated stress in such places. This is an example of how different people are in evaluating their surroundings and feelings about it, making it difficult to assess which exact factors in the built environment most can agree with is a negative contributor.

An element of the qualitative part of the method I am critical of is the weakness in my questions and its ranking. The questions, in which the first five were designed after the theories of affective quality by Russel and Pratt (1980), were quite similar. Participants struggled with understanding the difference between pleasant/unpleasant, exciting/boring and interesting/uninteresting, resulting in my explaining the question to virtually all participants. This confusion may have resulted in answers with generally the same score. Additionally, question score intervals from 1-5 may have resulted in less accurate answers. In hindsight, I think 1-7 or 1-9 could have given participants the possibility of rating the questions in a more nuanced and true fashion, instead of forcing them to generally choose between 2-4.

8. References

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Figure 5: Hyperice (2021/2022) *Heart rate variability* [screenshot] Available from: https://hyperice.zendesk.com/hc/en-us/articles/4410230339099-An-Introduction-to-Heart-Rate-Variability-HRV- (Accessed: 23. May 2023)

Figure 6: Polar (n.d.) *H10 heart rate sensor* [digital photo] Available from: https://www.polar.com/en/sensors/h10-heart-rate-sensor (Accessed: 23. May 2023)

Figure 7: Polar Beat application (2023) [screenshot]

Figure 8: Self-produced map in AutoCAD

Figure 9: Personal images taken with smartphone.

Figure 10: Personal images taken with smartphone.

Figure 11: Kubios Premium (2022) [digital screenshot].

Figure 12: Wulvik, A.S., Dybvik, H. and Steinert, M. (2020) *Physiological variables* [screenshot] Available from: https://doi.org/10.1007/s10111-019-00553-8. (Accessed: 04. May 2023)

Figure 13: Hillnhütter, H. (2022) *Environment matrix* [screenshot] Available from: https://doi.org/10.1177/23998083211002839 (Accessed: 24. May 2023)

Figure 14: Self-produced in AutoCAD

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