VILNIUS GEDIMINAS TECHNICAL UNIVERSITY

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DEVELOPMENT OF A METHOD AND INTELLIGENT DECISION SUPPORT SYSTEM FOR SUSTAINABLE RENOVATION OF THE BUILT ENVIRONMENT

DOCTORAL DISSERTATION

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Abstract

This dissertation examines the sustainable renovation of a built environment. The object of the dissertation research is the process of creating an analytical recommendation method with a knowledge-based decision support system integrated with a multi-layer artificial neural network, proposing an approach that provides obtained data from the architectural environment for making decisions and analysing all life cycles of it. The dissertation includes an introduction, three chapters, a research generalisation, a literature summary and the author's publications on the dissertation topic.

The introduction discusses the research issues, the importance of the dissertation, the object of research, scientific novelty and research methodology. The introduction ends with a presentation of the author's publications on the dissertation topic and the description of the dissertation structure.

The First Chapter gives a review of the literature on the sustainable built environment covering the period between 2015 and 2021, analyses methods of sustainability certification systems (e.g., BREEAM, LEED) and their inclusion in research related to sustainable valuation, and widespread use in the construction industry, provides existing methods of sustainability assessment for more holistic perspective in the assessment following the recommendations for performing the sustainable renovation.

The Second Chapter introduced a knowledge-based decision support system integrated with a multilayer artificial neural network for urbanisation in city construction. The chapter presents a method of a multivariant design and multiple criteria analysis of a building's renovation (on the example of the building reconstruction in Kyiv, Ukraine). Multiple criteria analyses in the selected location were made to determine the emotional and rational market segments by demographic criteria (males and females), psychographics and consumer behaviour criteria (e.g., happy, sad, angry, surprise and heart rate variability).

The Third Chapter covers how to measure the segmentation of crowd composition effects (by age and gender) and emotional and physiological indicators of potential buyers. This allows offering stakeholders rational, environmentally friendly and energy-efficient building alternatives. To achieve this goal, the developed multi-criteria analysis of neuromarketing and video advertising was used to create the required conditions. More than 200 million multisensory pieces of data were analysed. This experiment was performed on the example of energy-efficient buildings to demonstrate the developed method. The results presented in this chapter are confirmed by the results of worldwide research.

The research highlights were discussed at 5 scientific conferences; the key research study was presented in 3 research papers.

Reziumė

Disertacijoje nagrinėjama tvari užstatytos aplinkos renovacija. Disertacijos tyrimo objektas – sukurtas analitinis-rekomendacinis metodas ir žiniomis pagrįsta sprendimų paramos sistema, integruojant daugiasluoksnį dirbtinį neuroninį tinklą, sudarant galimybę panaudoti iš užstatytos aplinkos gaunamus duomenis sprendimų priėmimo procese ir analizuojant visą užstatytos aplinkos gyvavimo ciklą bei veiksnius, tokius kaip tarša, ekonominė aplinka, emocinė ir fiziologinė būsenos. Disertaciją sudaro įžanga, trys skyriai, mokslinio tyrimo apibendrinimas, literatūros santrauka ir autoriaus publikacijų disertacijos tema sąrašas.

Įžangoje aptariamos mokslinio tyrimo problemos, disertacijos tematikos svarba ir tyrimo objektas, aprašomi darbo uždaviniai ir tikslas, mokslinis naujumas ir mokslinio tyrimo metodologija. Įžangos pabaigoje pateikiamas disertacijos tema publikuotas straipsnių sąrašas ir disertacijos struktūros aprašymas.

Pirmajame skyriuje atlikta literatūros analizė tvarios užstatytos aplinkos tema, apimanti 2015–2021 metų laikotarpį, analizuojami tvarumo sertifikavimo sistemų metodai (pvz., BREEAM, LEED) ir jų mokslinis aspektas, atsižvelgiant į tvarumo vertinimą bei platų naudojimą statybos pramonėje, pabrėžiama būsto svarbą sveikatai ir saugumui, pateikiami esami tvarumo vertinimo metodai, siekiant atlikti holistinį vertinimą pagal tvarios renovacijos rekomendacijas.

Antrajame skyriuje pristatoma žiniomis pagrįsta sprendimų paramos sistema, skirta miesto urbanizacijai ir sprendimų priėmimui, integruojant daugiasluoksnį dirbtinį neuroninį tinklą. Šiame skyriuje aprašomas pastato renovavimo daugiavariančio projektavimo ir daugiakriterės analizės metodas (analizuojant pastato Kijive, Ukrainoje, rekonstrukcijos pavyzdį). Atlikta pasirinktos vietos daugiakriterė analizė, skirta emociniam ir racionaliam rinkos segmentui nustatyti pagal demografinius (vyrai ir moterys), psichografinius ir vartotojų elgesio kriterijus (pvz., laimingumas, liūdnumas, piktumas, nuostaba ir pulso dažnio kintamumas).

Trečiajame skyriuje nagrinėjamas minios sandaros poveikio vertinimas pagal segmentaciją (pagal amžiaus ir lyties), emocinius ir fiziologinius galimų pirkėjų rodiklius. Tai leidžia suinteresuotosioms šalims pasiūlyti racionalias, aplinkai nekenkiančių ir efektyviai energiją vartojančių pastatų alternatyvas. Atlikta atvejo analizė, kurios objektas – energiškai naudingas pastatas. Šiai atvejo analizei spręsti taikomas sukurtas daugiakriteris neurorinkodaros ir vaizdo įrašų reklamos analizė metodas. Atvejo analizės metu buvo išanalizuota daugiau kaip 200 mln. pojūčių duomenų. Šiame skyriuje pateikiami rezultatai patvirtinami pasauliniais mokslinių tyrimų rezultatais.

Esminiai mokslinio tyrimo rezultatai buvo aparti penkiose mokslinėse konferencijose ir publikuoti trijuose moksliniuose straipsniuose.

Notations

Symbols

E – weight of the comparative standard value;
e – repaying time of project;
f_i – monetary evaluation of a measuring unit of the i-th criterion;
g – number of quantitative criteria;
n – number of the alternatives compared;
P_i – total monetary expression of every quantitative criterion;
p_i – initial weight of the i-th criterion;
Qj – relative significance of each project;
q_i – final weights of quantitative criteria;
q_z – weight of the z-th quantitative criterion;
S_j – sum of values;
S_{+-j} – sums of weighted normalised indexes (sums of ‘‘pluses’’ S_{+j} and ‘‘minuses’’ S_{-j});
t – number of quantitative criteria;
V– total sum of quantitative criteria;
x_{ij} – value of the i-th criterion in the j-th alternative;
z_i (+;-) – indicates that a greater (less) criterion value corresponds to greater importance for a client.

Abbreviations

AEE – Automatic Emotion Recognition;
AI – artificial intelligence;
ANN – Artificial Neural Network;
ANS – autonomous nervous system;
AR – augmented reality;
AUs – Action Units;
BEST – Affect-Based Built Environment Video Analytics;
BMI – body mass index;
BREEAM – Building Research Environmental Assessment Method;
CASBEE – Comprehensive Assessment System for Built Environment Efficiency;
CO – Carbon Monoxide;
COPRAS – Complex proportional assessment method;
DBN – State building codes *(ukr. Державні будівельні норми);*
DGNB – German certification for sustainable buildings (*germ. Deutsche Gesellschaft für Nachhaltiges Bauen*);
DMM – Domain Mapping Matrices;
DSS – Decision Support Systems;
ECG – electrocardiogram;
ES – Expert System;
GPRS – general packet radio service;
HR – Heart Rate;
HRV – Heart Rate Variability;
IBI – inter-beat interval;
ICT infrastructure – information and communications technology infrastructure;
IDSS – Intelligent Decision Support Systems;
INVAR – Investment Value Assessments along with Recommendation Provisions;
KDD – Knowledge Discovery in Databases;
LCC – Life Cycle Cost;
LEED – Leadership in Energy and Environmental Design;
MCDM – Multiple-criteria decision-making;
NO_2– Nitrogen Dioxide;
$PM_{2.5}$, PM_{10} – particulate matter;
RSs – Recommender systems;
UMTS – universal mobile telecommunications system;
WLAN – wireless local area network.

Contents

Introduction

Problem Formulation

Sustainable renovation processes are more complicated and unsettled in terms of planning, execution and decision-making than the process of new building construction. The main idea is to realize the ongoing updated decision-making processes and make suggestions on how they can enhance.

Various research (e.g., Mouratidis, 2019; Nishant et al., 2020) suggest that a city's environment, such as public areas, buildings, land use mix, traffic flow and quality environment play a major role in the emotions of customers. Several researchers have analyzed human emotions, where subjective research by Roberts et al., (2019), Bower et al., (2019) at the same time, objective studies were established by Park et al., (2019), Labib et al., (2020). Numerous authors (e.g., Labib et al., 2020; Birenboim et al., 2019) have considered ways to make the physiological sense a core part of urban planning. But there is no analytical-recommended method of integration for sustainable renovation of a built environment, which would comprehensively analyze all life cycles of it and their factors. To overcome the gap in the existing literature will be proposed a framework for influencing the urban built environment on people's emotions and analysis of the connection between emotions and cognition that can provide a new perspective for the study of urban public emotions.

Relevance of the Dissertation

In urban design, emotion recognition and monitoring can play an important role, as the psychological impact of architectural decisions can have both negative and positive consequences. These new approaches may take into account the concepts of the smart city. The transition from “digital cities” to “smart cities” can be easily traced, as can the potential for spatial and urban planning (Çinar Umdu & Alakavuk, 2020). The ability to collect data in real-time and generate information about spatial processes opens new opportunities in the analysis of cities. The presented methodology can assist engineers and architects in the pre-construction decision-making process, helping them select options that could maximize the level of emotions they want to evoke in stakeholders.

Research Object

The object of the dissertation research is the process of creating an analytical-recommended method with a knowledge-based decision support system integrated with a multi-layer artificial neural network, proposing an approach that provides obtained data for making decisions and analyzing all life cycles of it.

Aim of the Dissertation

To develop the intelligent decision support system for the sustainable renovation of a built environment by applying a framework, set of steps and methods for the collection, measurement and analysis of data on physiological and emotional state, economic and social criteria in a human-centred built environment.

Objectives of the Dissertation

To achieve the goal of the work, the following tasks are solved at work:

1. To conduct an analytical survey of the most recent scientific research related to the dissertation.
2. To form rational solutions for the stability of the building at the stage of renovation, create a multicriteria analysis of building reconstruction based on the COPRAS method and use FaceReader software and practical use in a real project (case of study, Kyiv, Ukraine).
3. To perform a map of the physiological and emotional state of people based on the proposed neuro-decision matrix.

4. To integrate the affective attitudes of customers and their emotional and physiological state with the help of a decision-making neuromatrix (case of study, Vilnius, Lithuania).
5. To apply multi-criteria analysis of video advertising and neuromarketing to different consumer segments in the construction industry using neuro-decision tables. And investigate the levels of psychological comfort of end-users.
6. To reveal the benefits of integrating decision support systems, fuzzy systems and artificial neural networks in modeling rational solutions for sustainable buildings.

Research Methodology

Multi-criteria decision-making (MCDM) means that the crowd makes completely rational decisions. (Oses et al., 2018). In MCDM, decisions are usually made without the influence of the emotional state. Subjective research of human emotions in urban contexts has been conducted using qualitative methods i.e., self-reports, and interviews to record people's subjective experiences and explore their emotions.

Objective research of human emotions involved the use of biometric systems and methods such as heart rate variability, body temperature etc. (e.g., Kalantari, 2019; Ergan et al., 2019). More than 200 million data on physiological and emotional states and air and noise pollution were recorded and analysed.

A multi-criteria analysis of the built environment should be prepared using neuro-decision tables and values (e.g., investments, economic aspects, etc.). Thus, the scientific problem expands and deepens compared to previous studies. The research method will promote the development of monitoring human emotions in analyzing the influence of various design parameters on the emotional reactions of stakeholders. This project involves the development of a new set of methods using biostatistical and sensory technologies. The main idea is to integrate virtual space using sensor networks and technologies into the physical world. The results can be used as a modernized type of DSS and can provide a new perspective on current planning processes.

Scientific Novelty of the Dissertation

During the preparation of the dissertation, the following new results were obtained for the science of sustainable renovation of a built environment:

1. A system of recommendations and big data analysis were integrated into the provided research.
2. Multicriteria analysis and decision-making systems, biometric methods and systems are integrated into the process of intelligent and efficient building renovation.
3. A multi-criteria methodology for sustainable renovation of a built environment has been proposed and applied in practice.
4. The presented system has a decision support system integrated with a multilayer artificial neural network for urban development.

Practical Value of the Research Findings

The proposed approach and the developed decision support system also can be applied in the different fields of civil engineering, (e.g., construction, environmental, structural, transportation and water resources engineering etc.). The presented methodology can be practically used in two main contexts: scientific and commercial. At the same time, this methodology can assist engineers and architects in the decision-making process of designing a building environment before construction begins, and the implementation of proposed findings leverages significant gains over traditional construction techniques.

Defended Statements

The following statements based on the results of the current dissertation can serve as official hypotheses to be defended:

1. Sustainable development should be understood as the integration of environmental, social and economic indicators, and as the holistic creation of a safe, healthy and green built environment.
2. The developed system and recommendations for multi-criteria evaluation solutions for green and energy efficient buildings allow for determining the health class of buildings and assessing the risks in housing.
3. The developed recommendation system is an effective tool for risk management that allows homeowners, residents and other interested parties to evaluate emerging threats and reduce the possibility of them.
4. Developed method and system for sustainable renovation of a built environment enable stakeholders to solve housing issues more accurately, quickly and efficiently.

Approval of the Research Findings

The most important research results have been published in two scientific publications:

- Kaklauskas, A., Zavadskas, E. K., Seniut, M., ... & Velykorusova, A. (2019). An affect-based built environment video analytics. Automation in Construction, 106, 102888.
- Kaklauskas, A., Ubarte, I., Kalibatas, D., Lill, I., Velykorusova, A., Volginas, P., ... & Naumcik, A. (2019). A multisensory, green, and energy efficient housing neuromarketing method. Energies, 12(20), 3836.
- Kaklauskas A., Velykorusova A. & Skirmantas D. (2019). Development of the video neuroadvertising method and recommender system. VGTU Publishing house Technika, 10.20334/2019-013-M
- Velykorusova A., Zavadskas E.K., ... & Kaklauskas A. (2023). Intelligent Multi-Criteria Decision Support for Renovation Solutions for a Building Based on Emotion Recognition by Applying the COPRAS Method and BIM Integration. Appl. Sci. 2023, 13, 5453.

The results of the research conducted in the dissertation were presented at international fairs and scientific conferences in Lithuania:

- Fair of European Innovators in Cultural Heritage, November 15-16, 2018, Brussels, Belgium. Pitch presentations: Kaklauskas A., Velykorusova A., Cerkauskas, J., & Binkytė-Vėlienė A. ROCK Video Neuroanalytics and smart lighting system.
- The 17th Colloquium „Sustainable decisions in built environment“ and Meeting of EURO working group “OR in sustainable development and civil engineering”, 15 May 2019, Vilnius, Lithuania. Pitch presentations: Kaklauskas A., Velykorusova A. & Skirmantas D. (2019). Development of the video neuroadvertising method and recommender system.
- The 13 International Conference “Modern building materials, structures and techniques”, May 16-17, 2019, Vilnius, Lithuania. Poster: Kaklauskas A., Velykorusova A. & Skirmantas D. Development of the video neuroadvertising method and recommender system.
- The 9th Consortium Meeting & 3rd International Workshop, October 17-21, 2022, Tallinn, Estonia. Pitch presentations: Velykorusova A. Intelligent Multi-Criteria Decision Support for Sustainable Renovation Based on Emotion Recognition.
- 26th Conference of Lithuanian Young Scientists “Science – Lithuanian Future” Construction, section: Construction management and real estate, 13 April 2023, Vilnius Lithuania. Pitch presentations: Velykorusova A.

Intelligent decision support system for the sustainable renovation of a built environment.

The results of the research conducted in the dissertation were implemented in several projects:

- Horizon 2020. Regeneration and Optimisation of Cultural heritage in creative and Knowledge cities (ROCK), 2017–2021.
- Horizon 2020. Building Information modelling adapted to efficient renovation (BIM4REN), 2018–2022.
- Erasmus+ programme. Integrating education with human behaviour relevant to the influence of coronavirus and negative emotions in a built environment (MICROBE), 2020–2023.
- Erasmus+ programme. Integrating education with consumer behaviour relevant to energy efficiency and climate change at the Universities of Sri Lanka and Bangladesh (BECK), 2018–2021.

The Structure of the Dissertation

The dissertation includes an introduction, three chapters and general conclusions, a list of references, and a list of the author's scientific publications on the topic of the dissertation. There are also three Annexes.

The volume of the work is 132 pages, excluding annexes, 9 numbered formulas, 30 figures and 33 tables used in the text, 111 literature sources were used in writing the dissertation.

1

Theoretical Research on Knowledge Decision Support Systems for Sustainable Renovation

This Chapter analyses the process of sustainable renovation of a built environment, reviews different global intelligent decision support systems (recommender, advisory and expert systems, artificial neural networks, biometrics-based DSS, ambient intelligence and the Internet of Things-based DSS) and a brief explanation of their application.

The research results of this chapter are published in two author publications (Kaklauskas et al., 2019; Velykorusova et al., 2023;) and presented at two conferences (26th Conference of Lithuanian Young Scientists "Science – Lithuanian Future", The 9th Consortium Meeting & 3rd International Workshop).

1.1. Sustainable Renovation of a Built Environment

Renovation processes are complicated and contain a hazard of underestimating structural and social values in favour of internal and external remodelling, financing and productivity. Sustainable renovation of a built environment covers the renovation of existing buildings to improve their environmental performance with

sustainable methods and materials. The created structure can be implemented at different project stages and encourage the resolution of feasible advancement issues by supporting decision-making and communication among project partners. It can be used early in the process to characterise key performance criteria and then to compare/assess the pros and cons of selective improvement activities during the planning phase or after completion. An efficient process is required to create choices on recuperation measures. This chapter aims to review decision-making strategies used for building renovation. A stock of existing tools and strategies was examined during the literature review.

Renovation usually implies a reduction in energy consumption, making it a much better choice than demolition or new construction. The analysed studies showed that the actual lifespan of buildings exceeds the intended (Dwaikat & Ali, 2018), and the advantage of wear and tear (Canossa & Wuttke, 2020) is related to environmental impact and resource utilisation, including operation and production. However, smaller-scale studies focusing on, e.g., environmental impact can lead to methodologies that advance modern construction (Churkina et al., 2020; Mi et al., 2019). The created environment is a centre of socio-economic development, a major part of the European cultural heritage, and a regional and national identifier.

Renovation processes are more complicated and undetermined in terms of planning, execution and decision-making than the process of new building construction. They require knowing the qualities and disadvantages of an existing building. The lack of information can endanger the priceless heritage, e.g., its technical or artistic value, materials, low quality and shorter service life components. Additionally, there is a chance that cultural, social and structural values may be dismissed in favour of viability or due to financial reasons. Such intangible aspects of the anthropogenic environment are often perceived as indistinct and complicated. More supporting tools and information are required to form accurate, synthesised options in a reconstruction project which will allow for the regulation of different desires, demands and values in various important categories, such as ecological and energy conditions, financial and engineering indicators, and the cultural and social states (Mirarchi et al., 2020).

The main idea is to realise the ongoing updated decision-making processes and make suggestions on how they can be enhanced to better deal with important aspects of sustainable development. *Key issues:* DSS based on text analytics and production; Data sharing as a primary element in an intelligent decision support system; Integration of remote sensing into DSS; Integration of data analytics and Decision Support Systems; Artificial neural networks in DSS and biometrics; Biometrics-based Decision Support Systems; Surrounding Intelligence and the Internet-of-Things-Based Decision Support Systems and other intelligent Decision Support Systems.

There is a small number of sources that describe the decision-making process for upgrading. Reconstruction is considered from a wide perspective, inclusive of commercial and residential buildings owned and operated by municipal or private institutions. Attention is focused on the preliminary investigation stage, that is, the stage at which the main goals and direction of the repair are decided and determined.

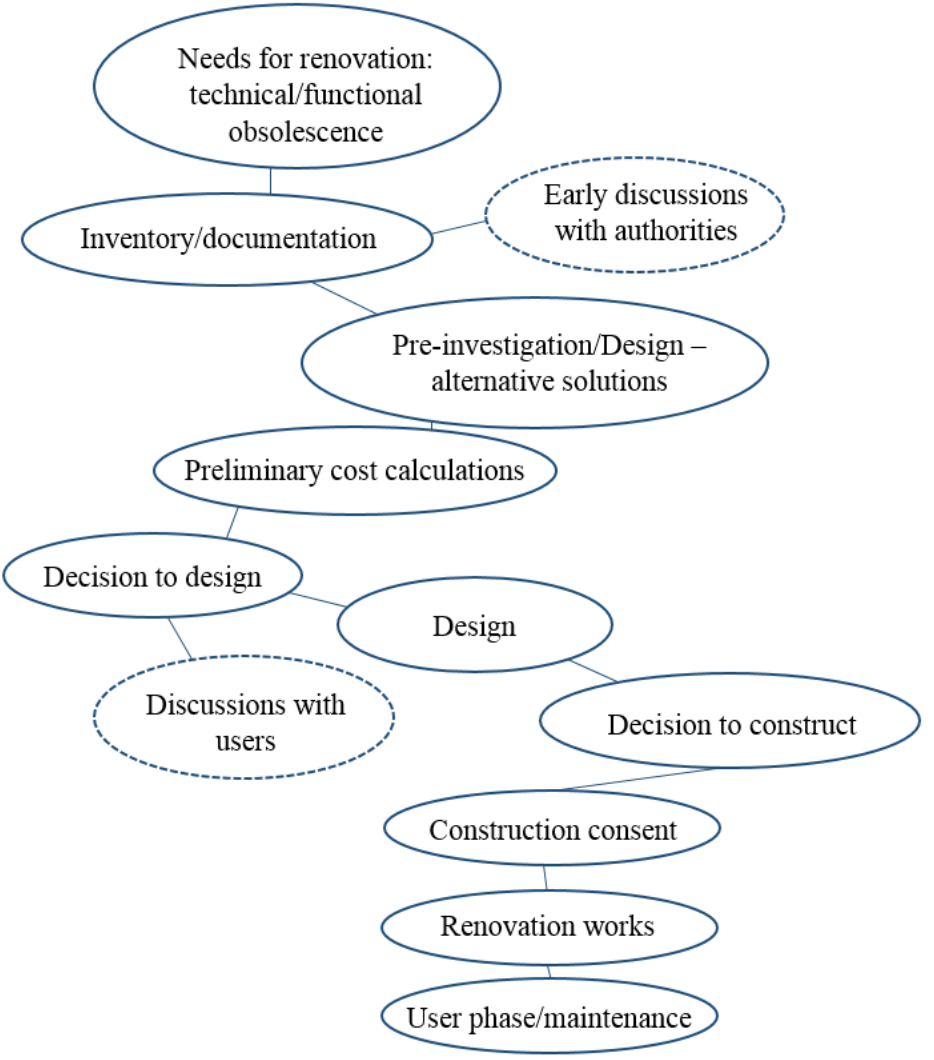


Fig. 1.1. Phases of renovation process (elaborated by the author)

Generally, the retrofit process follows roughly the same steps as new construction (preliminary design and research, construction work, putting into operation and end-use). Though, the upgrade phase should pay more attention to the preliminary investigation stage to obtain good results. In the developed framework, it is noticeable that reconstruction processes often have poor documentation construction conditions.

Previous research is a wide term which involves collecting different types of information, inventorying the condition of a building, and setting documentation on a building before making changes. According to Costin et al., (2018), the preliminary investigation has to contain a survey of the construction and its surroundings (e.g., general impressions, local context, technical condition, service status), property records, user requirements documents, contracts relating to the building, history (year construction, previous updates/changes, previous colour schemes), as well as schemes and drawings (e.g., construction and historical drawings, photographs, sketches). The previous research should also be objective and not contain subjective assessments.

1.2. Worldwide Methods for Sustainable Renovation of a Built Environment

The point of the literature review is to look at what existing instruments may be utilized for a more comprehensive approach within the decision-making handle for updates. This section consists of a literature review of previous articles examining and comparing building appraisals. The studied methods describe several values, separated into structural, cultural, social, historical, environmental, specialized and financial values, along with the quality of forms. A review of previous research on building renovation has shown that the efforts made today have not completely resolved the problems of sustainable development. Then there is the question of the overall aims of sustainable development in the context of building renovation.

To address this issue, research uses a multidimensional approach, including the study of existing methods and methodologies of assessment and literature review. The point of departure is to build environmental assessment methods.

Existing methods and tools were studied and formulated on a limited literature review and internet browsing. The literature review gives an outline of existing instruments and techniques that can be utilised to form decisions within the renovation process based on the appraisal of green buildings. These strategies have been explored for aspects of sustainable development, such as natural, specialized, architectural, cultural, social and economic.

There are a large number of worldwide instruments and strategies to evaluate or classify buildings according to environmental friendliness or sustainability in the analyzed studies (e.g., Omer & Noguchi, 2020; Ding et al., 2021). Some are used all over the world; others focus on regional, national or local characteristics. The most recognized and widely used valuation methods are the American LEED (Leadership in Energy and Environmental Design), BREEAM (Building Research Environmental Assessment Method, the first commercially available building assessment tool introduced in 1990 in the UK), DGNB (the German certification for sustainable buildings, Deutsche Gesellschaft für Nachhaltiges Bauen) Green Construction Tool, CASBEE (the Comprehensive Assessment System for Built Environment Efficiency, widely used in Japan). At the EU level, two projects are ongoing within the framework of the Seventh Framework Programme, OPEN HOUSE (2012) and SuPer-Buildings (2012).

LEED scheme. LEED is the most acknowledged environmental assessment scheme for buildings. The version LEED-NC v2.2 for new construction is set-based on credits and prerequisites. Each credit covers one of the following aspects (Alapati & Kavuri, 2020). This includes water efficiency, sustainable sites, environment and energy, resources and materials, natural quality of spaces, design and development. Each credit is awarded one point if the requirement is met, except for the Energy Efficiency Credit and the Renewable Energy Credit, which earn a certain number of points for each credit based on how much efficiency is achieved. There can be gotten up to 69 points. Depending on the points received, there are four levels to which certified buildings can claim: Certified (40-49 points), Silver (50-59 points), Gold (60-79 points) and Platinum (80+ points).

Two approaches exist to assessing energy characteristics in construction, known as Credit EA1-Optimize Energy Performance. The first is the Prescriptive Compliance Pathway, which enables projects to earn 4 points if they meet the ASHRAE Advanced Energy Design Guide for Small Buildings 2004. Another approach is to simulate the energy of the whole structure, allowing 10 points when the building shows an improvement in energy cost compared to the normalized building. In both approaches, the evaluated building must meet the minimum efficiency level of 2 points. This equates to a 14% improvement on any level of LEED-NC certification (Alapati & Kavuri, 2020). Building energy modeling requires the use of a modeling program that is capable of performing thermal analysis according to the specifications outlined in ASHRAE 90.1-2004 (Erbe et al., 2021), better known as the Performance Rating Method (PRM). Energy rating can be estimated according to the annual energy costs to operate the proposed building compared to the average annual operating costs of the base building using actual energy purchase tariffs or average state energy prices as shown below.

$$\% \text{ of improvement} = 100 \times [1 - (\text{Cost of Proposed/Average Cost of Baseline})].$$

BREEAM scheme. BREEAM is a generally utilized natural evaluation plot for buildings within the United Kingdom (available online: www.breeam.com). Whereas this is often a voluntary standard, energy productivity appraisal takes the UK Building Directions as a benchmark for evaluating efficiency gains. The latest adaptation for office buildings – BREEAM Workplaces 2008. Similar to the LEED credit rating system, BREEAM Workplaces 2008 characterizes credit categories corresponding to a building's natural impacts, including governance, well-being, vitality, transportation, water, materials, waste, land use and environmental pollution (Harisankar & Rakesh, 2021).

The overall score is based on available credits, the number of credits earned in each category, and a weighting calculation. High operational characteristics of the building can be categorised as Unclassified (30), Pass (≥30), Good (≥45), Very Good (≥55), Excellent (≥70) and Outstanding (≥85). A minimum number of credits must be earned in each category.

The BREEAM vitality rating is called Credit Ene 1 – CO_2 Emissions Reduction. This permits to the attainment of up to 15 credits when the evaluated building illustrates an advancement within the vitality and effectiveness of texture and building administrations. The building's vitality execution is displayed as a CO_2-based file. The amount of credit received is established by comparison of the building's CO_2 list with the Energy Performance Certificate (EPC). The Energy Performance Certificate is shaped on the premise of the National Calculation Methodology of the United Kingdom (NCM). It gives a viability rating for a building from A to G, where A is the most efficient and G is the less effective. In order to rank resources, needed to form two building models: real building and supporting building. The performance at this point is determined as the fraction of CO_2 emissions from the actual building to the standard outflow, which is estimated by applying the prescribed increase; calculating CO_2 emissions from a control building (Harisankar & Rakesh, 2021).

1.3. Global Intelligent Decision Support Systems for Sustainable Renovation of a Built Environment

Buildings account for around 20–40% of energy consumption in developed countries. Over the last decade, various global-scale organisations have contributed critical assets to finding solutions in the attempt to rectify the situation, emphasising building renovation forms to reduce energy consumption and carbon footprint (e.g., Tanrıkul, 2020; Asmone et al., 2019). Several ways are available for ascertaining and scaling the potential of a building’s vitality enhancement through remodelling. This can be done by focusing on climate change, energy supply security, natural or life cycle effects, the building’s usefulness, spatial quality, indoor

climate etc. The sum of all these causes can move the reason for renovation towards the goal of universality, which requires the improvement of comprehensive scenarios for major repairs.

Building renovation projects are challenging, given their multifaceted nature and many different partners. The DSS suggested in this work was mainly inspired by the challenge of distinguishing the objectives and criteria of a sustainable renovation process and related approaches, as well as the aim to address the complexity of making renovation scenarios with many different partners. It is vital to assess the components influencing the external and internal environment. Subsequently, choosing the most effective arrangement is seen as a multidimensional problem.

1.3.1. Recommender, Advisory and Expert Systems and their Integration with Decision Support Systems

It is well known that advisory systems and recommender systems are frequently utilized synonymously within the literature. The recommender system (e.g., Pinto et al., 2018; Guo et al., 2020), the advisory system (Al Amri & Marey-Pérez, 2020) and the expert system (Ding et al., 2021) are integrated into the decision support systems (DSSs).

Recommender systems (RSs) – instruments and methods that give counsel for user-friendly things. The exhortation given is planning to back clients in numerous decision-making forms, such as perusing books, selecting the playlist, what to purchase, and what motion pictures to observe etc. Recommendation systems have been demonstrated to be an important apparatus for Web clients to overcome data over-burden. Zhao et al., 2019 mentioned that creating recommender systems is multidisciplinary work including specialists in such areas as human-computer interaction, fake insights, data innovation, measurements, information preparation, responsive client interface, choice bolster frameworks, showcasing, or customer conduct.

Different strategies proposed Zhao et al., (2019) as a base for recommender systems:

Demographic: provides advice based on a user's demographic profile.

Collaborative: generates suggestions using only rating information for different users.

Content-based: generates offers from two sources – product-related features and user ratings.

Community-based: recommends items based on user friend preferences.

Knowledge-based: offers products based on the needs and preferences of the user.

Hybrid recommender systems: consists of a combination of the above techniques.

The methods mentioned above have the following disadvantages, including the cold start problem for shared systems and the bottleneck of knowledge-based approaches. A hybrid system of recommendation is a combination of several methods together to gain a certain synergy between them. Common, existing recommended methods with little knowledge, are used very often, and basic messages when reviewing/commenting on items for users. Other methods allow to stay away from knowledge but using them casts doubt on users or objects, limiting or relating to user actions. Besides a general classification, the data used by Recommender systems relate to three types of entities: transactions (i.e., user-object relationships), objects and users.

Some DSS can recommend choosing an alternative and explaining the rationale behind this advice. A knowledge-oriented DSS can offer or suggest actions to executives. This decision support system is a personal computer system that has specialized problem-solving expertise. At the information search stage, intelligent search approaches and intelligent decision support systems can sift through a wealth of information available on the Internet to provide suggestions that suit users' taste, personality, budget, pre-selection, or selection of customer groups (those who has a similar lifestyle, profiles and behaviours).

Expert systems and advisory are combinations that create problems that mimic human specialists in specialized science. These systems have been used when people know what works for people and when they are used, they can be used by a computer to evaluate alternative problems that relate to true knowledge. Advisory systems do not apply decisions, and on the contrary use, decision-makers to manage decisions using the most recent human user (Ding et al., 2021).

Advisory systems help manage the decision-maker through the decision-making process, leaving the final decision to the user. A mindful manager works in collaboration with an advisory structure to discern issues to address and re-evaluate possible arrangements from unstructured arrangements. Laage-Thomsen (2021) said that advisory systems offer assistance synthesize information and encounters related to a particular issue circumstance for the client; be that as it may, the decision-making specialist and duty rests with the client, not the system. Advisory systems are developed to support decision-making in situations where there is no single correct answer. Collaborative advisory systems that provide intelligent answers to widespread problems are more valuable and important in unstructured situations than expert systems that provide correct answers to a very limited number of issues.

Due to the organisational need for intellectual support for solutions, expert systems were developed through the integration of artificial intelligence (AI) and knowledge management techniques. In contrast to expert systems, the proposals

of advisory systems do not continuously speak to the conclusive reply to an issue. Instep, they show decision-making tips as a portion of an iterative problem-solving preparation.

1.3.2. Data Mining as an Important Component of Intelligent Decision Support Systems

Data mining includes the extraction of imperative data to assist in choice making of a choice bolster framework. Integration of information mining and choice bolster frameworks (DSS) can help resolve various issues of modern times. Data mining provides information from diverse viewpoints, making it a valuable and vital component in planning choice back frameworks.

Data mining handles changes data into information through instruments within the areas of computing insights, database innovations, machine learning, nonlinear flow, preparing to demonstrate, demonstrating and related disciplines. Information makes a difference you analyze commerce issues from diverse viewpoints, counting dimensionality diminishment, co-occurrence and relationship, classification and clustering, estimating and relapse, inconsistency location, and altering the examination (Guo et al., 2020). Prescient bits of knowledge from information recovery can be advanced and utilized through real-time examination and decision-making sciences, as well as human-based exemptions or objectives administration, to pick up current information. Tools that empower you to convert crude information into substantial prescient thoughts are collectively alluded to as decision-support tools. It can be divided process of knowledge discovery in databases into nine steps:

1. Creating and understanding the application space. Those responsible for the extension should obtain it and describe the end user's goals and the environment in which the disclosure will occur.

2. Making and selecting information sets on which disclosure will be performed. This incorporates finding out what data is accessible, getting extra essential information, and after that coordinating all the information for the information revelation into one information set, a count of the properties to be considered for the process.

3. Cleansing and pre-processing. In this organise, information unwavering quality is upgraded. It incorporates information clearing, such as taking care of lost values and evacuation of commotion or outliers.

4. Data transformation. At this step, the generation of higher information for information extraction is ready and created. This strategy includes measurement reduction and quality change.

5. Choosing the fitting Information mining errand. Choose which sort of Information mining to utilize, for illustration, clustering or classification. This generally depends on the Knowledge Discovery in Databases (KDD) objectives, additionally on the past steps. There are two main objectives in Information mining: forecast and portrayal. The expectation is regularly alluded to as directed Information mining, whereas graphic Information mining incorporates visualization and unsupervised angles of Information mining. Most information mining strategies are based on inductive learning, where the demonstration is developed unequivocally or certainly by generalizing from an adequate number of prepared examples.

6. Selecting the Information mining calculation. Having the technique can be chosen the strategies. It organises and incorporates selecting the particular strategy to be utilized for looking at patterns.

7. Utilizing the Data mining algorithm. At this stage, it may be necessary to perform the calculation a few times until the full result will be gotten, in this case by changing the algorithm's control parameters, including the smallest number of occurrences in one leaf of the selection tree.

8. Assessment. In this arrangement, assessed and translated the mined designs (rules, unwavering quality etc.), with regard to the objectives characterized within the, to begin with, the first step.

9. Utilizing the found information. Join the information into another framework for encouraging activity.

Data mining serves as the essential reason for finding designs among huge volumes of information and changing information into more refined/actionable information. This method utilizes particular calculations, measurable examination, fake insights & database frameworks. It points to extricating data from gigantic information sets and changing over it into a justifiable structure for future use.

Next, can be compared the list of commercial and free data modelling tools.

Rapid Miner. It is one of the leading prescient examination frameworks created by Rapid Miner. Written in the JAVA programming language. Rapid Miner gives an environment coordinated for profound learning, machine learning, content mining and prescient investigation. The tool can be used for more than an infinite number of applications, including commercial applications, preparation, instruction, application improvement, and prediction. Rapid Miner provides a server on private/public and local cloud bases. Rapid Miner is provided with template-based systems that ensure efficient migration with fewer errors (Şentürk, 2020).

Orange. Orange could be a culminating program suite for data mining and machine learning. It best helps with information visualization and can be a component program. Orange is written in Python language. Because Orange software

is component-based, its elements are named “widgets”. Its widgets array from data preprocessing and visualisation to algorithm evaluation and predictive modelling (Ratra & Gulia, 2020).

Weka. The so-called Waikato Environment may be a machine learning computer program created at Waikato College in New Zealand. It is best suited for predictive modelling and information exploration. Weka contains visualization and calculation tools that back machine learning. This program is written in the JAVA programming language. It supports key information mining assignments counting preparation, data mining, regression and visualisation, and works on suspicion that information is accessible within the frame of a level file (Camungao, 2020).

Oracle Data Mining. An element of Oracle Advance Analytics, Oracle's data intelligence application offers amazing intelligence computing for data classification, expectation, and specialised analytics that enable reviewers to analyse experience, provide forward forecasts, focus on the best stakeholders and distinguish between cross-selling and extortion. The calculations planned for interior ODM use the potential qualities of the Prophet database. The SQL data mining feature can extract information from database templates, views, and tables (Gul et al., 2021).

1.3.3. Integration of Data Analytics and Decision Support Systems

Big data require prior studies to infer relevance and potential respect for vital purposes, as they do not provide valuable data by themselves, as these data sets were not unique to planning for decision-making reasons or explanatory. In addition, this issue will require changes in the tools and models used to improve procedures, including information verification and collection. An illustration could be how stakeholders can be served through social media while their reactions and actions are tracked to create more personalized admins for them since these customers are both buyers and creators of data (Hamilton, 2021).

Keenan & Jankowski (2019) characterize analytics of big data as innovations (e.g., tools of data mining and database) and methods (exposure strategies) that the company can use for large-scale analysis, complex information for different applications, expecting to increase the reliability of execution in different dimensions.

Recently, various machine learning methods (Radial basis functions, Neural networks, Geospatial predictive modelling, k-nearest neighbours, Naïve Bayes and Support vector machines), open-source prescient explanatory devices (Rapid

Miner, Orange, Oracle Data Mining, Weka) and commercial prescient explanatory apparatuses (KXEN Modeler, IBM SPSS Modeler, Pervasive, STATISTICA, TIBCO and SAS) were used for analytics in predictive times.

Understanding the core components of a Decision Support System is also critical to identifying zones where steps will need to be taken to address the challenges presented by Big Data. Generally, the Decision Support Systems include the following major components:

- Data Source(s), this element characterizes the gathering of information from different sources, both from other infrastructures or stand-alone databases.
- Software System, this element characterizes the set of instruments required for the investigation of information and giving the yield to the choice producers.
- User Interface, this element characterizes the genuine set of screens and sees that the client is interatomic with to reach a choice. Most are graphically based and deeply intuitive to enable the energetic management of voiced information (Lokhande & Khare, 2015).

Islam et al., (2017) proposed a system where points coordinate the major elements required to guarantee the quality and pertinence of information being analyzed inside a DSS. This cycle of information preparation, analysis and decision-making also uses knowledge fragments built up over time based on past choices and positive propositions and stores them in a repository that organisations can tap into to obtain prior information when needed.

The system covers four primary components, which incorporate such as decision-making, data analytics, data preparation and an information repository. These elements are united to move information from a rough outline to meaningful and important data used in incentive exams and re-selection exercises. In extension to use for future analytics cycles (Hamilton, 2021). Islam et al., (2017) describe the framework for Effective Big Data Analytics for DSS.

Data Preparation. The data preparation element obtains input data from conventional information sources, e.g., databases or value-based systems, either receive information from information streams, such as information from versatile gadgets or social media. Quality channels ensure that either conventional or big data sources are networks use of variables of quality like metadata, relevance, accuracy, completeness and usability. The reason for such an action is to raise the fundamental information quality used for examination. The second part of this component is the coordination of important information, which selects if other sources of information can be coordinated with the screened information to make progress in its investigation or to transfer them to the analytical department. The

final part is planning information for examination, which performs any necessary changes or clean-ups required to produce information ready for examination.

Data Analytics Component. The data analytics component obtains clarifier and organised information from the preceding element to perform the desired transparent explanatory approach. This requires choosing a relevant calculation based on the numerous external components important to the release space. Thus, this element will require the classification of numerous pre-calculations based on the target trading space, which expands to recognize the needs of important external components. This would guarantee that the suitable expository calculation is chosen that best fits the issue space.

Decision-Making Component. The decision element obtains a collection of suggestions and is displayed to the choice maker during the exploration phase of the decision handle. This stage requires human interaction with the framework to see the results of the explanation and suggestions, at this stage moving to the planning stage, the choice maker will choose the most suitable components for him to propose options, and finally, with these choices in place, decision-maker can choose the leading a choice that meets commercial objectives and is supported by relevant offers and information. This requires the DSS to have an intelligent interface dashboard subsystem capable of displaying suggestions from data analysis components, allowing decision-makers to direct and organise options as needed.

Insights Component. The insights element guarantee that choices are put away into the system to supply the required criticism for future cycles of decision-making, information planning and information analytics. This will require the decision support system to be connected to a knowledge base repository that can direct, organise and sort bits of knowledge appropriately for further use within information curation and data analytics удуьутеі. Such a connection must be somewhat computerized to ensure that selection cycles occur and decision-makers are concerned about cases of recognized wasteful aspects based on previous recommendations or selections.

1.3.4. Artificial Neural Networks in Decision Support Systems and Biometrics

Artificial Neural Network (ANNs) strategy can be called a promising and extremely effective choice for characterizing the best management (e.g., Miguel et al., 2019; Çatal & Saplioğlu, 2018; Li et al., 2020). ANN enables providing decision support and modelling complex nonlinear relations. It is motivated by the structure of biological neural systems and starts with arbitrary weights to the included factors and then modifies these weights in forward and backpropagation modes to reduce the difference between true and predicted results. Neurons inside the hidden layer exchange weighted input information for output using a nonlinear

exchange operation (Gou et al., 2020). Neural networks (NNs) are characterized as extremely parallel processors that seek to protect test knowledge and extend its performance. They recreate the human brain with the expectation of obtaining experimental evidence in preparation for learning, and interneuronal associations (neuronal connections) are used to store information.

Muralitharan et al., (2018) suggest ANNs for energy demand optimization and prediction. For example, Li et al., (2020) applied artificial neural networks to economic and energy evaluation of the best renovation actions. Deb et al., (2018) utilized artificial neural networks to survey conceivable ventilation, and heating and discuss energy conditioning investment funds in cases of 56 modernized office buildings. Muralitharan et al., (2018) proposed a neural network-based subsystem that provides personalized smart home administration. Generally, Artificial Neural Network models are established by node characteristics, network topology, learning rules and training type, which, moreover to specifying an initial set of weights, specify how these parameters or weights should be adapted in such a way that the performance of the networks is the best. As specified by Diamantopoulou et al., (2015), procedures for the design and specification of learning algorithms are widely discussed and therefore add value to many types of research development.

Face recognition with thermal pictures has started to pull in noteworthy consideration steadily since the light of the environment would not influence the acknowledgement execution. In any case, the acknowledgement execution of conventional thermal confront recognizer is still deficient in the viable application (Ilikci et al., 2019). Kortli et al., (2020) display a novel thermal face recognizer utilizing not as it were warm high-lights but moreover, basic facial geometric highlights which would not be affected by haircuts to make strides in the acknowledgement execution. A three-level forward backpropagation neural mechanism is connected as a classifier. Conventional thermal facial recognition devices used bypassed data about blood vessel geography, such as thermograms, as backlight. To overcome this disadvantage, the proposed thermal face recognizer can use not only the bypass data but also the coordinate data of the geography of blood vessels, which are special for each individual. In addition, the recognition efficiency of the proposed thermal reflections would not decrease in case of displacement of breathing of the nose, hair on the frontal bone or blinking of the eyes. The proposed illuminators are more viable than conventional thermal illuminators, and the implementation of thermal face recognition verification has achieved significant success (Kortli et al., 2020).

Human support is essential when investigating information as well as making decisions. Computers are not yet able to supplant human skills and abilities. Visual intelligence data mining makes a difference by personalizing information by displaying and visualizing it in graphical form. Visualization gives a person the

opportunity to receive and analyze information, draw conclusions and make a decision. Artificial neural networks can perform clustering, classification, prediction, function approximation, optimization and many other possibilities.

1.3.5. Biometrics-based Decision Support Systems

Biometric-based systems are special that combine different techniques, concepts, and strategies from numerous ranges of the natural and social sciences, in specific picture handling and design acknowledgement, virtual environmental design and engineered biometric data generation, dispersed and avatar framework design, human-machine interaction, coordinates knowledge-intensive system design, communication, and psychology. In numerous applications, the investigation of biometric information (in specific, the investigation of biometrical information) is combined with the reverse issue, that's, the union of biometrics information (Patta, 2019).

An essential inspiration for using biometrics is effortlessly and more than once recognising a person to empower a mechanized activity based on that acknowledgement. The reasons for needing to consequently recognize people can shift an incredible bargain; they incorporate lessening mistake rates and moving forward precision, diminishing extortion and openings for circumvention, diminishing costs, progressing adaptability, expanding physical security, and progressing comfort. For case, nearly all advantage and privilege programs that have utilized biometrics have done so to decrease costs and extortion rates, but at the same time, comfort may have made strides as well (e.g., Patta, 2019; Ang & Seng, 2021).

Tsuei et al., (2021) created a biometric evaluation model for biometric administrators to improve their performance. Results demonstrated the particular process of improving biometrics and the impact weights of biometrics for performance evaluation under full consideration of impact criteria by adopting a hybrid Multiple-criteria decision-making model. All biometrics research studies focus on the factors and procedures that will affect biometrics, and whether they will have a negative or positive effect. Even so, the decision-making process needs the contemplation of multiple criteria with feedback and interdependence in reality. The interrelationship and influential weights among biometric criteria have also rarely been investigated. That is why this question will be considered in this work.

1.3.6. Ambient Intelligence and the Internet of Things-based Decision Support Systems

The concepts of the IoT and ambient intelligence (AmI) and their interface for selecting reverse frameworks are briefly reviewed. Ambient intelligence explores

electronic situations that are responsive and sensitive to people's daily activities. Concurring to Gams et al., (2019) encompassing worldview is categorized by achievements and frameworks that are implanted, personalized, contextual, expected and universal. In the conclusion of Duric et al., (2021), the Internet of Things alludes to the interrelationship of curiously identifiable implantable computing gadgets within the existing web framework. Latorre-Biel et al., (2018) outlined a Petri net model of a smart production line from an Industry 4.0 perspective as virtualization for decision support. Brodsky et al., (2019) examined a decision support system for counting information, reusable components, information, control factors and decisions to drive the environment to intelligence. In any case, there is a need for an excellent depiction of framework-based quantitative modelling approaches and patterns, emphasizing the exploration and elaboration of framework needs, the use of selective exposure strategies and systems evaluation.

Recently, the topic of an intelligent environment, which is also named ambient intelligence, has been intriguing. The term ambient intelligence is referred to the installation of devices and sensors in a room or environment that naturally responds to the needs of customers in that environment. The user hides the sensors so they are part of the environment and do not require any connection to the devices. These devices can be smaller phones, thermometers, motion sensors, cameras or any gadget that can transmit data to a robotic control system about the state of the environment (Lashmi & Pillai, 2019). AmI is depicted as a demonstration of interaction in which people are surrounded by smart gadgets, know about their proximity and privacy settings and are able to adapt to the needs of the user through implantable innovations. Ambient intelligence is linked to intelligent manufacturing to support industrial communication between components involved in generation preparation, manufacturing information stream and progressed apparatus. The shareable data ought to be reasonable between clients and ambience. The following highlights distinguish how AmI can consolidate and assist Intelligent Decision Support Systems. During preparation for production, part of the data is clarified by administrators (Bivard et al., 2020).

- Data can be within general input, including spoken dialect and handwriting using gestures and touch screen panels. Innovations that may offer assistance in data collection at this stage may include computerized writing or manuscript and discourse confirmation.
- The data may be within the shape of perceptions and encounters approximately the statute and issues within the handle and from the environment. Mobile phones, remote handheld gadgets, tablets, wearable gadgets such as consoles, clothing, information gloves, glasses or augmented reality (AR) can be used to record data during perception or participation. Biometric authentication and verification can offer administrator assistance in recognizing and recording observed or experienced data.

- The data may be within the framework of an administrator's request. Assuming that the administrator has the least information about data (no data name, approximate territory or organisation data), cellular communication and interaction innovations for instance general packet radio service (GPRS), wireless local area network (WLAN), the Universal Mobile Telecommunications System (UMTS) and Bluetooth can help the administrator get an overview of the data. The collaboration environment is the hub for delivering these administrative responsibilities.
- Data may well have any needs, and be unstructured, either sending materials from a single administrator or in a collaborative setting. For unstructured data, an interoperability mechanism and communication framework handle the assignment of a data-sharing strategy.

Analytical methods of the decision-making process progress inadequacy as well as complexity. In any case, in some cases, it is unlikely to use complex surveys under time-constrained conditions. Inserted analytics devices given by AmI can offer a successful and commonsense implies for real-time choice-making and crises. For this reason, inserted gadgets can be actualized in production tools and devices to record and gather all vital data, on the other hand, decision-makers can be prepared with embedded smart gadgets to gather online information and analyze structure setup. (Munir et al., 2019). In a smart manufacturing environment, decentralized Decision Support Systems can be used and controlled by decentralized manufacturers of choice. On such occasions, neighbourhood decision-makers need a customized Decision Support Systems framework based on their information, work environment, and decision-making mandates. Ambient intelligence can facilitate the personalization of IDSS for different levels of customers and decision-makers.

1.3.7. Other Intelligent Decision Support Systems

Fuzzy Logic for Intelligent Decision Support. Fuzzy logic amplifies decision support by allowing the representation of inputs or factors within the choice issue way the way that people reason approximately for them. Decision-makers frequently experience issues in which inputs are uncertain or questionable. For illustration, the climate may be sunny, mostly sunny, generally cloudy, or cloudy. By comparison, Boolean logic could be a framework of typical rationale that administers consistent capacities on a computer and is based on a binary framework of (completely false) and 1 (totally true). Fuzzy logic empowers a representation of instability by permitting input to have an extent of values between (totally false) and 1 (totally true).

Fuzzy logic is more flexible in representation so that the decision-maker includes a run of choices and is free to assess the values of inputs. There's no characteristic structure in fuzzy logic, so nonlinear connections can be typified normally without earlier arranging. As unused data gets to be accessible, values can be refined and modified effortlessly, giving the decision-maker a normal way to bargain with vulnerability. Fuzzy logic gives a way to speak to rule-based practices, such as information from a master, so that mastery can be captured and given to the decision-maker at the fitting time (Rodríguez et al., 2020).

Fuzzy logic can moreover be combined with NN so that the elucidation of decision factors is clearer. For illustration, input factors can be depicted with three values such as most extreme, least, and most likely esteem. These are characteristic dialect portrayals that improve the capacity of a decision-maker to communicate spatial information to a show and translate the yield.

Expert Systems for Intelligent Decision Support. An Expert System (ES) may be a computer framework that endeavours to illuminate issues that would ordinarily be illuminated by a human master (Medsker & Bailey, 2020). Frequently the term ES is utilized to depict a framework that inserts the insights of one or more identified human specialists. The framework originator must think about how the human master makes the decision and after that implant that information into the computer framework (Yan et al., 2019). The components of an ES are shown in Figure 1.2.

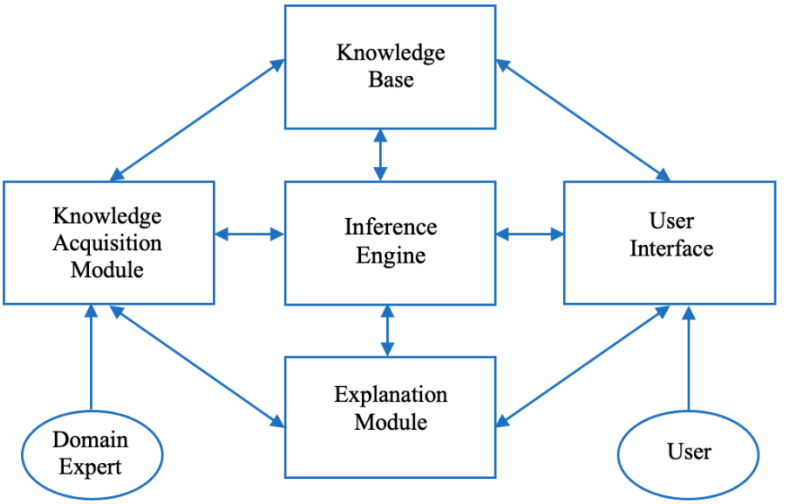


Fig.1.2. Components of an expert system (Yan et al., 2019)

It shows a domain expert who gives information to the Knowledge Acquisition Module. That information is encoded within the information Base, as a rule as a portion of the improvement handle. The client or choice producer enters the framework through an interface. The client may at that point specifically get to the KnowledgeBase for past cases, or the Inference Engine to gather from past cases to a modern case. The client may "drill down" for a clarification of the deduction from the Explanation Module. The ES in this way serves to capture, collect and gather information from a spacious master and pass that expertise to a decision-maker.

1.4. Conclusions of the First Chapter and Formulation of the Dissertation Tasks

Based on the conducted literature review, the following conclusions and main tasks can be drawn:

1. The analysis of literature in this field showed that there is no analytical-recommended method of integration for sustainable renovation of a built environment, which would comprehensively analyze all life cycles of it and factors such as pollution, economic, and physiological indicators of the crowd (by age groups and gender), emotional (happiness, sadness, surprise etc.) and physiological (heart rate variability) states.
2. All over the world, there is a sufficient amount of research that is applied to assess the impact of the city on human emotions, both from a subjective and objective perspective, including the development and application of a variety of methods and tools over the past decades. Analysed methods of sustainability certification systems (eg. BREEAM, LEED) related to sustainable renovation, can be used for the integration of emotional states into these systems for their further improvement. The main categories of BREEAM assessment and existing methods of sustainability assessment were analyzed to provide a more holistic perspective in the assessment in accordance with the recommendations for performing the sustainable renovation.
3. With the growing interest in new applications that integrate artificial neural networks, knowledge-based decision support systems and fuzzy systems, in dissertation will be presenting an integrated system where the decision support system is based on the integration of a multilayer artificial neural network for urban development.
4. After studying the different strategies related to sustainable built renovation, were identified numerous shortcomings and limitations in the approaches and methods used by various authors. The presented research

could justify its contribution to overcoming the limitations of previous scholars by proposing a framework for the influence of the urban built environment on people's emotions and a more in-depth analysis of the connection between emotions and cognition can provide a new perspective for the study of urban public emotions.

5. The proposed model requires the development of an integrated decision support system based on multi-criteria analysis. The creation of an automated system would allow for assessing the level of efficiency of building renovation, assessing the current situation in the real estate sector based on past data and conclude changes in the housing sector.

2

Development of a Method and Intelligent Decision Support System For Sustainable Renovation of a Built Environment

This Chapter details the methodology used in the dissertation. It includes a description of the selected building renovation strategy, a detailed description of the renovation object, data collection tools, the data collection procedure, and the approach to data analysis used in the study. It also describes the characteristics of organisations and respondents who participated in the experiment.

The research logic, applicable methods and interconnections of dissertation parts are reflected in the research design scheme (Fig. 2.1).

The method for sustainable renovation of a built environment using automatic emotion recognition was used in two international Horizon 2020 projects: Building Information Modelling Adapted to Efficient Renovation (BIM4REN), Regeneration and Optimisation of Cultural Heritage in Creative and Knowledge Cities (ROCK).

The research results of this chapter are published in two articles by the author (Kaklauskas et al., 2019; Velykorusova et al., 2023) and presented at three conferences (Fair of European Innovators in Cultural Heritage, The 9th Consortium

Meeting & 3rd International Workshop, 6th Conference of Lithuanian Young Scientists "Science – Lithuanian Future").

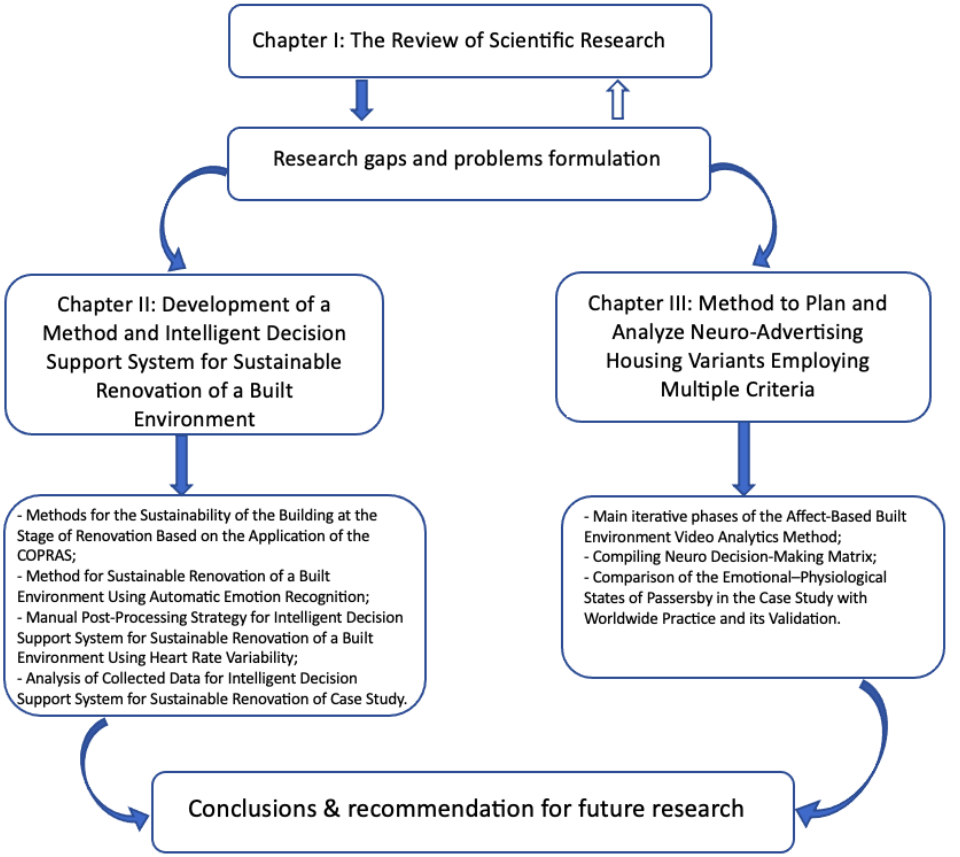


Fig. 2.1. Research design of the doctoral dissertation (created by the author)

Developing a Domain Mapping Matrix (DMM) enhances the identified knowledge to improve the operational framework for the decision architecture. It includes a solid impact to bargain with the existing complexity of the vast number of reconstruction approaches and different support objectives/criteria. Furthermore, the DMM can be used to understand and track the assessment (or included assessment) of other criteria (i.e., spatial quality), while the centre focuses on optimising a few general criteria, i.e., improving energy performance or reducing investment costs. The developed knowledge-based decision support system inte-

grated with a multilayer artificial neural network can allow to determine the degree of efficiency of housing and provide recommendations to stakeholders to work together on the rational management of housing.

2.1. Methods for the Sustainability of the Building at the Stage of Renovation Based on the Application of the Complex proportional assessment method

Recent examinations into building renovation, counting vitality enhancements of existing buildings, have appeared as an expanding consideration in numerous European nations as well as confronting modern huge challenges. Were uncovered that these activities can frequently be more cost-effective than modern building ventures. The existing building stock got to reach the European Union vitality and emission diminishment objectives. In expansion to that, it is additionally a need to ensure building capacities, and specialized qualities and to supply a great living environment (Galiotto et al., 2015). This means, that upgrading vitality effectiveness isn't the as it were objective for renovating existing buildings. The degree of the potential for vitality enhancements can be depicted and created in several ways.

This will happen centre on the climatic interface, life-cycle cost, security of supplies, indoor climate, natural impacts, spatial quality issues, building usefulness and other significant contentions. Existing buildings can benefit from a broader approach to portability that aims to reduce costs, reduce natural impact and increase the strength and flexibility of the building for future challenges. Therefore, buildings can be cheaper to run, last longer and contribute to the creation of an ideal, more profitable and useful environment for stakeholders. When all these conditions are taken into account, they can move the modernized corps towards the goal of general support, which requires more comprehensive approaches to modernization.

The advancement of existing buildings includes two major steps: current condition evaluation and future renovation techniques. Most of the strategies centre on the 1st step of the advancement preparation, understanding or foreseeing vitality utilization but no era of conceivable renovation scenarios. Whereas the last mentioned is about proposing long-term renovation arrangements. The coordinates remodel scenarios/packages that can be leveraged at an existing building – and are related to conceivable intuition between different remodel destinations – are not taken into thought in most retrofitting ventures. The comes about is, hence, imperfect remodel arrangements, which don't reach the total scope of supportability for repaired buildings. The major issue here can be considered as what the

extreme all-encompassing values are and how the values are included by utilizing remodelling choices.

Developing a Domain Mapping Matrix enhances the understanding needed to design an operating system for a decision architecture. This has a high impact to address the existing complexity of a large number of renewal approaches and the variety of sustainability goals and criteria. In addition, Domain Mapping Matrices can be used to understand and track value (or added value) concerning other criteria (i.e., spatial quality), while focusing on optimizing some general criteria, i.e., reducing investment cost or increasing energy efficiency.

Domain Mapping Matrices for building renovation involve three steps:

- Data distinguishing proof of the supportability objectives/criteria.
- Finding and organising the renovation approaches.
- Examination of the conditions among its components.

It gives the essential components for the framework engineering of a decision support system that can be utilised to create all-encompassing scenarios for renovation activities. Creating systems architecture for a decision support system for the generation of feasible building renovation scenarios is a perplexing, challenging assignment. The increasing complexity of the choice of meeting sustainability goals and aspects, the increasing number of subjects involved, and the fierce competition between conflicting costs and interfaces make picking and choosing troublesome. In arrange to include all the sources which can involve esteem in renovating ventures, the researchers (Kamari et al., 2017) investigated the decision-making forms for building renovation. Sustainability was characterized and represented in three categories, considering functionality, feasibility and accountability (18 value-oriented sustainable criteria were highlighted) for the deep and holistic renovation of buildings such as energy efficiency, indoor comfort, material, waste, pollution, water efficiency, services quality, aesthetic, identity, integrity, sociality, security, innovation, cost of operation and maintenance, management and flexibility, investment cost and involvement of stakeholders. The levels offer assistance to partners within the remodel handle to talk about the extended "on the same level" and make straightforward choices in a level-headed arrangement.

The assessment of the sustainability of alternative building solutions was carried out using multi-criteria methods and a decision-making model based on the application of COPRAS methodology (Kaklauskas et al., 2006). The structure of the model consists of literature analysis, the development of a system of indicators, expert interviews and a specific case study. The solution model is implemented in the following stages:

Stage 1. According to the literature analysis, an original system of indicators for evaluating the stability of structural solutions was chosen.

Stage 2. A model of complex determination of the significance of the criteria for alternatives (taking into account quantitative and qualitative characteristics) is created.

Stage 3. Calculation of values of indicators of alternative constructive solutions, analysis of alternative renovation technologies, determination of economic indicators (costs) during the implementation of alternative constructive solutions etc.

Stage 4. When applying the multi-objective methods COPRAS, alternative design solutions were compared using selected indicators of stability assessment. This stage includes results analyse. Figure 2.2 shows the main steps of the model.

Stage 5. Conducting emotion recognition experiment to understand participants emotional reactions toward construction projects

Stage 6. Creating a neuro decision-making matrix and initial data for the correlation analysis, considering the physiological and emotional state of stakeholders of different gender groups and ages. This stage also includes analysing the results.

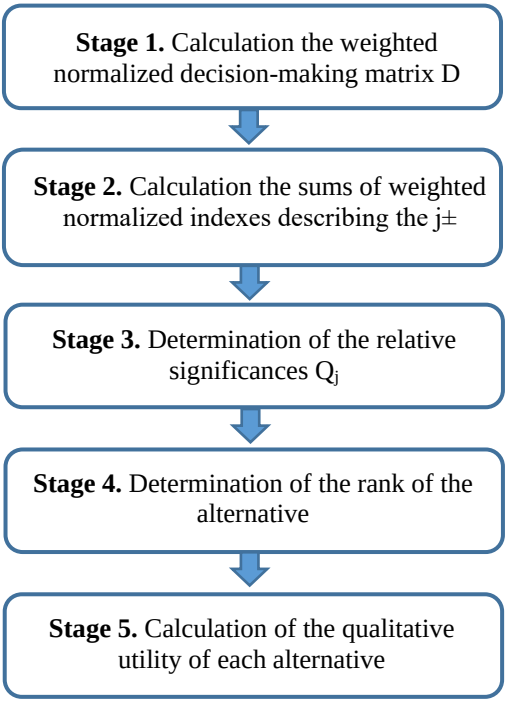


Fig. 2.2. The key stages of the COPRAS method (elaborated by author)

2.1.1. A Method of Multivariate Design and Multiple Criteria Analysis of a Building's Renovation

The goal of this chapter is to develop the method of multivariant design and multiple criteria analysis of a building's renovation. This will be realized by the example of the reconstruction of a building in Kyiv, Ukraine (see Annex B).

The renovation of the considered building takes place according to BREEAM technology. The essence is to reduce greenhouse gas emissions associated with construction and protect the environment through energy efficiency. Green building technologies further contribute to sustainability by helping to build healthy buildings, energy and water-efficient and save costs, such as those associated with maintenance and operation.

Steps:

- Maximising the use of solar energy and daylight, by orienting the windows to the south and increasing the area of the windows.
- Rational water consumption, the possibility of reusing water (rainwater collection system).
- Improved thermal insulation, the harmless use of insulating materials, allows maintaining a constant temperature indoors, regardless of temperature changes outside.
- Harmless automated heating systems (several solutions – biomass, solar collectors).
- Improved indoor air quality.

The qualitative interviews provided in a semi-structured manner were used in this work (see Annex A). Qualitative interviews were organised in order to obtain a deeper understanding of the ongoing incorporation of sustainability aspects into building renovation projects. Six Ukrainian real estate organizations were selected and interviewed to obtain a representative sample of the construction industry (A–F in Table 2.1) questions were open-ended and provided accordingly to the step-by-step developed methodology. The participants were 10 Ukrainian construction specialists who do not suffer from either cardiovascular or mental pathologies, both males and females (41% and 59% respectively) with an age range of 30–66 (the average age is 38.5 years); Ukrainian nationality, having at least two years of working experience; represent three main categories of property owners in Ukraine (e.g., small, medium-sized and large private companies). However, the main attention was paid to organisations that own rental offices. Participating organisations own about 371 apartments, which corresponds to more than 2.7 thousand square meters of housing. In addition, the two organisations also introduce a large number (about 180) of housing and construction cooperatives of

different sizes in Ukraine, which are responsible for facility management. A housing and building cooperative is a society in which each shareholder is a member and all members of the cooperative carry economic responsibility for buildings and real estate. Therefore, chosen ten organisations formed a relatively high percentage of the total number of housing units in Ukrainian office buildings.

Table 2.1. Characteristics of organisations and respondents during interviews

Organisation	Characterization of organisation	Role of the respondent(s)	Work area/main responsibilities of the respondent(s)
A	A large public company (operating in a growth market)	The consultant from the head of construction and engineering	The construction manager on a consulting basis. Responsible for project coordination, management and monitoring
B	A very small, private company (operating in a non-developing market)	Owner	The owner is active in the company and is responsible for the day-to-day work and all projects, only one person (administrator) works in the company.
C	A small, private company (operating in a non-developing market)	Co-owner	Inactive in daily work, provide consulting assistance on property management issues. Only one person (property manager) works in the company.
D	A large private member cooperative organisation (operates throughout Ukraine)	Manager of ecology and sustainable development	Supports the organisation with expert knowledge on aspects of ecology and sustainable development. Engages in lobbying and advocacy in the field of construction and housing construction.
		Real estate manager	Responsible for the development of the real estate portfolio and long-term planning and strategy of the company in the Kyiv region.
		Project Manager	Responsible for all capital repair projects from the early stages to the later stages in the Kyiv region. Responsible for project managers and reporting to the Real Estate Manager.
		Ecology and quality coordinator	Supports the organisation and implementation of internal procedures for environmental assessment tools and related issues.
		Project Manager of Redevelopment	Responsible for some major renovation projects from early stages to follow-up in central Ukraine
E	A medium-sized private cooperative organisation, (operates throughout Ukraine)	Environmental coordinator	Supports the organisation with expert knowledge of environmental aspects. Together with the project manager and the construction manager, responsible for the long-term planning and strategy of the company.
F	A large public company (operating in a growth market)	Project Manager	Together with the environmental coordinator and the construction manager, he is responsible for the long-term planning and strategy of the company. Responsible for project managers of the company.

The interview was based on research that found that sustainable renovation lacks simplified procedures, methods and checklists for addressing sustainability aspects of renovation projects. The questions were developed and divided into different categories. The categories represented different stages of the construction process and included questions about economic aspects and solutions in the field of information and communication technologies. Most of the questions were open-ended, as the aim was to gain an understanding of the challenges and opportunities in the ongoing reconstruction processes among the participating organisations.

The presentation of the interview is divided into six sections, the first section covering the economic aspects before the project and continuing to the follow-up (sections below) and how some aspects of sustainable development are handled at different stages.

Economic Aspects of Decision Making. Rental property owners first should obtain the consent of tenants for holding events in different apartments, as well as obtain the agreement of half of the tenants at least before holding events in the public area of the building that will result in a rent increase. The rent increase is based on the principle of utility value. The useful value is influenced by the floor, size and general standard of the flat and building, and should also display the values of the flat from the tenant's perspective. However, routine maintenance has not led to an increase in rental prices.

The interview shows that it is usually little or no funding for repairs, modernization or maintenance, despite public or private organisations. Every renovation project must be financed by increasing rent and reducing operating prices, leading to attempts to reduce prices. In the case of housing co-operatives, the situation is different: financial security is higher, as the housing co-operative usually organises its finances according to the maintenance plan and does not adhere to the aforementioned contract.

The next economic criterion that affects decisions about the actions to be taken is the return on investment. Five of the six surveyed organisations have a general necessary rate of return, while one organisation has a profit margin for separate property. Profitability among participating organisations is usually 4-7%. When assessing profitability, most participants mentioned that their organisation used some kind of Life Cycle Cost (LCC) approach, but this is sustained by the manager of the project and sometimes only simple payback time estimates are used. One of the defined problems was the missing general guidance on the economic evaluation that should be used. Within one organisation, different numbers are used to evaluate profitability for one parameter (for example, the yearly increase in prices for energy carriers). Usually, the manager of the project defines what options apply, and this leads to completely different estimates of the same indicator in similar projects.

Property Management. With regard to maintenance plans, two organisations use complex maintenance plans for facilities, but no one uses a framework of sustainability. Two small organisations don't have maintenance plans. The interview demonstrates that because of their small size, managers of the facility are well aware of the status of each construction project.

Three large organisations have common sustainability goals related to renewal. The rest three organisations stated that they did not have any overall sustainable development goals. All three larger public companies have Environmental Management Systems (EMS) certified to DBN 14-001E. But the picture is different for the general goals of sustainable development. Two of the three organisations with overall sustainability goals said their goal is to decrease demand for energy by 20% during the renovation, the goal is based on the Ukrainian project "Great Construction" for 2020. A third organisation stated that it aims to decrease the demand for energy by 50% during the renovation.

Observing and controlling the use of energy and water is also an important starting point for preparing appropriate sustainable development goals and choosing actions in the renovation process. Five of six organisations control the use of energy in some way. Only one of six organizations regularly discuss the use of energy with the manager of the property and the manager of energy. Neither organisation reports energy consumption in a level of detail but the general use of energy for the heating season and consumption of electricity for building operation. The water for domestic use is also measured as total consumption, but if domestic hot water use is measured separately, this will be reported apart.

Research on the quality of the indoor environment at the stage of use is very limited in the organisations under study. All three large companies regularly conduct customer satisfaction research, and only one company provides an investigation of the indoor environment (i.e., thermal and noise comfort). In addition, a dissatisfied user can only file a complaint, which will then be considered.

Renovation Process in General. Most companies do not use models to manage the sustainability aspects of retrofit projects. Only one large organisation stated that they have a common model for managing aspects of sustainability, called an "environmental statement" and customized for each specific renovation project. Additionally, another organisation stated that they managed the Law of Ukraine "On Environmental Protection" (1264-12). Creation of environmental programs and plans is rare among the participants, this is only done for large-scale renovation projects. Interviews revealed that managers of the projects have a limited understanding of the use of the model to manage aspects of sustainability, do not know when and how to decide on aspects of a renovation project, and they don't always know exactly what to ask for.

New construction and reconstruction projects have minor organizational differences. Large and medium-sized organisations have in-house project managers,

while smaller companies use experts in these issues. The two organisations employ “renovation coordinators” to act as a liaison between the project team and tenants and address issues and questions brought forward to tenants.

Building Inspection Stage. Before starting a renovation project, most respondents assured that they would conduct a building inspection in case if they had the required knowledge about the construction project before. But this review is usually carried out at a common level and does not include a detailed analysis of potential energy-saving measures, energy use or an assessment of indoor environmental aspects e.g., noise, thermal comfort, daylight and humidity. In participating organisations, alternative activities (for example, replacement or repair of windows) are usually evaluated using the LCC approach and experience from previous projects.

None of the surveyed organisations currently take into account greenhouse gas emissions due to the use of non-environmental materials during renovation. Four organisations expressed interest to start performing such estimations if they will have a simple budget tool. Incorporating residents' opinions about a future renovation project or involving residents in the process is a challenge that can influence the result as well as residents' satisfaction with the renovation project. The three organizations reported they hold joint meetings with tenants. The meetings are generally held to share information about future projects, also tenants are encouraged to utter their thoughts, which can influence decision-making to some extent. None of the organisations conducts a survey of tenants before the start of the renovation to establish, e.g., environmental problems in the premises that can be solved during the renovation.

Follow-Up Stage. After the completed reconstruction process, a follow-up period should begin to review the results of previous actions before proceeding with the normal property management process. Surveys have shown that there is very limited follow-up by participating organisations, although most participants expressed that it’s important to have happy residents. Generally, the consumption of energy is the only parameter controlled by every month's energy use data, while indoor environmental aspects are not monitored. Three of the organisations stated that they established sensors for measurements of the air temperature in a sampling of rooms in several buildings, other aspects were not considered. Indoor environmental quality is more than temperature, it can be defined by humidity, air velocity, noise and light. The provided analysis indicates an inconsistency between the thoughts of residents about the level of thermal comfort and the air temperature measured in the room.

Studies have shown that research organisations only carry out a thorough investigation of specific parameters when something goes wrong, for example, if energy consumption is significantly higher than expected or if there are a lot of

statements of dissatisfaction from inhabitants. Neither organisation uses any measurements or surveys for monitoring indoor environmental quality.

2.1.2. A method of complex determination of the significance of the criteria taking into account their quantitative and qualitative characteristics in the Case Study.

In order to design and implement an effective renovation of a building, it is necessary to conduct a study of all the solutions that make it up. The level of efficiency of the reconstruction of the building in question depends on many factors, including: cost of reconstruction, payback period, durability, functionality, maintenance properties, comfort, noise insulation and durability, etc. social

Criteria associated with a certain number of values; values are the details behind each criterion. The following tables present the results of the data that were gathered through literature analysis, research of existent assessment methodologies, interviews and focus group discussions, etc. Based on observations and a review of the repair case, the addressed criteria were further revised and confirmed with the participation of 10 residential property owners in 2020-2021. The reason was to critically examine the resilience framework (which will be discussed in the following sections) and to discuss the development of indicators based on collecting information and reviewing the results for reconstruction cases prior to the generation of the latest version of the framework.

Reconstruction of a non-residential building for a residential building (see Fig. 2.3). The building to be reconstructed is located at street Nizhniy Val, 31-A in the Podilskyi district of Kyiv, in dense urban development, the urban structure of the district within the Central historical area, in the zone of regulation of category I buildings, in the archaeological protection zone, which is an integral part of the memory of monuments and history of local significance “Historical landscape of the Kyiv mountains and valleys of the Dnieper River”, on the territory of the archaeological monument of local significance “Cultural layer of the Podil IX-XVIII centuries”.

The object of study – reconstruction of three floors of a brick building (out of 8 floors) with an unambiguous mountain roof type with metal tiles with the maximum public dimensions in terms of 46,940 x 9,400 m, which provides a significant amount, performed by LLC “Engineering and Construction” in 2019. The capital building, built before 1917, with load-bearing living and transverse brick walls 750 mm thick (external) and 620 mm (internal), overlapping over the coconut floor – monolithic on metal beams, over 1-3 floors wooden on wooden beams. Partitions – brick.

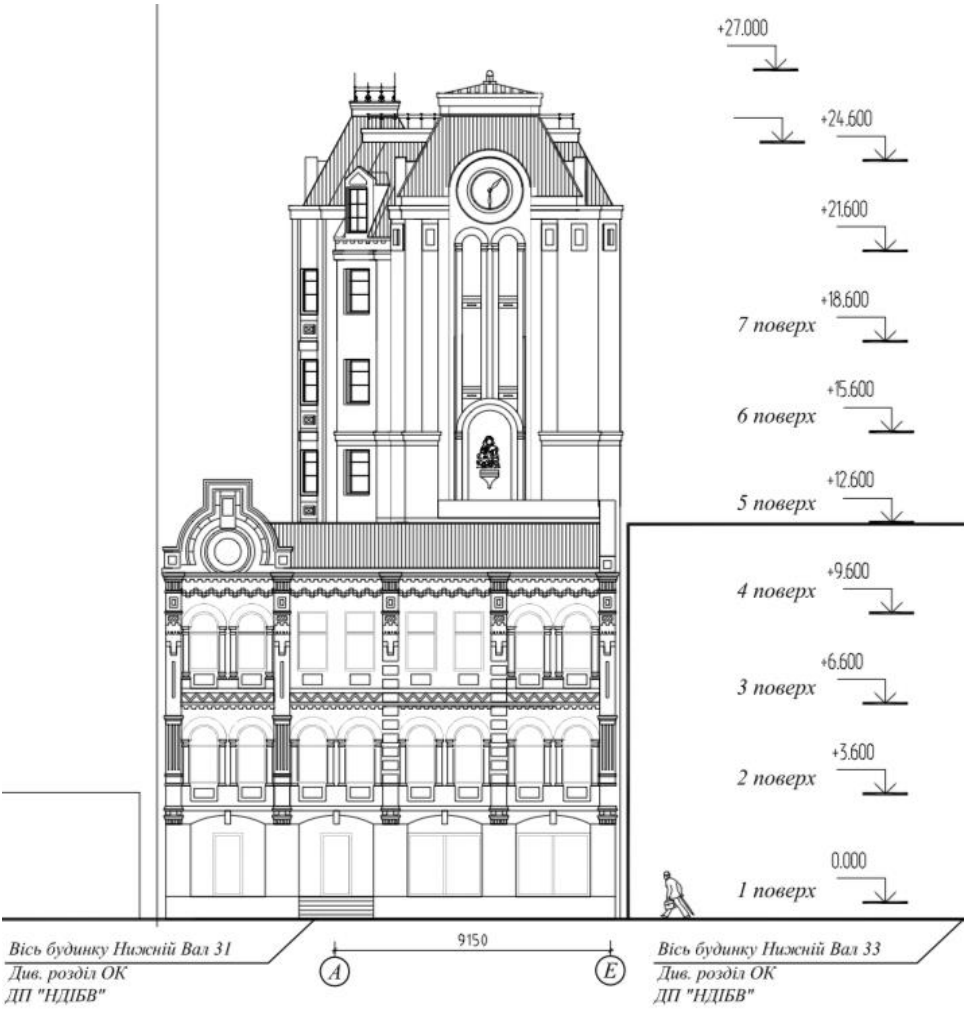


Fig 2.3. Facade A-E of the research building

The project provides for the exterior decoration of the house, installation of metal-plastic windows, ventilation (air conditioners), water supply system, heating and roof tiles in accordance with the project task (see Annex B). The project does not provide for the involvement or transfer of any structure located on the design site, as well as the removal of existing greenery.

Ventilation. Ventilation of a residential building is accepted supply and exhaust with natural and mechanical motivation. The airflow into the house is disorganised, and natural due to the windows and valves of the brand S710 company REHAU, located in the upper part of the plastic windows.

To create and ensure parameters of the air environment in the building established by the current norms, supply and exhaust ventilation is provided, with mechanical motivation. The capacity of ventilation systems is determined by the normative exchange of indoor air, as well as on a per capita basis. The project provides for the possibility of installing outdoor air conditioning units. The air ducts are made of galvanized sheet steel.

Next, the determination of significance, degree of usefulness and priority of the renovated ventilation will be analyzed. The project of ventilation of the object: "Construction of residential building" is developed based on the following initial data: Architectural – construction drawings;

Current building codes and regulations:

- DBN B.2.5-67: 2013 "Heating, ventilation and air conditioning"
- Estimated winter temperature for heating and ventilation design – 22C;
- Estimated summer temperature for ventilation design +23C;

Estimated wind speed:

- in the warm season – 2.1 m/s
- in the cold season – 2.8 m/s.

Estimated air exchanges in general and auxiliary rooms – adopted according to the normative multiplicity of air exchange, in premises with the allocation of harmful air exchange is designed for their assimilation. The consumption of outdoor air in administrative rooms is calculated in accordance with DBN B.2.5-67: 2013. The air supply in the parking lot is expected to be concentrated in the driveway. Air removal is carried out equally from the lower and upper zone. Ventilation equipment in the parking lot is installed in the ventilation chambers of the basement. Excess of consumption of exhaust air over supply according to item 8.39, DBN B.2.3-15-2007 is provided.

In administrative rooms, it is envisaged to reduce the productivity of ventilation systems to a single air exchange during non-working hours in order to save energy resources. Air ducts of supply and exhaust systems are laid hidden in ventilation shafts and behind architectural constructions. Air ducts are designed from galvanized steel according to GOST 19904-74 * and density class according to DBN B.2.5-67-2013.

Exhaust emissions are carried out in architectural mines. The bottom of the holes in the architectural mines is 1.0 m from the roof level of the building. The air intake is carried out at a height of 2.0 m from ground level and the distance from the air intake to the air outlet is not less than 8.0 m.

To reduce the noise of ventilation systems, the following measures are provided:

- Installation of pumps and fans on vibration-insulating bases.
- Connection of fans and air ducts on flexible inserts.

– Installation of mufflers.

The initial weights of the quantitative criteria are determined by expert methods. Respondents indicated the weights of the criteria. Then the completed questionnaires were processed and the reliability of the expertise was determined by calculating the concordance coefficient, which shows the compatibility of the experts' assessments. Applying the formula of the complex method of determining the weights of the criteria, the weight coefficients of the quantitative and qualitative criteria relating to the alternatives of the maintenance contractor were determined. As demonstrated in Table 2.2, the most important criteria are the following: total price ($q_1 = 0.6000$); guarantee period ($q_3 = 0.0382$); level of noise ($q_{11} = 0.0476$); etc.

Table 2.2. Complex determination of the significance of the criteria for ventilation alternatives (considering quantitative and qualitative characteristics)

Criteria under evaluation	Measuring units of criteria	*	Numerical values of criteria						Determination of		
			1	2	3	4	5	Initial weights, p_i	Total qualitative criteria, S_i	Total monetary expression, P_i	Ultimate weights of criteria, q_i
1	2	3	4	5	6	7	8	9	10	11	12
Quantitative criteria											
Price	Eur	–	47900	36700	28650	29430	31400	0.9	174080.9	156672.8	0.6000
Payback period	Years	–	10	10	23	20	25	843	931	784833	0.0391
Guarantee period	Years	+	10	10	10	10	20	1104	1164	1285056	0.0382
Durability	Years	–	50	50	55	40	50	228	473	107844	0.0282
Duration of works	Days	–	90	90	90	90	90	84	534	44856	0.0321
Qualitative criteria									**V = 2379262**		
Heat consumption for ventilation	W	+	650000	630000	644000	635000	635000	–	–	–	0.0452
Reliability	Cycles	–	1000	1000	1000	1000	1000	–	–	–	0.0277
Reliability	Cycles	–	1000	1000	1000	1000	1000	–	–	–	0.0277
Specific power (actual)	W/m2	+	50.1	54.2	51.83	53	55	–	–	–	0.0324
Power consumption (from)	W/m2	–	9	8,9	7,5	9	7	–	–	–	0.0379

End of the Table 2.2

1	2	3	4	5	6	7	8	9	10	11	12
Minimum total air consump-tion	m3/h	+	260	260	255	265	260	–	–	–	0.0331
Level of noise	dB	+	26	26	24	25	30	–	–	–	0.0476
Max pres-sure	Pa	+	9280	9100	9325	9428	8300	–	–	–	0.0385

* The sign z_i (+ (−)) indicates that a larger (smaller) value of the criterion corresponds to a greater importance for the stakeholder.

When the list of criteria is compiled and their initial weights and values are calculated and presented as a matrix, can be calculated the actual weights of the criteria.

Step 1: Calculation of the sum of values for each quantitative criterion using:

$$S_j = \sum_{j=1}^{n} x_{ij}, \quad i = 1,2,...,t; \;\; j = 1,2,...,n, \tag{1}$$

where: x_{ij} – the value of the *i*-th criterion in the *j*-th alternative; t – the number of quantitative criteria; n – the number of compared alternatives.

Step 2: The general monetary expression of each quantitative criterion describing the researched project is obtained by the expression:

$$P_i = S_i \times p_i, \quad i = 1,2,...t, \tag{2}$$

where: p_i – the initial weight of the i-th criterion; p_i must be measured so that after multiplying by the quantitative value of the criterion, an equivalent monetary expression can be obtained.

According to the impact of quantitative criteria on the execution of alternative projects over time, quantitative criteria can be divided into:

- Short-term factors affecting the process/project only for a certain period;
- Long-term factors affecting the process/project throughout its life cycle.

The initial weights of long-term criteria, such as the resources required for ventilation and environmental protection, depend on the payback time of the project and, in financial terms, on the evaluation of the monetary unit of measurement of the criterion, which is:

$$p_i = e \times f_i, \tag{3}$$

where: e – payback period of the project; f_i – the monetary value of the unit of measurement of the *i*-th criterion.

The initial weights of a separate criterion reflecting, e.g., the cost of a site or the cost of services, are equal in financial terms to the monetary expression of the unit of measure of the criterion.

The physical content of the initial weight of the quantitative criterion shows that the multiplication of the initial weight by the value of the quantitative criterion gives its expression in monetary units, which is calculated throughout the entire life cycle of the object.

$$p_i = f_i. \tag{4}$$

Step 3: The total amount of quantitative criteria of monetary expression is determined by the formula:

$$V = \sum_{i=1}^{t} P_i, \quad i = 1, 2, ..., t. \tag{5}$$

Step 4: The final weights of the quantitative criteria describing the alternatives are determined as follows:

$$q_1 = \frac{P_i}{V}, \quad i = 1, 2, ..., t. \tag{6}$$

The total sum of weights of quantitative criteria is always equal to 1:

$$\sum_{i=1}^{t} q_i = 1. \tag{7}$$

Step 5: To achieve consistency between the weights of quantitative and qualitative criteria, a standard value (E) is determined. E is equal to the sum of any selected weights of quantitative criteria. One of the main requirements for this standard value to be used in the comparison is that, according to its usefulness, it should be easily comparable with all qualitative criteria. Weighting coefficients of all qualitative criteria are determined by comparing their usefulness with a standard value. The weight of the comparative standard value E is determined by

$$E = \sum_{z=1}^{g} g_z, \tag{8}$$

where: g – number of quantitative criteria; q_z – the weight of the z-th quantitative criterion.

Step 6: The initial weight v_i of a qualitative criterion is determined by expert methods by comparing its relative importance with the importance E of the selected standard. The relative weights of quality criteria should be expressed as a percentage.

Step 7: The weight of the *i*-th qualitative criterion is determined as follows:

$$q_1 = \frac{v_i \times E}{100}, \quad i = t+1,...,m. \tag{9}$$

Determining the significance, usefulness and prioritization of renewed ventilation (see steps 1–6) will be briefly analyzed as an example. The alternative ventilation of five companies was analyzed according to 12 indicators (see Table 2.2). The values of these criteria are different. For example, prices for building repairs by five companies are offered within the range of EUR 28 650 to 47 900.

For a better understanding of the above facts, let's compare the third option with the second. The cost of renovation ventilation in the second option is higher, and the noise level of the second option is more profitable. The second option differs from the third in that it has better quality characteristics (ie, specific power, energy consumption, air consumption, noise level, etc.).

As can be seen from Table 2.3, the evaluation of the noise significance level through automated calculations, it was obtained that $q_{11} = 0.0476$, which is 1.44 (q_{11}:$q_{12} = 0.0476$:0.0385 = 1.24) times more significant for the stakeholder than the maximum pressure of ventilation (significant, $q_{12} = 0.0385$). Calculations showed that the main factors that affected the effectiveness of ventilation reconstruction are: cost (weight, $q_1 = 0.6000$), payback period ($q_2 = 0.0391$), heat consumption for ventilation ($q_6 = 0.0452$) etc. Determining the degree, significance and priority of usefulness of alternatives is carried out in five stages.

Table 2.3. Development of ventilation alternatives

Criteria under evaluation	**Measuring units of criteria**	*****	**Numerical values of criteria**					**Ultimate weights of criteria. q_i**		
			1	**2**	**3**	**4**	**5**			
1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
Price	Eur	–	47900	36700	28650	29430	31400	0.6000	174080	0.1256
Payback period	Years	–	10	10	23	20	25	0.0391	88.04	0.0111
Guarantee period	Years	+	10	10	10	10	20	0.0382	60,04	0.0127
Durability	Years	–	50	50	55	40	50	0.0282	245,03	0.0046
Duration of works	Days	–	90	90	90	90	90	0.0321	450,03	0.0064
Heat consumption for ventilation	W	+	650000	630000	644000	635000	635000	0.0452	3194000.05	0.0090
Reliability	Cycles	–	1000	1000	1000	1000	1000	0.0277	5000.03	0.0055

End of Table 2.3

1	2	3	4	5	6	7	8	9	10	11
Specific power (actual)	W/m^2	+	50,1	54,2	51,83	53	55	0.0324	264.16	0.0067
Power consumption (from)	W/m^2	-	9	8,9	7,5	9	7	0.0379	41.44	0.0064
Minimum total air consumption	m^3/h	+	260	260	255	265	260	0.0331	1300.03	0.0067
Level of noise	dB	+	26	26	24	25	30	0.0476	131.05	0.0109
Max pressure	Pa	+	9280	9100	9325	9428	8300	0.0385	45433.04	0.0070

* The sign z_i (+ (−)) indicates that a larger (smaller) value of the criterion corresponds to a greater importance for the stakeholder.

Step 1: The weighted normalized decision-making matrix D is formed. The first formula is used for this purpose:

$$d_{11} = 0.6000 \times 47900 : (47900 + 36700 + 28650 + 29430 + 31400) = 0.1651;$$

$$d_{12} = 0.1265; \quad d_{13} = 0.0987; \quad d_{14} = 0.1014; \quad d_{15} = 0.1082.$$

The significance value q_i of the investigated criterion is proportionally distributed among all versions of ventilations a_j according to their values x_{ij}. For instance:

$$q_8 = 0.00611 + 0.0066 + 0.0063 + 0.0066 + 0.0067 = 0.0331.$$

Step 2: Sums of weighted normalized indices describing the j_{th} version are calculated. The sums are calculated according to the following formula:

$$S_{+j} = \sum_{i=1}^{m} d_{+ij}, \quad S_{-j} = \sum_{i=1}^{m} d_{-ij}, \quad i = \overline{1,m}; \quad j = \overline{1,n};$$

$$S_{+1} = 0.00637 + 0.00918 + 0.00611 + 0.00665 + 0.00924 + 0.00788 = 0.04543;$$

$$S_{-1} = 0.1651 + 0.00444 + 0.00564 + 0.00642 + 0.00554 + 0.00844 = 0.19558.$$

Besides, the sums of "pluses" S_{+j} and "minuses" S_{-j} of all alternative projects are always, respectively, equal to all sums of the weights of maximising and minimising criteria.

Step 3: The relative importance *Qj* of each project *aj* is given by the following formula (see Table 3.3):

$$Q_1 = 0.04542 + \frac{0.19558(0.19558 + 0.1569 + 0.1342 + 0.1484 + 0.1399)}{0.19558((0.19558/0.19558) + (0.19558/0.1569) + (0.19558/0.1342) + (0.19558/0.1349) + (0.19558/0.1435)} = 0.1475.$$

$$Q_j = S_{+j} + \frac{S_{-\min}\sum_{j=1}^{n} S_{-j}}{S_{-j}\sum_{j=1}^{n} \frac{S_{-\min}}{S_{-j}}}, \quad j = \overline{1,n}.$$

Step 4: The greater the Q_j, the higher the efficiency (priority) of the ventilation alternatives. $Q_4 > Q_1 > Q_2 > Q_5 > Q_3$ (0.1484 > 0.1475 > 0.1415 > 0.1399 > 0.1343). Table 2.4 shows that the fourth version is the best in terms of utility, which is 100%. The first option was the second in priority and its degree of usefulness was equal to 97.66%.

Step 5: The sixth formula is used to calculate the degree of utility N_j:

$N_1 = (0.1475/0.1484) \times 100\% = 97.66\%$; $N_2 = 95.66\%$; $N_3 = 90.25\%$; $N_5 = 94.27\%$.

The results of a multiple criteria evaluation of five options for ventilation renovation are shown in Table 2.4. The table shows that the fifth option is the best in terms of usefulness, which is 100%.

Table 2.4. Ventilation renovation multiple criteria analysis results

Criteria under evaluation	Measuring units of criteria	*	Numerical values of criteria					Ultimate weights of criteria, q_i
			1	2	3	4	5	
1	2	3	4	5	6	7	8	9
Price	Eur	–	0.1651	0.1265	0.0987	0.1014	0.1082	0.6
Payback period	Years	–	0.0044	0.0044	0.0102	0.0089	0.0111	0.0391
Guarantee period	Years	+	0.0064	0.0064	0.0064	0.0064	0.0127	0.0382
Durability	Years	–	0.0056	0.0056	0.0062	0.0051	0.0056	0.0282
Durability	Years	–	0.0056	0.0056	0.0062	0.0051	0.0056	0.0282
Duration of works	Days	–	0.0064	0.0064	0.0064	0.0064	0.0064	0.0321
Heat consumption for ventilation	W	+	0.0092	0.0089	0.0091	0.009	0.009	0.0452
Reliability	Cycles	–	0.0055	0.0055	0.0055	0.0055	0.0055	0.0277
Specific power (actual)	W/m^2	+	0.0061	0.0066	0.0063	0.0066	0.0067	0.0324
Power consumption (from)	W/m^2	–	0.0084	0.0083	0.007	0.0075	0.0066	0.0379

End of Table 2.4

1	2	3	4	5	6	7	8	9
Minimum total air consumption	m^3/h	+	0.0067	0.0066	0.0065	0.0066	0.0066	0.0331
Level of noise	dB	+	0.0092	0.0092	0.0085	0.0099	0.0107	0.0476
Max pressure	Pa	+	0.0079	0.0077	0.0079	0.0079	0.007	0.0385
The sums of weighted normalized maximizing indices of the windows, S_{+j}			0.0454	0.0455	0.0447	0.0466	0.0528	
The sums of weighted normalized minimizing indices of the windows, S_{-j}			0.1956	0.1569	0.1342	0.1349	0.1435	
Ventilation significance, Q_j			0.1475	0.1415	0.1343	0.1484	0.1399	
			97.66%	95.66%	90.25%	**100%**	94.27%	

* The sign z_i (+ (−)) indicates that a larger (smaller) value of the criterion corresponds to a greater importance for the stakeholder.

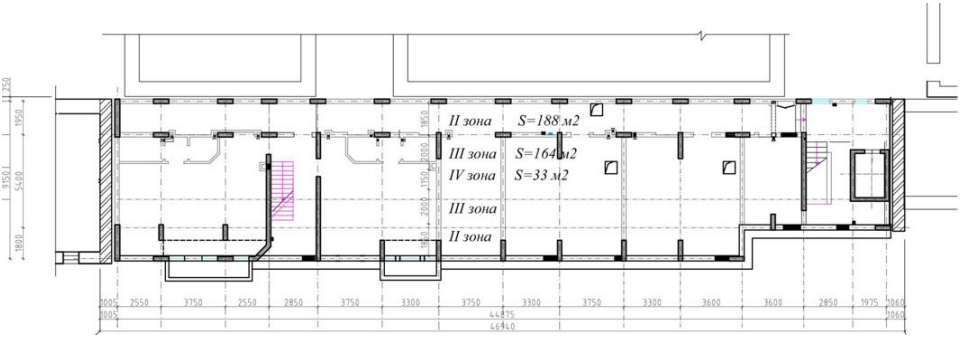
A multi-criteria analysis of decisions to renew windows, heating, roofing and water supply systems was carried out in the same way as for ventilation. Next, the first five stages were repeated until the importance, usefulness and priority of all elements of the building renovation were assessed.

Water supply system. The whole water supply system is mounted from steel enamelled pipes according to TU U 7308692-001-93, galvanized water and gas pipes according to GOST 3262-75 *, and plastic pipes for drinking water. Internal piping is supposed to be hidden. A hot water supply is provided from the heating point located in the basement. The water temperature in the hot water supply system is 55 °C.

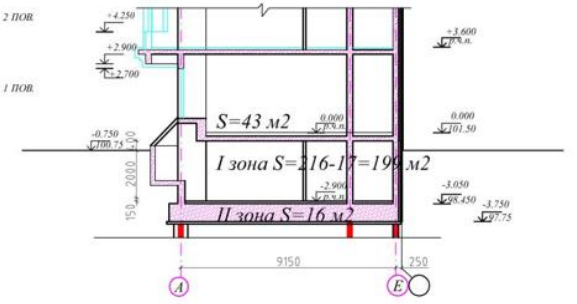
Heating. Estimated indoor air temperatures are taken in accordance with building rules and regulations. The heat carrier for heating systems is hot water with parameters Tp = 90C; Tz = 70C. The heating system is designed horizontally, made of metal-polymer pipes KAN-therm. Kermi steel panel radiators with a lower connection (H = 500 mm) and KAN-therm radiators with a side connection of H = 500 mm are used as heaters. Heating devices are equipped with thermostatic valves and Mayevsky's taps. In assisted areas (heating station, pumping stations and shield) take heaters with smooth steel pipes.

Main pipelines and vertical risers of the heating system are provided from steel water and gas pipes according to GOST 3262-75 * and steel electric welded

pipes according to GOST 10704-92. The main pipelines of heating systems are laid with a slope of i = 0.002 along the technical corridor of the basement. Heating area of the building F_h = 2771 m^2; the heating volume of the building V_h = 7369 m^3 (see Fig. 2.4 a–b).



a) Plan at the mark of 2.900



b) Fragment of a section

Fig. 2.4 (a–b). Scheme of heating systems

Windows. Window constructions (windows, balcony doors – see Fig. 2.5) are made of PVC profiles with filling with double-glazed windows with energy-saving coating on the inner glass (4i-10-4M 1 -10-4i). The area of translucent structures meets the standards of natural light in accordance with DBN B.2.5-28. The insolation mode of apartments meets the requirements of DSP 173-96. Moreover, the inflow of excess solar radiation in the hot period of the year is minimized in accordance with DSTU – N B B.2.2 27: 2010. Window filling – metal-plastic (two-chamber) windows, imposts and frames – colored, energy-saving glass 4mm IMO, with masking (sun protection) film type Llumar. The total area of window structures F = 381m^2 (314m^2 in window structures +67m^2 balcony doors); the dimensions of the windows are 1.5 m × 0.92 m; door area – 1.2m × 2.5m.

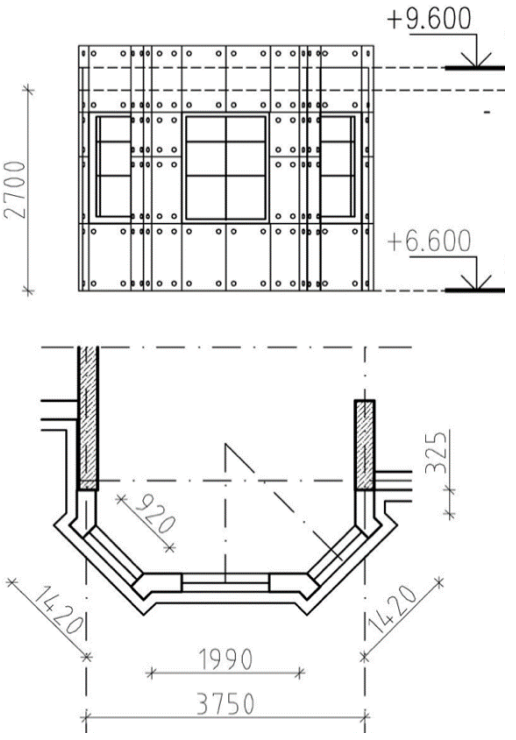


Fig. 2.5. Window plan of the research building

Roof. The roof of the house is designed mansard, a single-slope of metal structures, insulated with mineral wool slabs on a basalt basis, the roof is metal, roofing material. The mansard is single-sloped. Slope towards the main facade. The slope is formed by metal rafters, located with an average step of 1.2 m. The rafters rest at one end on the reinforced slab floor of the 5th floor, and the other end on the reinforced concrete slab. At the ends of the rafters are attached (welded) to the embedded parts of the floor slab of the 5th floor and the floor slab (see Fig. 2.6).

For the renovation of the roof were applied materials that have indicators of fire safety G1 (fire-resistant), RP1 (do not extend a flame on a surface), and B1 (fire-resistant). In places of difference of heights of a roof more than 1,0m external fire ladders are provided, the protection on a roof corresponds to parameters of item 6.13 DBN B.1.1-7-2002. On the roof of the building should be installed gutters with leaf traps and electric heating from the network 230V, power 10–30 W, by HL (Austria). Pipes of internal drains are laid hidden.

The total coverage area of the combined – F_{roof1} = 259 m^2 and pitched roof F_{roof2} = 226 m^2.

When performing calculations according to DBN V.1.2-2: 2006 "Loads and impacts" the following characteristic loads are accepted:

- snow load for the 5th district by weight of snow cover – 1600 Pa.
- wind load for 1 district from wind pressure – 400 Pa.

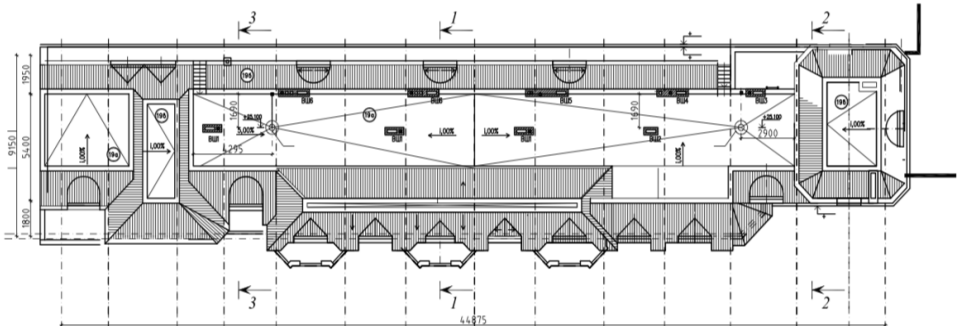


Fig. 2.6. Roof plan of the research building

As in the example of renovation of ventilation, after a multi-criteria analysis of the components of the reconstruction project (water supply, heating, ventilation, windows and roof systems) and selection of the most effective options (see Table 2.5), compatible and rational reconstruction components were combined into alternatives. By performing a multi-variant design and multi-criteria analysis of the building reconstruction in this way, it is possible to choose the most effective alternatives.

After passing all the stages, a summary decision-making table of all options for the reconstruction of the building was obtained. Prepared options for building reconstruction are evaluated according to various requirements. A version that does not meet these requirements will be deleted and not considered.

According to the case study of the project the water supply system, heating, ventilation, windows and roof had to be renovated in the building. For water supply systems were compared next companies: "Teplosoft" Ukraine (1), "Wilo pumpen intelligenz" Korea (2), "Grundfos" Denmark (3), "HP-trend s.r.o." Czech Republic (4) and "Gross" Ukraine (5). For heating were chosen "KAN-therm" EU (1), "HENCO" Belgium (2), "Global di fardelli ottorino & co" Italy (3), "Hi-Therm" Italy (4) and "Reflex winkelmann GmbH" Germany (5). For ventilation: "Danfoss" Denmark (1), "KERMI" Germany (2), "BT-Service" Ukraine (3), "VIKMA LTD" Ukraine (4) and "Вентс" Ukraine (5). For windows renovation was provided by Schüco Corona SI 82 Germany (1), Veka Euroline Germany (2),

WDS 400 Ukraine (3), Rehau Euro Design 70 Germany (4) and Rehau S710 Germany (5). For roof renovation were considered next types of metal tile “Ferrogal” China (1), metal tile “Modern 25 USS” Slovakia (2), metal tile “Thyssen krupp” Germany (3), slate roofing “IFCEM AT” Ukraine (4) and bituminous tile “Döcke” Germany (5). Further, all components were analysed in brief as an example.

Table 2.5. Comparison of tile types

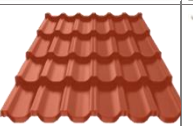
Metal tile Ferrogal (China)+B2:F7	***Metal tile Modern 25 USS (Slovakia)***	***Metal tile Thyssen krupp (Germany)***	***Slate roofing IFCEM AT (Ukraine)***	***Bituminous tile Döcke (Germany)***
Ferrogal is a classic metal tile that is easy to fix. Type of coverage (mat, gloss,pural mat) they are currently available in 8 colors and all tiles are coated with a special layer to ensure durability. The content of zinc, affects the resistance to corrosion (from 60 g m^2). Tile width 1200 mm, height 350 mm, suitable raking spacing: 320–375 mm. Price 8–12 Eur/m^2. The number of tiles in the package is 6 pcs. Weight 4.2 kg/pc. Weight per square meter 45 kg/m^2.	Metal tile Modern 25, manufacturer USS is a metal tile that is easy to fix. It goes in 8 colors and all tiles are coated with a special layer to ensure durability. The content of zinc, affects the resistance to corrosion (140 g/m^2). Tile width 1195 mm, height 350 mm, suitable raking spacing: 340–380 mm. Price 10–13 Eur/m^2. The number of tiles in the package is 8 pcs. Weight 4,4 kg/pc. Weight per square meter 49 kg/m^2.	Metal tile Thyssen krupp is a metal tile that is easy to fix. It goes in 8 colors and all tiles are coated with a special layer to ensure durability The content of zinc, affects the resistance to corrosion (300 g/m^2). Tile width 1210 mm, height 350 mm, suitable raking spacing: 350–380 mm. Price 12–16 Eur/m^2. The number of tiles in the package is 5 pcs. Weight 4,0 kg/pc. Weight per square meter 47 kg/m^2.	Slate roofing IFCEM AT 8-sided is a durable and rigid sheet of not flammable roofing material that reduces noise effects and has low thermal conductivity. It also provides safety with its protection from radioactive and electromagnetic radiation. Having a special hardness, slate can withstand significant loads, resistant to severe frosts and sudden temperature changes. Size 1750x1130x5.8mm, grey color Weight 25 kg/pc. Price 4 Eur/pc.	Bituminous tile Döcke provides strength, and durability of the material due to its use in the production of high-strength fiberglass, SBS modified bitumen. Available in 5 colors. Tile width 1000 mm, height 318 mm, Tensile strength in the transverse direction less than 400 N; the tensile force in the longitudinal direction is less than 600 N. Price 7–8 Eur/m^2. The number of tiles in the package is 3 m^2. Weight of pack 28,2 kg.
				
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Table 2.6. Decision-making matrix of components

Criteria under evaluation	Measuring units of criteria	*	Numerical values of criteria					Ultimate weights of criteria, q_i
			1	2	3	4	5	
1	2	3	4	5	6	7	8	9
Price	Eur/m^2	–	2300	2750	1790	2060	2400	0.6000
Payback period	Years	–	15	10	12	10	10	0.0295
Guarantee period	Years	+	20	25	20	25	25	0.0275
Durability	Years	–	30	30	35	30	35	0.0286
Duration of works	Days	–	60	60	60	60	60	0.0258
Water pressure	PSI	+	65	50	65	70	60	0.0308
Number of pumping stations		+	13	12	10	10	15	0.0363
Number of conduction lines	W/m^{2}K	+	4	2	5	3	6	0.0362
Water resources withdrawn	%	–	0.14	0.59	0.5	0.64	0.5	0.0392
Estimated Network Maximum Pressure	PSI	+	341	262	341	270	259	0.0428
Total Treatment Capacity	m^3/s	+	6.4	6	6.9	7	8	0.0371
New Treatment Capacity per PWTP	m^3/s	+	6.4	6	5.5	5	7	0.0343
System reliability	Cycles	+	1000	1000	1000	1000	1000	0.0319
Price	Eur/m^2	–	330	325	334	340	335	0.6000
Payback period	Years	–	25	30	25	25	20	0.0253
Guarantee period	Years	+	10	10	10	10	10	0.0281
Durability	Years	–	50	45	45	40	40	0.0311
Duration of works	Days	–	60	60	60	60	60	0.0264
Lower connection	mm	+	500	450	450	500	500	0.0275
Boiler efficiency	%	+	92	96	90	94	92	0.0335
Calorific value of gas	kW*h/m^3	+	8.83	8.6	8.75	8.8	8.9	0.0329
The average amount of gas per year	m^3	–	3051	2940	3050	3130	3010	0.0382
Approximate heat loss of the house	kW	+	11	9	10	12	11	0.0375
Pressure regulator (diameter)		+	1.5	2	0.75	1.5	2	0.0325
Boiler pressure	bar	+	1.7	0.75	1.5	1.5	1.8	0.0314
Boiler pressure	bar	+	1.7	0.75	1.5	1.5	1.8	0.0314
Max capacity	l/h	+	375	375	150	375	940	0.0265
Reliability	Cycles	+	10000	1000	1000	10000	1000	0.0291

Continued Table 2.6

1	2	3	4	5	6	7	8	9
Ventilation								
Price	Eur	–	47900	36700	28650	29430	31400	0.6000
Payback period	Years	–	10	10	23	20	25	0.0391
Guarantee period	Years	+	10	10	10	10	20	0.0382
Durability	Years	–	50	50	55	45	50	0.0282
Duration of works	Days	–	90	90	90	90	90	0.0321
Heat consumption for ventilation	W	+	650000	630000	644000	640000	635000	0.0452
Reliability	Cycles	–	1000	1000	1000	1000	1000	0.0277
Specific power (actual)	W/m2	+	50.1	54.2	51.83	54.5	55	0.0324
Power consumption (from)	W/m2	–	9	8,9	7,5	8	7	0.0379
Minimum total air consumption	m3/h	+	260	260	255	260	260	0.0331
Level of noise	dB	+	26	26	24	28	30	0.0476
Max pressure	Pa	+	9280	9100	9325	9340	8300	0.0385
Windows								
Price	Eur	–	23100	20100	17900	17550	19050	0.6000
Payback period	Years	–	15	15	20	20	18	0.0259
Guarantee period	Years	+	10	5	5	10	12	0.0247
Durability	Years	–	35	30	50	40	35	0.0227
Duration of works	Days	–	60	60	60	60	60	0.0257
Maximum glass unit thickness	mm	+	52	32	32	42	52	0.0288
Number of the glazed pane		–	6	3	4	5	5	0.0321
The thermal transmission coefficient of the glazing unit	W/m^2K	+	1.15	0.65	0.82	0.77	1.12	0.0330
Energy saving glass	mm	–	2	4	3	2	4	0.0318
Air leakage, when pressure difference Dp = 50 Pa	$m^3/m^2/h$	+	0.2	0.15	0.18	0.13	0.2	0.0296
Parameter of noise pollution	dB	+	47	44	42	44	48	0.0317
Condensation resistant	%RH	+	100	90	85	95	100	0.0286
Waterproofness	Pa	+	600	400	400	550	550	0.0295
Light transmission of a double-glazing unit	%	+	90	88	81	88	88	0.0278
Reliability	Cycles	+	10000	1000	1000	10000	1000	0.0281
Roof								
Price	Eur/m^2	–	10	11,5	14	4	7,5	0.6000
Price	Eur/m2	–	10	11,5	14	4	7,5	0.6000

End of the Table 2.6

1	2	3	4	5	6	7	8	9
Payback period	Years	–	15	15	20	20	18	0.0253
Guarantee period	Years	+	5	10	25	15	50	0.0232
Durability	Years	–	50	70	70	65	60	0.0381
Duration of works	Days	–	60	60	55	65	65	0.0371
The simplicity of the construction process		–	4	3	5	3	5	0.0268
Tile width	mm	+	1200	1195	1210	1750	1000	0.0339
Tile height	mm	+	350	350	350	1130	318	0.0339
Suitable raking spacing	mm	–	347.5	360	365	330	0	0.0338
Minimum roof pitch	°	+	14	15	14	7	7	0.0396
Sheet thickness	mm	+	0.4	0.45	0.5	5.8	3.1	0.0354
Zinc content	g/m²	+	60	140	300	0	130	0.0356
Reliability	Cycles	+	60	60	100	60	60	0.0373

* The sign z_i (+ (−)) indicates that a larger (smaller) value of the criterion corresponds to a greater importance for the stakeholder.

The next step is to form the weighted normalized decision-making matrix (previous steps formula 2 and Table 2.7).

Table 2.7. Building renovation multiple criteria analysis results

Criteria under evaluation	Measuring units of criteria	*	Numerical values of criteria					Ultimate weights of criteria. q_i
			1	2	3	4	5	
1	2	3	4	5	6	7	8	9
Water supply system								
Price	Eur/m²	–	0.1221	0.1460	0.0950	0.1094	0.1274	0.6000
Payback period	Years	–	0.0078	0.0052	0.0062	0.0052	0.0052	0.0295
Guarantee period	Years	+	0.0048	0.0060	0.0048	0.0060	0.0060	0.0275
Durability	Years	–	0.0054	0.0054	0.0063	0.0054	0.0063	0.0286
Duration of works	Days	–	0.0052	0.0052	0.0052	0.0052	0.0052	0.0258
Water pressure	PSI	+	0.0065	0.0050	0.0065	0.007	0.006	0.0308
Number of pumping stations		+	0.0079	0.0073	0.0061	0.0061	0.0091	0.0363
Number of conduction lines	W/m²K	+	0.0072	0.0036	0.0091	0.0054	0.0109	0.0362
Water resources withdrawn	%	–	0.0023	0.0098	0.0083	0.0106	0.0083	0.0392
Estimated Network Maximum Pressure	PSI	+	0.0099	0.0076	0.0099	0.0078	0.0075	0.0428
Total Treatment Capacity	m³/s	+	0.0069	0.0065	0.0075	0.0076	0.0087	0.0371
New Treatment Capacity per PWTP	m³/s	+	0.0073	0.0069	0.0063	0.0057	0.0080	0.0343

Continued Table 2.7

1	2	3	4	5	6	7	8	9
System reliability	Cycles	+	0.0064	0.0064	0.0064	0.0064	0.0064	0.0319
System reliability	Cycles	+	0.0064	0.0064	0.0064	0.0064	0.0064	0.0319
The sums of weighted normalized maximizing indices of the windows, S-j			0.1427	0.1715	0.1209	0.1357	0.1523	
Water supply significance, Qj			0.1513	0.1420	0.1471	0.1434	0.1496	
			100%	93.85%	97.22%	94.78%	98.88%	
Heating								
Price	Eur/m^2	–	0.1189	0.1172	0.1204	0.1226	0.1208	0.6000
Payback period	Years	–	0.0051	0.0061	0.0051	0.0051	0.0040	0.0253
Guarantee period	Years	+	0.0056	0.0056	0.0056	0.0056	0.0056	0.0281
Durability	Years	–	0.0071	0.0064	0.0064	0.0057	0.0057	0.0311
Duration of works	Days	–	0.0053	0.0053	0.0053	0.0053	0.0053	0.0264
Lower connection	mm	+	0.0057	0.0052	0.0052	0.0057	0.0057	0.0275
Boiler efficiency	%	+	0.0066	0.0069	0.0065	0.0068	0.0066	0.0335
Calorific value of gas	kW*h/m^3	+	0.0066	0.0064	0.0066	0.0066	0.0067	0.0329
The average amount of gas per year	m^3	–	0.0077	0.0074	0.0077	0.0079	0.0076	0.0382
Approximate heat loss of the house	kW	+	0.0078	0.0064	0.0071	0.0085	0.0078	0.0375
Pressure regulator (diameter)		+	0.0063	0.0084	0.0031	0.0063	0.0084	0.0325
Boiler pressure	bar	+	0.0074	0.0032	0.0065	0.0065	0.0078	0.0314
Max capacity	l/h	+	0.0024	0.0024	0.0009	0.0024	0.0059	0.0265
Reliability	Cycles	+	0.0127	0.0013	0.0013	0.0127	0.0013	0.0291
The sums of weighted normalized maximizing indices of the windows, S+j			0.0611	0.0458	0.0428	0.061	0.0558	
The sums of weighted normalized maximizing indices of the windows, S-j			0.1441	0.1423	0.1448	0.1465	0.1433	
Heating significance, Qj			0.1379	0.1372	0.1341	0.1364	0.1298	
			100%	99.49%	97.24%	98.91%	94.13%	
Ventilation								
Price	Eur	–	0.1651	0.1265	0.0987	0.1014	0.1082	0.6000
Payback period	Years	–	0.0044	0.0044	0.0102	0.0089	0.0111	0.0391
Guarantee period	Years	+	0.0064	0.0064	0.0064	0.0064	0.0127	0.0382
Durability	Years	–	0.0057	0.0056	0.0062	0.0051	0.0056	0.0282
Duration of works	Days	–	0.0064	0.0064	0.0064	0.0064	0.0064	0.0321
Heat consumption for ventilation	W	+	0.0092	0.0089	0.0091	0.0090	0.0090	0.0452
Reliability	Cycles	–	0.0055	0.0055	0.0055	0.0055	0.0055	0.0277

Continued Table 2.7

1	2	3	4	5	6	7	8	9
Specific power (actual)	W/m^2	+	0.0061	0.0066	0.0063	0.0066	0.0067	0.0324
Specific power (actual)	W/m2	+	0.0061	0.0066	0.0063	0.0066	0.0067	0.0324
Power consumption (from)	W/m2	–	0.0084	0.0083	0.007	0.0075	0.0066	0.0379
Minimum total air consumption	m^3/h	+	0.0067	0.0066	0.0065	0.0066	0.0066	0.0331
Level of noise	dB	+	0.0092	0.0092	0.0085	0.0099	0.0107	0.0476
Max pressure	Pa	+	0.0079	0.0077	0.0079	0.0079	0.0070	0.0385
The sums of weighted normalized maximizing indices of the windows, S+j			0.0454	0.0455	0.0447	0.0466	0.0528	
The sums of weighted normalized maximizing indices of the windows, S-j			0.1956	0.1569	0.1342	0.1349	0.1435	
Ventilation significance, Qj			0.1475	0.1415	0.1343	0.1484	0.1399	
			97.66%	95.66%	90.25%	100%	94.27%	
Windows								
Price	Eur	–	0.1419	0.1234	0.1099	0.1078	0.117	0.6000
Payback period	Years	–	0.0044	0.0044	0.0059	0.0059	0.0053	0.0259
Guarantee period	Years	+	0.0059	0.0029	0.0029	0.0059	0.0071	0.0247
Durability	Years	–	0.0042	0.0036	0.0060	0.0048	0.0042	0.0227
Duration of works	Days	–	0.0051	0.0051	0.0051	0.0051	0.0051	0.0257
Maximum glass unit thickness	mm	+	0.0071	0.0044	0.0044	0.0058	0.0071	0.0288
Numbers of glazed pane		–	0.0084	0.0042	0.0056	0.007	0.007	0.0321
Thermal transmission coefficient of glazing unit	W/m2K	+	0.0084	0.0048	0.0060	0.0056	0.0082	0.033
Number of sealing circuits		–	0.0042	0.0085	0.0064	0.0042	0.0085	0.0318
Air leakage, when pressure difference Dp = 50 Pa	$m^3/m^2/h$	+	0.0069	0.0052	0.0062	0.0045	0.0069	0.0296
Parameter of noise pollution	dB	+	0.0066	0.0062	0.0059	0.0062	0.0068	0.0317
Condensation resistant	%RH	+	0.0061	0.0055	0.0052	0.0058	0.0061	0.0286
Waterproofness	Pa	+	0.0042	0.0028	0.0028	0.0039	0.0039	0.0295
Light transmission of double-glazing unit	%	+	0.0058	0.0056	0.0052	0.0056	0.0056	0.0278
Reliability	Cycles	+	0.0122	0.0012	0.0012	0.0122	0.0012	0.0281

End of the Table 2.7

1	2	3	4	5	6	7	8	9
The sums of weighted normalized maximizing indices of the windows, S+j			0.0354	0.0301	0.0288	0.0329	0.0392	
The sums of weighted normalized maximizing indices of the windows, S+j			0.0354	0.0301	0.0288	0.0329	0.0392	
The sums of weighted normalized maximizing indices of the windows, S-j			0.1729	0.1457	0.1384	0.1343	0.1487	
Windows significance, Qj			0.1463	0.1433	0.1352	0.1384	0.1498	
			97.66%	95.66%	90.25%	92.34%	100%	
Roof								
Price	Eur/m^2	–	0.1276	0.1468	0.1787	0.0510	0.0957	0.6000
Payback period	Years	–	0.0043	0.0043	0.0058	0.0058	0.0052	0.0253
Guarantee period	Years	+	0.0011	0.0022	0.0055	0.0033	0.0111	0.0232
Durability	Years	–	0.0060	0.0085	0.0085	0.0078	0.0073	0.0381
Duration of works	Days	–	0.0073	0.0073	0.0067	0.0079	0.0079	0.0371
The simplicity of the construction process		–	0.0053	0.0040	0.0067	0.0040	0.0067	0.0268
Tile width	mm	+	0.0064	0.0064	0.0065	0.0093	0.0053	0.0339
Tile height	mm	+	0.0047	0.0047	0.0047	0.0153	0.0043	0.0339
Suitable raking spacing	mm	–	0.0084	0.0087	0.0087	0.0079	0	0.0338
Minimum roof pitch	°	+	0.0097	0.0104	0.0097	0.0049	0.0049	0.0396
Sheet thickness	mm	+	0.0014	0.0016	0.0017	0.0200	0.0107	0.0354
Zinc content	g/m²	+	0.0034	0.0079	0.0170	0	0.0073	0.0356
Reliability	Cycles	+	0.0067	0.0066	0.0109	0.0066	0.0066	0.0373
The sums of weighted normalized maximizing indices of the windows, S+j			0.0333	0.0398	0.0561	0.0595	0.0502	
The sums of weighted normalized maximizing indices of the windows, S-j			0.1590	0.1796	0.2151	0.0845	0.1228	
Roof significance, Qj			0.1918	0.2177	0.1923	0.1874	0.1907	
			80.10%	100%	88.33%	86.08%	87.59%	

* The sign z_i (+ (−)) indicates that a larger (smaller) value of the criterion corresponds to a greater importance for the stakeholder.

A complex multi-criteria analysis of building reconstruction was carried out based on the five best solution options (see Table 2.8), which were selected sepa-

rately for different components. For instance, renovation of heating systems versions with the highest priority respectively 1, 2, 4, 3 and 5; while those dealing with the roof renovation are 2, 1, 3, 5 and 4.

Table 2.8. Development of alternative options for the reconstruction of buildings based on alternative solutions

The solution considered for renovation	Priority of versions				
Water supply system	1	5	3	4	2
Heating	1	2	4	3	5
Ventilation	4	1	2	5	3
Windows	5	1	2	4	3
Roofs	2	1	3	5	4

For the renovation of the building chosen next components: water supply system by “Tep-losoft” Ukraine (1); heating “KAN-therm” EU (1); ventilation “VIKMA LTD” Ukraine (4); windows Rehau S710 Germany (5) and roof renovating with metal tile “Modern 25 USS” Slovakia (2).

2.2. Method for Sustainable Renovation of a Built Environment Using Automatic Emotion Recognition

Automatic Emotion Recognition (AEE) is an important issue in a variety of industries that use human emotional responses as a signal for technical equipment, human-robot interaction and marketing. Products that enhance positive consumer emotions can stimulate purchasing behavior. The following emotional effects can also influence consumers' feelings and perceptions. Additionally, in structured qualitative interviews, physiological cues can be used to understand consumer emotions. For construction companies important to understand the emotions of customers and the reasons behind them in order to build an emotional connection between the customer and the product and create consumer demands.

In this part, an emotion recognition experiment was conducted to understand participants emotional reactions toward the construction project. First of all, need to be prepared neuro decision-making matrix and initial data for the correlation analysis, considering the emotional and physiological state of stakeholders of different gender groups and ages. The presented matrix consists of three criteria:

- Criteria for defining a green and energy-efficient construction project.

- Criteria for defining local air pollution (CO, NO_2, PM_{10}, $PM_{2,5}$) and level of noise (see table 2.9).
- Criteria for participants depersonalized emotional and physiological states across the examined site, including states of sadness, happiness, fear, anger, disgust, surprise, valence and heart rate variability.

Table 2.9. Data on the air and noise pollution measurements at the examined location in Ukrainian

Site of the measurements and their number	CO, ppm	Noise, dB	Particulate matter (PM_{10}), mg/m^3	Particulate matter ($PM_{2,5}$), mg/m^3	NO_2, ppb
Allowable values					
	4.4	30-40	20	12	53
Nyzhniy Val 31-A in the Podilskyi district of Kyiv	0.7	41	27.00	36.45	56.38

According to the Ukrainian State Sanitary Norms, the daily limit value of particulate matter $PM_{2,5}$ (20 mg/m^3), PM_{10} (20 mg/m^3), CO (4,4 ppm) and NO_2 (53ppb) should not be exceeded for more than 35 days per year. The nose in residential premises must not exceed 40 dB during the day and 30 dB at night according to Law: Order No. 463 of 22 February 2019 on the Adoption of the State Sanitary Norms for the Noise Impact for Residential and Public Premises and in Residential Areas. The data are taken from the open data source https://www.saveecobot.com/maps#14/50.3535/30.8966/pm25/

The selected site in Ukraine was the location used for the multi-criteria analysis in the green and energy-efficient renovation project. Gathered data from this site were used to compare the results conducted by this study and similar studies of other world authors. In this case study, measurements of pollution, physiological indicators of the crowd by age and gender groups, emotional (happiness, sadness, anger, etc.) and physiological (heart rate variability) states of the participants were carried out from September 2020 until September 2021 using biometric methods and technologies.

The hardware subsystem for physiological and emotional states includes FaceReader 7.1 with an optional remote photoplethysmography module, the X4M200 breath sensor, the FLIP A35SC infrared camera, and the 720p FaceTime HD camera in the MacBook Air 2018. FaceReader is software for automatically analyzing facial expressions and is adapted to recognize participants' emotions. In the meantime, participants' self-reports were collected for comparison with those elicited by viewing the sample data. The software is based on artificial intelligence tools which allow the detection of human reactions and subjective emotions based on input videos or even images. In general, the output of the software takes the form of a series of quantitative charts and data that can be used to interpret underlying emotional states. The above data was collected every second during the experiment. The techniques of the devices mentioned during the study were used as well as technology XeThru technology (Novelda, 2019) and Noldus Information Technology (2019). A model-based face modelling method – the Active Appearance

Model, was used (2019). This model synthesizes an artificial face model by describing the location of 500 facial key points along with the facial texture of the area that these points entangle. In addition, the Facial Action Coding System (1978), the Method of Automatic Facial Expression Recognition (2005) and the Participant and Continuous calibration methods found in FaceReader (2019) were used.

Each set of equipment has certain requirements:

- High-speed Internet access of at least 600 MB/s is required. 50 GB/s download speed required. Also, there must be a static external IP address.
- Network connection must be enabled.
- Identification of all optimal sites being analyzed is required. Depersonalized, emotional and physiological states of the participants should be taken from a distance of 50 cm.

Results: (1) participants express significant emotional differences in neutral, happy, sad, disgust and surprise states regarding the construction project (see Figure 2.7). (2) Participants had higher positive ratings for the building design. (3) Three-dimensional drawings could inspire participants to come up with more relevant ideas. In addition, the following limitations and precautions have been summarized when using FaceReader under experimental conditions. (1) When participants viewed static data, the statistical significance of negative emotions may have been lower.

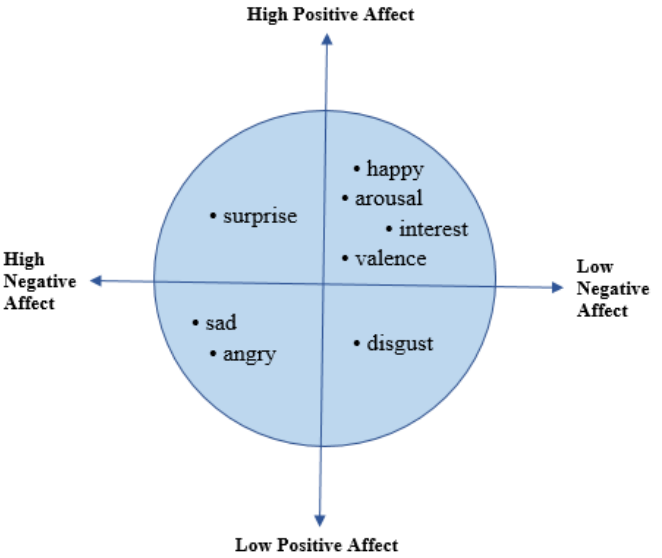


Fig. 2.7. Emotion model for the reconstruction project using Russel's circumplex model (created by author)

(2) FaceReader recognizes neutral facial expressions as sadness. This study can be useful for researchers who use the evaluation and analysis of human emotions when there is a need to choose an appropriate method for their purposes or to find alternative solutions. This approach provides a preferred foundation for researchers and designers in their respective areas of the construction industry and marketing. The results of this study present applicable methods for each type of emotion and their intensity and suggest their classification. A classification of emotion sensors is presented to reveal the scope and expected results of each method, with their limitations.

Emotions are triggered by many factors, like judging an unexpected situation, making a decision, talking about past emotional experiences, or observing another person's emotional reactions. Friesen and Ekman (1978) proposed the main emotions that are common to all people: happy, sad, angry, fear, surprise, and disgust. Emotional experience is caused by the interaction of physiological arousal and associated cognitions related to situational determinants or cues. Facial expression plays an important role in reflecting changes in emotional states. When a unique facial feature is recognized as a particular emotion, it expresses that person's feelings and provides social information.

Additionally, to the reference "neutral" state, standard classification performed by the software includes baseline definitions for individual states (total N = 6) targeting "sad", "happy", "disgusted", "fearful", "surprised" and "angry". From a practical point of view, the software offers an instant rating of action units (from 0 to 1) for all these measured emotions. Another useful feedback can be obtained by quantifying baseline parameters such as arousal, valence, the orientation of the head, gaze direction, heart rate variability (based on remote skin conductance analysis) and several additional personal characteristics of the participants (such as age, gender, beard or presence of glasses).

2.2.1. Method of Experimental Procedure

Step 0: first it is necessary to recruit participants.

Step 1: the research method used for this study consists of qualitative interviews conducted in a semi-structured manner to obtain an overview (A–F in Table 2.1, Section 2.1) and analysis of facial expressions to identify seven emotional states.

Step 2: virtual experimental analysis is based on the study of human behavior in reconstruction scenarios and considers facial expression analysis. For this, FaceReaderTM automatic facial expression recognition software (version 8, Noldus Information Technology bv, Wageningen, The Netherlands, 2013) was used to support the quantitative analysis of the experimental measurements. The participants were seated in a room, the survey was conducted from 8 am to 1 pm. A 720p

FaceTime HD camera in the 2018 MacBook Air was used for video recording of emotional expressions. Two dimmable panel lamps of 110 W each were used for optimizing lighting conditions. During filming, the participants sat on a chair, and the camera was located at a distance of 50 cm from them.

Step 3: the analysis after processing the experimental measurements with Step 2 was partly based on the automatic software analysis and improved. Detailed comparative results are presented. As shown, the results of the proposed methodology indicate that when designing building structures, subjective parameters can be used, which should be taken into account in the overall design process.

The procedure of the experiment is as follows: the participant viewed a set of images of a building, illustrations, diagrams, a matrix of alternatives, etc. Participants have to make some decisions about certain situations they are shown, in which some offers they can accept or reject. In addition, the participants were told that the proposed solutions relate to the following different contexts: economic aspects, simplicity of the construction process, durability of materials, guarantee period and aesthetic appearance, etc. The participants were instructed to verbalize their feelings in qualitative interviews. Only one participant could take part in the experiment at a time. The duration of the experiment was analyzed and recorded using FaceReader to obtain numerical values. The maximum numerical value for each emotion and each participant was extracted to determine emotional differences from renovation projects.

Were collected 226 810 valid samples after excluding invalid ones, with 22 890 data in all (249 700 data from viewing the samples by 10 experts). Data on the physiological and emotional states, arousal and valence of experts were accumulated. Table 2.10 shows the summary results of these measurements. States of happiness, sadness, anger, etc. were evaluated with points from 0 to 1. The emotion with the highest rating is dominant.

Table 2.10. Data of facially recognized emotions

Neutral	Happy	Sad	Angry	Surprised	Scared	Disgusted	Valence	Arousal	Gender	Mouth	Left Eye	Right Eye
0.9016	0.0009	0.0077	0.0398	0.0560	0.0921	0.0053	-0.0912	0.2475	Female	Closed	Open	Open
0.9016	0.0009	0.0077	0.0398	0.0560	0.0921	0.0053	-0.0912	0.2475	Female	Closed	Open	Open
0.9018	0.0009	0.0077	0.0398	0.0563	0.0921	0.0053	-0.0912	0.2475	Female	Closed	Open	Open
0.9024	0.0009	0.0076	0.0395	0.0570	0.0917	0.0052	-0.0908	0.2475	Female	Closed	Open	Open
0.9031	0.0009	0.0075	0.0391	0.0575	0.0915	0.0051	-0.0906	0.2475	Female	Closed	Open	Open
0.9041	0.0009	0.0073	0.0386	0.0579	0.0910	0.0051	-0.0901	0.2475	Female	Closed	Open	Open
0.9052	0.0009	0.0072	0.0382	0.0580	0.0905	0.0049	-0.0895	0.2475	Female	Closed	Open	Open
0.9063	0.0009	0.0071	0.0378	0.0582	0.0898	0.0048	-0.0888	0.2475	Female	Closed	Open	Open
0.9074	0.0009	0.0071	0.0374	0.0582	0.0889	0.0047	-0.0879	0.2475	Female	Closed	Open	Open
0.9079	0.0010	0.0076	0.0373	0.0575	0.0870	0.0046	-0.0860	0.2475	Female	Closed	Open	Open
0.9066	0.0010	0.0095	0.0371	0.0563	0.0844	0.0047	-0.0833	0.2475	Female	Closed	Open	Open

End of the Table 2.10

Neutral	Happy	Sad	Angry	Surpri-sed	Scared	Disgus-ted	Valence	Arousal	Gender	Mouth	Left Eye	Right Eye
0.9040	0.0011	0.0131	0.0369	0.0548	0.0812	0.0051	-0.0800	0.2475	Female	Closed	Open	Open
0.9024	0.0012	0.0164	0.0368	0.0531	0.0778	0.0052	-0.0765	0.2475	Female	Closed	Open	Open
0.9019	0.0014	0.0189	0.0367	0.0514	0.0744	0.0055	-0.0730	0.2475	Female	Closed	Open	Open
0.9023	0.0015	0.0209	0.0367	0.0499	0.0713	0.0057	-0.0698	0.2475	Female	Closed	Open	Open
0.9034	0.0016	0.0224	0.0367	0.0485	0.0686	0.0058	-0.0669	0.2475	Female	Closed	Open	Open
0.9053	0.0017	0.0234	0.0368	0.0472	0.0661	0.0059	-0.0643	0.2475	Female	Closed	Open	Open
0.9076	0.0019	0.0239	0.0367	0.0460	0.0639	0.0059	-0.0621	0.2475	Female	Closed	Open	Open
0.9102	0.0020	0.0241	0.0366	0.0449	0.0619	0.0059	-0.0599	0.2475	Female	Closed	Open	Open
0.9130	0.0020	0.0241	0.0363	0.0439	0.0604	0.0058	-0.0583	0.2475	Female	Closed	Open	Open
0.9130	0.0020	0.0241	0.0363	0.0439	0.0604	0.0058	-0.0583	0.2475	Female	Closed	Open	Open
0.9160	0.0021	0.0238	0.0359	0.0432	0.0591	0.0057	-0.0569	0.2475	Female	Closed	Open	Open
0.9190	0.0021	0.0233	0.0354	0.0424	0.0579	0.0055	-0.0557	0.2475	Female	Closed	Open	Open
0.9221	0.0022	0.0226	0.0348	0.0419	0.0568	0.0053	-0.0546	0.2475	Female	Closed	Open	Open
0.9249	0.0022	0.0219	0.0342	0.0413	0.0561	0.0051	-0.0539	0.2475	Female	Closed	Open	Open
0.9276	0.0022	0.0211	0.0336	0.0409	0.0558	0.0049	-0.0536	0.2475	Female	Closed	Open	Open
0.9301	0.0022	0.0202	0.0330	0.0408	0.0556	0.0047	-0.0534	0.2475	Female	Closed	Open	Open
0.9326	0.0022	0.0193	0.0325	0.0410	0.0554	0.0045	-0.0532	0.2475	Female	Closed	Open	Open
0.9350	0.0022	0.0184	0.0319	0.0413	0.0551	0.0043	-0.0529	0.2475	Female	Closed	Open	Open
…	…	…	…	…	…	…	…	…	…	…	…	…
0.7967	0.01616	0.0192	0.0120	0.1999	0.0581	0.0041	-0.0418	0.3546	Female	Closed	Open	Open

For comparing the effects of participants' neutral and six primary emotions on the alternatives for the renovation project conducted measurements. Figure 2.8 presents the results of facial emotion recognition.

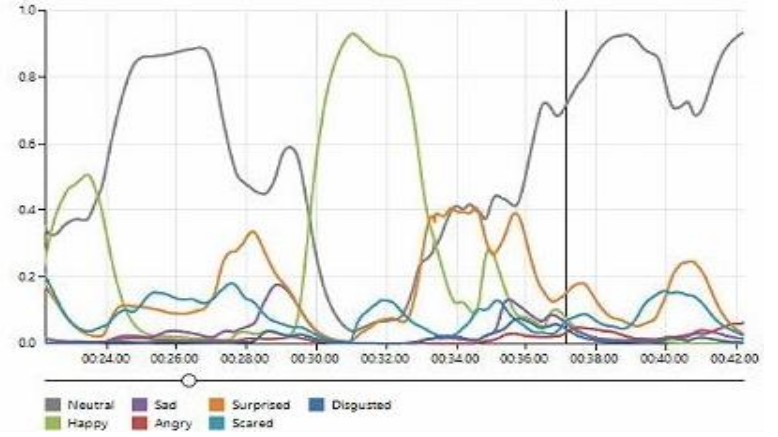


Fig. 2.8. An example of action units of recordings of the main emotional states obtained for one of the participants (created by the author)

After capturing the maximum value of each emotion from every participant, were imported emotion data into to run measures. The comparison was provided to locate the source of emotional differences. The result data of facially recognized emotions is in Table 2.7 and the result data for each category is in the tables below.

Happiness. The values of happiness have noticeable changes in the facial expression recognition result. It shows that the participants feel happier Parameter of noise pollution compared with the number of Glazed panes or Number of sealing circuits by referring to comparisons, which are detailed in Table 2.11.

Table 2.11. The result of "happiness"

Participant	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**
	Eur	Years	Years	Years	Days	mm	$W/m^2 K$	$m^3/m^2/h$	dB	%RH	Pa	%	Cycles
	-	-	+	-	-	+	+	+	+	+	+	+	+
1	0.048	0.1146	0.3136	0.1551	0.0836	0.5051	0.1987	0.7927	0.8999	0.9259	0.889	0.8652	0.8561
2	0.052	0.1298	0.331	0.1423	0.765	0.5003	0.2356	0.8074	0.9066	0.9222	0.8846	0.8647	0.8532
3	0.0568	0.1463	0.3459	0.1304	0.07	0.4934	0.2746	0.8209	0.9123	0.9183	0.8806	0.864	0.8492
4	0.0623	0.166	0.3617	0.1193	0.0641	0.4835	0.3136	0.8334	0.9173	0.9142	0.8773	0.8632	0.8438
5	0.0682	0.1873	0.3756	0.1092	0.0587	0.4728	0.3526	0.845	0.9218	0.9101	0.8748	0.8626	0.8361
6	0.0748	0.2105	0.3875	0.0999	0.0538	0.4616	0.3911	0.8558	0.9259	0.9064	0.8727	0.8619	0.8265
7	0.0815	0.2329	0.3983	0.0914	0.0494	0.4496	0.4284	0.8661	0.9289	0.9033	0.8704	0.8612	0.8144
8	0.0883	0.2553	0.4077	0.0836	0.0455	0.4371	0.4642	0.8757	0.9305	0.9003	0.8684	0.8603	0.7999
9	0.0955	0.2766	0.417	0.0765	0.042	0.4239	0.4988	0.8845	0.9304	0.8969	0.8669	0.8592	0.7847
10	0.1027	0.2964	0.4255	0.07	0.039	0.4084	0.5322	0.8926	0.9286	0.8932	0.866	0.858	0.7677

* Category and its number: (1) Price, (2) Payback period, (3) Guarantee period, (4) Durability, (5) Duration of works, (6) Maximum glass unit thickness, (7) Numbers of the glazed pane, (8) Thermal transmission coefficient of the glazing unit, (9) Number of sealing circuits, (10) Air leakage, (11) Parameter of noise pollution, (12) Condensation resistant, (13) Waterproofness, (14) Light transmission of double-glazing unit and (15) Reliability.

Sadness. The subjects did not have notable changes in sad emotion while viewing the alternatives of window reconstruction (see Table 2.12).

Table 2.12. The result of "sadness"

Participant	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**
	Eur	Years	Years	Years	Days	mm	$W/m^2 K$	$m^3/m^2/h$	dB	%RH	Pa	%	Cycles
	–	–	+	–	–	+	+	+	+	+	+	+	+
1	0.0464	0.0263	0.0128	0.0206	0.024	0.0042	0.0861	0.0140	0.0050	0.0019	0.0015	0.0014	0.0013
2	0.0444	0.0246	0.0119	0.0214	0.0239	0.004	0.0798	0.0126	0.0045	0.0018	0.0015	0.0014	0.0013
3	0.0423	0.023	0.0111	0.0222	0.0237	0.0039	0.0738	0.0114	0.004	0.0017	0.0015	0.0013	0.0013
4	0.0401	0.0214	0.0103	0.0231	0.0234	0.0038	0.0681	0.0103	0.0036	0.0016	0.0015	0.0013	0.0014
5	0.038	0.0199	0.0097	0.0237	0.0232	0.0037	0.0627	0.0093	0.0033	0.0016	0.0015	0.0013	0.0014

End of Table 2.12

Participant	1	2	3	4	5	6	7	8	9	10	11	12	13
6	0.0359	0.0185	0.0091	0.024	0.0229	0.0036	0.0577	0.0084	0.0029	0.0017	0.0015	0.0013	0.0014
7	0.0338	0.0172	0.0086	0.0241	0.0225	0.0035	0.0529	0.0076	0.0027	0.0015	0.0015	0.0013	0.0014
8	0.0318	0.0159	0.0082	0.024	0.0221	0.0034	0.0485	0.0068	0.0024	0.0015	0.0014	0.0013	0.0015
9	0.0299	0.0148	0.0078	0.0239	0.0216	0.0034	0.0443	0.0061	0.0022	0.0015	0.0014	0.0013	0.0015
10	0.0281	0.0137	0.0074	0.0237	0.0211	0.0034	0.0405	0.0055	0.0021	0.0015	0.0014	0.0013	0.0016

* Category and its number: (1) Price, (2) Payback period, (3) Guarantee period, (4) Durability, (5) Duration of works, (6) Maximum glass unit thickness, (7) Numbers of the glazed pane, (8) Thermal transmission coefficient of the glazing unit, (9) Number of sealing circuits, (10) Air leakage, (11) Parameter of noise pollution, (12) Condensation resistant, (13) Waterproofness, (14) Light transmission of double-glazing unit and (15) Reliability.

Anger. According to the result, the subjects' angry emotion stays low values during the experiment.

Table 2.13. The result of "angry"

Participant	1	2	3	4	5	6	7	8	9	10	11	12	13
	Eur	Years	Years	Years	Days	mm	W/m^2 K	$m^3/m^2/h$	dB	%RH	Pa	%	Cycles
	–	–	+	–	–	+	+	+	+	+	+	+	+
1	0.0025	0.002	0.0131	0.0155	0.0018	0.0131	0.0003	0.0010	0.0006	0.0006	0.0005	0.0004	0.0025
2	0.0024	0.002	0.002	0.0136	0.0158	0.0018	0.0138	0.0025	0.0009	0.0006	0.0006	0.0005	0.0005
3	0.0023	0.002	0.0019	0.014	0.016	0.0019	0.0129	0.0022	0.0008	0.0006	0.0006	0.0005	0.0005
4	0.0022	0.002	0.0019	0.0143	0.0162	0.0019	0.0121	0.0020	0.0008	0.0006	0.0006	0.0005	0.0005
5	0.0022	0.002	0.0019	0.0146	0.0164	0.002	0.0112	0.0018	0.0007	0.0006	0.0006	0.0005	0.0006
6	0.0022	0.002	0.0019	0.0149	0.0165	0.0022	0.0104	0.0017	0.0007	0.0006	0.0006	0.0004	0.0006
7	0.0021	0.002	0.0018	0.0152	0.0166	0.0023	0.0096	0.0015	0.0007	0.0006	0.0006	0.0004	0.0006
8	0.0021	0.002	0.0018	0.0155	0.0168	0.0025	0.0089	0.0014	0.0006	0.0006	0.0006	0.0004	0.0006
9	0.0021	0.002	0.0017	0.0158	0.0167	0.0026	0.0082	0.0012	0.0006	0.0006	0.0005	0.0004	0.0006
10	0.0021	0.002	0.0016	0.016	0.0166	0.0029	0.0075	0.0011	0.0006	0.0006	0.0005	0.0004	0.0006

* Category and its number: (1) Price, (2) Payback period, (3) Guarantee period, (4) Durability, (5) Duration of works, (6) Maximum glass unit thickness, (7) Numbers of the glazed pane, (8) Thermal transmission coefficient of the glazing unit, (9) Number of sealing circuits, (10) Air leakage, (11) Parameter of noise pollution, (12) Condensation resistant, (13) Waterproofness, (14) Light transmission of double-glazing unit and (15) Reliability.

*Surprised***.** Comparisons show that the participants' values of surprise are significantly higher while viewing Price, Number of sealing and Reliability blocks. Please refer to Table 2.14.

Table 2.14. The result of "surprised"

Participant	1	2	3	4	5	6	7	8	9	10	11	12	13
	Eur	Years	Years	Years	Days	mm	$W/m^2 K$	$m^3/m^2/h$	dB	%RH	Pa	%	Cycles
	–	–	+	–	–	+	+	+	+	+	+	+	+
1	0.2589	0.2288	0.1544	0.1113	0.1135	0.0264	0.0864	0.0157	0.0070	0.019	0.0190	0.0721	0.0732
2	0.2565	0.2231	0.1478	0.1129	0.1133	0.0252	0.0803	0.0144	0.0066	0.0233	0.0233	0.0730	0.0713
3	0.2538	0.2166	0.1426	0.1138	0.113	0.0243	0.0744	0.0132	0.0063	0.0273	0.0273	0.0737	0.0693
4	0.2511	0.2095	0.1375	0.1140	0.1127	0.0234	0.0688	0.0121	0.0061	0.0306	0.0306	0.0744	0.0674
5	0.2477	0.2019	0.1319	0.1142	0.1126	0.0227	0.0636	0.0111	0.0060	0.0335	0.0335	0.0749	0.0662
6	0.2442	0.1937	0.1265	0.1141	0.1125	0.0221	0.0586	0.0102	0.0064	0.0362	0.0362	0.0755	0.0652
7	0.2413	0.1856	0.1206	0.1139	0.1122	0.0217	0.054	0.0093	0.0077	0.0384	0.0384	0.0761	0.0651
8	0.2383	0.1776	0.1145	0.1135	0.1119	0.0213	0.0497	0.00867	0.0096	0.0405	0.0405	0.0762	0.0670
9	0.2354	0.1692	0.1082	0.1133	0.1115	0.0212	0.0457	0.0080	0.0122	0.0428	0.0428	0.0758	0.0705
10	0.2333	0.1614	0.1019	0.1130	0.1107	0.0222	0.0420	0.0075	0.0154	0.0451	0.0451	0.0747	0.0755

* Category and its number: (1) Price, (2) Payback period, (3) Guarantee period, (4) Durability, (5) Duration of works, (6) Maximum glass unit thickness, (7) Numbers of the glazed pane, (8) Thermal transmission coefficient of the glazing unit, (9) Number of sealing circuits, (10) Air leakage, (11) Parameter of noise pollution, (12) Condensation resistant, (13) Waterproofness, (14) Light transmission of double-glazing unit and (15) Reliability.

Scared. The values of scared do not have noticeable changes as shown in Figure 2.7. Results indicate that Price blocks make the subjects' values of scared higher than the other types of alternatives.

Table 2.15. The result of "scared"

Participant	1	2	3	4	5	6	7	8	9	10	11	12	13
	Eur	Years	Years	Years	Days	mm	$W/m^2 K$	$m^3/m^2/h$	dB	%RH	Pa	%	Cycles
	–	–	+	–	–	+	+	+	+	+	+	+	+
1	0.2496	0.2466	0.179	0.0946	0.0988	0.0372	0.0464	0.0114	0.0048	0.0539	0.1032	0.1301	0.1146
2	0.2485	0.2421	0.1708	0.0968	0.0969	0.0378	0.0446	0.0105	0.0044	0.0637	0.1073	0.1299	0.1102
3	0.2475	0.2367	0.1622	0.0985	0.0959	0.0387	0.0426	0.0097	0.0041	0.0714	0.1106	0.1294	0.1057
4	0.2472	0.2305	0.1541	0.1003	0.0961	0.0400	0.0405	0.0089	0.0039	0.0775	0.01136	0.1287	0.1012
5	0.2481	0.2241	0.1460	0.1013	0.0971	0.0414	0.0383	0.0081	0.0042	0.0825	0.1156	0.1281	0.0966
6	0.2493	0.2171	0.1380	0.1012	0.0993	0.0429	0.0361	0.0074	00.56	0.0867	0.1186	0.1276	0.0921
7	0.2503	0.2099	0.1301	0.1003	0.1026	0.0445	0.0338	0.0068	0.0098	0.0903	0.1225	0.1266	0.0878
8	0.2515	0.2023	0.1222	0.0988	0.1068	0.0461	0.0317	0.0062	0.0183	0.0935	0.1257	0.1249	0.0836
9	0.2514	0.1945	0.1145	0.0969	0.1109	0.0475	0.0295	0.0057	0.0298	0.0965	0.1284	0.1222	0.0795
10	0.2497	0.1868	0.1070	0.0959	0.1156	0.0492	0.0275	0.0052	0.0422	0.0999	0.1298	0.1188	0.0758

* Category and its number: (1) Price, (2) Payback period, (3) Guarantee period, (4) Durability, (5) Duration of works, (6) Maximum glass unit thickness, (7) Numbers of the glazed pane, (8) Thermal transmission coefficient of the glazing unit, (9) Number of sealing circuits, (10) Air leakage, (11) Parameter of noise pollution, (12) Condensation resistant, (13) Waterproofness, (14) Light transmission of double-glazing unit and (15) Reliability.

Disgust. Disgust emotion stays at the lowest value during the experiment. The participants did not have notable changes in disgust and emotion.

Table 2.16. The result of "disgusted"

Par-ticipant	1	2	3	4	5	6	7	8	9	10	11	12	13
	Eur	Years	Years	Years	Days	mm	W/m^2 K	$m^3/m^2/h$	dB	%RH	Pa	%	Cycles
	–	–	+	–	–	+	+	+	+	+	+	+	+
1	0.0042	0.0026	0.0018	0.0042	0.0040	0.0051	0.0259	0.0057	0.0022	0.0009	0.0008	0.0009	0.0010
2	0.0040	0.0025	0.0018	0.0042	0.0039	0.0051	0.0249	0.0052	0.0019	0.0009	0.0008	0.0009	0.0010
3	0.0039	0.0024	0.0018	0.0042	0.0038	0.0050	0.0237	0.0047	0.0018	0.0008	0.0008	0.0009	0.0011
4	0.0037	0.0023	0.0019	0.0042	0.0037	0.0050	0.0225	0.0043	0.0016	0.0008	0.0008	0.0009	0.0012
5	0.0035	0.0022	0.0021	0.0042	0.0036	0.0050	0.0212	0.0039	0.0014	0.0008	0.0008	0.0009	0.0012
6	0.0034	0.0021	0.0023	0.0042	0.0035	0.0050	0.0199	0.0035	0.0013	0.0008	0.0009	0.0009	0.0014
7	0.0031	0.0020	0.0026	0.0041	0.0034	0.0050	0.0186	0.0032	0.0012	0.0008	0.0009	0.0009	0.0015
8	0.0032	0.0020	0.0030	0.0040	0.0033	0.0050	0.0174	0.0029	0.0011	0.0008	0.0009	0.0009	0.0016
9	0.0029	0.0019	0.0034	0.0039	0.0032	0.0050	0.0161	0.0026	0.0010	0.0008	0.0009	0.0009	0.0018
10	0.0028	0.0019	0.0037	0.0038	0.0031	0.0049	0.0150	0.0024	0.0010	0.0008	0.0009	0.0009	0.0019

* Category and its number: (1) Price, (2) Payback period, (3) Guarantee period, (4) Durability, (5) Duration of works, (6) Maximum glass unit thickness, (7) Numbers of the glazed pane, (8) Thermal transmission coefficient of the glazing unit, (9) Number of sealing circuits, (10) Air leakage, (11) Parameter of noise pollution, (12) Condensation resistant, (13) Waterproofness, (14) Light transmission of double-glazing unit and (15) Reliability.

2.3. Manual Post-Processing Strategy for Intelligent Decision Support System for Sustainable Renovation of a Built Environment Using Heart Rate Variability

Heart rate variability (HRV) is a method of assessing emotional state based on the measurement of specific changes in time (or variability) between successive heartbeats. The time between beats is measured in milliseconds and is called the "R-R interval" or "interbeat interval" (see Fig. 2.9). Heart rate variability is regulated by the synergistic action of two branches of the autonomic nervous system, namely the sympathetic and parasympathetic nervous systems. Heart rate is the total effect of parasympathetic nerves, which slow down the heart rate, and sympathetic nerves, which speed it up. These changes are influenced by stress, emotions physical activities and emotions (Ribeiro et al., 2019).

In addition, HRV depends on gender and age, smoking, coffee, alcohol, blood pressure and excess weight, depression, etc. Hereditary genes also significantly affect heart rate variability.

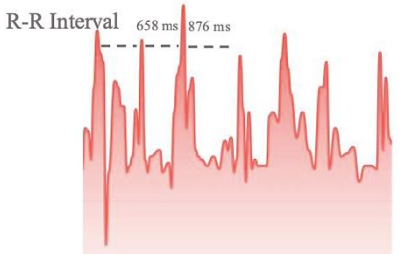


Fig. 2.9. R-R interval of heart rate variability (elaborated by author)

A low HRV indicates a state of relaxation, while an elevated HRV indicates a potential state of frustration or mental stress. An alternative to HRV based on an electrocardiogram is photoplethysmography, which is available in smart bracelets and smart watches (Apple Watch, Xiaomi Mi Smart Band, Huawei, etc). The main advantage of HRV based on photoplethysmography is that there is no need for special human training. It is usually enough to touch the active surface of the sensor for a few seconds. The photoplethysmography method allows non-contact measurement (Noaman et al., 2017). The pros of this methodology reveal the potential of its implementation in a wide range of applications, especially in the field of IoT and human-machine interaction. In the studied cases, when the accuracy of emotion detection requires certain conditions, the HRV technique should be supplemented with other techniques, such as FaceReader. This situation creates a high potential for the application of big data analysis methods.

In this case, following market and scientific trends, were taking advantage of these new devices to develop solutions in the decision-making process for property owners and clients in a research context. Real-time measures of high/low valence, arousal, and stress were collected from participants, similar to how recent research projects have investigated. This information can be used to gain a better understanding of the satisfaction value of each alternative for the customer.

In the first step, it introduces and analyzes the variety of wrist wearable devices, the operating systems available, and the ability to transfer data from wearable devices to third-party servers. An overview of the major software integration platforms is provided, including iOS and Mi Fit/Android Wear. The second part of the case study presented the results of using wrist wearables in study cases. The data is captured by sensors available in smartphones and wearable devices. Gathered data in wearable devices were transferred to a computer or smartphone as an intermediate step before its final transfer. This transfer was carried out using proprietary solutions. Transferring data from the wearable device to a third-party system can be done using an app on an intermediate smartphone. Figure 2.10 shows how data is transmitted through links 1 and 2.

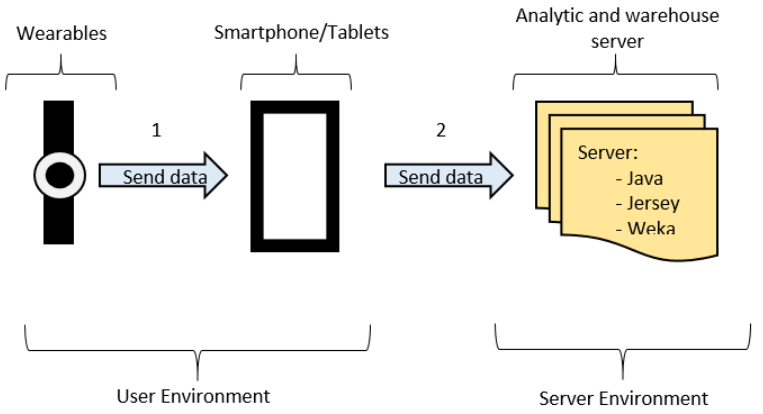


Fig. 2.10. Representation of a system for transferring data of a wearable device – indirect access (created by author)

Link 1. The application on the smartphone can collect data from the wearable device. For this, a native app running on a smartphone is signed up as an event collector in handheld sensors. The wearable device periodically reports new data, and the smartphone collects it. In studied cases, this is done via Bluetooth.

Link 2. The application on the smartphone sends data to the server. Periodically, the built-in program running on the smartphone checks for an Internet connection. When a connection is available, the application sends the gathered data to the server. The smartphone app stores data gathered from wearable devices until an internet connection is available.

At the first stage of the study, the following criteria were taken into account for the selection of wearables devices for use in experiments:

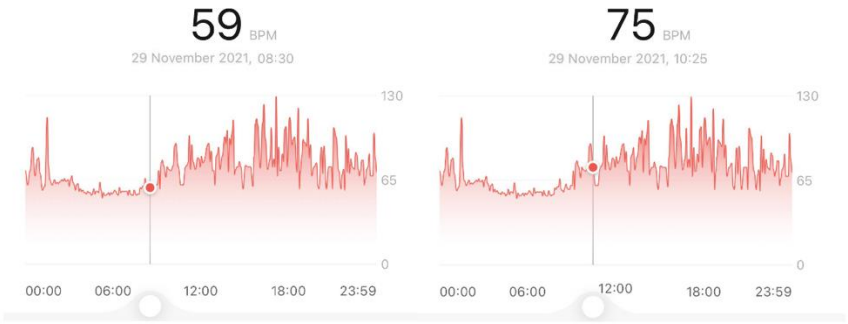
- *Developer's market share.* It is important to use simple devices because of their availability in the market.
- *The availability of sensors.* Development of algorithms that do not needs many sensors, but some of them are key to calculating indicators. Therefore, there should be a minimum set of sensors: accelerometer and heart rate (Fig. 2.11).
- *The options to collect data from the device.* There must be some Application Programming Interface or method that allows collecting data from the device.
- *Price and availability.* From a sustainable development perspective, the work was done with devices that were easy to acquire and affordable.

Fig. 2.11. HR sensor in Xiaomi Mi Smart Band 9 (available online: https://www.mi.com/ua/)

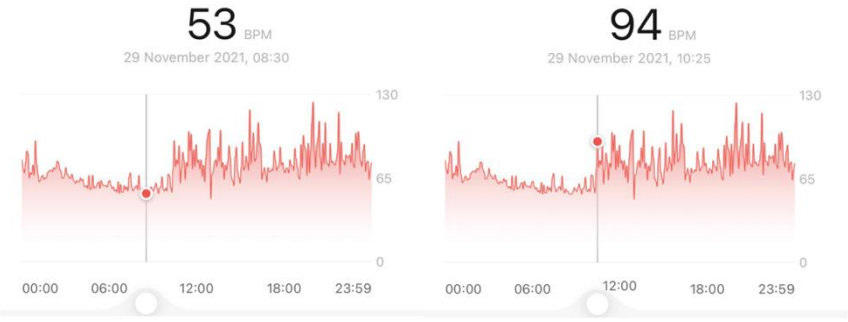
Based on these criteria, it was decided to select Xiaomi, Apple and some Android Wear devices (such as Huawei) to work with certain Mi Fit/IHealth and Google Fit apps. These devices allow the transfer of warehouse data – direct access. To initiate the transfer and synchronize data, needed to install a special application on a computer (Windows/Mac) or smartphone (Android, iOS or Windows). Data are available to third parties related to physical activity: heart rate, sleep patterns, skin temperature, walking distance, calories consumed, number of steps, etc. Data transfer on wearables – indirect access. For example, The Mi Fit app must be installed on the wearable device and as an app on the smartphone. Using available transmission modes, selected wearable devices provide data to calculate heart rate and skin temperature in real-time. Data analysis was carried out on a computer. Here, the heart rate during the measurement period is used to determine the heart rate variability during the decision time. As a physiological indicator, heart rate variability is mainly used in medical research and is associated with the mental, emotional and psychological state. The understanding of HRV is based on its connection with the autonomic nervous system. The autonomic nervous system is influenced by the sympathetic and parasympathetic systems, the relative influence of which is displayed in an external file that contains a matrix of alternatives, images of buildings, diagrams, illustrations, etc. For example, a higher ratio of sympathetic to parasympathetic activity has been connected to increased mental stress. Since a higher heart rate reflects increased sympathetic or less parasympathetic activity, it indicates higher stress. Interpretations of HRV and its relationship to economic decisions, as explored in research, are based on the concept of measuring mental stress, which is also reflected in the existing literature using HRV data in economic research (Dulleck et al., 2016). Specifically, decisional stress and heart rate variability reflect mental stress caused by emotions.

2.3.1. Procedure of Experiment

Heart rate data were analysed at the stage of recording the emotions of each participant. This experiment relied on images of renovation projects, diagrams, and alternative matrices as sources of emotional stimulus materials to elicit the corresponding emotions. The survey was conducted from 8 a.m. to 1 p.m. and during the task, HR was recorded via a smartwatch system (see Fig. 2.12 a-b).



a) participant #1



b) participant #3

Fig. 2.12 (a-b). The HR segments in Mi Fit of the subjects were collected using a smart bracelet (created by the author)

Specifically, the task required participants to make certain decisions about situations they were shown, which had offers they could accept or reject. In addition, the participants were told that the proposed solutions relate to the following different contexts: economic aspects, simplicity of the construction process, the durability of materials, warranty period and aesthetic appearance, etc. Since changes in emotional mood cause changes in cardiac activity, the extracted features can be used to express the state of various emotions (Brownson et al., 2009). Figure 2.13 shows some typical parameters used to extract features.

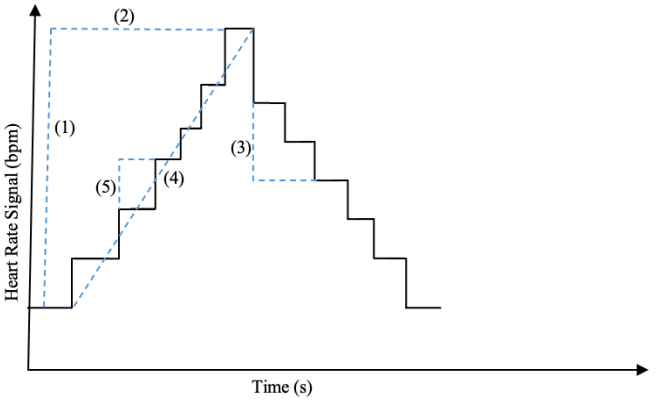


Fig. 2.13. Typical heart rate parameters for distinguishing signs are: (1) amplitude of increase; (2) Hours of Operation; (3) Amplitude down; (4) Slope; (5) T Continue (elaborated by the author)

Parameters (1) and (3) represent the change in HR amplitude. Parameter (2) indicates that the heart rate continues to increase over time and (4) shows the slope of the change in heart rate. Parameter (5) indicates the duration during which the heart rate data remains unchanged.

The experiment proved that when a participant's emotions change (happiness, sadness, and a neutral state), their heart rate should reflect their mood accordingly. Statistical analysis showed that the rise in heart rate was significant when participants felt positive emotions and vice versa negative emotions caused the heart rate to decrease. It also showed that real-time emotion recognition and monitoring can be achieved with affordable wearable devices. This method was simple, fast and easy to use on many portable devices available. For real-world emotion recognition applications using a smart bracelet, it is suggested to first show the user standard neutral stimulation videos to obtain neutral mood heart rate data as a baseline. This operation helps to eliminate personalized differences.

2.4. Analysis Of Collected Data for Intelligent Decision Support System for Sustainable Renovation of Case Study

An intelligent decision support system was developed using the results of the previous sections. The aim of developing this framework was to propose a new sus-

tainable building renovation decision-making framework to support project development and reporting of results to stakeholders. For each reconstruction project, the priorities are quite different from case to case, so the comparison of criteria is interdependent.

The Intelligent DSS developed during the study is not only intended to evaluate whether one solution (among possible options) is better than another but it can also be used in the early stages of design to characterize the main areas and initiatives to achieve a holistic renovation building. The collected data related to key factors provide background and general knowledge about the renovation project. The main part of the developed decision-making system, which functions as a Value Map (see Fig. 2.14), visualizes the main goals for sustainable renovation. It focuses on multi-criteria analysis and can be used in conjunction with the services of sustainability consultants. As a result, all data collected must be performed: a review of literature, review meetings, desktop studies (emotional state and HRV tests), site visits and participation of relevant stakeholders are possible methods of data collection.

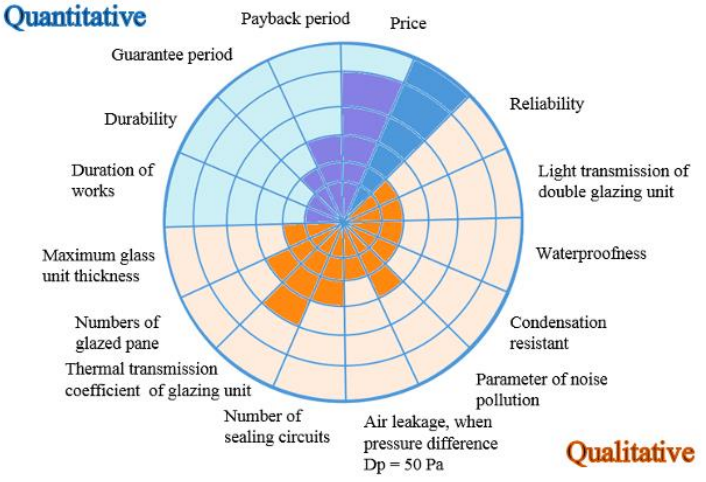


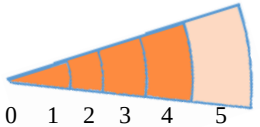
Fig. 2.14. Emotional and economic criteria. A Value Map relating to the same researched area in the developed decision-making framework (example of Windows renovation in Case Study – created by the author)

In addition, data must be examined to ensure that they have been collected methodologically and statistically soundly. The results can be used to monitor, audit and evaluate the effectiveness of renovation and support decision-making

throughout the project life cycle. This can be useful for identifying and establishing key performance criteria and indicators at an early stage of design. It can also be used to guide decision-making and stakeholder engagement. Additionally, the advantages and disadvantages of each alternative reconstruction solution can be compared to determine their specific value, which affects differently from case to case.

The performance evaluation system for the criteria of the decision support system for sustainable development is presented in Table 2.17. It exhibits a graded rating system ranging from 1 to 5, where a value of 1 indicates substandard quality, while a value of 5 is the maximum value in this framework, which refers to what can currently be considered a more or less "fully sustainable retrofitting" – e.g., almost zero energy renewable projects (Tomislav, 2018).

Table 2.17. A system for evaluating the performance of a decision support system for sustainable development – for example, an indicator: Thermal transmission coefficient of a double-glazed window.

The thermal transmission coefficient of a double-glazed window	Value	Standards	Ratio	Example
	1	Sub-standard	Low	0.65
	2	Minimum standard	Reasonable	0.77
	3	Good practice	Moderately	0.82
	4	Best practice	High	1.12
	5	Exemplary	Very high	1.15

Depending on the type of criteria that were developed in this study, they are divided into qualitative and quantitative. Factors corresponding to Quantitative indicators in the Value Map are mostly quantifiable, such as service life or investment costs, duration of work or durability which can be measured in a sufficiently objective way. Quality factors mean that they need to be evaluated qualitatively. They need to be met and designed at the drawing stage.

In this regard, in order for reconstruction projects to meet sustainability in its full sense, it seems important to focus on the interaction and interdependence of qualitative and quantitative aspects corresponding to subjective and objective values during the life cycle of the project. Applying the COPRAS method (Complex proportional assessment method). The purpose of the multi-criteria analysis in the selected location was to establish emotional and rational segments of the market according to demographic criteria (men and women aged 30-40 years, 41-50 years and 51–66 years), psychographic criteria and criteria of consumer behaviour (hap-

piness, sadness and anger, as well as valence and heart rate variability). Multicriteria analysis and related calculations were performed according to Stages 1–5 of the COPRAS method (Kaklauskas et al., 2006). Next, the application of the COPRAS method is described in the comprehensive determination of the importance of the criteria of various alternatives, taking into account their qualitative and quantitative characteristics for reconstruction projects.

Determining the value of the alternative for the construction project was carried out using Stages 1–5 of the COPRAS method (see Fig. 2.1, section 2.1). Table 2.18 shows the results of the criterion evaluation of the researched trading platforms. The initial weights of the quantitative criteria are determined by expert methods. Respondents indicated the weights of the criteria. Then the completed questionnaires were processed and the reliability of the expertise was determined by calculating the concordance coefficient, which demonstrates the compatibility of experts' assessments. The obtained results are displayed below in Table 2.18.

Table 2.18. Decision matrix and results of the evaluation of window alternatives using the COPRAS method

				Integrated emotional compared alternatives					Compared alternatives				
Criteria under evaluation	**Measuring units of criteria**	*****	**Ultimate weights of criteria, q_i**	**Numerical values of criteria**									
				1	**2**	**3**	**4**	**5**	**1**	**2**	**3**	**4**	**5**
1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**
Economic criteria													
Price	Eur	–	0.6	23100	20100	17900	17550	19050	23100	20100	17900	17550	19050
				0.1418	0.1616	0.1971	0.2877	0.5999	0.1418	0.1617	0.1971	0.2877	0.5999
Payback period	Years	–	0.0259	15	15	20	20	18	15	15	20	20	18
				0.0044	0.0053	0.0089	0.0136	0.0258	0.0044	0.0053	0.0089	0.0136	0.0258
Guarantee period	Years	+	0.0247	10	5	5	10	12	10	5	5	10	12
				0.0058	0.0038	0.0045	0.0112	0.0246	0.0058	0.0039	0.0045	0.0112	0.0246
Durability	Years	–	0.0227	35	30	50	40	35	35	30	50	40	35
				0.0042	0.0043	0.0091	0.0121	0.0226	0.0042	0.0044	0.0091	0.0121	0.0226
Duration of works	Days	–	0.0257	60	60	60	60	60	60	60	60	60	60
				0.0051	0.0051	0.0051	0.0051	0.0051	0.0051	0.0051	0.0051	0.0051	0.0051
Maximum glass unit thickness	mm	+	0.0288	52	32	32	42	52	52	32	32	42	52
				0.0071	0.0058	0.0074	0.0128	0.0287	0.0071	0.0058	0.0073	0.0129	0.0287
Numbers of the glazed pane		–	0.0321	6	3	4	5	5	6	3	4	5	5
				0.0084	0.0057	0.0092	0.0160	0.0318	0.0084	0.0057	0.0092	0.0161	0.0318
The thermal transmission coefficient of the glazing unit	W/m^2 K	+	0.033	1.15	0.65	0.82	0.77	1.12	1.15	0.65	0.82	0.77	1.12
				0.0084	0.0064	0.0099	0.0133	0.0319	0.0084	0.0064	0.0099	0.0132	0.0319
Number of sealing circuits		–	0.0318	2	4	3	2	4	2	4	3	2	4
				0.0042	0.0098	0.0106	0.0106	0.0315	0.0042	0.0097	0.0106	0.0105	0.0315

End of Table 2.18

1	2	3	4	5	6	7	8	9	10	11	12	13	14
Number of sealing circuits		–	0.0318	2	4	3	2	4	2	4	3	2	4
				0.0042	0.0098	0.0106	0.0106	0.0315	0.0042	0.0097	0.0106	0.0105	0.0315
Air leakage. when pressure difference Dp = 50 Pa	$m^3/m^2/h$	+	0.0296	0.2	0.15	0.18	0.13	0.2	0.2	0.15	0.18	0.13	0.2
				0.0069	0.0067	0.0102	0.0109	0.0252	0.0069	0.0067	0.0102	0.0108	0.0252
Parameter of noise pollution	dB	+	0.0317	47	44	42	44	48	47	44	42	44	48
				0.0066	0.0078	0.0099	0.0152	0.0317	0.0066	0.0078	0.0099	0.0152	0.0317
Condensation resistant	%RH	+	0.0286	100	90	85	95	100	100	90	85	95	100
				0.0061	0.0069	0.0087	0.0139	0.0285	0.0061	0.0069	0.0086	0.0139	0.0285
Waterproof-ness	Pa	+	0.0295	600	400	400	550	550	600	400	400	550	550
				0.0071	0.0062	0.0078	0.0147	0.0295	0.0071	0.0062	0.0078	0.0147	0.0294
Light transmis-sion of a dou-ble-glazing unit	%	+	0.0278	90	88	81	88	88	90	88	81	88	88
				0.0058	0.0071	0.0087	0.0138	0.0278	0.0057	0.0071	0.0087	0.0139	0.0277
Reliability	Cycles	+	0.0281	10000	1000	1000	10000	1000	10000	1000	1000	10000	1000
				0.0122	0.0022	0.0023	0.0255	0.0281	0.0122	0.0022	0.0023	0.0255	0.0281
Emotional and biometrical criteria													
Happiness	Points	+	0.1	0.2785	0.1191	0.0795	0.0156	0.3701	-	-	-	-	-
				0.0323	0.0193	0.0153	0.0034	0.0841					
Sadness	Points	–	0.1	0.0089	0.0031	0.0021	0.0101	0.0421	-	-	-	-	-
				0.0134	0.0044	0.0027	0.0139	0.0549					
Anger	Points	–	0.1	0.0191	0.0124	0.0088	0.0023	0.0048	-	-	-	-	-
Surprise	Points	+	0.1	0.1496	0.4783	0.6211	0.0286	0.0216	-	-	-	-	-
				0.0115	0.0411	0.0857	0.0152	0.0123					
Scared	Points	–	0.1	0.0844	0.0917	0.0725	0.0574	0.0199	-	-	-	-	-
				0.0259	0.0342	0.0345	0.0334	0.0134					
Disgust	Points	–	0.1	0.0014	0.0005	0.0004	0.0218	0.0035	-	-	-	-	-
				0.0051	0.0018	0.0012	0.0649	0.0047					
Valence	Points	+	0.1	0.1941	0.0272	0.0069	-0.042	0.3279	-	-	-	-	-
				0.0324	0.0062	0.0017	0.0102	0.0866					
Arousal	Points	+	0.1	0.4482	0.6598	0.7741	0.2567	0.4026	-	-	-	-	-
				0.0176	0.0312	0.0522	0.0337	0.0749					
Heart rate	BMP	+	0.1	86	78	94	72	93	-	-	-	-	-
The sums of weighted nor-malized max indices of the windows, S+j				0.1803	0.1741	0.2609	0.2377	0.6141	0.0301	0.0329	0.0354	0.0288	0.0392
The sums of weighted nor-malized max indices of the windows, S-j				0.2526	0.2521	0.2939	0.4682	0.8168	0.1457	0.1343	0.1728	0.1384	0.1487
Windows sig-nificances Qj				0.7418	0.7369	0.7435	0.5407	0.7876	1.48	1.35	1.485	1.28	1.605
Priority of the alternative				3	4	2	5	1	3	4	2	5	1
Utility degree of the alterna-tive (%)				94.17	93.56	94.39	68.64	**100**	92.50	92.20	79.75	84.10	**100**

The difference between the integrated emotion in comparing alternatives and traditional analysis of comparing alternatives results explains that the emotion indirectly increases the value of each alternative.

Previous studies (e.g., Loijens & Krips, 2013; Bedon & Mattei, 2021) have shown that the software is an effective emotion analysis tool with 90% accuracy. Although previous research showed that participants took the experimental task seriously, FaceReader attributed their emotions to anger (Zneng et al., 2019). The above results prove that FaceReader can objectively detect instantaneous and subtle changes in facial expression and make judgments based on potentially representative emotion components with a high degree of accuracy. However, the researchers' observations and participants' verbal responses are necessary to understand the participants' feelings and to further discuss the face recognition results. The main task of the facial recognition experiment is to distinguish emotional changes. The duration of each emotion is short, approximately 0.5–4 seconds (Friesen & Ekman, 1978), making it difficult to quantify differences between data points, therefore, not every frame of a participant's video is necessarily analysed. FaceReader is a reliable tool for analyzing emotions by studying participants' facial expressions, but researcher observation, participant self-reports, and proper experimentation are also needed to minimize the potential for inconsistent results. The correlation signs shown in Table 2.19 are consistent with studies conducted around the world (e.g., Lee et al., 2020; Yang et al., 2018). For example, numerous studies show that sadness decreases as happiness increases (e.g., Storbeck et al., 2019; Yilmaz et al., 2019).

Table 2.19. Correlations between the level of happiness, sadness and heart rate obtained in this experiment and the data of other scholars

	Data from experiment			Data by other authors		
	Happiness level (Case Study)	Heart Rate (Case Study)	Sadness level (Case Study)	Happines level (Li et al., 2020)	Heart Rate (Lin et al., 2019)	Sadness level (Storbeck et al., 2019)
Happiness level (Case Study)	—	0.6055	–0.7826	0.6464	0.6908	–0.7431
Heart Rate (Case Study)		—	–0.2411	0.4182	0.7203	–0.3408
Sadness level (Case Study)			—	–0.8201	0.2967	0.7791
Happines level (Li et al., 2020)				—	–0.1149	–0.6121
Heart Rate (Lin et al., 2019)					—	0.2801
Sadness level (Storbeck et al., 2019)						—

Various studies also show that happiness levels and age have a U-shaped connection, meaning that people are happier when they are younger and when they are older (e.g., Ingraham, 2019; Lebowitz & Kiersz, 2019; Larson, 2019; Stone et al., 2018; Blanchflower, 2021). To confirm this concept was conducted the research and the results were presented in Figure 2.15. During the experiment, data on the level of emotions and heart rate variability were collected from both female and male participants (58% and 42%, respectively) in the age range of 30-66 years.

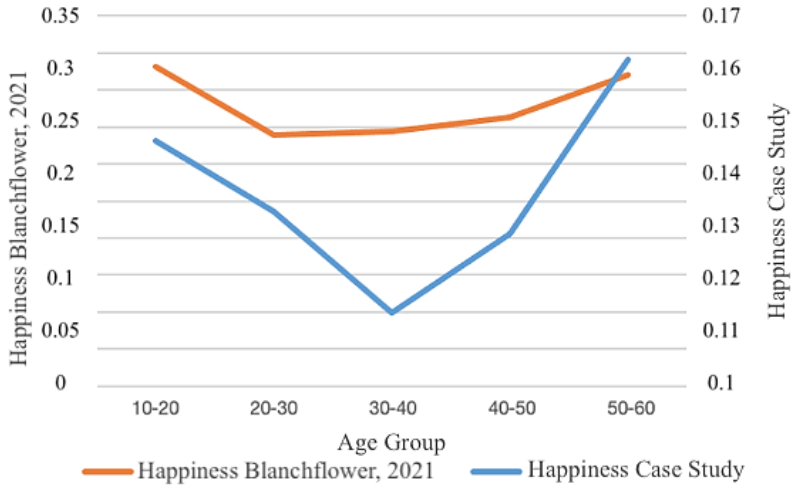


Fig. 2.15. The U-shaped curve of correlation between the level of happiness measured during the case study and its level obtained by Blanchflower (2021) and age (created by the author)

Blanchflower (2021) worked on an analysis of life satisfaction and observed that a U-shaped age curve prevailed, with the lowest point of satisfaction in the late 40s to mid-50s. The shape of these curves resembles a U-shape, where periods of high levels of happiness experienced by younger and older people cause an upward curve. Whereas lower levels of happiness are observed as people reach middle age and the curve goes down. Another author (Stone et al., 2018) notes that people in their early 50s reach the bottom of the curve, and their level of happiness is much lower than in youth. The well-being of people aged 60 and over is generally higher than that of younger people. A U-shaped happiness curve means that young people are happier. Gana et al. (2013) write about the "paradox of well-being", where older people perceive their lives better than younger people, also showing a contrast compared to middle-aged people.

The level of happiness among women and men measured in the Case Study and the level of sadness Newport & Pelham (2019) are inverted U-shaped (see Fig. 2.16). Newport & Pelham (2019) used a scale of levels from 25 to 40, the measurement in the Case Study was from 0 to 1. The results of the analysis of emotions (sadness and happiness) from this study coincide with the data obtained by other authors (Graham & Pozuelo, 2017).

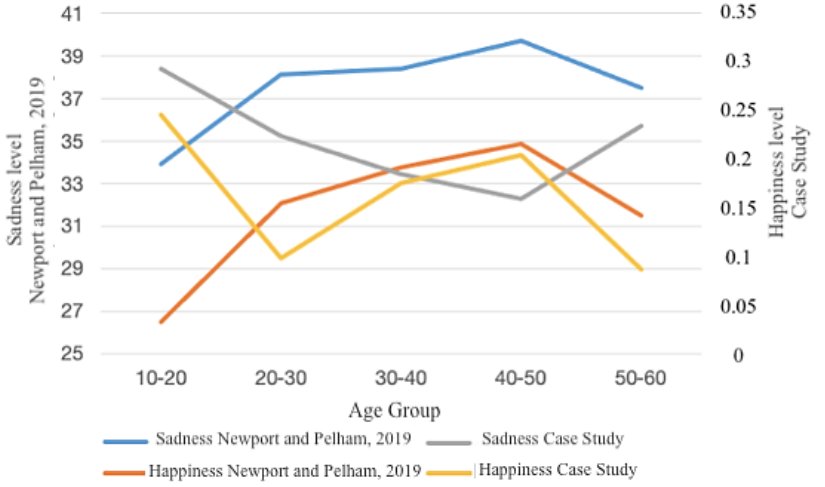


Fig. 2.16. The U-shaped levels of happy state among females and males as measured in a Case Study and inverse U-shaped levels of sad state among females and males, Newport and Pelham, 2019 (created by author)

In measures of sadness and worry, the U-shape is inverted. Sadness levels are low in early adulthood and then peak around midlife (for example, 38.7 for women, 33.9 for men). Then the sadness begins to decline. Stone et al., (2018) noted that the age of sadness is essentially the inverse of the level of happiness, and this study shows moderate variation with age, represented by an inverted U-shaped curve. Positive affect, surprise, and happiness showed a U-shaped curve. Graham & Pozuelo (2017) argue that stress is an inverted U-pattern worldwide, with stress levels increasing, peaking at a certain point and then decreasing, and overall stress levels gradually decreasing with age. Stone et al., (2018) also found that levels of sadness follow an inverted U-shaped curve over time. Compared to males, the level of stress, worry and sadness are significantly higher in females (in all age groups). A significant inverted U-shaped curve was reported for negative affect and sadness, with (late) middle-aged adults reporting higher values than

younger and older adults. Blanchflower (2021) notes that the pattern of unhappiness is an inverted U-shape. Young people feel happier than older people.

Resting heart rate increases with age, and the results of this study (see Fig. 2.17) support previous findings by Polar (2019). In people aged 35 and 45, a higher heart rate was associated with higher blood pressure, higher body mass index, higher mortality, smoking, physical activity and more (Stoffels et al., 2017). Additionally, Polar (2019) notes that as people age, their resting heart rate typically increases. In the study group, young people have a lower mean resting blood pressure than older people. This means that with age people's pulse pressure drops sharply.

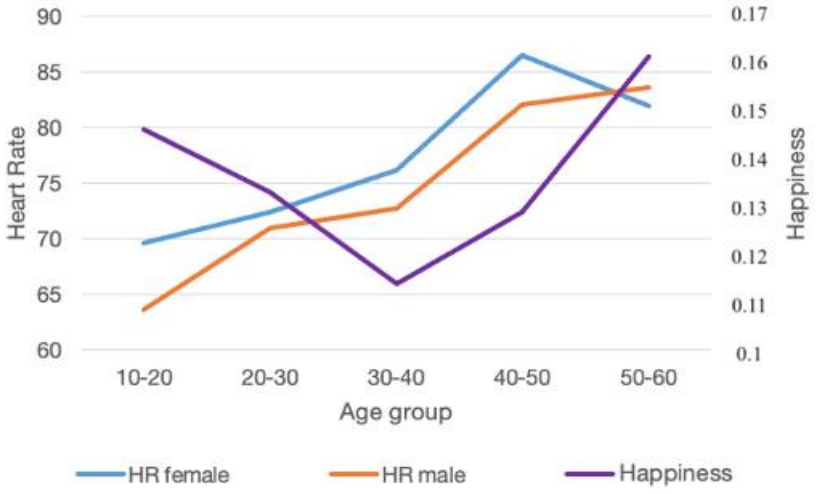


Fig. 2.17. Increasing heart rate with age (created by author)

After analyzing the depersonalized emotional and physiological states of the participants according to different ages and genders obtained in this study, the results of this study seem to be in line with the world research that states that the human emotional-physiological state depends on age. Hence, the data used for the multicriteria analysis were reliable (conducted on the depersonalized emotional and physiological states of the participants according to different ages and genders, for green and energy-efficient alternatives in renovated residential buildings).

2.4.1. Automation process in Intelligent database and model base management system

When studying expensive and time-consuming processes, it is justified to strive to obtain mathematical models with minimal cost and time expenditures. The human factor in decision-making can lead to incomplete or distorted data, which ultimately calls into question the reliability of the processed datasets. In this case, due to the large amount of data, it is advisable to automate the stages of analysis and processing of measurement results in order to build relevant mathematical models. This, in turn, will allow to exclude the influence of the human factor on the results of the experiment and to reduce the time for its implementation. Therefore, users need an automatic tool to support them in decision-making that satisfies their requirements.

Based on the methodology COPRAS method and using the Python language (www.python.org), an automated stand for modeling intelligent decision support system were developed by the author for its implementation, the script of which is presented in Annex C. The input information (see Table 2.20): initial a list of criteria, indicators of a greater (less) criterion value, ultimate weights of criteria etc. After receiving the input information, with the help of the developed script (which consists of the formulas of stages 1–5 of the COPRAS method) the importance, degree of usefulness and priority of the updated items will be determined.

The input information must be provided in Excel format, data consists of the initial list of criteria, indicators of a greater (less) criterion value, ultimate weights of criteria etc. Excel is the most settled file extension for spreadsheets and can be exported by many free programs such as LibreOffice Calc, Numbers and Google Sheets. The data of these files are processed using the library. Attribute weights are assigned by decision-makers based on relative importance and are subjective in nature.

Table 2.20. Input data

Criteria under evaluation	Measuring units of criteria	z_i	Ultimate weights of criteria, qi	Criteria 1	Criteria 2	Criteria 3	Criteria 4	Criteria 5
Price	Eur	FALSE	0,6	23100	20100	17900	17550	19050
Payback period	Years	FALSE	0.0259	15	15	20	20	18
Guarantee period	Years	TRUE	0.0247	10	5	5	10	12
Durability	Years	FALSE	0.0227	35	30	50	40	35
Duration of works	Days	FALSE	0.0257	60	60	60	60	60

End of Table 2.20

Criteria under evaluation	Measuring units of criteria	z_i	Ultimate weights of criteria, qi	Criteria 1	Criteria 2	Criteria 3	Criteria 4	Criteria 5
Maximum glass unit thickness	mm	TRUE	0.0288	52	32	32	42	52
Number of the glazed pane		FALSE	0.0321	6	3	4	5	5
The thermal transmission coefficient of the glazing unit	W/m^2K	TRUE	0.0330	1.15	0.65	0.82	0.77	1.12
Number of sealing circuits		FALSE	0.0318	2	4	3	2	4
Air leakage, when pressure difference Dp = 50 Pa	$m^3/m^2/h$	TRUE	0.0296	0.2	0.15	0.18	0.13	0.2
Parameter of noise pollution	dB	TRUE	0.0317	47	44	42	44	48
Parameter of noise pollution	dB	TRUE	0.0317	47	44	42	44	48
Condensation resistant	%RH	TRUE	0.0286	100	90	85	95	100
Waterproofness	Pa	TRUE	0.0295	600	400	400	550	550
Light transmission of a double-glazing unit	%	TRUE	0.0278	90	88	81	88	88
Reliability	Cycles	TRUE	0.0281	10000	1000	1000	10000	1000
Happiness	Points	TRUE	0.1	0.2784	0.1191	0.0795	0.0156	0.3701
Sadness	Points	FALSE	0.1	0.0088	0.0031	0.0020	0.0101	0.0421
Anger	Points	FALSE	0.1	0.0191	0.0124	0.0088	0.0023	0.0048
Surprise	Points	TRUE	0.1	0.1495	0.4783	0.6210	0.0286	0.0216
Scared	Points	FALSE	0.1	0.0844	0.0917	0.0725	0.0574	0.0199
Disgust	Points	FALSE	0.1	0.0014	0.0005	0.0004	0.0218	0.0036
Valence	Points	TRUE	0.1	0.1941	0.0272	0.0069	0.0418	0.3279
Arousal	Points	TRUE	0.1	0.4481	0.6598	0.7741	0.2566	0.4026
Heart rate	BMP	TRUE	0.1	86	78	94	72	93

* The sign z_i (TRUE/FALSE) indicates that a larger (smaller) value of the criterion corresponds to greater importance for the stakeholder.

The standard steps for the proposed method, after receiving the input information, determine the significance, usefulness and priority of the recovered elements. The script consists of formulas from Stages 1–5 of the COPRAS method (see Figure 2.13).

After downloading all the necessary files and other information, the next step is to run the script. The output data, which is the result of the calculation of the

automated system for choosing the best alternative to the object of research, comes in the form of the final Excel table (see Table 2.21). The proposed system allows for automating calculation processes in an Intelligent decision-making support system for sustainable renovation. In addition, a possible modification of these utility functions will allow decision-makers to choose a better alternative under conditions of fuzzy uncertainty.

Table 2.21. Results/Output data

Criteria under evaluation	Measuring units of criteria	z_i	Ultimate weights of criteria, qi	Criteria 1	Criteria 2	Criteria 3	Criteria 4	Criteria 5
Price	Eur	0	0.6	0.1418	0.1616	0.1971	0.2877	0.5999
Payback period	Years	0	0.0259	0.0044	0.0053	0.0089	0.0136	0.0258
Guarantee period	Years	1	0.0247	0.0058	0.0038	0.0045	0.0112	0.0246
Guarantee period	Years	1	0.0247	0.0058	0.0038	0.0045	0.0112	0.0246
Durability	Years	0	0.0227	0.0041	0.0043	0.0091	0.0121	0.0227
Duration of works	Days	0	0.0257	0.0051	0.0064	0.0085	0.0128	0.0256
Maximum glass unit thickness	mm	1	0.0288	0.0071	0.0058	0.0073	0.0128	0.0287
Number of the glazed pane		0	0.0321	0.0083	0.0056	0.0091	0.0161	0.0318
The thermal transmission coefficient of the glazing unit	W/m^2K	1	0.033	0.0084	0.0063	0.0099	0.0132	0.0319
Number of sealing circuits		0	0.0318	0.0042	0.0097	0.0106	0.0105	0.0315
Air leakage, when pressure difference Dp = 50 Pa	$m^3/m^2/h$	1	0.0296	0.0068	0.0066	0.0102	0.0108	0.0252
Parameter of noise pollution	dB	1	0.0317	0.0066	0.0078	0.0099	0.0152	0.0316
Condensation resistant	%RH	1	0.0286	0.0061	0.0069	0.0086	0.0139	0.0285
Waterproofness	Pa	1	0.0295	0.0071	0.0062	0.0078	0.0147	0.0294
Light transmission of a double-glazing unit	%	1	0.0278	0.0057	0.0071	0.0087	0.0138	0.0277
Reliability	Cycles	1	0.0281	0.0122	0.0021	0.0023	0.0255	0.0281
Happiness	Points	1	0.1	0.0322	0.0193	0.0153	0.0034	0.0841
Sadness	Points	0	0.1	0.0133	0.0044	0.0027	0.0139	0.0549
Anger	Points	0	0.1	0.0401	0.0182	0.0119	0.0031	0.0061
Surprise	Points	1	0.1	0.0115	0.0412	0.0857	0.0152	0.0123
Scared	Points	0	0.1	0.0258	0.0342	0.0345	0.0334	0.0134
Disgust	Points	0	0.1	0.0051	0.0019	0.0012	0.0649	0.0046

End of the Table 2.21

Criteria under evaluation	Measuring units of criteria	z_i	Ultimate weights of criteria, qi	Criteria 1	Criteria 2	Criteria 3	Criteria 4	Criteria 5
Valence	Points	1	0.1	0.0324	0.0062	0.0017	0.0102	0.0866
Arousal	Points	1	0.1	0.0176	0.0313	0.0522	0.0337	0.0749
Heart rate	BMP	1	0.1	0.0203	0.0231	0.0363	0.0436	0.0998
The sums of weighted normalized max indices of the windows, S_{+j}				0.1802	0.1741	0.2609	0.2377	0.6141
The sums of weighted normalized max indices of the windows, S_{-j}				0.2526	0.2521	0.2939	0.4681	0.8168
Windows significance, Qj				0.7417	0.7369	0.7435	0.5406	0.7876
Priority of the alternative				3	4	2	5	1
Utility degree of the alternative (%)				**94.17**	**93.56**	**94.39**	**68.64**	**100**

* The sign z_i (1/0) indicates that a larger (smaller) value of the criterion corresponds to a greater importance for the stakeholder.

2.5. Conclusions of the Second Chapter

Considering the described research and the presented methods in this Chapter, the following conclusions can be drawn:

1. An original framework has been proposed that performs a comprehensive analysis of emotional and rational market segments by demographic criteria (males and females), psychographics and consumer behaviour criteria (e.g., happy, sad, angry, surprise and heart rate variability), the impact of emotions on the decision-making process was revealed.
2. The achieved aim was the assessment of the possibility of experimental methods and the practical combination of quantitative indicators of subjective sensations with engineering goals together in architectural concepts and technological solutions in the fields of construction. To solve this problem, it is proposed to use an analytical-recommended model of basic data of an energy-efficient building, based on which an automated system has been developed.
3. The developed method of multi-variant design and multi-criteria analysis of building renovation (implemented in the example of building renovation in Kyiv, Ukraine) differs from the previously considered methods by the fact that it helps in determining the degree of efficiency of the housing stock and providing recommendations to stakeholders for joint work on

rational housing management, which is at a stage of renovation or an early-stage construction design.

4. To increase the transparency and reliability in the process of decision-making in real situations, a combination of sustainability principles, and multi-criteria decision-making support, combined with the COPRAS method and automatic data processing tools, both emotional and statistical (using a Python script), were applied.
5. The research presented in this section has shown the influence of emotions on the decision-making process during building renovation, but these aspects are supposed a complex analysis during the life cycle of a building. The difference between the integrated emotion when comparing alternatives and the traditional analysis of the results of the comparison of alternatives may be that the emotion indirectly increases the value of each alternative. For example, the decision matrix of window alternatives shows that alternative 1 has a utility degree of 92.50% in the traditional analysis and 94.17% in the analysis with integrated emotional states. That is why the next section will include an emotional analysis of the crowd related to green and energy-efficient buildings.

3

Method to Plan and Analyze Neuro-Advertising Housing Variants Employing Multiple Criteria

This chapter presents the Affect-Based Built Environment Video Analytics (BEST) method to analyze and collect different types of data: physiological and emotional states, affective attitudes, weather conditions, pollution, etc. It is also considered the applying multi-criteria analysis of neuromarketing and video advertising for different consumer segments in the construction industry using neuro decision tables. This chapter provides an analysis of a large sample of the affective attitudes dataset and further comparison with worldwide studies.

The presented research was used in two international − Erasmus+ programme projects: Integrating education with human behaviour relevant to the influence of coronavirus and negative emotions in a built environment (MICROBE), Integrating education with consumer behaviour relevant to energy efficiency and climate change at the Universities of Sri Lanka and Bangladesh (BECK).

The research results of this chapter are published in two articles by the author (Kaklauskas et al., 2019, Kaklauskas A., Velykorusova A. & Skirmantas D., 2019) and presented at two conferences (The 17th Colloquium „Sustainable decisions in built environment“ and Meeting of EURO working group “OR in sustainable development and civil engineering”, The 13 International Conference “Modern building materials, structures and techniques”).

3.1. Main iterative phases of the Affect-Based Built Environment Video Analytics Method

This research aims to build an Affect-Based Built Environment Video Analytics (BEST) that is developed to analyze and collect different types of data: e.g., physiological and emotional states, arousal and valence, affective attitude, pollution etc. The BEST method allows selecting the best places to live or rent and provides neuro advertisement of buildings for sale. It combines the somatic marker, biometrics, physiological methods (Novelda, 2019) and INVAR method. The method offers a spatial analysis of categorical data according to several criteria using analytical methods, such as creating maps of affective attitudes with maps of physiological and emotional states. Below are the stages of a multi-sensory, environmentally friendly and energy-efficient method of neuromarketing for housing. First, it is necessary to prepare the neural decision-making matrix and the raw data for correlation analysis, as in the previous example (see Section 2.2.). Matrix provides information on environmental and energy-efficient building projects, pollution, emotional and physiological state of participants at four sites in Vilnius. In this multicriteria analysis experiment, the following locations in Vilnius, Lithuania were selected for the use of green and energy-efficient building advertisements. Table 3.1 shows the descriptions of it.

Table 3.1. Residential units and their descriptions

No	Name of project	Video, Tour, Gallery	Project descriptions	Targeted age group*
1	Residential units of apartment type at Pilies-2 street in Vilnius Old Town district, Lithuania	https://www.yit.lt/bustas/nauji-butai-vilniuje/raitininku-sodas	The upper-middle-class project in the city center is designed for families with young children and the elderly. The quality of construction is high. Excellent accessibility to both the historic city center and other districts. A river flows along. There are walking paths with a rest area.	II, III
2	Residential units of apartment type at Gedimino pr. 3 in Vilnius Old Town district, Lithuania	http://livesquare.lt/galerija-vizualizacijos/	The luxury project is located in the city center. It is equally suitable both for investment and for modern comfortable living. The highest standards of construction quality are guaranteed. Excellent accessibility in all directions is combined with infrastructure and good neighbourhood. Potential buyers are older people, usually businessmen or high-level professionals.	II, III
3	Residential units of apartment type at Lukiskes – 11 street, Vilnius, Lithuania	https://www.youtube.com/watch?v=eFpwwkm9Zd4 (video-films)	A middle-class project in the central area of the city. Buyers are offered apartments with 2-4 rooms. Excellent accessibility to both the historic city center and other districts. Many business centers of the city are adjacent to the	II, III

End of the Table 3.1

No	Name of project	Video, Tour, Gallery	Project descriptions	Targeted age group*
			project. The target group of buyers is employed persons.	
3	Residential units of apartment type at Lukiskes – 11 street, Vilnius, Lithuania	https://www.youtube.com/watch?v=eFpwwkm9Zd4 (video- films)	A middle-class project in the central area of the city. Buyers are offered apartments with 2-4 rooms. Excellent accessibility to both the historic city center and other districts. Many business centers of the city are adjacent to the project. The target group of buyers is employed persons.	II, III
4	Residential units of apartment type at the Mindaugo tiltas – 13, Vilnius, Lithuania	http://www.veikme.lt/uploads/files/dir248/dir12/8_0.php	A modern project of the middle class in one of the bedroom districts. Nature surrounds the building. It demonstrates exceptional engineering and architectural solutions using passive house technologies.	II, III

*Target age groups: **I –** (20 – 30) **II –** (31 – 40) **III –** (41 – 50) **IV –** (51 – 60)

Collected data on pollution, and emotional and physiological states (happiness, sadness, anger and heart rate) were compared with the results of similar worldwide studies. Information was collected from passers-by by using equipment subsystem FaceReader (Loijens & Krips, 2013), biometric techniques and technologies such as Noldus Information Technology (2019) and XeThru technology (Novelda, 2019) etc. In accordance with the requirements of the General Data Protection Regulation which applies in all European Union (EU) Member States from 25 May 2018 (Consensus, 2019), data protection was performed to collect the necessary de-identified data for this study. The GDPR means that EU citizens have more control over their data and the measures foreseen in the regulation contribute to better security both online and offline. This research involved analyzing passersby at four sites in Vilnius and establishing their affective attitudes, emotional and biometrical states, as well as their valence and arousal. To adhere to the GDPR requirements and the applicable laws of the Republic of Lithuania, a data protection impact assessment was received for the equipment subsystem before were launched data gathering activities (Table 3.2).

The use of this subsystem enabled the gathering of the aforementioned data for this research. The goal was to conduct an advertising campaign for the sale of green and energy-efficient buildings, aimed at the most fortunate groups of passers-by. A somatic marker associated with a positive result can make a person happy, while a somatic marker associated with negative consequences may make a person feel sad, which then acts as an internal alarm and warns a person to avoid certain actions (such as buy or rental of housing in this case study). Table 3.2 shows the emotional measurements of passers-by at the four sites.

Table 3.2. Measurement of human emotions in four cities

Site of Measurements	Gender	Age Groups				
		10-20	21-30	31-40	41-50	51-60
Happy						
2-Pilies	Female	0.1283	0.1309	0.1171	0.1027	0.1226
	Male	0.1393	0.1376	0.1153	0.0979	0.0855
3-Gedimino pr.	Female	0.1277	0.1246	0.1161	0.0807	0.0893
	Male	0.1035	0.1348	0.1145	0.0845	0.0605
11-Lukiskes	Female	0.1384	0.1234	0.1145	0.0803	0.0739
	Male	0.1627	0.1536	0.1008	0.0887	0.0662
13-Mindaugo titlas	Female	0.1422	0.1413	0.1391	0.0592	0.0835
	Male	0.0921	0.2511	0.1616	0.0981	0.0706
Sad						
2-Pilies	Female	0.2363	0.1974	0.1579	0.1495	0.1535
	Male	0.2136	0.1827	0.1554	0.1421	0.1441
3-Gedimino pr.	Female	0.2131	0.1947	0.1613	0.1763	0.1076
	Male	0.1867	0.1885	0.1584	0.1371	0.1157
11-Lukiskes	Female	0.2214	0.2128	0.1533	0.1261	0.1188
	Male	0.1701	0.1680	0.1289	0.1163	0.0983
13-Mindaugo titlas	Female	0.2249	0.2240	0.2246	0.2301	0.2063
	Male	0.2496	0.0893	0.1525	0.2308	0.1423
Angry						
2-Pilies	Female	0.0922	0.0857	0.0909	0.0941	0.0915
	Male	0.1163	0.1224	0.1195	0.1228	0.1291
3-Gedimino pr.	Female	0.0858	0.0793	0.0927	0.0857	0.0701
	Male	0.1181	0.1093	0.1106	0.1191	0.1353
11-Lukiskes	Female	0.0871	0.1031	0.0889	0.0937	0.0706
	Male	0.1159	0.1274	0.1092	0.1065	0.1037
13-Mindaugo titlas	Female	0.1473	0.1345	0.1359	0.1253	0.0561
	Male	0.1471	0.0801	0.1466	0.1991	0.1371

Pollution data for the four sites being analyzed were taken from the Environmental Protection Agency and presented in Table 3.3. According to the EPA of Lithuania (2018), daily CO norms should not be exceeded 10 $\mu g/m^3$. $PM_{2.5}$ short-term standard (24-hour or average daily) – 35 $\mu g/m^3$. PM_{10} – daily limit value 50 $\mu g/m^3$ and EPA set the 1-hour NO_2 standard at 100 parts per billion (ppb).

Table 3.3. Air pollution measurement data in four cities of Vilnius

		CO Pilies	CO Gedimino	CO Lukiskes	CO Mindaugo	$PM_{2.5}$ Pilies	$PM_{2.5}$ Gedimino	$PM_{2.5}$ Lukiskes	$PM_{2.5}$ Mindaugo	PM_{10} Pilies	PM_{10} Gedimino	PM_{10} Lukiskes	PM_{10} Mindaugo	NO_2 Pilies	NO_2 Gedimino	NO_2 Lukiskes	NO_2 Mindaugo
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**
Hours	**0**	0.55	0.41	0.59	0.60	18.17	18.67	13.46	20.06	33.20	13.69	38.57	21.66	15.76	32.60	20.45	23.44
	1	0.53	0.40	0.53	0.53	16.75	18.33	11.03	19.96	31.31	13.74	35.26	21.60	13.17	23.86	17.93	18.85
	2	0.51	0.39	0.47	0.49	15.88	16.82	9.46	18.82	28.84	12.62	31.63	20.37	10.99	18.31	16.21	15.93
	3	0.50	0.38	0.40	0.46	15.30	15.69	8.23	17.79	26.43	11.93	28.11	19.24	9.75	15.17	14.87	13.77
	4	0.49	0.38	0.36	0.44	15.49	15.56	7.74	17.12	25.25	11.48	26.93	18.55	8.84	15.20	14.57	12.46
	5	0.51	0.38	0.33	0.43	15.98	15.64	8.52	16.56	24.56	11.29	26.25	18.78	8.93	21.61	14.84	12.38

End of the Table 3.3

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Hours	5	0.51	0.38	0.33	0.43	15.98	15.64	8.52	16.56	24.56	11.29	26.25	18.78	8.93	21.61	14.84	12.38
	6	0.52	0.39	0.31	0.43	17.00	17.41	11.62	17.32	23.86	11.12	28.75	18.97	9.60	27.59	17.97	14.24
	7	0.59	0.43	0.33	0.47	18.18	19.80	16.87	18.88	24.03	10.59	33.46	19.95	13.78	34.87	24.31	18.66
	8	0.64	0.44	0.37	0.51	18.70	21.93	20.00	20.25	26.73	11.19	37.83	23.24	20.55	40.62	27.14	23.25
	9	0.61	0.43	0.40	0.50	17.90	21.82	17.90	21.86	29.61	13.45	41.82	25.33	21.26	38.97	24.84	22.82
	10	0.57	0.41	0.39	0.45	17.22	20.06	14.48	20.39	30.57	15.27	41.69	25.29	17.40	35.25	21.03	19.02
	11	0.55	0.39	0.37	0.43	16.56	19.23	12.52	18.85	30.24	15.13	40.59	24.58	14.60	31.91	18.12	15.84
	12	0.53	0.38	0.35	0.42	15.58	18.67	11.58	17.57	28.12	14.47	38.95	23.41	12.39	31.07	16.24	14.72
	13	0.51	0.39	0.32	0.41	15.45	18.04	10.87	16.49	26.97	14.05	37.93	22.60	10.97	31.37	15.68	13.91
	14	0.51	0.37	0.31	0.41	15.18	17.86	10.70	15.59	26.11	13.20	37.28	24.17	10.57	31.96	15.99	14.00
	15	0.50	0.37	0.31	0.41	15.32	17.78	11.38	15.45	26.73	12.76	38.12	24.50	10.78	33.60	16.70	14.74
	16	0.51	0.37	0.33	0.42	15.56	17.61	12.93	15.60	26.66	12.40	36.89	23.03	12.09	35.19	18.78	16.05
	17	0.54	0.39	0.36	0.44	16.20	18.18	15.87	15.83	26.23	12.43	35.08	20.93	14.61	38.99	22.09	18.46
	18	0.55	0.40	0.42	0.46	16.95	18.72	17.30	16.28	26.22	12.02	35.11	20.29	17.38	41.19	24.84	21.35
	19	0.56	0.41	0.49	0.50	17.55	19.55	18.09	17.06	27.05	12.33	34.93	20.70	18.06	41.92	26.45	23.62
	20	0.57	0.42	0.54	0.55	17.91	19.33	18.59	17.54	28.87	12.54	34.93	21.57	18.42	42.62	27.86	25.92
	21	0.58	0.42	0.59	0.61	18.54	20.34	19.31	18.25	30.47	12.82	37.19	22.50	18.68	42.61	27.61	27.01
	22	0.60	0.43	0.63	0.66	18.82	21.13	18.21	18.85	32.73	13.23	38.44	22.12	18.88	40.39	27.13	27.96
	23	0.60	0.43	0.63	0.65	18.44	20.73	15.56	19.52	33.29	13.89	38.84	22.37	18.10	38.28	24.52	26.47

Multi-criteria analysis in the selected locations was performed using the INVAR method with the establishment of emotional and rational market segments: such as geographical criteria (noise and air pollution at four Vilnius sites, data taken from the Environmental Protection Agency, 2018), demographic criteria and emotional criteria of consumers. The steps for INVAR Method are presented in Figure 3.1.

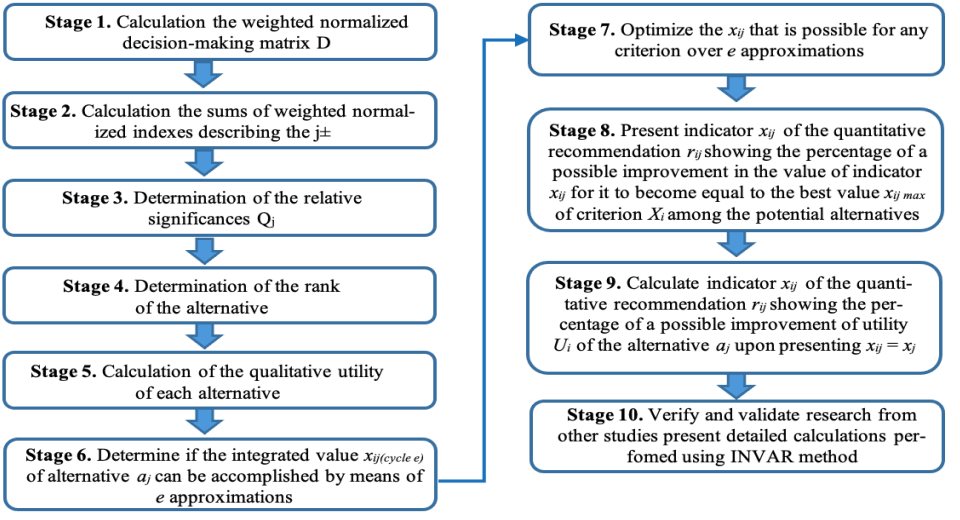


Fig. 3.1. Steps for INVAR Method (elaborated by the author)

The decision-making neuromatrix was created based on data on physiological and emotional states, as well as atmospheric air pollution (CO, NO_2, PM_{10}, $PM_{2.5}$). Table 3.4 presents alternatives compiled by dividing two groups of potential buyers (women and men) and four age groups (21–30; 31–40; 41–50 and 51–60 years) for 4 projects. Evaluation of criteria from 1 to 10 points, where 1 is not very important, and 10 is very important.

Table 3.4. Groups of passers-by by age and gender at selected locations

Criteria describing alternatives	Sub-criteria describing alternatives	*	Weight, q_i	Initial weight (number of passers-by) w_i	Housing unit alternatives under comparison			
					1	2	3	4
Individual differences of buyers								
Age (X_1)	20–30 years	+	0.0079	4635	6	2	3	5
	31–40 years	+	0.0047	2895	6	5	6	8
	41–50 years	+	0.0381	4981	9	7	8	9
	51-60 years	+	0.0270	3286	6	3	3	3
Gender (X_2)	Male	+	0.0097	7060	8	5	8	8
	Female	+	0.0128	8737	7	6	9	8

The purpose of Case Study 2 was to analyse the multiple criteria of housing alternatives in four locations with the highest demand for rental and sale of apartments and where people are feeling better.

Table 3.5. Segmentation of passers-by by gender and age at selected sites

		2-Pilies 19122 (100%)		**3-Gedimino pr. 31841 (100 %)**		**11-Lukiskes 15797 (100%)**		**13-Mindaugo 38041 (100%)**	
		Man Total: 8005 (41.86%)	**Woman Total: 11117 (58.14%)**	**Man Total: 14312 (44.95%)**	**Woman Total: 17529 (55.05%)**	**Man Total: 7060 (44.69%)**	**Woman Total: 8737 (55.31%)**	**Man Total: 15638 (41.11%)**	**Woman Total: 22403 (58.89%)**
Age	20-30 y.	2240 (11.71%)	2786 (14.57%)	3758 (11.80%)	4384 (13.77%)	2134 (13.51%)	2501 (15.83%)	4083 (10.73%)	4667 (12.27%)
	31-40 y.	1498 (7.83%)	1627 (8.51%)	3726 (11.70%)	3995 (12.55%)	1483 (9.39%)	1412 (8.94%)	3059 (8.04%)	3481 (9.15%)
	41-50 y.	2693 (14.08%)	3535 (18.49%)	4752 (14.92%)	5873 (18.44%)	2312 (14.63%)	2669 (16.90%)	4579 (12.04%)	6126 (16.10%)
	51-60 y.	1574 (8.24%)	3169 (16.57%)	2076 (6.53%)	3277 (10.29%)	1131 (7.16%)	2155 (13.64%)	3917 (10.30%)	8129 (21.37%)

3.2. Compiling neuro decision-making matrix

In the following step, a general decision-making neuromatrix was formed for 4 ecological and energy-efficient residential buildings. The analyzed criteria were used as the basis for creating a neuromatrix of decisions. Table 3.6 presents an example of a cumulative general neural decision matrix for two selected locations in Vilnius, Lithuania. The weights of the criteria are determined by expert evaluation.

Table 3.6. The cumulative general neural decision-making matrix

				2-Pilies								3-Gedimino pr.							
Criteria describing alternatives	*	**Weight q_i**	**Measuring units**	**Female**				**Male**				**Female**				**Male**			
				I	**II**	**III**	**IV**	**I**	**II**	**III**	**IV**	**I**	**II**	**III**	**IV**	**I**	**II**	**III**	**IV**
Price	-	0.8	€/m^2	1750	1750	1750	1750	1750	1750	1750	1750	1830	1830	1830	1830	1830	1830	1830	1830
Type of residential housing unit	+	0.166		7	9	8	9	8	7	7	8	5	8	5	6	9	7	7	9
Ownership form of residential dwelling	+	0.073	Points	5	8	8	7	7	6	5	6	9	8	7	8	8	5	5	8
Building materials	+	0.096	Points	9	6	8	7	8	8	9	9	6	7	3	6	6	9	8	6
Noise and air pollution	+	0.08	Points	8	8	7	7	7	6	8	8	6	8	5	7	8	9	9	9
Energy consumption (floor heating, renewable energy sources etc.)	+	0.184	Points	8	9	6	7	7	6	9	9	6	7	4	5	7	8	8	7
Aesthetic properties	-	0.04		9	8	7	7	8	7	9	8	6	8	4	6	6	9	9	7
Environmental influences																			
Urban quality	+	0.144	Points	9	6	8	7	8	7	9	9	7	7	7	6	5	8	8	6
Green spaces	+	0.096	Points	6	7	6	6	6	6	7	9	6	7	5	8	7	9	9	7
Sums of weighted normalized max indices (“pluses”, S+)				0.078	0.088	0.086	0.085	0.085	0.080	0.081	0.092	0.074	0.081	0.062	0.077	0.084	0.079	0.083	0.086
Sums of weighted normalized min indices (“minuses”, S-)				0.085	0.027	0.041	0.028	0.044	0.048	0.078	0.050	0.025	0.035	0.024	0.028	0.028	0.056	0.037	0.027

End of the Table 3.6

Sums of weighted normalized min indices (“minuses”, S-)	0.085	0.027	0.041	0.028	0.044	0.048	0.078	0.050	0.025	0.035	0.024	0.028	0.028	0.056	0.037	0.027
Significance Q of housing unit alternatives	0.106	0.093	0.084	0.092	0.084	0.085	0.101	0.086	0.096	0.086	0.098	0.091	0.092	0.087	0.085	0.093
Priority of housing unit alternatives	**1**	**6**	**16**	**8**	**15**	**13**	**2**	**12**	**4**	**11**	**3**	**9**	**7**	**10**	**14**	**5**
Utility degree N of housing unit alternatives (%)	100	87.59	79.67	86.78	79.71	80.36	95.07	80.89	90.46	81.19	92.37	86.27	86.78	82.70	80.28	87.88

*Target age groups: **I –** (20 – 30) **II –** (31 – 40) **III –** (41 – 50) **IV –** (51 – 60)

Carrying out a multi-criteria evaluation of two locations, Site 1 (2 – Pilies Street) has the highest demand among women in the age group of 21-30 years (N1 = 100%). It also took second place in terms of the best demand among men in the age group of 41–50 years (N2 = 95.07%). Site 1 performed the lowest demand upon females in the 41–50-year age group (N16 = 79.67%). The results show that people between the ages of 20 and 40 are generally looking for cheaper properties than older buyers, but the degree of usefulness and priority level of green and energy-efficient housing projects are higher for passers-by aged 21–30 yy. then the older group. Males are more oriented to technical aspects. Their interests are in the state of the building, the used construction materials, and the decisions made by engineers. While females generally pay more attention to the emotional aspects and the comforts of life for themselves and their families. Security, children’s playgrounds, sunshine entering the housing unit and kitchen size – these are the things to which women pay greater attention.

3.3. Comparison of the Emotional–Physiological States of Passersby in Case Study 2 with Worldwide Practice and its Validation

3.3.1. Data correlation according to circadian rhythm

The obtained results were compared with worldwide studies. For example, many research shows that happiness increases as sadness decreases (e.g., Storbeck et al., 2019; Yilmaz et al., 2019). This relationship between the data is shown in Figure 3.2.

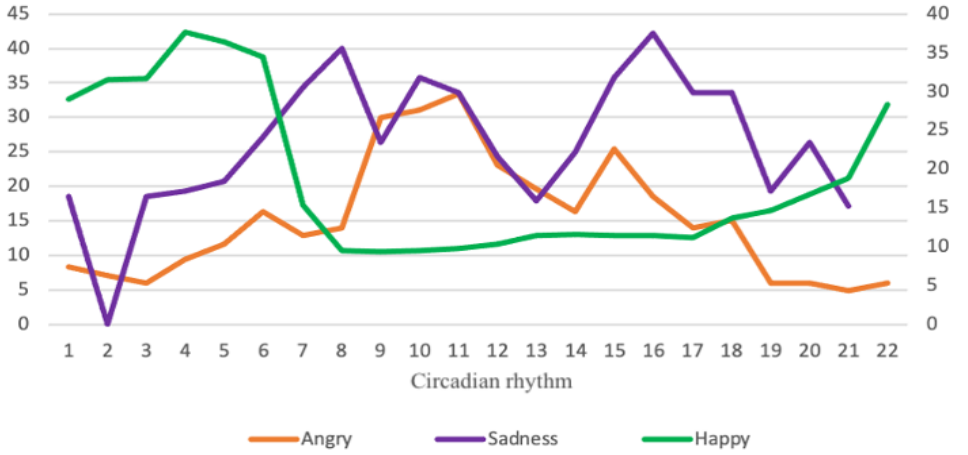


Fig. 3.2. Dependency between sad, angry and happy states (created by the author)

A notably larger heart rate cycle was observed in the emotions of happiness, which is consistent with a study by Siedlecka & Denson (2019). Also, other authors show that happiness reduces heart rate (Mohamed et al., 2020). The correlation signs shown in Table 3.7 are consistent with studies conducted around the world (Li et al., 2020; Yang et al., 2018).

Table 3.7. Correlations between the level of happiness, sadness and heart rate variability obtained in this experiment and the data of other scientists

	Happy Case Study 2 Female	**Happy Case Study 2 Male**	**Happy [1] Female**	**Happy [1] Male**	**Sad Case Study 2 Female**	**Sad Case Study 2 Male**	**Sad [2] Female**	**Sad [2] Male**	**Anger Case Study 2 Female**	**Anger Case Study 2 Male**	**Anger [3] Female**
Happy Case Study 2 Female	—	0.9272	0.8366	0.3028	–0.9402	–0.9351	–0.6581	–0.9402	–0.6663	–0.7402	–0.9354
Happy Case Study 2 Male		—	–0.6286	–0.6246	–0.9899	–0.9972	–0.9735	–0.9446	–0.6154	–0.9634	–0.9242
Happy [1] Female			—	0.0913	–0.7303	–0.5036	–0.7376	–0.7473	–0.4731	0.0281	0.1259
Happy [1] Male				—	–0.9523	–0.9815	–0.5789	–0.5665	–0.9787	–0.7789	–0.8742
Sad Case Study 2 Female					—	0.9951	0.1349	0.9807	0.9019	0.8718	0.9687

End of the Table 3.7

Happy Case Study 2 Female	**Happy Case Study 2 Male**	**Happy [1] Female**	**Happy [1] Male**	**Sad Case Study 2 Female**	**Sad Case Study 2 Male**	**Sad [2] Female**	**Sad [2] Male**	**Anger Case Study 2 Female**	**Anger Case Study 2 Male**	**Anger [3] Female**	**Happy Case Study 2 Female**
Sad Case Study 2 Female					—	0.9951	0.1349	0.9807	0.9019	0.8718	0.9687
Sad Case Study 2 Male						—	0.8756	0.8558	0.6533	0.8876	0.9335
Sad [2] Female							—	0.9895	0.2509	0.9605	0.7176
Sad [2] Male								—	0.2207	0.9243	0.7425
Anger Case Study 2 Female									—	0.7526	0.5079
Anger Case Study 2 Male										—	0.8321
Anger [3] Female											—

*Authors: **Happy [1]** – Blanchflower, 2021 **Sad [2]** – Newport, 2019 **Angry [3]** – Stone et al., 2019

Many authors mentioned that heart rate depends on the temperature of the air (Zheng et al., 2019, Breitner et al., 2019), circadian rhythm (Morelli et al., 2019), age (on average up to 100 beats per minute for babies under 2 years old, 95 beats per minute for children 3–7 years old, 80 for children 8–14 years old, 70–75 for adults and 70–73 for the elderly), physical activity, various diseases and some medicines, fever (it increases to 8-10 beats per minute), gender (female have a higher heart rate than male), intense emotions such as anger, fear and stress, (Shu et al., 2020), energy products (coffee, tea and cigarettes), environment and other factors. The resting heart rate ranges from 60 to 100 beats per minute for most adults.

Many studies around the world have measured levels of happiness, sadness, surprise, heart rate variability, etc in natural environments. As a rule, these studies provide alternative explanations for variation in emotion. However, they identified very precise trends and correlations in specific areas such as age, physical activity, wind, air temperature, air pollution, atmospheric pressure, medications and diseases, fever, excitement, intense emotions, tonic foods energy, daily

rhythm, environment and other factors. The following sections provide an overview of several studies. Table 3.7 shows the correlation dependents between heart rate, level of happiness and sadness, obtained in this experiment, and the same data obtained by other authors during the day (circadian rhythm). According to Dzogang (2017) on weekdays, the level of sadness reaches the minimum at 5 a.m. of the morning, followed by the maximum value at 8 a.m. Anger has a minimum value in the morning: at 9–10 a.m., but reaches the maximum in the night after 9–10 p.m. Positive emotions reach the minimum at 8 a.m. followed by a visible increase after 8 p.m. Different authors present this correlation in the form of a U-shaped curve, where the highest level of happiness is fixed at each end of the curve (Larson, 2019). Provided experiment in Case Study 2 showed the same results (see Fig. 3.3).

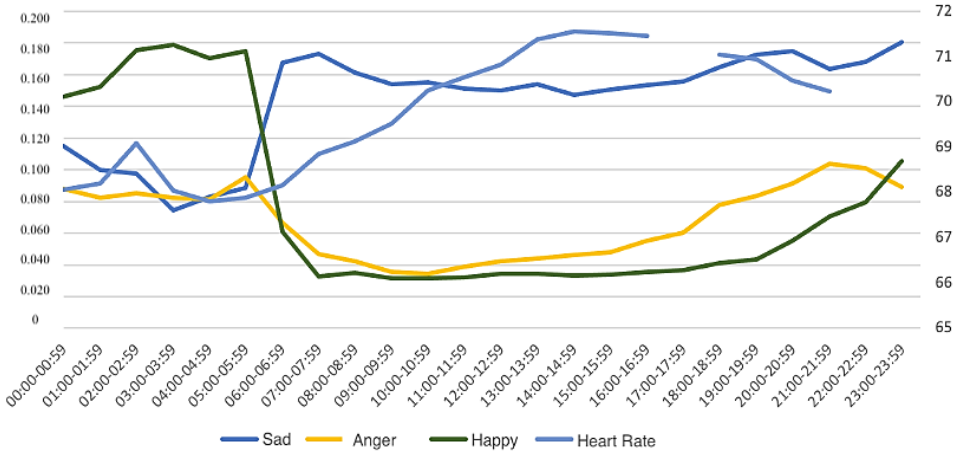


Fig. 3.3. Curves of emotional states during the day (created by the author)

Based on collected data (see Table 3.8) from Vilnius and other authors (e.g., Morelli et al., 2019; Newport & Pelham, 2019; Stone et al., 2018; Blanchflower, 2021; Gupta et al., 2018) were calculated for the coefficient of correlation in such data sets, Happiness Case Study 2 (data from 2-Pilies), Heart Rate Case Study 2 Female & Male (11-Lukiskes), Happiness (Blanchflower, 2021) Heart Rate Female & Male (Morelli et al., 2019) etc.

Table 3.8. Collected data according to hours

		Happy Case Study 2	Heart Rate Case Study 2	Sur-prise Case Study 2	Anger Case Study 2	Anger[1]	Sad[2]	Sur-prise[3]	Happy[4]	Heart Rate[5]
Hours	**1**	28.94	94.99	8.79	5.12	8.25	18.57	6.71	0.06	73.97
	2	31.50	61.68	8.22	5.37	7.11	0.01	2.79	0.05	68.18
	3	31.71	75.35	8.50	6.19	5.96	8.57	2.43	0.05	63.51
	4	37.63	78.96	8.21	5.89	9.39	19.29	2.57	0.05	59.66
	4	37.63	78.96	8.21	5.89	9.39	19.29	2.57	0.05	59.66
	5	36.45	72.96	8.10	5.46	11.68	20.71	2.29	0.05	57.43
	6	34.39	73.63	9.56	5.28	16.24	27.14	2.36	0.05	63.43
	7	15.30	73.26	6.66	4.62	12.82	34.29	2.57	0.05	68.89
	8	9.47	66.11	4.67	4.95	13.96	40.00	1.86	0.05	75.99
	9	9.33	65.11	4.21	6.71	29.95	26.43	2.50	0.05	85.56
	10	9.52	64.72	3.55	7.85	31.09	35.71	2.64	0.05	95.94
	11	9.79	64.00	3.44	7.58	33.38	33.57	3.93	0.05	98.12
	12	10.32	65.24	3.90	6.98	23.10	24.29	2.71	0.05	99.18
	13	11.41	65.64	4.23	6.74	19.67	17.86	2.57	0.05	99.41
	14	11.59	66.39	4.42	6.70	16.24	25.00	3.79	0.05	94.57
	15	11.44	65.17	4.61	6.34	25.38	35.71	4.00	0.05	88.67
	16	11.47	67.24	4.79	6.22	18.53	42.14	3.29	0.05	84.10
	17	11.23	64.69	5.53	5.33	13.96	33.57	3.79	0.05	81.69
	18	13.73	63.98	7.80	3.37	15.10	33.57	4.71	0.05	81.78
	19	14.62	66.69	8.32	3.24	5.96	19.29	6.07	0.05	84.27
	20	16.74	71.43	9.13	2.92	5.96	26.43	3.07	0.06	86.49
	21	18.79	68.86	10.38	3.09	4.82	17.14	2.71	0.06	87.33
	22	28.36	73.19	8.93	5.76	5.96	18.57	6.71	0.06	80.38
	23	28.94	95.00	8.79	5.12	8.25	0.00	2.79	0.06	73.97

*Authors: **Anger [1]** – Stone et al., 2019; **Sad [2]** – Newport, 2019; **Surprise [3]** – Gupta et al., 2018; **Happy [4]** – Blanchflower, 2021; **Heart Rate [5]** – Moreli et al., 2019

Table 3.9. Correlation between obtained data in Case Study 2 and data obtained by other authors

	Happy Case Study 2	**HR Case Study 2**	**Surprise Case Study 2**	**Disgust Case Study 2**	**Anger [1]**	**Sad [2]**	**Surprise [3]**	**Happy [4]**	**Heart Rate [5]**
Happy Case Study 2	—	0.5889	0.7277	–0.1528	–0.5557	–0.6249	0.2626	0.6036	–0.8525
Heart Rate Case Study 2		—	0.5115	–0.2055	0.5796	–0.2065	0.3351	0.2435	–0.48988
Surprise Case Study 2			—	–0.7139	–0.8201	–0.18071	0.6258	0.1829	–0.6298
Surprise Case Study 2			—	–0.7139	–0.8201	–0.18071	0.6258	0.1829	–0.6298
Disgust Case Study 2				—	0.7335	–0.1321	–0.4692	–0.0233	0.2966
Anger [1]					—	0.4723	–0.3571	–0.214	0.5592
Sad [2]						—	–0.0434	–0.6121	0.2801
Surprise [3]							—	06316	0.1822
Happy [4]								—	–0.1149
Heart Rate [5]									—

*Authors: **Anger [1] –** Stone et al., 2019; **Sad [2] –** Newport, 2019; **Surprise [3] –** Gupta et al., 2018; **Happy [4] –** Blanchflower, 2021; **Heart Rate [5] –** Moreli et al., 2019

To better demonstrate the results were performed graphs of correlation between collected data during the experiment and obtained data from other authors. Figures below show the correlation between happiness (see Fig. 3.4), sadness (see Fig. 3.5), angry (see Fig. 3.6) during circadian rhythm. First figure 3.4 shows that the correlation between the level of happiness measured in the case study and its level obtained by Blanchflower (2021) equals 0.603627.

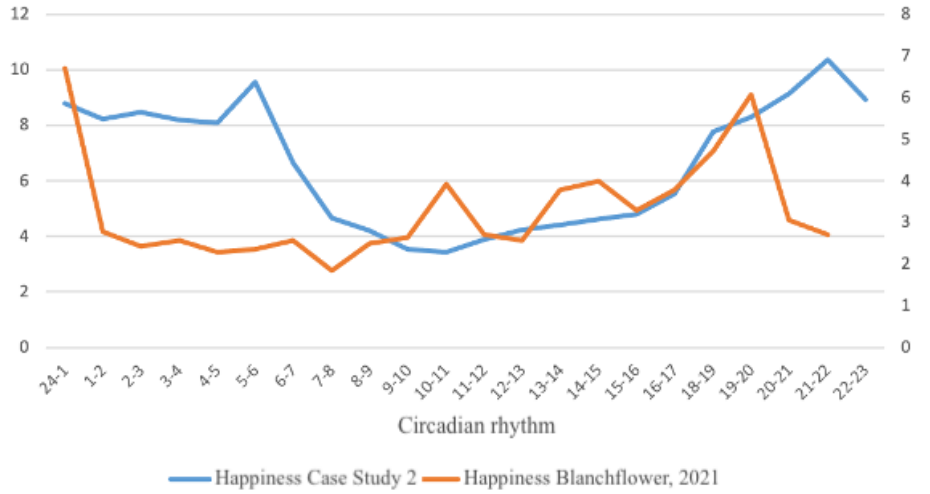


Fig. 3.4. The U-shaped curve of correlation between the happiness measured in Case Study 2 and by Blanchflower, 2021 (created by the author)

Diurnal changes were noticeable in psychological statements such as "strenuous, demanding", "angry, sadness" and "stress'", which are all presented by an inverted U-shape curve (Scheibe, 2021). Figures 3.5–3.6 show an inverted U-shape curve of correlation between the level of sadness and anger measured in the survey and its levels gotten by another author (Stone et al., 2018, Scheibe, 2021).

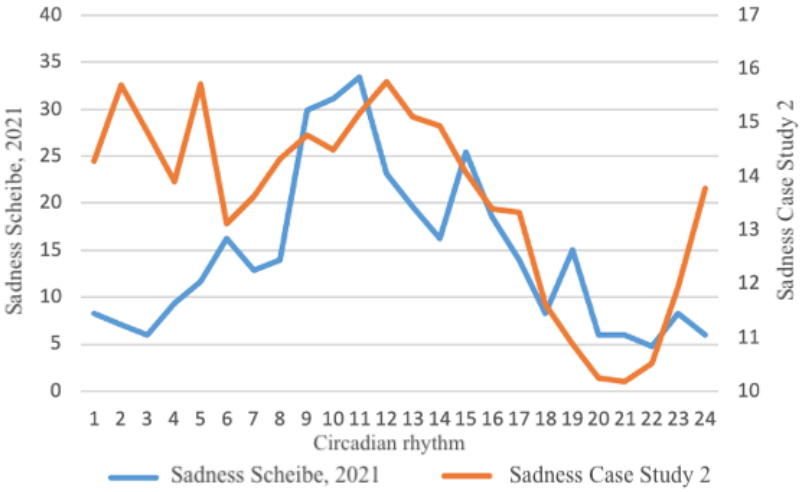


Fig. 3.5. Inverted U-shaped curve of correlation between the level of sadness measured in the survey and its level gotten by Scheibe, 2021 (created by the author)

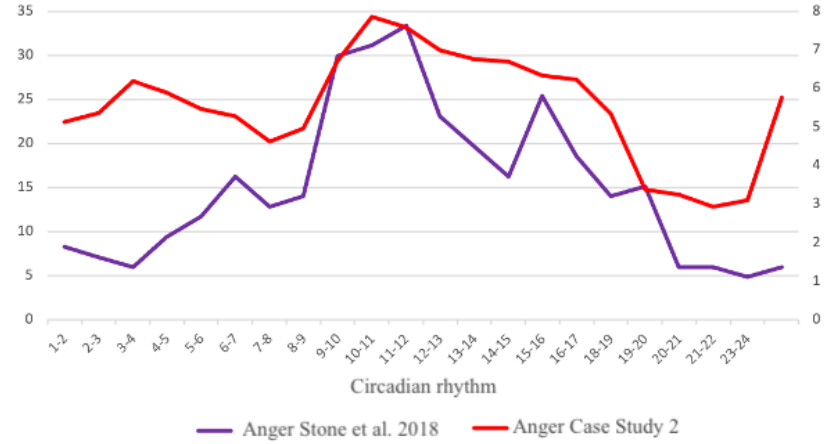


Fig. 3.6. Correlation between the angry levels measured in Case Study 2 and by Stone et al., 2018 (created by author)

Figure 3.7 shows while happiness decreases, heart rate increases, as well (Lin et al., 2019, Shu et al., 2020). A notably larger heart rate cycle was observed during negative emotions, which is consistent with a study by Siedlecka & Denson (2019). Also, other authors show that happiness reduces heart rate (Mohamed et al., 2020).

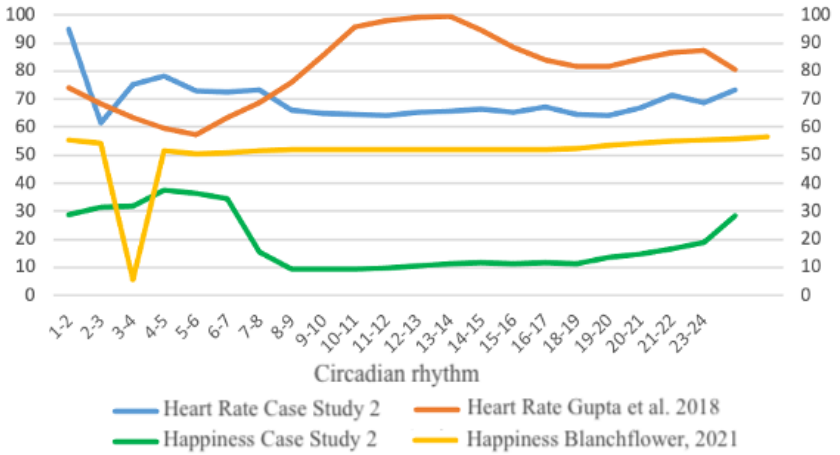


Fig. 3.7. Correlation between the happiness and heart rate levels measured in Case Study 2 and studies by Blanchflower, 2021; Gupta et al., 2018 (created by the author)

3.3.2. Data correlation according to weekdays

The next important investigation was to explore changes in the emotions by weekdays. To obtain results were calculated the coefficient of correlation between datasets from Vilnius (e.g., sad, happy, angry) and Internet sources as well (e.g., Newport & Pelham, 2019, Stone et al., 2018; Blanchflower, 2021). These results reveal the characteristics of the emotional states in the city and provide support for analyzing the happiness of passers-by in the city and help optimize the criteria of the building environment. All data is grouped into the following days: Monday – Sunday (see Table 3.10).

Table 3.10. Data of emotional states by weekdays

Weekday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Saturday
Sad Case Study 2	12.13	12.18	11.79	11.59	12.73	15.05	16.37
Happy Case Study 2	15.34	15.49	14.82	15.53	13.93	13.02	12.51
Anger Case Study 2	12.92	14.03	13.11	14.33	14.20	13.62	13.61
Sad [1]	13.23	13.27	11.98	11.82	14.24	14.92	17.06
Happy [2]	12.22	13.18	12.41	14.46	12.82	10.63	10.10
Anger [3]	14.22	15.08	13.28	15.67	15.47	14.72	13.72

*Authors: **Sad [1] –** Newport, 2019; **Happy [2] –** Blanchflower; **Anger [3] –** Stone et al., 2019

Based on the calculated coefficient of correlation between datasets from Vilnius and data from other studies was created the matrix, which shows the strong correlation between Vilnius and Internet data (see Table 3.11).

Table 3.11. Correlation analysis results

	Sad Case Study 2	Happy Case Study 2	Anger Case Study 2	Sad [1]	Happy [2]	Anger [3]
Sad Case Study 2	—	–0.4477	0.7371	0.6883	–0.9429	0.6133
Happy Case Study 2		—	–0.8442	–0.9087	0.2999	–0.1363
Anger Case Study 2			—	0.9891	–0.6477	0.6302
Sad [1]				—	–0.5962	0.5107
Happy [2]					—	–0.6119
Anger [3]						—

*Authors: **Sad [1] –** Newport, 2019; **Happy [2] –** Blanchflower, 2021; **Anger [3] –** Stone et al., 2019

Taking collected data shows six curves, three of which include emotional states from Vilnius city (happiness, sadness, anger), and the same data which were identified from worldwide research. The results obtained by this study also confirm this (see Fig. 3.8).

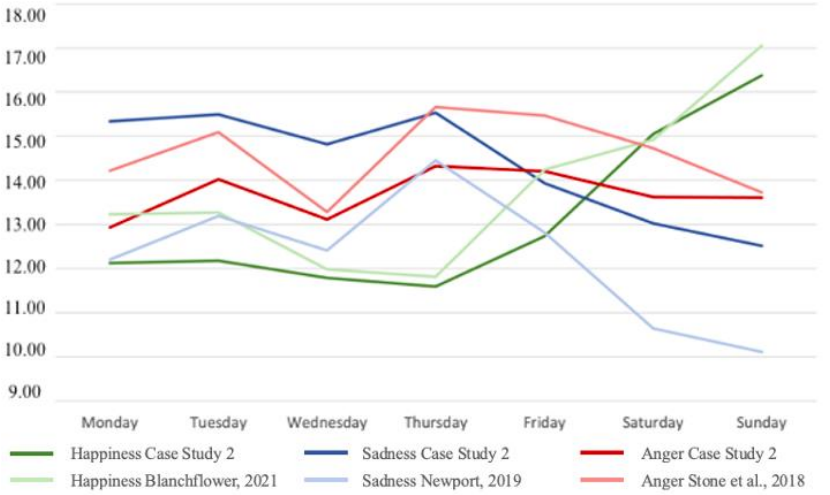


Fig. 3.8. Analysis of emotional states by weekdays (created by author)

The next step was to perform the graphs, for better demonstrate the correlation, data collected in Vilnius was divided by 200 for the correct presentation of it (see Table 3.12). The results show that the calculation in Case Study 2 is similar to the correlation made by using data from another author.

Table 3.12. Data of emotional states by weekdays (divided by 200)

Weekday	Monday	Tuesday	Wednesday	Thursday	Friday
Happy Case Study 2	5.5584	5.3077	5.4239	5.1489	5.3971
Sad Case Study 2	15.3392	15.4978	14.8191	15.5351	15.4248
Anger Case Study 2	12.9254	14.0278	13.1127	14.3266	14.2030
Happy [1]	0.1021	0.0547	0.0865	0.0559	0.0589
Sad [2]	0.0643	0.0764	0.0612	0.0897	0.0668
Anger [3]	0.0030	0.0025	0.0022	0.0030	0.0025

Authors: **Happy [1]** – Blanchflower, 2021; **Sad [2]** – Newport, 2019; **Anger [3]** – Stone et al., 2019

Weekends were rated as days with a higher value of happiness and lower sense of negative emotions in contrast to working days. Daily studies confirm that sadness or anger increases during the weekdays. This explains that during weekdays people are less resilient to work stress and daily stressors are a negative effect on their well-being. The figures below show the day-to-day (Monday – Friday) changes in emotional states. The results obtained by this study confirm the investigations of another author.

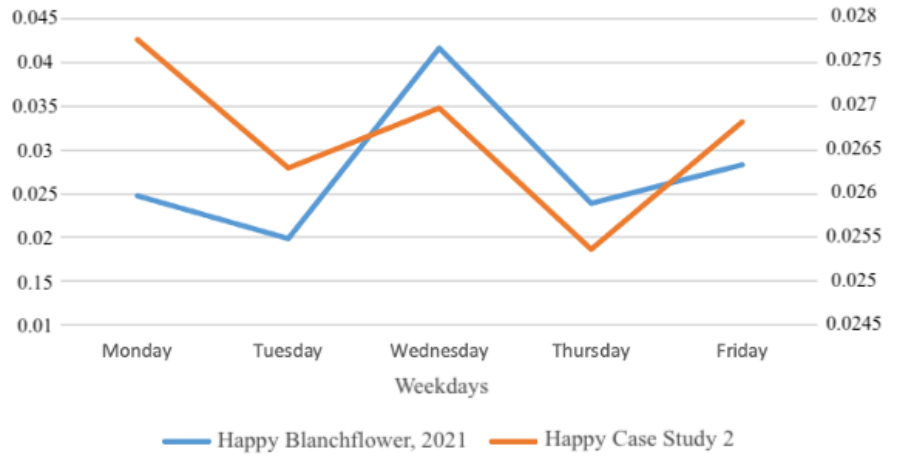


Fig. 3.9. Correlation between the dataset of happiness in Vilnius and by Blanchflower, 2021 (created by the author)

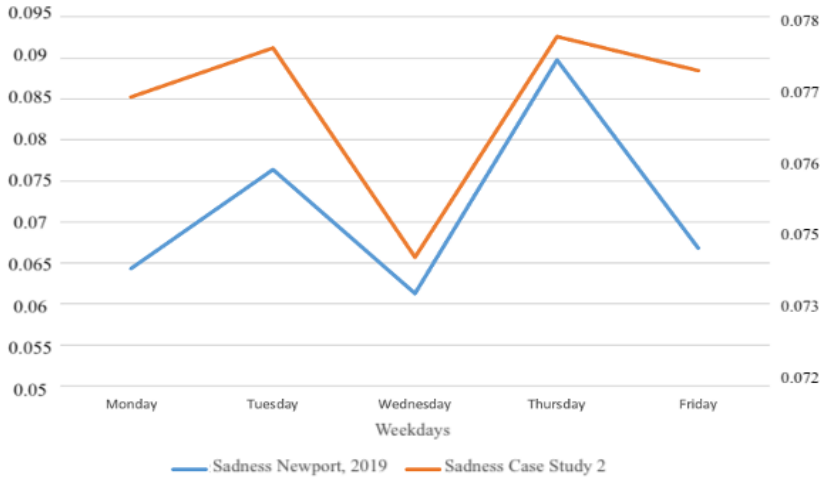


Fig. 3.10. Correlation between the dataset of sadness in Vilnius and by Newport & Pelham, 2019 (created by the author)

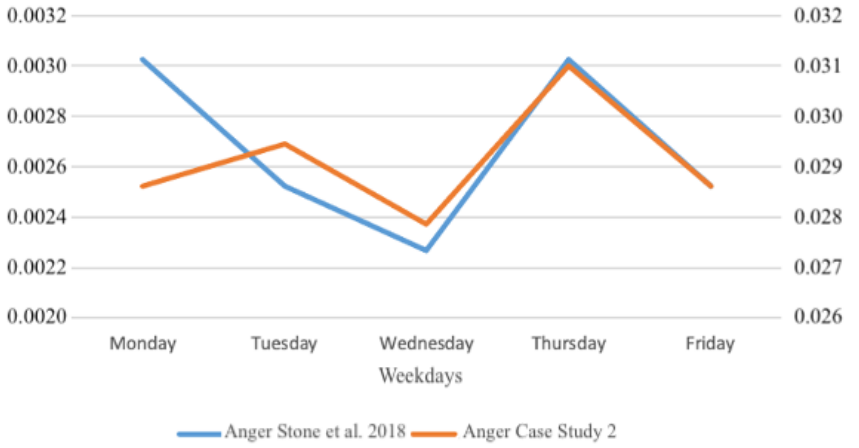


Fig. 3.11. Correlation between dataset of anger in Vilnius and by Stone et al., 2018 (created by the author)

The completed study showed that in order to ensure the effective performance of the life cycle of the building environment, it is important to take into account the emotional state of potential buyers (Pollack, 2021). Positive emotions play an important role in the decision to buy or rent energy-efficient housing. The results show that energy-efficient renovations impact satisfaction and positive emotional states of people. Understanding daily emotional states is important clue for successfully managing green and energy-efficient building advertisements.

3.4. Conclusions of the Third Chapter

This Chapter covers how to measure the segmentation of crowd composition effects (by age and gender), and emotional and physiological indicators of potential buyers.

1. The method obtained in this chapter allows to integrate the affective attitudes of customers, their emotional (e.g., happiness, sadness, anger, etc.) and physiological state (heart rate variability) with the help of a decision-making neuromatrix. Extensive data from the analysis of the affective attitude, and physiological and emotional state of passers-by in the example of real building structures in Vilnius, Lithuania were processed.
2. As part of this study, the provided data were applied to the multi-criteria analysis of neuromarketing and video advertising for different consumer segments in the construction industry using neurodecision tables. When the developed method is used, millions of alternative advertising variants

can be generated and evaluated against a system of criteria, values and weights to pick a rational neuro-marketing alternative. These are the main differences between earlier findings and available neuromarketing methods.

3. After testing the proposed method using neurodecision tables, it was found that with their help, the organisation can analyze benefits and costs in neuromarketing to identify the most rational segments of consumers and conduct analysis according to several criteria. The study has confirmed that residential neuromarketing requires a comprehensive approach to take into account the most rational segments of consumers, desired apartment features, individual differences, the impact of the environment on the property, and physiological and emotional states.
4. Further research should be conducted on the application of the decision-making neuromatrix and the developed method on a larger scale, performing neuromarketing for agricultural organisations, industrial design, business management, services, branding, architecture and work environment, politics and social units.

General Conclusions

The present study aims to develop an intelligent decision support system for the sustainable renovation of a built environment by applying a framework and methods for the collection, measurement and analysis of data on physiological and emotional states. The following conclusions can be drawn.

1. After conducting an analytical survey of the most recent scientific research, it was noted that there is no analytical-recommended method of integration for the sustainable renovation of a built environment, which would comprehensively analyze all its life cycles of it. Also in different strategies related to sustainable built renovation, were identified numerous shortcomings and limitations in the approaches and methods used by various authors. The presented research could justify its contribution to overcoming the limitations of previous scholars by proposing a framework for the influence of the urban built environment on people's emotions.
2. In the Second Chapter was developed a multicriteria analysis of building reconstruction is based on the COPRAS method and the usage of FaceReader software for automatic emotion recognition with specific devices for measuring heart rate variability. Also was performed a comprehensive analysis of emotional and rational market segments by demographic criteria, psychographics and consumer behaviour criteria.

The developed method of multi-variate design and multicriteria analysis of building reconstruction was tested in a real construction project in Kyiv, Ukraine. An important difference between the proposed method and the considered methods is the possibility for residents to indirectly participate in the management of activities and maintenance of the built environment. The presented research has shown the influence of emotions on the decision-making process during building renovation, emotions increase the value of each alternative.

3. By using FaceReader and wearable devices were collected 226 810 valid samples and presented comparing subjective and objective measures of physiological and emotional states in the built environment. A measure was taken to compare the influence of participants' six main emotions on the alternatives for the reconstruction project. During the experiment was noticeable that the value of happiness changed, for example, the participants feel happier with the Parameter of noise pollution (0.8999; 0.9173; 0.9259 etc) compared with the Price (0.048; 0.0568; 0.0623; etc) and values of surprise are significantly higher while viewing Price (0.2589; 0.2565; 0.2538 etc.) compared with Maximum glass unit thickness (0.0018; 0.0019; 0.002 etc), referring to comparisons in section 2.2.1. The proposed method allows to development of recommendations for improving quality-of-life indicators. The practical implementation of the presented model allows avoiding irrational and subjective decisions regarding the reconstruction of buildings, and helps to identify options for reconstruction that have a greater effect and require less investment. For a more accurate and wide practical application of the proposed model, was developed an automation process in an Intelligent database (using the Python language).
4. A developed automated system makes it possible to assess the level of efficiency of the reconstruction of the building, assess the current situation in the real estate sector based on past data, and draw conclusions about changes in the housing sector. The neuromatrix of decisions, as well as physiological and emotional maps, can be used as input to determine the value of public space. The performance evaluation system for the criteria of the DSS for sustainable development displays a graduated rating. Depending on the criteria developed in this study, they are divided into quantitative and qualitative. Aspects that correspond to quantitative indicators in the Value Map are mostly quantifiable, such as duration of work, costs or service life, which can be measured objectively. Qualitative aspects mean that they need to be evaluated qualitatively. For reconstruction projects to meet the requirements of sustainable development,

it is important to consider the interaction and interdependence of qualitative and quantitative factors that correspond to subjective and objective values during the life cycle of the project.

5. The research in the Third Chapter aimed to create Affect-Based Built Environment Video Analytics (BEST) to analyze and collect different types of data: physiological and emotional states, affective attitudes, weather conditions, pollution, etc. Extensive data were processed by the example of real building structures in Vilnius, Lithuania. The innovation is that considered data types are interconnected in a built environment and can be used with the help of a non-contact approach with contactless biometrics. This built environment data can be used for multi-criteria analysis of the architectural environment and to prepare recommendations for interested parties using neurodecision tables. Stakeholders (architects, urban planners, landowners, environmentalists, etc.) can apply this data set to make effective decisions based on a resident-oriented and sustainable environmental approach.
6. The next weighty step in this research was to collate objective and subjective indicators of psychological effects and emotions in an anthropogenic environment. Previous researchers that studied and analyzed the data on affective expression, the physiological and emotional state of humans in built environments have considered only a small sample of data, and the presented research in this dissertation contains a large sample of affective attitudes dataset. It can also be argued that the proposed method increases this line of research compared to the research of other scientists. A much larger number of indicators can be comprehensively analyzed by conducting biometric studies with the help of remote tracking, contactless biometrics and the BEST method.
7. The research confirmed that housing neuromarketing requires an integrated approach to take into account the most rational segments of consumers, desirable features of the apartment, individual differences, the impact of the environment on the property, and emotional and physiological state. This can be achieved by using neural decision tables, the data above can be implemented in neuromarketing to identify the most rational and logical consumer segments and perform a multi-criteria analysis of healthy and safe housing. These findings can be helpful for users who want to apply the evaluation and analysis of human emotions when there is a necessity of choosing an appropriate method for their goals or in finding alternative solutions. Considered methodology can be used in two main contexts (commercial and research) in the construction and architecture spheres. It could improve knowledge about the emotional impact that different project parameters can have and therefore contribute

to the increase of best practices and related normative acts. Several stakeholder groups deal with the stages of the project life cycle: customers, designers, contractors, manufacturers and suppliers of materials and products, users, managers, local governments, etc. Simultaneously, this method can assist engineers and architects in the decision-making process of designing an architectural environment before construction begins, implementation of proposed findings leverage significant gains over traditional construction techniques, such as a speedy construction or renovation process, lesser construction waste, improved quality control, and higher sustainability.

References

Al Amri, T., & Marey-Pérez, M. (2020). Value engineering as a tool for sustainability in the construction industry of Oman. *Value Eng*, *29*, 7433–7444. http://sersc.org/journals/index.php/IJAST/article/view/7614

Alapati, L. K. S. P., & Kavuri, N. C. (2020, August). Analysis of Green Building Certification Attainment through LEED System for SDC Block at KLEF, India. In *IOP conference series: Materials science and engineering* (Vol. 912, No. 6, p. 062044). IOP Publishing. https://doi.org/10.1088/1757-899x/912/6/062044

Ang, K. L. M., & Seng, K. P. (2021). Biometrics-based Internet of Things and Big data design framework. *Mathematical Biosciences and Engineering*, *18*(4), 4461–4476. https://doi.org/10.3934/mbe.2021226

Asmone, A. S., Conejos, S., & Chew, M. Y. (2019). Green maintainability performance indicators for highly sustainable and maintainable buildings. *Building and Environment*, *163*, 106315. https://doi.org/10.1016/j.buildenv.2019.106315

Bedon, C., & Mattei, S. (2021). Facial expression-based experimental analysis of human reactions and psychological comfort on glass structures in buildings. *Buildings*, *11*(5), 204. https://doi.org/10.3390/buildings11050204

Benezeth, Y., Li, P., Macwan, R., Nakamura, K., Gomez, R., & Yang, F. (2018). Remote heart rate variability for emotional state monitoring. In *IEEE EMBS international conference on biomedical & health informatics (BHI)* (pp. 153–156). https://doi.org/10.1109/BHI.2018.8333392

Birenboim, A., Dijst, M., Scheepers, F. E., Poelman, M. P., & Helbich, M. (2019). Wearables and location tracking technologies for mental-state sensing in outdoor environments. *The Professional Geographer*, *71*(3), 449–461. https://doi.org/10.1080/00330124.2018.1547978

Bivard, A., Churilov, L., & Parsons, M. (2020). Artificial intelligence for decision support in acute stroke—current roles and potential. *Nature Reviews Neurology*, *16*(10), 575–585. https://doi.org/10.1038/s41582-020-0390-y

Blanchflower, D. G. (2021). Is happiness U-shaped everywhere? Age and subjective well-being in 145 countries. *Journal of Population Economics*, *34*(2), 575–624. https://doi.org/10.1007/s00148-020-00797-z

Borgianni, Y., Rauch, E., Maccioni, L., & Mark, B. G. (2018, December). User experience analysis in industry 4.0-the use of biometric devices in engineering design and manufacturing. In *2018 IEEE International conference on industrial engineering and engineering management (IEEM)* (pp. 192–196). https://doi.org/10.1109/IEEM.2018.8607367

Bower, I., Tucker, R., & Enticott, P. G. (2019). Impact of built environment design on emotion measured via neurophysiological correlates and subjective indicators: A systematic review. *Journal of Environmental Psychology*, *66*, 101344. https://doi.org/10.1016/j.jenvp.2019.101344

Breitner, S., Peters, A., Zareba, W., Hampel, R., Oakes, D., Wiltshire, J., ..., & Rich, D. Q. (2019). Ambient and controlled exposures to particulate air pollution and acute changes in heart rate variability and repolarization. *Scientific Reports*, *9*(1), 1–12. https://doi.org/10.1038/s41598-019-38531-9

Brodsky, A., Nachawati, M. O., Krishnamoorthy, M., Bernstein, W. Z., & Menascé, D. A. (2019). Factory optima: a web-based system for composition and analysis of manufacturing service networks based on a reusable model repository. *International Journal of Computer Integrated Manufacturing*, *32*(3), 206–224. https://doi.org/10.1080/0951192X.2019.1570805

Calabrese, F., Colonna M., Lovisolo,P., Parata D., Ratti, C. (2011) real-time urban monitoring using cell phones: A case study in Rome. *Transactions on Intelligent Transportation Systems, 12*(1), 141–151 IEEE. https://doi.org/10.1109/TITS.2010.2074196

Camungao, R. (2020). Decision support system framework with k-means algorithm for faculty performance evaluation rating. *International Journal of Scientific & Technology Research*, *9*(03).

Canossa, S., Ji, Z., & Wuttke, S. (2020). Circumventing wear and tear of adaptive porous materials. *Advanced Functional Materials*, *30*(41), 1908547. https://doi.org/10.1002/adfm.201908547

Çatal, Y., & Saplioğlu, K. (2018). Comparison of adaptive neuro-fuzzy inference system, artificial neural networks and non-linear regression for bark volume estimation in brutian pine (Pinus brutia Ten.). *Applied Ecology and Environmental Research*, *16*(2), 2015–2027. https://doi.org/10.15666/aeer/1602_20152027

Churkina, G., Organschi, A., Reyer, C. P., Ruff, A., Vinke, K., Liu, Z., ..., & Schellnhuber, H. J. (2020). Buildings as a global carbon sink. *Nature Sustainability*, *3*(4), 269–276. https://doi.org/10.1038/s41893-019-0462-4

Çinar Umdu, D. & Alakavuk, E. (2020) Understanding of smart cities, digital cities and intelligent cities: similarities and differences. *Int. Arch. Photogramm. Remote Sens. Spatial Inf. Sci 4*(3), 173–180. 10.5194/isprs-archives-XLIV-4-W3-2020-173-2020

Costin, A., Adibfar, A., Hu, H., & Chen, S. S. (2018). Building Information Modeling (BIM) for transportation infrastructure–Literature review, applications, challenges, and recommendations. *Automation in Construction*, *94*, 257–281. https://doi.org/10.1016/j.autcon.2018.07.001

Deb, C., Lee, S. E., & Santamouris, M. (2018). Using artificial neural networks to assess HVAC related energy saving in retrofitted office buildings. *Solar Energy*, *163*, 32–44. https://doi.org/10.1016/j.solener.2018.01.075

Diamantopoulou, M. J., Özçelik, R., Crecente-Campo, F., & Eler, Ü. (2015). Estimation of Weibull function parameters for modelling tree diameter distribution using least squares and artificial neural networks methods. *Biosystems Engineering*, *133*, 33–45. https://doi.org/10.1016/j.biosystemseng.2015.02.013

Ding, D., Wu, J., Zhu, S., Mu, Y., & Li, Y. (2021). Research on AHP-based fuzzy evaluation of urban green building planning. *Environmental Challenges*, *5*, 100305. https://doi.org/10.1016/j.envc.2021.100305

Dulleck, U., Fooken, J., Newton, C., Ristl, A., Schaffner M. & Torgl, B. (2016) Tax compliance and psychic costs: Behavioral experimental evidence using a physiological Marker. *J. Public Econ., 134*, 9–18 (2016). https://doi.org/10.1016/j.jpubeco.2015.12.007

Duric, I., Barac, D., Bogdanovic, Z., Labus, A., & Radenkovic, B. (2021). Model of an intelligent smart home system based on ambient intelligence and user profiling. *Journal of Ambient Intelligence and Humanized Computing*, 1–13. https://doi.org/10.1007/s12652-021-03081-4

Dwaikat, L. N., & Ali, K. N. (2018). Green buildings life cycle cost analysis and life cycle budget development: Practical applications. *Journal of Building Engineering*, *18*, 303–311. https://doi.org/10.1016/j.jobe.2018.03.015

Dzogang, F., Lightman, S., & Cristianini, N. (2017). Circadian mood variations in Twitter content. *Brain and Neuroscience Advances*, *1*(2), https://doi.org/10.1177/2398212817744501

Environmental Protection Agency (2018). http://oras.gamta.lt/cms/index?rubricId=260ccbe85401-4f3b-adb1-b4ab1b9aa2b5

Erbe, D. H., Culp T., Lord R., Amrane K., Lane, M. D., Beilman, S., Baselici, P. A., Hanson, S., …, & Kurtz, R. D. (2021). *Energy standard for buildings except low-rise residential buildings*. https://www.ashrae.org/

Ergan, S., Radwan, A., Zou, Z., Tseng, H. A., & Han, X. (2019). Quantifying human experience in architectural spaces with integrated virtual reality and body sensor networks.

Journal of Computing in Civil Engineering, *33*(2), 04018062. https://doi.org/10.1061/(ASCE)CP.1943-5487.0000812

FaceReader. Reference Manual Version 7. Tool for Automatic Analysis of Facial Expressions, Noldus Information Technology http://sslab.nwpu.edu.cn/uploads/1500604789-5971697563f64.pdf

Friesen, E., & Ekman, P.(1978) *Facial action coding system: A technique for the measurement of facial movement.* Consulting Psychologists Press.

Galiotto, N., Heiselberg, P., & Knudstrup, M. (2015) Integrated renovation process: Overcoming barriers to sustainable renovation. *Journal of Architectural Engineering.*

Gams, M., Gu, I. Y. H., Härmä, A., Muñoz, A., & Tam, V. (2019). Artificial intelligence and ambient intelligence. *Journal of Ambient Intelligence and Smart Environments*, *11*(1), 71-86. https://doi.org/10.3233/AIS-180508

Gana, K., Bailly, N., Saada, Y., Joulain, M., Alaphilippe, D. (2013) Does life satisfaction change in old age: Results from an 8-year longitudinal study. *J. Gerontol. Ser. B Psychol. Sci. Soc. Sci.*, *68*, 540–552. https://doi.org/10.1093/geronb/gbs093

Graham, C., & Pozuelo, J. R. (2017) Happiness, stress, and age: How the U curve varies across people and places. *J. Popul. Econ. 30*, 225–264. https://doi.org/10.1007/s00148-020-00797-z

Gul, S., Bano, S., & Shah, T. (2021). Exploring data mining: facets and emerging trends. *Digital Library Perspectives*, *37* (4), 429-448 https://doi.org/10.1108/DLP-08-2020-0078

Guo, Y., Wang, N., Xu, Z. Y., & Wu, K. (2020). The internet of things-based decision support system for information processing in intelligent manufacturing using data mining technology. *Mechanical Systems and Signal Processing*, *142*, 106630. https://doi.org/10.1016/j.ymssp.2020.106630

Gupta, A., Eilert, M., & Gentry, J. W. (2018). Can I surprise myself? A conceptual framework of surprise self-gifting among consumers. *Journal of Retailing and Consumer Services. Elsevier Ltd.* https://doi.org/10.1016/j.jretconser.2018.11.017

Hamilton, S. (2021). Real-time big data analytics, sustainable Industry 4.0 wireless networks, and Internet of Things-based decision support systems in cyber-physical smart manufacturing. *Economics, Management, and Financial Markets*, *16*(2), 84-94. https://doi.org/10.22381/emfm16220215

Harisankar, R., & Rakesh, P. (2021). Simulation-Based Comparative Study on Energy Efficiency Criteria for LEED and BREEAM Systems. *Journal of Physics: Conference Series*, *2070*(1), 012222. https://doi.org/10.1088/1742-6596/2070/1/012222

Hassan, A., Tao, J., Li, G., Jiang, M., Aii, L., Zhihui, J., ..., & Qibing, C. (2018). Effects of walking in bamboo forest and city environments on brainwave activity in young adults. *Evidence-Based Complementary and Alternative Medicine*. https://doi.org/10.1155/2018/9653857

Ilikci, B., Chen, L., Cho, H., & Liu, Q. (2019, October). Heat-map based emotion and face recognition from thermal images. In *2019 computing, communications and IOT applications (ComComAp)* (pp. 449–453). IEEE. https://doi.org/10.1109/ComComAp46287.2019.9018786.

Ingraham, C. (2019) *This chart predicts the age at which you'll be happiest.* https://www.weforum.org/agenda/2017/08/youll-probably-have-a-midlife-happiness-crisis-heres-why

Islam, O., Alfakeeh, A., & Nadeem, F. (2017). A framework for effective big data analytics for decision support systems. *Int. J. Comput. Netw. Appl.(IJCNA), 4*(5), 129–137. https://doi.org/10.22247/ijcna/2017/49227

Jacobs, J. (1961). The uses of sidewalks: safety. *The City Reader,* 114–118. https://www.taylorfrancis.com/chapters/edit/10.4324/9780429261732-25/uses-sidewalks-safety-jane-jacobs

Kaklauskas, A., Zavadskas, E. K., Raslanas, S., Ginevicius, R., Komka, A., & Malinauskas, P. (2006) Selection of low-e windows in retrofit of public buildings by applying multiple criteria method COPRAS: a Lithuanian case. *Energy and Buildings, 38*(5), 454–462. https://doi.org/10.1016/j.enbuild.2005.08.005

Kalantari, S. (2019). A new method of human response testing to enhance the design process. In *Proceedings of the design society: International conference on engineering design, 1*(1), 1883–1892. Cambridge University Press. https://doi.org/10.1017/dsi.2019.194

Kamari, A., Corrao, R., Petersen, S. & Kirkegaard P.H. (2017). Sustainable Renovation Framework: Introducing three levels of integrated design process implementation and evaluation. In *PLEA 2017 conference, Edinburgh, UK* (pp. 781–788). http://nceub.org.uk/PLEA2017/proceedings/PLEA2017_proceedings_volume_I.pdf

Keenan, P. B., & Jankowski, P. (2019). Spatial decision support systems: Three decades on. *Decision Support Systems, 116*, 64–76. https://doi.org/10.1016/j.dss.2018.10.010

Kesebir, P., Gasiorowska, A., Goldman, R., Hirshberg, M. J., & Davidson, R. J. (2019). Emotional style questionnaire: A multidimensional measure of healthy emotionality. *Psychological Assessment, 31*(10), 1234. https://doi.org/10.1037/pas0000745

Kloeckl, K., Senn, O., & Lorenzo, G.D. (2012). *LIVE Singapore! - An urban platform for real-time data to program the city.* https://doi.org/10.1080/10630732.2012.698068

Komuro, N., Hashiguchi, T., Hirai, K., & Ichikawa, M. (2021). Predicting individual emotion from perception-based non-contact sensor big data. *Scientific Reports, 11*(1), 1–9. https://doi.org/10.1038/s41598-021-81958-2

Kortli, Y., Jridi, M., Al Falou, A., & Atri, M. (2020). Face recognition systems: A survey. *Sensors, 20*(2), 342. https://doi.org/10.3390/s20020342

Kummitha, R. K. R., & Crutzen, N. (2019). Smart cities and the citizen-driven internet of things: A qualitative inquiry into an emerging smart city. *Technological Forecasting and Social Change, 140*, 44–53. https://doi.org/10.1016/j.techfore.2018.12.001

Laage-Thomsen, J. (2021). Professional expertise in policy advisory systems: How administrators and consultants built behavioral insights in Danish public agencies. *Public Administration*. https://doi.org/10.1111/padm.12725

Labib, S. M., Lindley, S., & Huck, J. J. (2020). Spatial dimensions of the influence of urban green-blue spaces on human health: A systematic review. *Environmental Research, 180*, 108869. https://doi.org/10.1016/j.envres.2019.108869

Larson, E.B. (2019). *Who's Happier—People in Their 40s or 80s?* https://wa-health.kaiserpermanente.org/whos-happier-people-in-their-40s-or-80s/

Lashmi, K., & Pillai, A. S. (2019). Ambient intelligence and IoT based decision support system for intruder detection. In *IEEE International Conference on Electrical, Computer and Communication Technologies (ICECCT)* (pp. 1–4). IEEE. https://doi.org/10.1109/ICECCT.2019.8869327

Latorre-Biel, J. I., Jiménez-Macías, E., Blanco, J., & Perez, M. (2018). Size rate of an alternatives aggregation Petri net developed under a modular approach. In *Proceedings of The 9th EUROSIM Congress on Modelling and Simulation, EUROSIM 2016, The 57th SIMS Conference on Simulation and Modelling SIMS, 142* (pp. 626–631). https://doi.org/10.3384/ecp17142626

Lebowitz, S. & Kiersz, A. (2019). *Your happiness might keep dropping all the way into your 50s—before a midlife crisis turns it around*. https://www.businessinsider.com/midlife-crisis-controversialstudy-2017-9

Li, J., Nazir Jan, M., & Faisal, M. (2020). Big data, scientific programming, and its role in internet of industrial things: a decision support system. *Scientific Programming*. https://doi.org/10.1155/2020/8850096

Lin, I. M., Fan, S. Y., Yen, C. F., Yeh, Y. C., Tang, T. C., Huang, M. F., ..., & Tsai, Y. C. (2019). Heart rate variability biofeedback increased autonomic activation and improved symptoms of depression and insomnia among patients with major depression disorder. *Clinical Psychopharmacology and Neuroscience*, *17*(2), 222. https://doi.org/10.9758/cpn.2019.17.2.222

Loijens, L., & Krips, O. (2013). FaceReader methodology. *Wageningen: Noldus Information Technology*.

Lokhande, S., and Khare, N. (2015). An outlook on Big data and Big data analytics. *International Journal of Computer Applications*, *124*(11). https://doi.org/10.5120/ijca2015905658

Medsker, L. R., & Bailey, D. L. (2020). Models and guidelines for integrating expert systems and neural networks. *Hybrid Architectures for Intelligent Systems*, 153–171.

McStay, A. (2020). Emotional AI and EdTech: serving the public good?. *Learning, Media and Technology, 45*(3), 270–283. https://doi.org/10.1080/17439884.2020.1686016

Mi, Z., Guan, D., Liu, Z., Liu, J., Viguié, V., Fromer, N., & Wang, Y. (2019). Cities: The core of climate change mitigation. *Journal of Cleaner Production, 207*, 582–589. https://doi.org/10.1016/j.jclepro.2018.10.034

Miguel, F., Frutos, M., Tohmé, F., & Babey, M. M. (2019). A decision support tool for urban freight transport planning based on a multi-objective evolutionary algorithm. *IEEE Access*, *7*, 156707–156721. https://doi.org/10.1109/ACCESS.2019.2949948

Mirarchi, C., Lucky, M. N., Ciuffreda, S., Signorini, M., Lupica Spagnolo, S., Bolognesi, C., ..., & Pavan, A. (2020). *An approach for standardization of semantic models for building renovation processes*. https://doi.org/10.5194/isprs-archives-XLIII-B4-2020-69-2020

Mohamed, M., Yoshizawa, M., Sugita, N., Yamaki, S., & Ichiji, K. (2020). Noncontact monitoring of heart rate responses to taste stimuli using a video camera. *Indonesian Journal of Electrical Engineering and Computer Science*, *18*(1), 293–300. https://doi.org/10.11591/ijeecs.v18.i1

Morelli, D., Bartoloni, L., Rossi, A., & Clifton, D. A. (2019). A computationally efficient algorithm to obtain an accurate and interpretable model of the effect of circadian rhythm on resting heart rate. *Physiological Measurement*, *40*(9), 095001. https://doi.org/10.1088/1361-6579/ab3dea

Mouratidis, K. (2019). Compact city, urban sprawl, and subjective well-being. *Cities*, *92*, 261–272. https://doi.org/10.1016/j.cities.2019.04.013

Munir, M. S., Bajwa, I. S., & Cheema, S. M. (2019). An intelligent and secure smart watering system using fuzzy logic and blockchain. *Computers & Electrical Engineering*, *77*, 109–119. https://doi.org/10.1016/j.compeleceng.2019.05.006

Muralitharan, K., Sakthivel, R., & Vishnuvarthan, R. (2018). Neural network based optimization approach for energy demand prediction in smart grid. *Neurocomputing*, *273*, 199–208. https://doi.org/10.1016/j.neucom.2017.08.017

Newport, F.; Pelham, B. Don't Worry, Be 80: *Worry and stress decline with age worry, stress lowest for those in their 80s, 90s*. https://news.gallup.com/poll/124655/dont-worry-be-80-worrystress-decline-age.aspx

Nishant, R., Kennedy, M., & Corbett, J. (2020). Artificial intelligence for sustainability: Challenges, opportunities, and a research agenda. *International Journal of Information Management*, *53*, 102104. https://doi.org/10.1016/j.ijinfomgt.2020.102104

Noaman, A. Y., Nadeem, F., Ragab, A., Jamjoom, A., Al-Abdullah, N., Nasir, M., & Ali, A. G. (2017). Improving prediction accuracy of "Central line-associated blood stream infections" using data mining models. *BioMed Research International*, *2017*, 3292849. https://doi.org/10.1155/2017/3292849

Novelda, A.S. (2019). *X4M200 Datasheet*. https://www.codico.com/shop/media/datasheets/Novelda_X4M200_respiration_sensor_rev_c_preliminary.pdf

Omer, M. A., & Noguchi, T. (2020). A conceptual framework for understanding the contribution of building materials in the achievement of sustainable development Goals (SDGs). *Sustainable Cities and Society*, *52*, 101869. https://doi.org/10.1016/j.scs.2019.101869

OpenHouse Homepage. (2012). http://www.openhouse-fp7.eu/

Oses, U., Rojí, E., Cuadrado, J., & Larrauri, M. (2018). Multiple-criteria decision-making tool for local governments to evaluate the global and local sustainability of transportation systems in urban areas: case study. *Journal of Urban Planning and Development*, *144*(1), 04017019. https://doi.org/10.1061/(ASCE)UP.1943-5444.0000406

Outram, C., Ratti, C., & Bidermann, A. (2010). The Copenhagen wheel: An innovative electric bicycle system that harnesses the power of real-time information and crowd sourcing. *EVER Monaco International.*

Park, J. H., Salim, M. M., Jo, J. H., Sicato, J. C. S., Rathore, S., & Park, J. H. (2019). CIoT-Net: a scalable cognitive IoT based smart city network architecture. *Human-centric Computing and Information Sciences*, *9*(1), 1–20. https://doi.org/10.1186/s13673-019-0190-9

Patta, S. V. P. (2019). *Intelligent decision support systems for compliance options: A systematic literature review and simulation (Dissertation).* http://urn.kb.se/resolve?urn=urn:nbn:se:bth-18449

Pinto, T., Faia, R., Navarro-Cáceres, M., Santos, G., Corchado, J. M., & Vale, Z. (2018). Multi-agent-based CBR recommender system for intelligent energy management in buildings. *IEEE Systems Journal*, *13*(1), 1084–1095. https://doi.org/10.1109/JSYST.2018.2876933

Polar. (2019). *Your resting heart rate is telling you something—so listen*. https://www.polar.com/blog/resting-heart-rate/

Pollack, B. L. (2021). Green service attributes and amplifiers of the warm emotions evoked by them. *Journal of Service Theory and Practice*. https://doi.org/10.1108/JSTP-07-2020-0163

Ratra, R., & Gulia, P. (2020). Experimental evaluation of open source data mining tools (WEKA and Orange). *International Journal of Engineering Trends and Technology*, *68*(8), 30–35. *Retrieved from:* http://www.ijettjournal.org/

Ribeiro, F. S., Santos, F. H., Albuquerque, P. B., & Oliveira-Silva, P. (2019). Emotional induction through music: Measuring cardiac and electrodermal responses of emotional states and their persistence. *Frontiers in Psychology*, *10*, 451. https://doi.org/10.3389/fpsyg.2019.00451

Roberts, H., Sadler, J., & Chapman, L. (2019). The value of Twitter data for determining the emotional responses of people to urban green spaces: A case study and critical evaluation. *Urban Studies*, *56*(4), 818-835. https://doi.org/10.1177/0042098017748544

Rodríguez, G., Gonzalez-Cava, J. M., & Méndez Pérez, J. A. (2020). An intelligent decision support system for production planning based on machine learning. *Journal of Intelligent Manufacturing*, *31*(5), 1257–1273. https://doi.org/10.1007/s10845-019-01510-y

Scheibe, S. (2021). Employee age moderates within-person associations of daily negative work events with emotion regulation, attention, and well-being. *European Journal of Work and Organizational Psychology*, *30*(6), 872–886. https://doi.org/10.1080/1359432X.2021.1873772

Şentürk, Z. K. (2020). Artificial Neural Networks based decision support system for the detection of diabetic retinopathy. *Sakarya University Journal of Science*, *24*(2), 424–431. https://doi.org/10.16984/saufenbilder.630482

Shoval, N., Schvimer, Y., & Tamir, M. (2018). Tracking technologies and urban analysis: Adding the emotional dimension. *Cities*, *72*, 34–42. https://doi.org/10.1016/j.cities.2017.08.005

Shu, L., Yu, Y., Chen, W., Hua, H., Li, Q., Jin, J., & Xu, X. (2020). Wearable emotion recognition using heart rate data from a smart bracelet. *Sensors*, *20*(3), 718. https://doi.org/10.3390/s20030718

Siedlecka, E., & Denson, T. F. (2019). Experimental methods for inducing basic emotions: A qualitative review. *Emotion Review*, *11*(1), 87–97. https://doi.org/10.1177/1754073917749016

Stoffels, M., Nijs, M., Spinhoven, P., Mesbah, R., & Hagenaars, M. A. (2017). Emotion avoidance and fear bradycardia in patients with borderline personality disorder and healthy controls. *Journal of Behavior Therapy and Experimental Psychiatry*, *57*, 6–13. https://doi.org/10.1016/j.jbtep.2017.02.001

Stone, A. A., Schneider, S., Krueger, A., Schwartz, J. E., & Deaton, A. (2018). Experiential wellbeing data from the American Time Use Survey: Comparisons with other methods and analytic illustrations with age and income. *Social Indicators Research*, *136*(1), 359–378. https://doi.org/10.1007/s11205-016-1532-x

Storbeck, J., Dayboch, J., & Wylie, J. (2019). Fear and happiness, but not sadness, motivate attentional flexibility: A case for emotion influencing the ability to split foci of attention. *Emotion*, *19*(4), 655. https://doi.org/10.1037/emo0000471

SuPerBuildings Homepage. (2012). http://cic.vtt.fi/superbuildings/

Tanrıkul, A. (2020). *An applicable framework for the regeneration process of historic city centres: Learning from the Mediterranean*. http://hdl.handle.net/11129/5067

Tomislav, K. (2018). The concept of sustainable development: From its beginning to the contemporary issues. *Zagreb International Review of Economics & Business*, *21*(1), 67–94. https://doi.org/10.2478/zireb-2018-0005

Tsuei, H. J., Shen, G., & Tzeng, G. H. (2021). Evaluating biometrics by using a hybrid MCDM model. *Scientific Reports*, *11*(1), 1–9. https://doi.org/10.1038/s41598-021-00180-2

Xiaomi Mi Smart Band characteristics. https://www.mi.com/ua/

Yan, R., Jian, Y., Hao, L. C., Han, X. Y., & Tang, L. L. (2019). Research on automatic knowledge acquisition technology for software fault diagnosis. In *International conference on quality, reliability, risk, maintenance, and safety engineering (QR2MSE)* (pp. 901–907). https://doi.org/10.1109/QR2MSE46217.2019.9021109

Yilmaz, M., Psychogiou, L., Javaid, M., Ford, T., & Dunn, B. D. (2019). Making the worst of a good job: Induced dampening appraisals blunt happiness and increase sadness in adolescents during pleasant memory recall. *Behaviour Research and Therapy*, *122*, 103476. https://doi.org/10.1016/j.brat.2019.103476

Zeile, P., Resch, B., Loidl, M., Petutschnig, A., & Dörrzapf, L. (2016). Urban emotions and cycling experience–enriching traffic planning for cyclists with human sensor data. *GI_Forum*, *1*(2013), 204–216. https://doi.org/10.1553/giscience2016_01_s204

Zhang, L., Fu, C. H., Hong, H., Xue, B., Gu, X., Zhu, X., & Li, C. (2021). Non-contact Dual-modality emotion recognition system by CW radar and RGB camera. *IEEE Sensors Journal*, *21*(20), 23198–23212. https://doi.org/10.1109/JSEN.2021.3107429

Zhao, X., Zuo, J., Wu, G., & Huang, C. (2019). A bibliometric review of green building research 2000–2016. *Architectural Science Review*, *62*(1), 74–88. https://doi.org/10.1080/00038628.2018.1485548

Zheng, G., Li, K., Bu, W., & Wang, Y. (2019). Fuzzy comprehensive evaluation of human physiological state in indoor high temperature environments. *Building and Environment*, *150*, 108–118. https://doi.org/10.1016/j.buildenv.2018.12.063

List of Scientific Publications by the Author on the Topic of the Dissertation

Papers in the Reviewed Scientific Journals

Kaklauskas, A., Zavadskas, E. K., Bardauskiene, D., Cerkauskas, J., Ubarte, I., Seniut, M., & Velykorusova, A. (2019). An affect-based built environment video analytics. *Automation in Construction, 106,* 102888. https://doi.org/10.1016/j.autcon.2019.102888

Kaklauskas, A., Ubarte, I., Kalibatas, D., Lill, I., Velykorusova, A., Volginas, P., & Bublienė, R. (2019). A multisensory, green, and energy efficient housing neuromarketing method. *Energies*, *12*(20), 3836. https://doi.org/10.3390/en12203836

Velykorusova, A., Zavadskas, E. K., Tupenaite, L., Kanapeckiene, L., Migilinskas, D., Kutut, V., Ubarte, I., Abaravicius, Z., & Kaklauskas, A. (2023). Intelligent multi-criteria decision support for renovation solutions for a building based on emotion recognition by applying the COPRAS method and BIM integration. *Appl. Sci.*, *13*, 5453. https://doi.org/10.3390/app13095453

Papers in Other Editions

Kaklauskas, A., Velykorusova, A., & Skirmantas, D. (2019). Development of the video neuroadvertising method and recommender system. In *The 17th Colloquium „Sustainable decisions in the built environment" and Meeting of EURO working group "OR in sustainable development and civil engineering"*, Vilnius, Lithuania. Technika. https://doi.org/10.20334/2019-013-M

Summary in Lithuanian

Įvadas

Problemos formulavimas

Tvarios renovacijos procesai yra sudėtingesni ir permainingesni, atsižvelgiant į jų planavimo, vykdymo ir sprendimų priėmimo procesus nei naujo pastato statybos procesas. Pagrindinė idėja – suvokti vykstančius atnaujinimo sprendimų priėmimo procesus ir pateikti pasiūlymus, kaip juos būtų galima tobulinti.

Remiantis įvairias tyrimai (pvz., Mouratidis, 2019; Nishant et al., 2020), teigiama, jog miesto aplinka, tokia kaip viešosios erdvės, pastatai, žemės naudojimo kompleksiškumas, transporto srautai ir kokybiška aplinka, atlieka svarbų vaidmenį pirkėjų emocijoms. Nemažai mokslininkų analizavo žmogaus emocijas, subjektyvius tyrimus atliko Roberts ir kt. (2019), Bower ir kt. (2019), o objektyvius tyrimus atliko Park ir kt. (2019), Labib ir kt. (2020). Daugelis autorių (pvz., Labib et al., 2020); Birenboim et al., 2019) analizavo būdus, kaip fiziologinį pojūtį paversti pagrindine miesto planavimo dalimi. Tačiau nėra sukurta analitinio-rekomendacinio metodo, skirto integruotai analizuoti tvarią užstatytą aplinką, užstatytos aplinkos gyvavimo ciklą bei jos veiksnius. Remiantis esamomis literatūros spragomis, pasiūlyta urbanizuotos užstatytos aplinkos poveikio žmonių emocijoms struktūra ir atlikta tarpusavio ryšio tarp emocijų ir pažinimo analizė, kuri gali pateikti naują perspektyvą miesto tyrimams.

Darbo aktualumas

Miesto planavimo etape emocijų atpažinimas ir stebėjimas gali atlikti svarbų vaidmenį, nes psichologinis architektūrinių sprendimų poveikis gali turėti tiek neigiamų, tiek teigiamų pasekmių. Taikant šiuos naujus planavimo metodus gali būti atsižvelgta į išmaniojo miesto koncepcijas. Nesunku atsekti perėjimą nuo skaitmeninių prie išmaniųjų miestų, kaip ir erdvių bei miestų planavimo potencialą (Çinar Umdu & Alakavuk, 2020). Galimybė rinkti duomenis realiuoju laiku ir generuoti informaciją apie erdvinius procesus atveria naujų miestų analizės galimybių. Pateikta metodika gali padėti inžinieriams ir architektams projektuojant užstatytą aplinką priimti sprendimus prieš statybos darbus, renkantis alternatyvas, kurios maksimizuotų emocijų, kurias jie nori sukelti suinteresuotiems asmenims, lygį.

Tyrimo objektas

Disertacijos tyrimo objektas – analitinio rekomendacinio metodo ir žiniomis pagrįstos sprendimų paramos sistemos, integruotos su daugiasluoksniu dirbtiniu neuroniniu tinklu, kūrimo procesas, pasiūlant, kaip pateikti iš užstatytos aplinkos gautus duomenis ir priimti sprendimus bei analizuoti jos gyvavimo ciklą.

Darbo tikslas

Sukurti išmanią sprendimų paramos sistemą, skirtą tvariam užstatytos aplinkos atnaujinimui, taikant pasiūlytą struktūrą, nuoseklius etapus ir metodus duomenų rinkimui, matavimams ir analizei atlikti atsižvelgiant į holistinės užstatytos aplinkos fiziologines ir emocines būkles bei ekonominius ir socialinius kriterijus.

Darbo uždaviniai

Siekiant pasiekti šio darbo tikslą, darbe sprendžiami šie uždaviniai:

1. Atlikti naujausių mokslinių tyrimų, susijusių su disertacija, analitinę apžvalgą.
2. Suformuoti racionalius pastato stabilumo sprendinius renovacijos etape, sukurti daugiakriterę pastato rekonstrukcijos analizę, taikant COPRAS metodą ir naudojant „FaceReader“ programinę įrangą, bei atlikti praktinį pritaikymą realiame projekte (tyrimo atvejis Kijeve, Ukraina).
3. Remiantis pasiūlyta neurosprendimų matrica, sudaryti žmonių fiziologinės ir emocinės būsenos žemėlapį
4. Taikant sprendimų priėmimo neuromatricą, integruoti pirkėjų afektines nuostatas ir jų emocinę bei fiziologinę būseną (tyrimo atvejis Vilniuje, Lietuva).
5. Taikyti daugiakriterę reklaminių vaizdo klipų ir neurorinkodaros analizę įvairiems vartotojų segmentams statybos sektoriuje, naudojant neurosprendimų lenteles. Taip pat ištirti vartotojų psichologinio komforto lygius.
6. Atskleisti sprendimų palaikymo sistemų, neraiškiųjų sistemų ir dirbtinių neuroninių tinklų integravimo naudą modeliuojant racionalius tvarių pastatų sprendimus.

Tyrimų metodika

Daugiakriteris sprendimų priėmimas (MCDM) reiškia, kad minia priima visiškai racionalius sprendimus (Oses et al., 2018). MCDM atveju priimant sprendimus emocinė būsena įtakos paprastai nedaro. Subjektyvus žmogaus emocijų tyrimas miesto kontekste buvo atliktas taikant kokybinius metodus, t. y. savęs vertinimą ir interviu, siekiant užfiksuoti subjektyvią žmonių patirtį ir ištirti jų emocijas.

Objektyvus žmogaus emocijų tyrimas apėmė biometrinių sistemų ir metodų, tokių kaip širdies ritmo kintamumas, kūno temperatūra ir kt., naudojimą (pvz., Kalantari, 2019; Ergan et al, 2019). Užfiksuota ir ištirta daugiau nei 200 mln. fiziologinių ir emocinių būsenų, oro ir triukšmo taršos duomenų.

Daugiakriterė užstatytos aplinkos analizė turėtų būti parengta naudojant neurosprendimų lenteles ir vertes (pvz., investicijos, ekonominiai aspektai ir kt.). Taigi mokslinė problema yra didesnė ir gilesnė, lyginant su ankstesniais tyrimais. Pasiūlytas tyrimo metodas skatins žmogaus emocijų stebėjimo plėtrą analizuojant įvairių projektavimo parametrų ir jų įtaką suinteresuotų šalių emocijoms. Šis darbas apima naujo metodų rinkinio sukūrimą naudojant biostatistines ir sensorines technologijas. Pagrindinė idėja – integruoti virtualiąją erdvę į fizinį pasaulį, naudojant jutiklių tinklus ir technologijas. Rezultatai gali būti naudojami kaip modernizuotas DSS tipas ir gali sukurti naują dabartinių planavimo procesų perspektyvą.

Darbo mokslinis naujumas

Rengiant disertaciją gauti toliau nurodyti nauji rezultatai, susiję su užstatytos aplinkos tvarios renovacijos mokslu:

1. Rekomendacijų ir didžiųjų duomenų analizės sistema integruota atliekant tyrimą.
2. Daugiakriterės analizės ir sprendimų priėmimo sistemos, biometriniai metodai ir sistemos yra integruotos į intelektinės ir efektyvios pastatų renovacijos procesą.
3. Pasiūlyta ir praktiškai pritaikyta daugiakriterė užstatytos aplinkos tvarios renovacijos metodika.
4. Pateiktoje sistemoje sprendimų paramos sistema yra integruota su daugiasluoksniu dirbtiniu neuroniniu tinklu miesto plėtrai.

Mokslinio tyrimo rezultatų praktinė reikšmė

Siūlomas metodas ir sukurta sprendimų paramos sistema taip pat gali būti pritaikyta įvairiose civilinės inžinerijos srityse (pvz., statybos, aplinkosaugos, konstrukcijų, transporto ir vandens išteklių inžinerijoje bei kt.). Pateikta metodika gali būti praktiškai taikoma dviejose pagrindinėse srityse: mokslinėje ir komercinėje. Taip pat ši metodika gali padėti inžinieriams ir architektams priimti sprendimus pastato aplinkos projektinių sprendinių klausimais prieš pradedant statybos darbus, o, įgyvendinus siūlomus rezultatus, galima labai pagerinti tradicinius statybos metodus.

Ginamieji teiginiai

Toliau pateikiami teiginiai, pagrįsti dabartinės disertacijos rezultatais, gali būti oficialios gintinos hipotezės:

1. Darnus vystymasis turėtų būti suprantamas kaip aplinkosaugos, socialinių ir ekonominių rodiklių integravimas ir kaip holistinės saugios, sveikos ir ekologiškos užstatytos aplinkos kūrimas.

2. Sukurta ekologiškų ir energiškai efektyvių pastatų daugiakriterio vertinimo sprendinių sistema ir rekomendacijos leidžia nustatyti pastatų sveikumo klasę ir įvertinti būsto rizikas.

3. Sukurta rekomendacijų sistema yra efektyvi rizikos valdymo priemonė, leidžianti namų savininkams, gyventojams ir kitiems suinteresuotiesiems asmenims įvertinti kylančias grėsmes ir sumažinti jų tikimybę.

4. Sukurtas darnaus užstatytos aplinkos atnaujinimo metodas ir sistema įgalina suinteresuotuosius asmenis tiksliau, greičiau ir efektyviau spręsti kylančias būsto problemas.

Darbo rezultatų aprobavimas

Svarbiausi mokslinio tyrimo rezultatai buvo paskelbti keturiose mokslinėse publikacijose:

- Kaklauskas, A., Zavadskas, E. K., Bardauskiene, D., Cerkauskas, J., Ubarte, I., Seniut, M., ..., & Velykorusova, A. (2019). An affect-based built environment video analytics. *Automation in Construction*, *106*, 102888.
- Kaklauskas, A., Ubarte, I., Kalibatas, D., Lill, I., Velykorusova, A., Volginas, P., ..., & Naumcik, A. (2019). A multisensory, green, and energy efficient housing neuromarketing method. *Energies*, *12*(20), 3836.
- Kaklauskas, A., Velykorusova A., & Skirmantas D. (2019). Development of the video neuroadvertising method and recommender system. In *The 17th Colloquium „Sustainable decisions in the built environment" and Meeting of EURO working group "OR in sustainable development and civil engineering"*. Technika. 10.20334/2019-013-M
- Velykorusova A., Zavadskas E.K., Tupenaite L., ..., & Kaklauskas A. (2023). Intelligent multi-criteria decision support for renovation solutions for a building based on emotion recognition by applying the COPRAS method and BIM integration. *Appl. Sci*., *13*, 5453. https://doi.org/10.3390/app13095453

Rengiant disertaciją atlikto tyrimo rezultatai buvo pristatyti tarptautinėse mugėse ir mokslinėse konferencijose Lietuvoje ir užsienyje:

- Europos kultūros paveldo novatorių mugė, 2018 m. lapkričio 15–16 d., Briuselis, Belgija. Pristatymas: Kaklauskas A., Velykorusova A., Čerkauskas, J. ir Binkytė-Vėlienė A. ROCK videonauroanalitika ir išmani apšvietimo sistema.
- 17-asis kolokviumas „Darnūs sprendimai užstatytoje aplinkoje" ir EURO darbo grupės „ARBA darnioje plėtroje ir civilinėje inžinerijoje" posėdis, 2019 m. gegužės 15 d., Vilnius, Lietuva. Pristatymas: Kaklauskas A., Velykorusova A. ir Skirmantas D. (2019). Vaizdo neuroreklamos metodo ir rekomendacijų sistemos kūrimas.

– 13-oji tarptautinė konferencija „Šiuolaikinės statybinės medžiagos, konstrukcijos ir technologijos“, 2019 m. gegužės 16–17 d., Vilnius, Lietuva. Stendas: Kaklauskas A., Velykorusova A. ir Skirmantas D. Videoneuroreklamos metodo ir rekomendacijų sistemos kūrimas.

– 9-asis konsorciumo susitikimas ir 3-iosios tarptautinės dirbtuvės spalio 17–21 dienomis, 2022 m. Taline, Estijoje. Pristatymas: Velykorusova A. Tvarios renovacijos išmanus daugiakriteris sprendimų priėmimas, pagrįstas emocijų atpažinimu.

– 26-oji Lietuvos jaunųjų mokslininkų konferencija „Mokslas – Lietuvos ateitis“ Statyba. Sekcija „Statybos valdymas ir nekilnojamasis turtas“, 2023 m. balandžio 13 d., Vilnius, Lietuva. Pristatymas: Velykorusova A. Intelektinė sprendimų paramos sistema, skirta tvariai užstatytos aplinkos renovacijai.

Disertacijoje atlikto tyrimo rezultatai buvo įgyvendinti keliuose projektuose:

– „Horizon 2020“. Kultūrinio paveldo regeneravimas ir optimizavimas kūrybiniuose ir žinių miestuose (ROCK), 2017–2021.

– „Horizon 2020“. Pastato informacinio modelio pagrindu sukurtos priemonės ir technologijos greitam ir efektyviam gyvenamųjų pastatų renovavimui (BIM4REN), 2018–2022.

– „Erasmus+“ programa. Koronaviruso poveikio sumažinimas užstatytoje aplinkoje (MICROBE), 2020–2023.

– „Erasmus+“ programa. Integruotas vartotojų elgsena pagrįstas švietimas energinio efektyvumo ir klimato kaitos srityse Rusijos, Šri Lankos ir Bangladešo universitetuose (BECK), 2020–2023.

Disertacijos struktūra

Disertaciją sudaro įvadas, trys skyriai, bendrosios išvados, literatūros sąrašas ir autorės mokslinių publikacijų disertacijos tema sąrašas. Taip pat yra trys priedai.

Darbo apimtis – 132 puslapiai, neįskaitant priedų, 9 sunumeruotos formulės, 30 paveikslų ir 33 lentelės, pateiktos tekste, rašant disertaciją remtasi 111 literatūros šaltinių.

1. Mokslinių tyrimų disertacijos tema apžvalga

Pirmajame skyriuje atlikta literatūros analizė tvarios užstatytos aplinkos tema, apimanti 2015–2021 metų laikotarpį, analizuojami tvarumo sertifikavimo sistemų metodai (pvz., BREEAM, LEED) ir jų mokslinis aspektas, atsižvelgiant į tvarumo vertinimą ir platų naudojimą statybos pramonėje, pabrėžiama būsto svarbą sveikatai ir saugumui, pateikiami esami tvarumo vertinimo metodai, siekiant atlikti holistinį vertinimą pagal tvarios renovacijos rekomendacijas. Šiame skyriuje analizuojama mokslinė literatūra apie pasaulyje taikomus tvarios užstatytos aplinkos renovavimo metodus. Taip pat nagrinėjamos mokslininkų sukurtos pasaulinės intelektinės sprendimų paramos sistemos (rekomendacinės, patariamosios, ekspertinės, duomenų gavyba, duomenų analizės integravimas, dirbtiniai neuroniniai tinklai, aplinkos intelektas, biometrika, daiktų internetas ir jo integravimas į sprendimų paramos sistemas).

Remiantis pirmajame skyriuje atlikta analize, galima daryti išvadas, jog:

1. Didėjant susidomėjimui tvarios užstatytos aplinkos renovavimo metodais ir intelektinių sprendimų paramos sistemų pritaikymo galimybėmis, integruojant neuroninius tinklus, žiniomis pagrįstas sistemas bei neraiškiąsias sistemas, sukurta integruota sprendimų paramos sistema, skirta miesto urbanizacijai ir sprendimų priėmimui. Integruojant žiniomis pagrįstas sistemas, neraiškiąsias sistemas ir dirbtinius neuroninius tinklus, integruota sistema padeda tiksliau atlikti skaičiavimus sprendimui priimti ir didina integruotų sistemų taikymo mastą.

2. Pasiūlytas modelis, kuriam reikalinga sprendimų paramos sistemos ir daugiakriterės analizės integracija. Remiantis sukurta automatizuota sistema, galima įvertinti pastatų renovacijos efektyvumo lygį, esamą nekilnojamojo turto rinkos situaciją ir padaryti išvadas apie būsto sektoriaus pokyčius ateityje.

3. Sprendimų neuromatrica, fiziologiniai ir emociniai žemėlapiai gali būti naudojami siekiant nustatyti viešosios erdvės vertę. Atsižvelgiant į pastebėtus trūkumus atlikus literatūros analizę, siūlomas užstatytos aplinkos poveikio žmonių emocijoms vertinimas. Detalesnė emocijų ir pažinimo ryšio analizė sukuria naują perspektyvą miesto visuomenės emocijų tyrimams.

2. Metodo ir išmaniosios sprendimų priėmimo sistemos tvariai užstatytai aplinkos renovacijai sukūrimas

Pasaulyje atliekama daug tyrimų naujų strategijų, įrankių kūrimo ir taikymo srityje, norint įvertinti pastatų stabilumą ir būklę. Atliekant literatūros analizę aptariami metodai, priežastys ir poreikis kurti šiuos mechanizmus ir įrankius. Tačiau nėra sukurta analitinio-rekomendacinio metodo, padedančio integruotai analizuoti tvarią užstatytą aplinką, užstatytos aplinkos gyvavimo ciklą bei veiksnius, tokius kaip tarša, ekonominė aplinka, fiziologiniai minios rodikliai (amžius, lytis), emocinė (laimė, liūdesys, nuostaba ir kt.) ir fiziologinė (pulso dažnio pokyčiai) būsena.

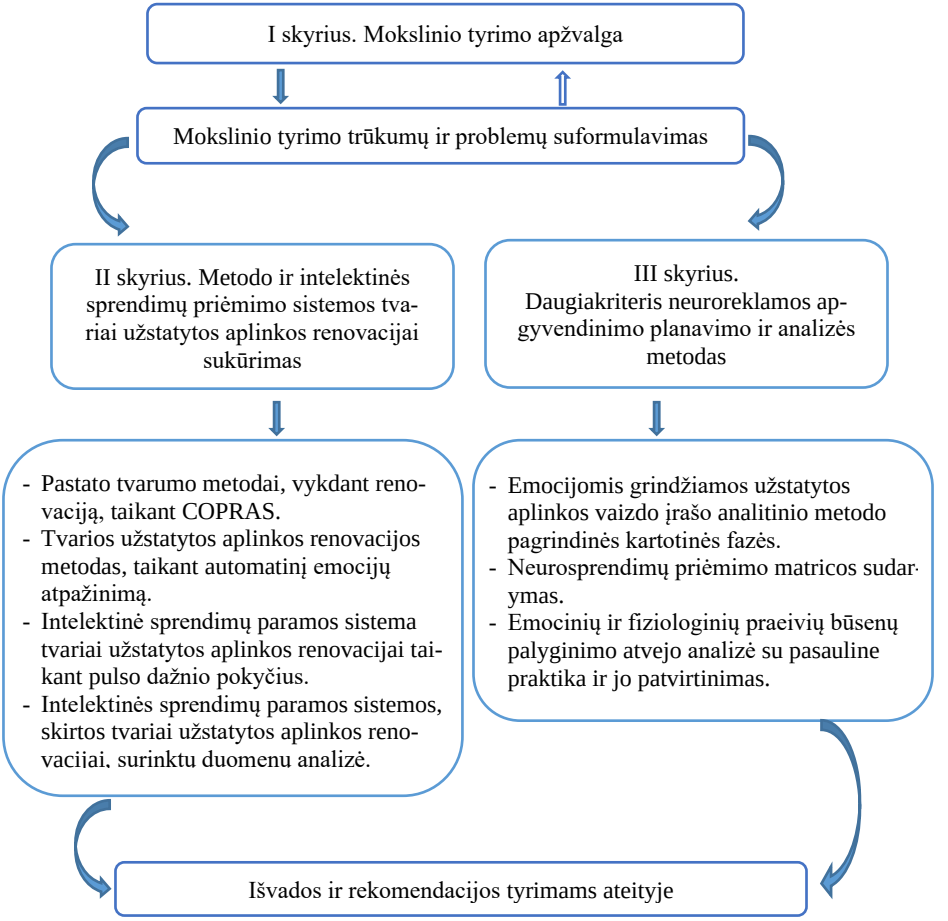
Remiantis literatūros analize ir nustatytais trūkumai, siūlomas urbanizuotos užstatytos aplinkos poveikio žmonių emocijoms mechanizmas. Loginė schema, taikomi metodai ir disertacijos dalių tarpusavio ryšys pateikiamas mokslinio tyrimo schemoje (S.2.1 pav.).

Sukurtas pastato renovavimo daugiavariančio projektavimo ir daugiakriterės analizės metodas išsiskiria tuo, jog padeda nustatyti būsto efektyvumo lygį ir pateikia rekomendacijas suinteresuotosioms šalims racionaliam būsto valdymui, kuris yra renovuojamas arba kurio statybos plano ankstyvasis etapas yra pradėtas.

Rengiant disertaciją pasiūlytas praktinis daugiavariančio projektavimo ir daugiakriterės analizės metodo įgyvendinimas emociniam ir racionaliam rinkos segmentui nustatyti pagal demografinius, fiziografinius ir vartotojų elgesio kriterijus. Alternatyvų pastato sprendimų tvarumo vertinimas buvo atliktas taikant daugiakriterius metodus ir sprendimų priėmimo modelį, pagrįstą COPRAS metodologijos taikymu (Kaklauskas et al., 2006). Sprendimų modelis įgyvendinamas šiais etapais:

1. Remiantis literatūros analize, sudaryta struktūrinių sprendimų kriterijų sistema.

2. Sukurtas kompleksinis kriterijų reikšmių alternatyvoms nustatymo modelis (atsižvelgiant į kiekybines ir kokybines charakteristikas).



S2.1 pav. Daktaro disertacijos mokslinio tyrimo planas (parengė autorius)

3. Apskaičiuotos alternatyvių statybos sprendimų rodiklių vertės, atlikta alternatyvių renovacijos technologijų analizė, nustatyti ekonominiai rodikliai (sąnaudos) įgyvendinant alternatyvius statybos sprendimus ir kt.

4. Taikant COPRAS metodą, alternatyvų sprendimai buvo lyginami tarpusavyje atsižvelgiant į pastatų stabilumą. Šiame etape yra gaunami analizės rezultatai.

Siekiant veiksmingai įgyvendinti pastato renovaciją, būtina atlikti visų ją sudarančių etapų analizę: atlikti kokybinio pokalbio analizę (aiškiau ir giliau suprasti tvarumo kriterijų įtraukimą į pastato renovacijos procesą) ir nustatyti pirmines kiekybinių kriterijų įtakos vertes. Taip pat nagrinėjamos alternatyvos, kiekybinės ir kokybinės charakteristikos yra sugrupuojamos tam tikra tvarka, t. y. parengiama daugiakriterė analizė. Norint pasirinkti efektyviausią alternatyvą, būtina atlikti daugiakriterę alternatyvų analizę sukūrus sprendimų priėmimo matricą. Daugiakriterė analizė atlikta taikant COPRAS metodą, lyginant alternatyvius renovaciją sprendinius remiantis tvarumo kriterijais.

Kitame etape buvo taikomas užstatytos aplinkos renovacijos metodas, taikant automatinį emocijų atpažinimą. Parengta neurosprendimų priėmimo matrica su pradiniais duomenimis koreliacijos analizei atlikti, atsižvelgiant į emocinę bei fiziologinę suinteresuotų grupių būseną pagal lytį ir amžių. Šiame etape buvo atlikta taršos, fiziologinių minios rodiklių pagal amžiaus ir lyčių grupes, emocinės (laimės, liūdesio, pykčio ir kt.) ir fiziologinės (pulso dažnio kintamumo) dalyvių būsenos analizė, kuri buvo vykdoma nuo 2020 m. rugsėjo iki 2021 m. rugsėjo mėn. Tyrimui atlikti buvo taikomi biometriniai metodai, naudojama „FaceReaderTM“ – automatinė veido išraiškos atpažinimo programinė įranga ir dėvimieji įrenginiai.

Atsižvelgiant į antrajame skyriuje pasiūlytus metodus ir modelius bei atlikta analize, galima teigti:

1. Eksperimentinė analizė padės pagrįsti naujų strategijų ir įrankių apibrėžtį bei poreikį užstatytos aplinkos renovacijos procese.

2. Įvertinta eksperimentinių metodų galimybė ir praktinis kiekybinių subjektyvių pojūčių rodiklių suderinimas su inžineriniais tikslais architektūrinėse koncepcijose ir technologiniuose statybos sričių sprendimuose. Šiai problemai spręsti siūloma naudoti siūlomą analitinį-rekomendacinį metodą, kuriuo remiantis sukurta automatizuota sistema.

3. Sukurtasis daugiavariantis projektavimo ir daugiakriterės pastatų renovacijos analizės metodas išsiskiria tuo, jog padeda nustatyti būsto efektyvumo lygį ir pateikti rekomendacijas suinteresuotosioms šalims racionaliam būsto valdymui, kuris yra renovuojamas arba kurio statybos plano ankstyvasis etapas yra pradėtas.

4. Šiame skyriuje atlikta emocijų įtakos sprendimų priėmimo procesui analizė įgyvendinant renovacijos etapus, analizuojant visą užstatytos aplinkos gyvavimo ciklą. Lyginant sprendimo priėmimą su integruotais emocijų matavimas ir be jų, skirtumas matomas toks, kad emocijos netiesiogiai didina kiekvienos alternatyvos vertę. Pavyzdžiui, lango alternatyvų sprendimų matrica rodo, kad pagal tradicinę analizę pirmosios alternatyvos naudingumo laipsnis sudaro 92,50 %, o pagal integruotų emocinių būsenų analizę – 94,17 %. Todėl kitame skyriuje bus pateikta emocinė minios būsenos analizė, susijusi su žaliaisiais ir energiškai naudingais pastatais.

5. Siekiant didesnio skaidrumo ir patikimumo priimant sprendimus tam tikrose situacijose integruoti tvarumo principai, daugiakriteriai metodai (COPRAS) ir automatiniai duomenų apdorojimo įrankiai (emociniai ir statistiniai, naudojantis „Python“ scenarijų).

3. Daugiakriteris neuroreklamos apgyvendinimo planavimo ir analizės metodas

Remiantis pirmajame skyriuje atlikta literatūros analize ir antrajame skyriuje atliktais moksliniais tyrimais, nustatyta, jog žalieji produktai, energiškai efektyvūs ir žalieji pastatai bei aplinkos inovacijos yra labai populiarios bei plačiai naudojamos visame pasaulyje. Šiame skyriuje nagrinėjama ir vertinama minios segmentaciją pagal lytį ir amžių, taip pat emocinė (laimė, liūdesys, nuostaba ir kt.) bei fiziologinė (pulso dažnis) galimų pirkėjų būklė. Vertinant šiuos duomenis, sudaromos sąlygos išsamiau įvertinti pirkėjų poreikius ir pasiūlyti pirkėjams palankias aplinkai ir energiškai naudingas statybos alternatyvas.

Norint pasiekti šį tikslą, buvo sukurtas daugiakriteris neurorinkodaros ir vaizdo įrašų reklamos analizės metodas. Atvejo analizės metu buvo išanalizuota daugiau kaip 200 milijonų pojūčių duomenų, susijusių su fiziologinėmis ir emocinėmis būsenomis, ir oro taršos rodiklių (CO, NO2, PM10, PM2.5). Metodo pritaikomumui įrodyti pateikiami konkretūs aplinkai draugiškų ir energiškai naudingų pastatų pavyzdžiai. Atvejo analizės rezultatai patvirtinami ankstesnių ir dabartinių mokslinių tyrimų rezultatais, kuriais teigiama, kad ryšys tarp atsako į aplinką ir žmogaus amžiaus išreiškiamas atvirkštine U forma (Ingraham, 2019; Blanchflower, 2021 ir t. t.), o domėjimasis energiniu naudingumu ir žaliuoju būstu priklauso nuo lyties ir amžiaus (Stone, 2018; Graham & Pozuelo, 2017).

Tyrimui atlikti ir duomenimis gauti buvo sudarytas įrangos posistemis, kuris apėmė „FaceReader“ programinę įrangą, „Noldus Information Technology“ ir „XeThru“ technologijas. Šio mokslinio tyrimo metu keturiose Vilniaus vietose buvo analizuojami praeiviai, nustatant jų emocijas ir biometrinius duomenis, valentingumą bei susijaudinimo lygį.

Tuo siekta vykdyti žaliųjų ir energiškai naudingų pastatų pardavimo reklamos kampanija, skirta laimingiausių praeivių grupei. S3.1 lentelėje pateikti emociniai praeivių matavimų duomenys keturiose Vilniaus miesto vietose.

Buvo atlikta daugiakriterė analizė pasirinktose keturiose Vilniaus miesto vietose taikant INVAR metodą, nustatant rinkos segmentus pagal geografinius kriterijus (triukšmą ir oro taršą keturiose Vilniaus sankryžose), demografinius kriterijus (lyčių ir amžiaus grupių) ir emocinius praeivių būseną.

Sudaryta sprendimų priėmimo neuromatrica pagal gautus fiziologinius, emocinės būsenos ir oro taršos duomenis. Trečiajame skyriuje išanalizuoti būsto alternatyvų kriterijai keturiose Vilniaus miesto vietose, kuriose yra didžiausias nuomos ir butų pardavimo poreikis bei didžiausias gyventojų tankumas.

S3.1 lentelė. Žmonių emocijų matavimas keturiuose miestuose

		2 – Pilies 19 122 (100 %)		3 – Gedimino pr. 31 841 (100 %)		11 – Lukiškės 15 797 (100 %)		13 – Mindaugo 38 041 (100 %)	
		Vyrai Iš viso: 8005 (41,86 %)	Moterys Iš viso: 11 117 (58,14 %)	Vyrai Iš viso: 14 312 (44,95 %)	Moterys Iš viso: 17 529 (55,05 %)	Vyrai Iš viso: 7060 (44,69 %)	Moterys Iš viso: 8737 (55,31 %)	Vyrai Iš viso: 15 638 (41,11 %)	Moterys Iš viso: 22 403 (58,89 %)
Amžius, metais	20–30	2240 (11,71 %)	2786 (14,57 %)	3758 (11,80 %)	4384 (13,77 %)	2134 (13,51 %)	2501 (15,83 %)	4083 (10,73 %)	4667 (12,27 %)
	31–40	1498 (7,83 %)	1627 (8,51 %)	3726 (11,70 %)	3995 (12,55 %)	1483 (9,39 %)	1412 (8,94 %)	3059 (8,04 %)	3481 (9,15 %)
	41–50	2693 (14,08 %)	3535 (18,49 %)	4752 (14,92 %)	5873 (18,44 %)	2312 (14,63 %)	2669 (16,90 %)	4579 (12,04 %)	6126 (16,10 %)
	51–60	1574 (8,24 %)	3169 (16,57 %)	2076 (6,53 %)	3277 (10,29 %)	1131 (7,16 %)	2155 (13,64 %)	3917 (10,30 %)	8129 (21,37 %)

Atlikus daugiakriterį vertinimą ir palyginus gautus rezultatus su kitų mokslininkų tyrimais, galima daryti šias išvadas:

1. Disertacijoje siūlomas metodas leidžia integruoti emocinius ir fiziologinius vartotojų parametrus, sudarant sprendimų priėmimo neuromatricą.
2. Apdoroti išsamūs duomenys, gauti atlikus praeivių emocinius matavimus Vilniaus mieste (Lietuvoje), atliktos emocinio požiūrio, fiziologinės ir emocinės būsenos analizės.
3. Atliekant šį tyrimą pateiktieji duomenys buvo taikomi naudojantis neurosprendimų lentelėmis daugiakriterei neurorinkodaros analizei ir vaizdo įrašų reklamai, skirtai įvairiems vartotojų segmentams statybų pramonėje. Taikant sukurtą metodą, galima generuoti milijonus alternatyvių reklamos variantų ir įvertinti juos lyginant pagal kriterijų sistemą ir reikšmingumą, siekiant parinkti racionalią neurorinkodaros alternatyvą. Tai pagrindiniai skirtumai tarp ankstesnių kitų mokslininkų išvadų ir naudojamų neurorinkodaros metodų.
4. Taikant pasiūlytą metodą ir neurosprendimų lenteles buvo nustatyta, kad jomis remdamasi organizacija gali atlikti neurorinkodaros srities naudos ir sąnaudų analizę, taip pat identifikuoti racionaliausius vartotojų segmentus, atlikti analizę pagal kelis kriterijus.
5. Atliktas tyrimas patvirtino, kad gyvenamojo būsto neurorinkodarai reikalingas visapusis požiūris, norint atsižvelgti į racionaliausius vartotojų segmentus, pageidaujamas buto ypatybes, individualius skirtumus, aplinkos poveikį nuosavybei, fiziologinei ir emocinei būsenai.
6. Reikėtų atlikti daugiau mokslinių tyrimų sprendimų priėmimo neuromatricos taikymo tema ir parengti platesnio masto metodą, atliekant žemės ūkio organizacijų, pramoninės, verslo valdymo, paslaugų, prekių ženklo kūrimo, architektūros ir darbo aplinkos, politikos ir socialinės aplinkos neurorinkodarą.

Bendrosios išvados

Šiuo tyrimu siekiama sukurti intelektinę sprendimų paramos sistemą, skirtą tvariam užstatytos aplinkos atnaujinimui, taikant pasiūlytą struktūrą ir metodus duomenų rinkimui, matavimams ir analizei atlikti atsižvelgiant į fiziologines ir emocines būkles. Toliau pateikiamos išvados.

1. Atlikus analitinę naujausių mokslinių tyrimų apžvalgą, pastebėta, kad nėra sukurto integruoto analitinio-rekomendacinio tvarios užstatytos aplinkos atnaujinimo metodo, kuris kompleksiškai išanalizuotų visus jos gyvavimo ciklus. Taip pat įvairiose strategijose, susijusiose su tvaria statybų renovacija, buvo nustatyta daug trūkumų ir apribojimų autorių taikomoje metodikoje ir taikomuose metoduose. Pateiktas tyrimas galėtų pagrįsti savo indėlį, siekiant įveikti ankstesnių mokslininkų nustatytus apribojimus, pasiūlydamas urbanistinės aplinkos įtakos žmonių emocijoms sistemą.
2. Antrajame skyriuje pateikta sukurta daugiakriterė pastato rekonstrukcijos analizė, pagrįsta COPRAS metodu ir „FaceReader“ programine įranga, skirta automatiniam emocijų atpažinimui su specialiais prietaisais širdies ritmo kintamumui matuoti. Taip pat atlikta išsami emocinių ir racionalių rinkos segmentų analizė pagal demografinius, psichografinius ir vartotojų elgsenos kriterijus. Sukurtas pastato rekonstrukcijos daugiavariantis projektavimo ir daugiakriterės analizės metodas buvo pritaikytas realiame statybos projekte Kijeve, Ukrainoje. Svarbus siūlomo ir analizuotų metodų skirtumas – galimybė

gyventojams netiesiogiai dalyvauti užstatytos aplinkos valdymo ir priežiūros veikloje. Pateiktas tyrimas parodė emocijų įtaką sprendimų priėmimo procesui renovuojant pastatą, emocijos didina kiekvienos alternatyvos vertę.

3. Naudojant „FaceReader“ ir nešiojamuosius prietaisus, buvo surinkta 226 810 tinkamų duomenų, kurie naudoti palyginti subjektyvius ir objektyvius fiziologinių ir emocinių būsenų užstatytoje aplinkoje matavimus. Naudotos priemonės, siekiant palyginti šešių pagrindinių dalyvių emocijų įtaką rekonstrukcijos projekto alternatyvoms. Eksperimento metu nepastebėta, kad laimingumas pasikeitė, pavyzdžiui, dalyviai jaučiasi laimingesni dėl triukšmo taršos parametro (0,8999; 0,9173; 0,9259 ir kt.), palyginti su kaina (0,048; 0,0568; 0,0623 ir kt.). Tačiau nuostabos emocija yra žymiai didesnė matant objekto kainą (0,2589; 0,2565; 0,2538 ir t.t.), palyginti su maksimaliu stiklo paketo storiu (0,0018; 0,0019; 0,002 ir t.t.), atsižvelgiant į pateiktus palyginimus 2.2.1 skyrelyje. Siūlomas metodas leidžia parengti rekomendacijas gyvenimo kokybės rodikliams gerinti. Pateikto modelio praktinis įgyvendinimas leidžia išvengti neracionalių ir subjektyvių sprendimų dėl pastatų rekonstrukcijos, padeda identifikuoti efektyvesnius ir mažiau investicijų reikalaujančius rekonstrukcijos variantus. Tikslesniam ir platesniam siūlomo modelio praktiniam pritaikymui buvo sukurtas automatizavimo procesas intelektinėje duomenų bazėje (naudojant *Python* kalbą).

4. Sukurta automatizuota sistema leidžia įvertinti pastato rekonstrukcijos efektyvumo lygį, pagal praeities duomenis įvertinti esamą situaciją nekilnojamojo turto sektoriuje, daryti išvadas apie pokyčius būsto sektoriuje. Sprendimų neuromatrica, taip pat fiziologiniai ir emociniai žemėlapiai gali būti naudojami kaip įvestis viešosios erdvės vertei nustatyti. Darnaus vystymosi DSS kriterijų vertinimo sistemoje pateikiamas laipsniškas įvertinimas. Pagal šiame tyrime parengtus kriterijus jie skirstomi į kiekybinius ir kokybinius. Verčių žemėlapio kiekybinius rodiklius atitinkantys aspektai dažniausiai yra kiekybiškai įvertinami, pavyzdžiui, darbo trukmė, sąnaudos ar naudojimo trukmė, kuriuos galima išmatuoti objektyviai. Kokybiniai aspektai reiškia, kad juos reikia įvertinti kokybiškai. Tam, kad rekonstrukcijos projektai atitiktų darnaus vystymosi reikalavimus, svarbu atsižvelgti į subjektyvias ir objektyvias vertes atitinkančių kokybinių ir kiekybinių veiksnių sąveiką bei tarpusavio priklausomybę projekto gyvavimo ciklo metu.

5. Trečiajame skyriuje atliktas tyrimas buvo skirtas sukurti afektinę užstatytos aplinkos videoanalitiką (BEST), siekiant analizuoti ir rinkti įvairių tipų duomenis: fiziologines ir emocines būsenas, afektines nuostatas, oro sąlygas, taršą ir kt. Didieji duomenys buvo apdoroti realių pastatų konstrukcijų Vilniuje, Lietuvoje, pavyzdžiu. Inovatyvumas yra tas, jog turimi duomenų tipai yra tarpusavyje sujungti užstatytoje aplinkoje ir gali būti pritaikomi naudojant nekontaktinį metodą su bekontakčiais biometriniais duomenimis. Šie užstatytos aplinkos duomenys gali būti naudojami atliekant daugiakriterę urbanistinės aplinkos analizę ir rengiant rekomendacijas suinteresuotoms šalims naudojant neurosprendimų lenteles. Suinteresuotosios šalys (architektai, miestų planuotojai, žemės savininkai, aplinkosaugininkai ir kt.) gali taikyti šį duomenų rinkinį, siekdami priimtų efektyvius sprendimus, pagrįstus į gyventojus orientuotu ir tvariu aplinkosaugos požiūriu.

6. Kitas svarbus šio tyrimo žingsnis – objektyvių ir subjektyvių psichologinio poveikio ir emocijų rodiklių palyginimas antropogeninėje aplinkoje. Ankstesni mokslininkai, tyrę ir išanalizavę duomenis apie emocinę išraišką, žmonių fiziologinę ir emocinę būseną užstatytoje aplinkoje, atsižvelgė tik į nedidelę duomenų imtį, o šioje disertacijoje

pateiktame tyrime yra didelis afektinių nuostatų duomenų rinkinys. Taip pat galima teigti, kad siūlomas metodas padidina šią tyrimų kryptį, palyginti su kitų mokslininkų tyrimais. Daug didesnį rodiklių skaičių galima kompleksiškai išanalizuoti atliekant biometrinius tyrimus taikant nuotolinio sekimo, bekontaktės biometrijos ir BEST metodus.

Tyrimas patvirtino, kad būsto neurorinkodara reikalauja integruoto požiūrio, atsižvelgiant į racionaliausius vartotojų segmentus, pageidaujamas buto savybes, individualius skirtumus, aplinkos įtaką turtui, emocinę ir fiziologinę būseną. Tai galima pasiekti naudojant neuroninių sprendimų lenteles, pirmiau pateikti duomenys gali būti diegiami neuromarketinge, siekiant nustatyti racionaliausius ir logiškiausius vartotojų segmentus bei atlikti daugiakriterę sveiko ir saugaus būsto analizę. Šios išvados gali būti naudingos vartotojams, norintiems taikyti žmogaus emocijų vertinimą ir analizę, kai reikia pasirinkti tinkamą metodą savo tikslams pasiekti arba ieškant alternatyvių sprendimų. Siūloma metodika gali būti taikoma dviejuose pagrindiniuose kontekstuose (komercinėje ir mokslinėje) statybos ir architektūros srityse. Tai galėtų patobulinti žinias apie emocinį poveikį, kurį gali turėti skirtingi projekto parametrai, ir taip prisidėti prie geriausios praktikos ir susijusių norminių aktų tikslinimo. Yra kelios suinteresuotųjų šalių grupės, nagrinėjančios projekto gyvavimo ciklo etapus: klientai, projektuotojai, rangovai, medžiagų ir produktų gamintojai bei tiekėjai, vartotojai, vadovai, vietos valdžios institucijos ir kt. Kartu šis metodas gali padėti inžinieriams ir architektams priimti sprendimus urbanistinės aplinkos projektavimo klausimais prieš pradedant statybos darbus. Siūlomų išvadų įgyvendinimas, palyginti su tradicinėmis statybos technologijomis, suteikia daug naudos, pavyzdžiui, greitas statybos ar renovacijos procesas, mažesnis statybinių atliekų kiekis, geresnė kokybės kontrolė ir didesnis tvarumas.

Annexes

Annex A. The qualitative interviews (with provided questionnaires)
Annex B. The technical task of the research building under construction
Annex C. Automation process in Intelligent data-base and model base management system

Annex A. The qualitative interviews (with provided questionnaires)

ТОВ "ІНЖЕНЕРНІ СИСТЕМИ ПЛЮС"

Reconstruction of a non-residential building at 31-A Nyzhniy Val Street in the Podilskyi district of Kyiv

Reconstruction project of a non-residential building for a residential building with built-in public premises at 31-A Nyzhniy Val Street in the Podilskyi district of Kyiv

Questionnaire

A survey was conducted among participants (21 in total) to make design decisions, determine the scope of major construction and installation work, equipment needs, material and labour resources, as well as to determine the basic estimated cost of construction and selection of materials.

1. Water supply system
2. Ventilation (air conditioners)
3. Windows
4. Heating systems
5. Roof tiles

The provided documentation developed by the designers was used in preparing the explanatory note and other sections of the project, which are submitted for examination and approval and are part of the materials submitted to the stakeholders.

Зм.	Кіл.	Арк	№док	Підпис	Дата
Н. контр.		Кагаловський			10.19
Перевір.		Ільченко			10.19
Розроб.		Тунікова			10.19

Questionnaire

A survey was conducted among participants (21 in total) to make design decisions, determine the scope of major construction and installation work, equipment needs, material and labour resources, as well as to determine the basic estimated cost of construction and selection of materials.

1. *Water supply system*
    - 1.1. Price (*Eur/m^2)*
    - 1.2. Payback period (*Years)*
    - 1.3. Guarantee period (*Years)*
    - 1.4. Durability (*Years)*
    - 1.5. Duration of works (*Days)*
    - 1.6. Water pressure (*PSI)*
    - 1.7. Number of pumping stations
    - 1.8. Number of conduction lines (*W/m^2K)*
    - 1.9. Water resources withdrawn (%*)*
    - 1.10. Estimated Network Maximum Pressure (*PSI)*
    - 1.11. Total Treatment Capacity (*m^3/s)*
    - 1.12. New Treatment Capacity per PWTP (*m^3/s)*
    - 1.13. System reliability (*Cycles)*

2. *Heating system*
    - 2.1. Price (*Eur/m^2)*
    - 2.2. Payback period (*Years)*
    - 2.3. Guarantee period (*Years)*
    - 2.4. Durability (*Years)*
    - 2.5. Duration of works (*Days)*
    - 2.6. Lower connection (*mm)*
    - 2.7. Boiler efficiency (*%)*
    - 2.8. Calorific value of gas (*kW*h/m^3)*
    - 2.9. The average amount of gas per year (*m^3)*
    - 2.10. Approximate heat loss of the house (*kW)*
    - 2.11. Pressure regulator (diameter)
    - 2.12. Boiler pressure (*bar)*
    - 2.13. Max capacity (*1/h)*
    - 2.14. Reliability (*Cycles)*

3. *Ventilation*
    - 3.1. Price (*Eur)*
    - 3.2. Payback period (*Years)*
    - 3.3. Guarantee period (*Years)*
    - 3.4. Durability (*Years)*
    - 3.5. Duration of works (*Days)*
    - 3.6. Heat consumption for ventilation (*W)*

3.7. Relability (*Cycles)*
3.8. Specific power (actual) (*W/m^2)*
3.9. Power consumption (from) (*W/m^2)*
3.10. Minimum total air consumption (*m^3/h)*
3.11. Level of noise (*dB)*
3.12. Max pressure (*Pa)*

4. Windows

4.1. Price (*Eur)*
4.2. Payback period (*Years)*
4.3. Guarantee period (*Years)*
4.4. Durability (*Years)*
4.5. Duration of works (*Days)*
4.6. Maximum glass unit thickness (*mm)*
4.7. Numbers of the glazed pane
4.8. Thermal transmission coefficient of glazing unit (*W/m^{2}K)*
4.9. Energy saving glass (*mm)*
4.10. Air leakage, when pressure difference Dp = 50 Pa (*m^3/m^2/h)*
4.11. Parameter of noise pollution (*dB)*
4.12. Condensation resistant (*%RH)*
4.13. Waterproofness (*Pa)*
4.14. Light transmission of double-glazing unit (*%)*
4.15. Reliability (*Cycles)*

5. Roof

5.1. Price (*Eur/m^2)*
5.2. Payback period (*Years)*
5.3. Guarantee period (*Years)*
5.4. Durability (*Years)*
5.5. Duration of works (*Days)*
5.6. The simplicity of the construction process
5.7. Tile width (*mm)*
5.8. Tile height (*mm)*
5.9. Suitable raking spacing (*mm)*
5.10. Minimum roof pitch (°)
5.11. Sheet thickness (*mm)*
5.12. Zinc content (*g/m^2)*
5.13. Reliability (*Cycles)*

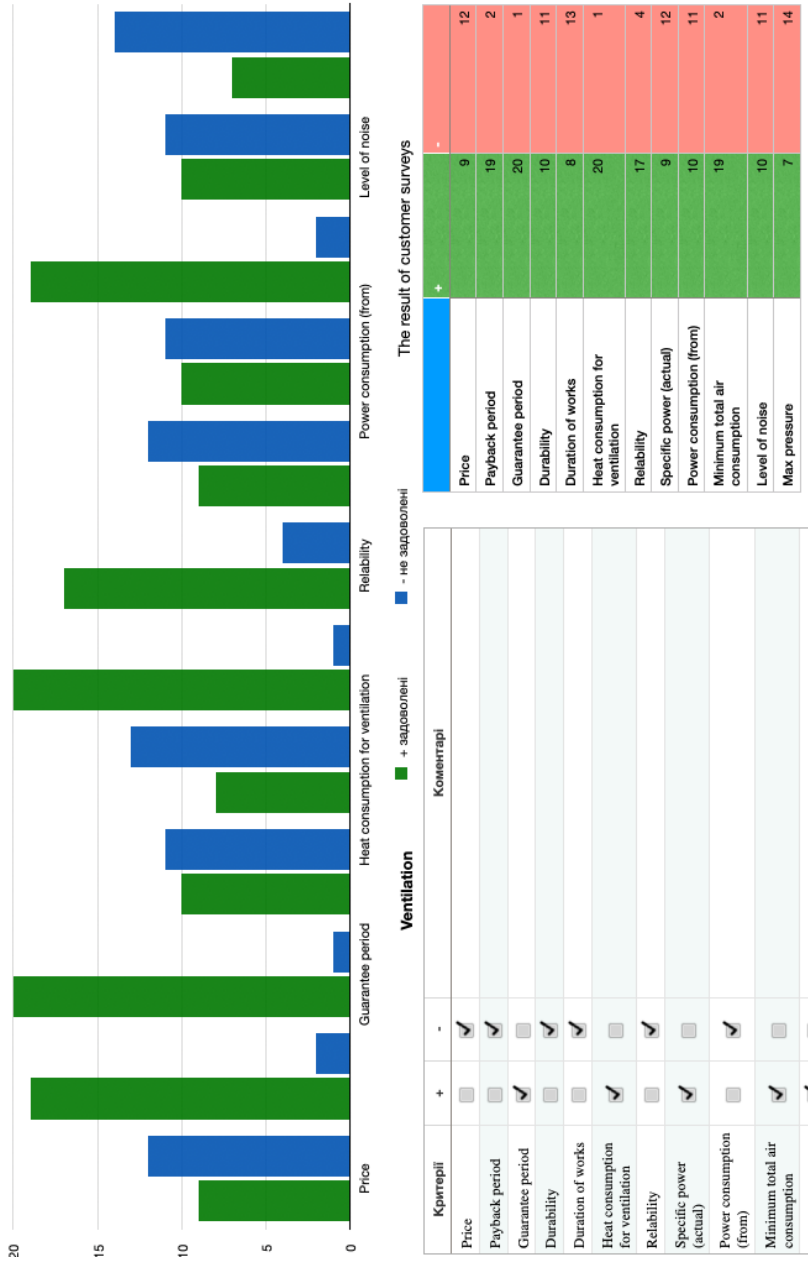


Fig. A1. Example of survey of ventilation

Annex B. The technical task of the research building under construction

ТОВ «ВАРДА СПЕЦБУД МОНТАЖ»

Україна, м. Київ, вул. М.Житомирська, 9-Б

Замовник: Комунальне підприємство з утримання та експлуатації житлового фонду спеціалізованого призначення «Спецжитлофонд»
04071 м. Київ, вул. Оболонська, 34

Реконструкція нежитлової будівлі під житловий будинок з вбудованими приміщеннями громадського призначення на вул. Нижній Вал, 31-А у Подільському районі м. Києва

ПРОЕКТ

ТОМ 1
Вихідні дані
Загальна пояснювальна записка
16-01-ЗПЗ
Генеральний план
16-01-ГП
Архітектурні рішення
16-01-АР
Конструктивні рішення
16-01-КР

Директор М. В. Кузьменко

Головний архітектор проекту М. М. Бахарєва

2019

ЗАГАЛЬНА ПОЯСНЮВАЛЬНА ЗАПИСКА

1.1 Підстава для розроблення проекту

Підставою для розробки Реконструкції нежитлової будівлі під житловий будинок з вбудованими приміщеннями громадського призначення на вул. Нижній Вал, 31-А у Подільському районі м. Києва є:

- розпорядження Київської міської державної адміністрації №506 від 26.05.2015 про реконструкцію будинку по вул. Нижній Вал, 31-А;
- Містобудівні умови і обмеження забудови земляної ділянки, видані Департаментом містобудування та архітектури м. Києва від 24.05.2016 р. №406/16/12/2009-16;
- завдання на проектування;
- витяг з бази даних чергового кадастрового плану від 02.06.2015 р.
- топоплану, виконаного інститутом «Київгеоінформатика»;
- передпроектні пропозиції розроблені ЗАТ «Транспроект»;
- інші документи, які додаються і розділі «Вихідні дані».

1.2. Характеристика майданчику будівництва

Існуючий триповерховий нежитловий будинок, що підлягає реконструкції, знаходиться в Подільському районі м. Києва, на вулиці Нижній Віл, в умовах щільної міської забудови, містобудівній структурі розташований в межах Центрального історичного ареалу, в зоні регулювання забудови І категорії, в археологічної охоронній зоні, та є складовою частиною пам'ятки ландшафту та історії місцевого значення «Історичний ландшафт Київських гір і долини р. Дніпра», на території пам'ятки археології місцевого значення «Культурний шар Подолу IX-XVIII ст..».

Орієнтовна площа ділянки, яку займає будинок становить 0,045 га згідно з черговим кадастровим планом виданим 02.06.2015 та обмірними кресленнями виконаними ТОВ «ІТЦ «Будівельне проектування»;

Оточуючі забудови – житлова та нежитлова забудова (малоповерхові та середньоповерхові будинки).

Земельна ділянка, на якій розміщуються будинок реконструкції безпосередньо межує:

- з півночі – 2-х поверховий цегляний будинок за адресою вул. Ярославська, 20 корп.1 ;

					16-01-ПЗ			
Зм.	Кільк.	Арк.	№ док	Підпис	Дата			
ГАП		Бахарєва			Пояснювальна записка	Стадія	Аркуш	Аркушів
Перевір.		Ваганова				П	1	
Розробив		Дикун				ТОВ «ВАРДА СПЕЦБУД МОНТАЖ»		

- зі заходу – із землями загального користування (вул. Костянтинівська);
- з півдня – 3-х поверховий цегляний будинок по вул. Нижній Вал, 31 (КП «Київжитлоспецексплуатація»),
- з сходу – 3-х поверховий цегляний будинок по вул. Нижній Вал, 33;

Згідно з Генеральним планом міста Києва та проекту планування його приміської зони на період до 2020 року, затвердженого рішенням Київської міської ради від 28.03.2002 р. №370/1804 за функціональним призначення дана територія належить до громадської забудови.

Рельєф земельної ділянки має ухил з південного заходу на північний схід та характеризується відмітками 101,0 – 99,5 м.

Проектом не передбачається знесення чи перенесення будь-яких споруд, що знаходяться на ділянці проектування, а також видалення існуючих зелених насаджень.

1.3. Коротка характеристика об'єкта реконструкції

Будівля, що підлягає реконструкції, знаходиться за адресою: вул. Ніжний Вал, 31-А у Подільському районі м. Києва.

Об'єкт реконструкції представляє собою триповерхову цегляну будівлю з односкатним дахом горищного типу з покрівлею з металочерепиці з максимальними габаритними розмірами у плані 46.940 х 9.400 м, що надані у обмірних кресленнях, виконаних ТОВ «Інженерно-технічний «Будівельне проектування» у 2016р. Будівля капітальна, збудована до 1917 року, з несучими поздовжніми та поперечними цегляними стінами товщиною 750 мм (зовнішні) та 620 мм (внутрішні), перекриття над цокольним поверхом – монолітне з.б. по металевим балкам, над 1-3 поверхами - дерев'яні по дерев'яним балкам. Перегородки – цегляні.

Призначення будівлі під час експлуатації – поліклініка для обслуговування працівників лінійного відділу міліції метрополітену. На даний час будівля не експлуатується та відключена від інженерних комунікацій.

Будівля не є об'єктом культурної спадщини, але знаходиться в охоронній зоні щойно виявлених пам'яток і містобудування місцевого значення, а саме: на вул. Нижній Вал, 33 – «Садиба міська», на вул. Нижній Вал,33-А - «Будинок прибутковий», на вул. Нижній Вал,33-Б та 33-В – «Флігелі»

Згідно з висновками, наданими ТОВ «Інженерно-технічний «Будівельне проектування», технічний стан будівлі розцінюється як непридатний до експлуатації. Проектом передбачається демонтаж покрівлі, горищного та міжповерхового перекриттів, стін та перегородок цокольного та 1-3 поверхів, зовнішніх та внутрішніх сходів, віконних та дверних блоків.

При будівництві житлового будинку використовуються дві зовнішні торцеві цегляні стіни будинку.

1.4. Генплан, благоустрій, озеленення та організація рельєфу

Генеральний план розроблено з урахуванням топоплану М1:500, технічних умов відповідних міських служб, діючих нормативів та максимально раціонально використовуючи земельну ділянку з виділенням необхідних функціональних зон та з забезпеченням безпечного в'їзду та виїзду на територію майданчика проектування. Розбивка проїздів вирішена з врахуванням внутрішніх та зовнішніх транспортних потоків та протипожежного обслуговування.

Під'їзд автомобільного транспорту та пожежної спецтехніки здійснюється з боку вул. Ярославська. Забезпечена нормативна відстань від пожежних машин до будинку, що підлягає реконструкції.

Техніко-економічні показники рішень генерального плану приведені на аркуші «План розпланування».

План організації рельєфу розроблено на топооснові М1:500 з перетином горизонталей через 0,1 м.

В основі проектних рішень вертикального планування території закладені наступні принципи:

- забезпечення водовідводу майданчика закритою системою з підключенням до існуючої дощової каналізації згідно технічних умов, виданих КК «Київавтодор»;
- створення оптимальних ухилів по проїздах, майданчиках і пішохідних доріжках;
- виконання мінімального обсягу земляних робіт при будівництві;

Вертикальне планування території запроектовано з урахуванням відміток існуючих будівель та прилеглої території. Тротуари відділені від проїжджих частин бортовим каменем БР 100.30.18 ДСТУ 6665-91, в якості упорів для покриття тротуарів застосовано бортовий камінь БР 100.20.8.

Розділом «Благоустрій та озеленення» передбачається улаштування майданчиків для обслуговування мешканців будинків та озеленення прибудинкової території.

Цільовим призначенням зелених насаджень є утворення найбільш сприятливих умов перебування на відкритому повітрі, покращення екологічних умов, а також захист внутрішніх приміщень від вітру та пилу. Проектом передбачається збереження існуючих дерев та додавання нових зелених насаджень. Ігрові майданчики для дітей та спортивні майданчики розміщуються на території житлової групи до якої відноситься даний житловий будинок, за умови їх спільного користування.

Рішеннями генерального плану не передбачається знесення чи перенесення будь-яких споруд, що знаходяться на ділянці проектування, а також видалення існуючих зелених насаджень.

Проектні рішення прокладання трас внутрішньомайданчикових мереж і споруд до них розробляються окремо.

1.6. Архітектурні рішення

Ділянка проектування знаходиться у Центральному історичному ареалі м. Києва, в археологічній охоронній зоні та потрапляє до зони регулювання забудови 1 категорії, тому архітектурні рішення прийняті з урахуванням основних закономірностей історичної забудови, масштабних, стильових, колористичних та інших особливостей середовища.

Проектом передбачається будівництво в межах існуючої забудови 7-ми поверхового будинку з мансардним поверхом з граничною висотою 27,0 м.

Площа першого поверху дорівнює площі забудови існуючої будівлі та розміщується на плямі забудови існуючої споруди. Максимальні габаритні розміри становлять 47,250х9,150 м. Висота приміщень першого поверху (від підлоги до стелі) становить 3,3 м. На першому поверсі розташовані:

- вбудовані нежитлові приміщення громадського призначення (офіси);
- вхідна група житлового будинку, сміттєзбірна камера.

Цокольний поверх розміщується в обсягах існуючих конструкцій. Висота приміщень цокольного поверху становить – 2,7 м, коридорів цокольного поверху – 2,5 м. В цокольному поверсі розміщуються:

- вбудовані нежитлові приміщення громадського призначення (офіси);
- технічні приміщення (електрощитова, ІТП, насосна, венткамера);

З другого по шостий поверх розташовані квартири – дві однокімнатні та дві трикімнатні квартири. На сьомому та мансардному поверхах запроектовано квартири у двох рівнях – одна двокімнатна, три трикімнатні та одна п'ятикімнатна квартира. Висота приміщень житлових поверхів – 2,7 м.

Будівля запроектована каркасно-монолітна, з несучими монолітними стінами (пілонами) товщиною 250 мм та монолітними перекриттями товщиною 250 мм.

Зовнішні стіни – з повнотілої цегли товщиною 250 мм, утеплені жорсткими мінераловатними плитами, з подальшим оздобленням декоративною штукатуркою та пофарбуванням згідно з паспортом опорядження фасадів. Цоколь оздоблений керамогранітними плитами.

Міжквартирні перегородки – цегляні товщиною 250 мм, внутріквартирні – цегляні товщиною 120 мм.

Зв'язок між поверхами здійснюється за допомогою сходової клітки типу СК-1 та ліфту. Сходи запроектовані збірні, залізобетонні по серії 1.050.1 – 2, вип. 1, ліфт типу «Отіс» з управлінням на мікропроцесорі, вантажопідйомністю 1000 кг, машинне відділення розташовано на мансардному поверсі.

Дах будинку запроектовано мансардний, односкатний з металоконструкцій, утеплений мінераловатними плитами на базальтової основі, покрівля даху – металочерепиця, руберойд.

Заповнення віконних прорізів - металопластикові (двокамерні) вікна, імпости та рами прийняти кольорові, скло енергозберігаюче 4 мм ІМО, з маскируючої (сонцезахисної) плівкою типа Llumar. Заповнення внутрішніх дверних прорізів – металопластикові двері, вхідні двері до будинку – металеві протиударні.

Проектом передбачається часткове внутрішнє оздоблення приміщень будинку та улаштування підлог згідно з завданням на проектування. У внутрішньому оздоблені застосовано матеріали, переважно вітчизняного виробництва. У вестибюлях і коридорах, службових приміщеннях (приміщення конс'єржу), санвузлах, технічних приміщеннях передбачено застосування високоміцних матеріалів, що важко стираються та легко миються, зокрема керамічна плитка.

Оздоблення квартир та вбудованих офісних приміщень не передбачається.

Підлоги в житлових приміщеннях запроектовано з урахуванням конструктивних, експлуатаційних і архітектурних вимог та у залежності від призначення приміщення у якому вони влаштовуються. Тип підлог та місця їх улаштування див. креслення «Експлікація підлог».

Всі передбачені в проекті матеріали, конструкції та вироби є тільки такими, що мають відповідні сертифікати якості Держстандарту України.

На шляхах евакуації використані негорючі конструкції та оздоблювальні матеріали сертифіковані в системі УкрСЕПРО, огороджувальні конструкції для проходження вертикальних комунікацій та двері ніш доступу до них прийняті з межею вогнестійкості 2 години.

Проектними рішеннями передбачено місця для встановлення кондиціонерів та архітектурне підсвітлювання будівлі.

1.10. Інженерні рішення

1.10.1. Водопостачання

Джерелом водопостачання та пожежогасіння є внутрішньоквартальна водопровідна мережа. Холодна вода, яка подається в будинок, відповідає стандарту "питна вода".

На вводі встановлюється водомірний вузол з лічильником для врахування витрат води. Після лічильника вода направляється споживачам. На кожну квартиру та на кожне вбудоване приміщення передбачається окремий водолічильник. Квартирні водолічильники води розташовуються поза межами квартир, в нішах, в шафах, в коридорах загального користування. Лічильники обладнуються антимагнітним захистом (Антимагніт 100%) та модулем дистанційного зняття показників з диспетчеризацією. Перед лічильником встановлюється сітчастий фільтр.

Для поливання території передбачені зовнішні поливальні крани діаметром 25мм, які встановлюються в нішах зовнішніх стін будинку. На полив передбачається окремий водолічильник.

Розрахунковий тиск води для господарсько-питного водопостачання визначається з умов подавання води на потрібну висоту із забезпеченням необхідного вільного тиску з урахуванням всіх витрат в мережі.

Розрахунковий тиск в системі забезпечується насосною установкою, встановленою в насосній станції. Насосна установка встановлюється на віброопору, а з'єднання трубопроводів з патрубками насосів виконуються з застосуванням гнучких вставок або спеціальних гумових компенсаторів, призначених для зменшення шумів і вібрації. Включення і відключення насосної установки відбувається автоматично в залежності від тиску в мережі. Блок автоматики входить в комплект постачання обладнання.

В проекті прийнята насосна установка (2 робочих та 1 резервний насос).

В будинку проектом передбачається влаштування однозонної системи господарсько-питного водопостачання з розведенням водопроводу по технічному коридору цокольного поверху.

У сміттєзбірній камері встановлюється раковина та поливальний кран діаметром 20мм.

Вся система водопроводу монтується із сталевих емальованих труб по ТУ У 7308692-001-93, водогазопроводних оцинкованих труб по ГОСТ 3262-75*, пластикових труб для питної води. Внутрішнє розведення трубопроводів передбачається прихованим.

Запірна та регулююча арматура запроектована сталева та чавунна.

Ввід водопроводу в будинок запроектований з герметизацією по типовому комплексу 7373-3 «Типовые детали уплотнения вводов инженерных сетей в гражданские здания».

1.10.4. Побутова каналізація

Побутові стічні води від сантехприладів житлових квартир передбачається відводити у дворову мережу каналізації.

Внутрішні мережі проектуються із поліпропіленових каналізаційних труб Ду50 – 110 мм, магістралі та стояки передбачені із чавунних труб з емальованим покриттям.

Для відведення стоків від сантехприладів вбудованих офісних приміщень передбачена окрема система побутової каналізації з окремими випусками у зовнішню мережу. Для вентиляції системи каналізації вбудованих приміщень передбачено встановлення повітряних клапанів.

Випуски каналізації з будинку запроектовані з герметизацією по типовому комплексу 7373-3 «Типовые детали уплотнения вводов инженерных сетей в гражданские здания» г. Вильнюс 1975.

В підлозі сміттєкамери улаштовується трап діаметром 100 мм, який підключається до будинкового випуску побутової каналізації.

1.10.5. Внутрішні водостоки, дренаж.

Внутрішні водостоки будівлі проектуються із сталевих труб з емальованим покриттям по ТУ 7308692-001-93 Д= 108мм або із чавунних труб з емальованим покриттям.

На покрівлі будівлі встановлюються водостічні воронки з листвоуловлювачем та електрообігрівом від мережі 230В, потужністю 10-30 Вт, фірми HL.

Трубопроводи внутрішніх водостоків прокладаються приховано.

Для відкачування дренажних та аварійних вод з приміщень насосної станції, теплового пункту та венткамери передбачається влаштування дренажних приямків з встановленням дренажних насосів, які включаються при певному рівні води у приямках.

1.10.6. Протипожежні заходи

У відповідності з п.4.18 ДБН В. 1.1-7-2002 «Пожежна безпека об'єктів будівництва», в проекті передбачений вогнезахист вузлів перетину інженерних комунікацій з протипожежними стінами, перегородками і перекриттями, а саме:

- при перетині протипожежних перешкод металевими трубами водопроводу і каналізації для закладення щілин використовується вогнезахисна суміш «Формула КП»;
- при перетині пластмасовими трубами каналізації використовуються протипожежні манжети

Вогнестійкість проходок по EI прийнята не менше границі вогнестійкості протипожежних перешкод (EI 45 або EI 60).

1.10.7. Опалення.

Розрахункові температури внутрішнього повітря у приміщеннях будинку прийняті згідно з будівельними нормами та правилами.

Теплоносієм для систем опалення будинку є гаряча вода з параметрами Тп = 90°С; Тз = 70°С.

Система опалення будинку передбачена закрита, незалежна, двотрубна, з нижнім розведенням магістралей по технічному коридору цокольного поверху. Схема опалення будинку запроектована з установкою некомерційних приладів обліку тепла для кожної квартири та кожного вбудованого приміщення. Комерційний облік тепла загалом на кожен будинок передбачається у проектованому теплопункті.

Система опалення запроектована горизонтальна, з металополімерних труб Kan-therm або Rehau. Трубопроводи системи опалення прокладаються по периметру приміщення в підготовці підлоги за технологією фірми виробника. У ваннах передбачені електросушарки. Проектом передбачено опалення ванних кімнат, що примикають до зовнішніх стін.

Опалення вбудованих нежитлових приміщень передбачається самостійними системами, на яких у приміщенні ІТП встановлюються прилад комерційного обліку витрати тепла.

В якості опалювальних приладів прийняті сталеві панельні радіатори Kermi, з нижнім підключенням (Н=500мм), та в сходових клітинах - радіатори Kermi, з боковим підключенням Н=500мм. Опалювальні прилади обладнані термостатичними клапанами та кранами Маєвського. У допоміжних приміщеннях (теплопункт, насосні станції та щитові) приймаємо опалювальні прилади з гладких сталевих труб.

Вертикальні стояки системи опалення обладнані автоматичними повітровипускними кранами. Вертикальні стояки прокладаються у штрабах стін. В місцях перетину перекриття стояки прокладаються в гільзах, з чорної тонколистової сталі.

Магістральні трубопроводи та вертикальні стояки системи опалення передбачені із сталевих водогазопровідних труб за ГОСТ3262-75* та сталевих електрозварних труб за ГОСТ 10704-92.

Магістральні трубопроводи систем опалення прокладаються з ухилом і=0,002 по технічному коридору цокольного поверху. Магістральні трубопроводи обладнані повітровипускними кранами, а також спускною арматурою для опорожнення систем від води за допомогою шлангів у трапи тех. поверху та приямки підвалу.

Для компенсації видовження труб (магістральні трубопроводи та вертикальні стояки), що виникає за рахунок температури теплоносія встановлюємо компенсатори.

Магістральні трубопроводи і стояки необхідно теплоізолювати.

1.10.8. Вентиляція.

Вентиляція приміщень житлового будинку прийнята припливно-витяжна із природним та механічним спонуканням.

У кухнях та санітарних вузлах передбачаються витяжні канали для видалення забрудненого повітря. З кожної кухні та санітарного вузла проектується індивідуальний вертикальний витяжний канал з випуском повітря в атмосферу або в збірну вентиляційну шахту. На вентиляційних каналах кожної кухні та санітарного вузла передбачено встановлення настінного вентилятора.

Приплив повітря в житлові приміщення житлового будинку неорганізований, природній за рахунок кватирок та клапанів марки S710 фірми REHAU, що знаходяться в верхній частині металопластикових вікон.

Для створення та забезпечення встановлених діючими нормами параметрів повітряного середовища в приміщеннях вбудованих приміщень передбачена припливно-витяжна вентиляція, з механічним спонуканням.

Потужність систем вентиляції визначається нормативним обміном повітря в приміщеннях, а також виходячи з розрахунку на одну особу .

Припливно-витяжні установки встановлюється в венткамері.

Проектом передбачається можливість встановлення зовнішніх блоків кондиціонерів, при цьому розділами ОВ та АБ враховуються заходи проти негативного впливу їх роботи на мешканців будинку:

Повітропроводи виконані з тонколистової оцинкованої сталі.

1.10.9. Електропостачання. Внутрішнє електрообладнання.

Згідно ДБН В.2.5-23:2010 електроспоживачі комплексу по категорії надійності електропостачання віднесені до:

І категорії з АВР (п.4.17 ДБН В.2.5-23:2010):

- пожежна сигналізація;
- сигналізатори загазованості;
- протипожежне обладнання.

ІІ категорії (табл.2.1 ДБН В.2.5-23:2010) - всі інші споживачі житлової частини будинку та споживачі вбудованої частини будинку.

Для живлення споживачів І-ї категорії з АВР передбачається улаштування секції АВР на ввідно-розподільному пристрої, яка підключається після ввідних комутаційних апаратів.

Основними силовими електроспоживачами є технологічне та сантехнічне обладнання, ліфт.

В будівлі передбачена спільна електрощитова для житлової частини та вбудованих приміщень з встановленням в ній окремих вводно-розподільчих пунктів (ВРП).

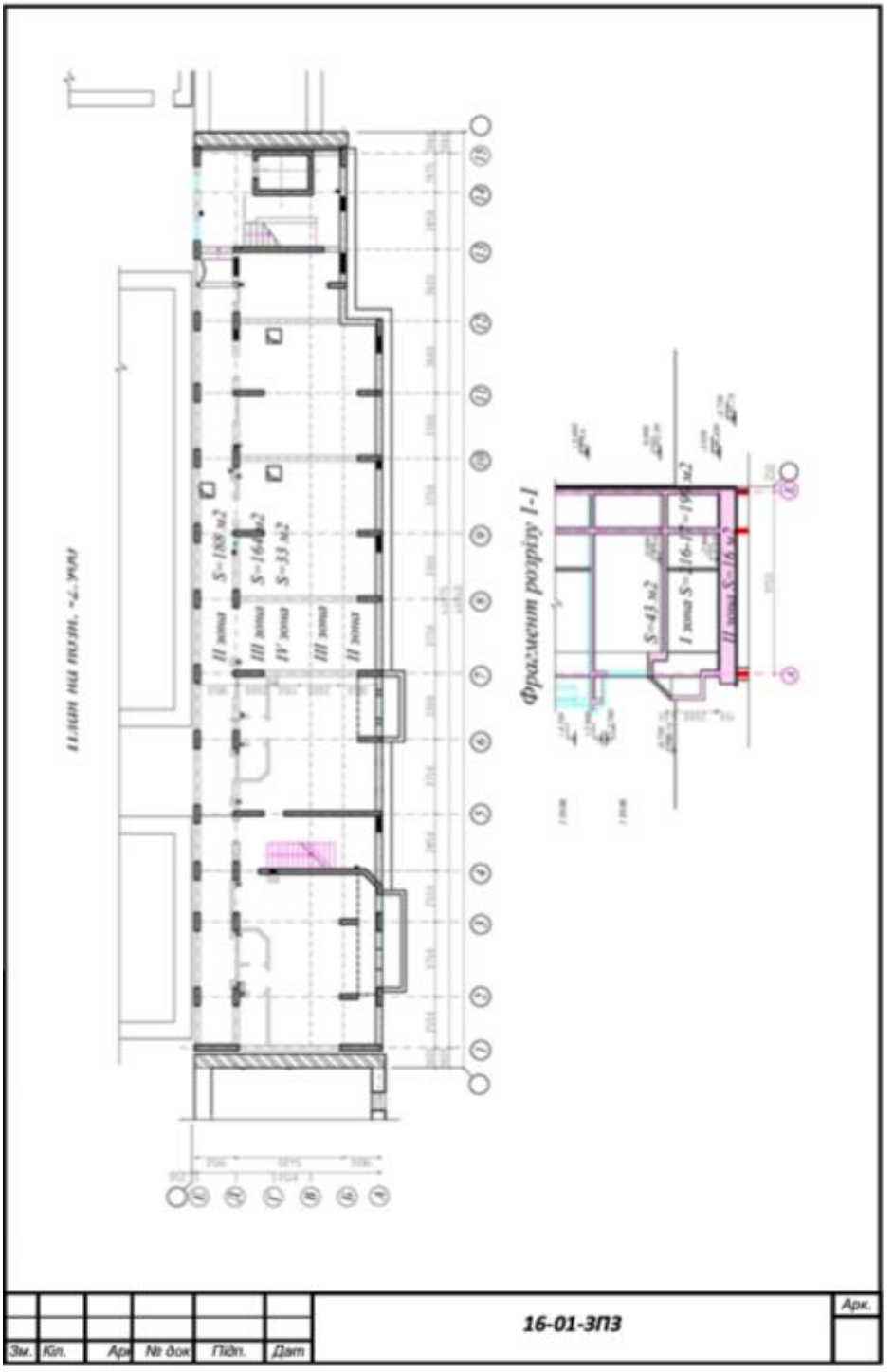


Fig. B1. Cross section of the research building under construction

Приведений коефіцієнт теплопередачі теплоізоляційної оболонки об'ємно-планувальних елементів будинку $k_{\sum пр}$, Вт/(м²·К), визначається за формулою (5) ДСТУ-Н Б А.2.2-5:2007.

Для житлової частини:

$$k_{\sum пр} = \zeta \cdot \frac{\frac{F_{нп\,1}}{R_{\sum пр\,нп\,1}} + \frac{F_{нп\,2}}{R_{\sum пр\,нп\,2}} + \frac{F_{сп}}{R_{\sum пр\,сп}} + \frac{F_{пк\,1}}{R_{\sum пр\,пк\,1}} + \frac{F_{пк\,2}}{R_{\sum пр\,пк\,2}} + \frac{F_{п\,1}}{R_{\sum пр\,п\,1}}}{F_{\sum}}, \quad (5)$$

де ζ – коефіцієнт, що враховує додаткові тепловитрати, пов'язані з орієнтацією огороджень за сторонами світу, наявністю кутових приміщень, надходженням холодного повітря через входи в будинок; для житлових будинків ζ=1,13;

$$k_{\sum пр} = 1{,}13 \cdot \frac{\frac{1455}{3{,}59} + \frac{634}{3{,}41} + \frac{381}{0{,}93} + \frac{259}{5{,}42} + \frac{226}{6{,}59} + \frac{32}{3{,}98}}{2987} =$$

$$= 1{,}13 \cdot \frac{1091}{2987} = 0{,}41 \text{ Вт/(м}^2\text{·К)},$$

Для громадської частини:

$$k_{\sum пр} = \zeta \cdot \frac{\frac{F_{нп\,1}}{R_{\sum пр\,нп\,1}} + \frac{F_{нп\,2}}{R_{\sum пр\,нп\,2}} + \frac{F_{сп}}{R_{\sum пр\,сп}} + \frac{F_{ц}}{R_{\sum ц}} + \frac{F_{кр\,ц}}{R_{\sum пр\,кр\,ц}}}{F_{\sum}}, \quad (5)$$

$$k_{\sum пр} = 1{,}13 \cdot \frac{\frac{205+32}{3{,}59} + \frac{133+15}{3{,}41} + \frac{52+13}{0{,}93} + \frac{600}{5{,}6} + \frac{22}{3{,}82}}{1072} =$$

$$= 1{,}13 \cdot \frac{292}{1072} = 0{,}30 \text{ Вт/(м}^2\text{·К)},$$

2.1.7 Енергетичні показники (житлової частини)

Розрахункові витрати теплової енергії на опалення будинку протягом опалювального періоду $Q_{рік}$, кВт·год, визначається за формулою (2):

$$Q_{рік} = [Q_k - (Q_{вн\ п} + Q_s) \cdot \nu \cdot \zeta] \cdot \beta_h, \quad (2)$$

де Q_k – загальні тепловитрати будинку через огороджувальну оболонку, кВт·год, визначається за п.5.3 ДСТУ – Н Б А.2.2-5:2007,

$Q_{вн\ п}$ – побутові теплонадходження протягом опалювального періоду, кВт·год, визначається за п.5.8 ДСТУ – Н Б А.2.2-5:2007,

Q_s – теплові тепло надходження через вікна від сонячної радіації протягом опалювального періоду, кВт·год, визначається за п.5.9 ДСТУ – Н Б А.2.2-5:2007,

ν – коефіцієнт, що враховує здатність огороджувальних конструкцій будинків акумулювати або віддавати тепло під час періодичного теплового режиму; для будинку, що розглядається ν= 0,8;

ζ – коефіцієнт авторегулювання подачі тепла в системах опалення; в будинку використовується двотрубна система опалення з термостатами та з центральним авторегулюванням на ІТП; ζ = 0,95;

β_h – коефіцієнт, що враховує додаткове тепло споживання системи опалення, пов'язане з дискретністю номінального теплового потоку номенклатурного ряду опалювальних приладів додатковими тепловитратами через радіаторні ділянки огороджень, тепловитратами трубопроводів, що проходять через неопалювальні приміщення: для багатосекційного та інших протяжних будинків β_h = 1,13.

Загальні тепловитрати будинку через огороджувальну оболонку за опалювальний період, визначається за формулою (3):

$$Q_k = \chi_1 \cdot K_{буд} \cdot D_d \cdot F_\Sigma = 0,024 \cdot 0,65 \cdot 3538 \cdot (2987+1072) = 2,240 \cdot 10^5 \text{ кВт·год}, \quad (3)$$ *- для будинку*

D_d – кількість градусо-діб опалювального періоду, що визначається за формулою:
$D_d = (t_в - t_{оп\ з}) \cdot z_{оп} = (20 - (-0,1)) \cdot 176 = 3538$ °С·діб.

Побутові теплонадходження протягом опалювального періоду визначається за формулою (13) *для житлової частини*:

$$Q_{вн\ п} = \chi_1 \cdot q_{вн\ п} \cdot z_{оп} \cdot F_{ж}, \quad (13)$$

де $q_{вн\ п}$ – величина побутових теплонадходженьна 1м^2 житлової площі будинку; для житлових будинків $q_{вн\ п}$= 10Вт/м^2 .

$z_{оп}$ – тривалість, діб, опалювального періоду, що визначається згідно з ДСТУ-Н Б В.1.1-27;

$F_{f\,ж} = 1734,7$ (площа квартир будинку, згідно ТЕП)

Побутові теплонадходження протягом опалювального періоду визначається за формулою (13) *для громадської частини:*

$$Q_{вн\ п} = \chi_1 \cdot q_{вн\ п} \cdot z_{оп} \cdot F_{f\,р}, \qquad (13)$$

де $q_{вн\ п}$ – величина побутових теплонадходжень на 1м^2 розрахункової площі громадського будинку, Вт/м^2; враховується за розрахунковою кількістю людей (90 Вт/чол), що знаходяться в будинку, освітленням (за встановленою потужністю) та офісної техніки з урахуванням кількості робочих годин на тиждень – 40 год. Загальна кількість годин на тиждень - 168.

Тепловиділення протягом тижня *для громадської частини*:

– від людей, що знаходяться в будівлі

$$Q_1 = \frac{90 \cdot 35 \cdot 40}{168} = 0,75 \text{ кВт};$$

– від штучного освітлення, приймається з розрахунку 35 Вт/м^2 (із коефіцієнтом використання 0,8)

$$Q_2 = 35 \cdot 347,5 \cdot \frac{40}{168} \cdot 0,8 = 2,32 \text{ кВт};$$

– від офісної техніки (комп'ютерів), приймається з розрахунку 300 Вт від одного комп'ютера, розрахункова кількість комп'ютерів 35, коефіцієнт використання часу протягом тижня 0,95, тоді

$$Q_3 = \frac{300 \cdot 35 \cdot 40 \cdot 0,95}{168} = 2,38 \text{ кВт};$$

$$q_{вн\ п} = \frac{(Q_1 + Q_2 + Q_3)}{F_{f\,р}} = \frac{(0,75 + 2,32 + 2,38) \cdot 10^3}{347,5} = 15,68 \text{ Вт/м}^2.$$

$Q_{вн\ п\ ж\ ч} = 0,024 \cdot 10 \cdot 176 \cdot 1734,7 = 0,732 \cdot 10^5$ кВт·год - *для житлової частини*

$Q_{вн\ п\ гр\ ч} = 0,024 \cdot 15,68 \cdot 176 \cdot 347,5 = 2,302 \cdot 10^4$ кВт·год - *для громадської частини*

$Q_{вн\ п\ буд} = 0,732 \cdot 10^5 + 2,302 \cdot 10^4 = 0,962 \cdot 10^5$ кВт·год - *для будинку.*

Теплові надходження через вікна від сонячної радіації протягом опалювального періоду визначається за формулою (14) *для житлової частини:*

$$Q_в = \zeta_в \cdot \varepsilon_в \cdot (F_{Пн3} \cdot I_{Пн3} + F_{ПнС} \cdot I_{ПнС} + F_{ПдС} \cdot I_{ПдС} + F_{Пд3} \cdot I_{Пд3}), \qquad (14)$$

де $\zeta_в$ – коефіцієнт, що враховує затінення світлового прорізу вікон непрозорими елементами заповнення, приймається згідно табл. 1, ДСТУ -Н Б А.2.2-5:2007; $\zeta_в = 0,8$

2.2 Енергетичний паспорт житлової частини будинку

Таблиця 1. Загальна інформація

Дата заповнення (рік, місяць, число)	05. 01. 2017 р.
Адреса будинку	вул. Нижній Вал, 31-А у Подільський район м. Києва
Розробник проекту	ТОВ «ВАРДА СПЕЦБУД МОНТАЖ»
Адреса і телефон розробника	вул. Мала Житомирська, 9-Б, офіс 6, Шевченківський район м. Києва,
Шифр будинку	16-01-ЗПЗ
Рік будівництва	2017-2018рр

Таблиця 2. Розрахункові параметри

Найменування розрахункових параметрів	Позначення	Одиниця виміру	Величина
Розрахункова температура внутрішнього повітря	$t_в$	°С	+20
Розрахункова температура зовнішнього повітря	$t_з$	°С	-22
Тривалість опалювального періоду	$z_{оп}$	діб	176
Середня температура зовнішнього повітря за опалювальний період	$t_{оп\ з}$	°С	-0,1
Розрахункова кількість градусо- діб опалювального періоду	D_d	°С·діб	3538
Функціональне призначення, тип і конструктивне рішення будинку			
Призначення	житловий будинок з вбудованими приміщеннями та підвалом		
Розміщення в забудові	в містобудівній структурі розташований в межах Центрального історичного ареалу, в зоні регулювання забудови І категорії, в археологічній охоронній зоні, та є складовою частиною пам'ятки ландшафту та історії місцевого значення. Оточуючі забудови – житлова та нежитлова забудова (малоповерхові та середньоповерхові будинки).		

Індивідуальний проект	8-поверховий будинок з вбудованими приміщеннями на першому поверсі та підвалом, збудований за індивідуальним проектом
Конструктивне рішення	монолітний залізобетонний каркас з заповненням з повнотілої цегли

Таблиця 3. Геометричні, теплотехнічні та енергетичні показники

Показники	Позначення і розмірність показника	Нормативне значення показника	Розрахункове (проектне) значення показника	Фактичне значення показника
Геометричні показники				
Загальна площа зовнішніх огороджувальних конструкцій будинку	F_{Σ}, м^2	-	2987	-
В тому числі:				
- стін в.ч.	$F_{нп}$, м^2	-	2089	-
по повнотілій цеглі	$F_{нп\,1}$, м^2	-	1455	-
по залізобетону	$F_{нп\,2}$, м^2	-	634	-
- вікон і балконних дверей та вітражів (на фасаді/мансардні)	$F_{сп}$, м^2	-	381 (314/67)	-
- дверей	$F_{д}$, м^2	-	-	-
- покриттів (суміщених) в т.ч.	$F_{пк}$, м^2	-	485	-
суміщена плоска крівля	$F_{пк\,1}$, м^2	-	259	-
скатна крівля	$F_{пк\,2}$, м^2	-	226	-
- перекриття над проїздами і під еркерами	$F_{п}$, м^2	-	32	-
Площа опалювальних приміщень	F_{h}, м^2	-"-	2771	-
Площа житлових приміщень і кухонь (взято з ТЕП)	$F_{f\,ж}$, м^2	-"-	1734,7	-
Опалювальний об'єм (житлового будинку)	$V_{h\,б}$, м^3	-	7369	-
Коефіцієнт скління	$m_{ск}$	-	0,14	-
Показник компактності будинку	$A_{к\,буд}$	-	0,32	-

Теплотехнічні та енергетичні показники				
Теплотехнічні показники				
Приведений опір теплопередачі зовнішніх стін огороджувальних конструкцій	$R_{\sum пр}$, $м^2 \cdot К/Вт$			
- стін в т.ч.	$R_{\sum пр нп}$			
по повнотілій цеглі	$R_{\sum пр нп 1}$	3,3	3,59	-
по залізобетону	$R_{\sum пр нп 2}$	3,3	3,41	-
- вікон і балконних дверей та вітражів	$R_{\sum пр сп}$	0,75	0,98	-
- покриттів (суміщених) в т.ч.	$R_{\sum пр пк}$			
суміщена плоска крівляскатна крівля	$R_{\sum пр пк 1}$	5,35	5,42	-
	$R_{\sum пр пк 2}$	5,35	6,59	-
- перекриття над проїздами і під еркерами	$R_{\sum пр п}$	3,75	3,98	-
Енергетичні показники				
Розрахункові питомі тепловитрати	$q_{буд}$, $кВт \cdot год/м^2$	-	[39]	-
Максимальне допустиме значення питомих тепловитрат на опалення будинку	E_{max}, $кВт \cdot год/м^2$	[55]	-	-
Клас енергетичної ефективності	-	-	B	-
Термін ефективності експлуатації теплоізоляційної оболонки та її елементів	термін ефективності експлуатації теплоізоляційної оболонки та її елементів відповідає терміну експлуатації конструкцій будинку і складає не менше 25 років			
Відповідність проекту будинку нормативним вимогам	Так			
Необхідність доопрацювання проекту будинку	Ні			

Таблиця 3. Висновки за результатами оцінки енергетичних параметрів будинку.

Вказівки щодо підвищення енергетичної ефективності будинку
Проект відповідає вимогам ДБН В.2.6-31 до теплотехнічних та енергетичних показників огороджувальних конструкцій будинку і порядку їх розрахунків, що забезпечує: - раціональне використання енергетичних ресурсів на обігрівання приміщень будинку; - нормативні показники санітарно- гігієнічних параметрів мікроклімату приміщень; - довговічність огороджувальних конструкцій під час експлуатації будинку.

3. ТЕХНІКО-ЕКОНОМІЧНІ ПОКАЗНИКИ

«Реконструкція нежитлової будівлі під житловий будинок з вбудованими приміщеннями громадського призначення на вул. Нижній Вал, 31-А у Подільському районі м. Києва»

№ п/п	Найменування показника	Од. виміру	Кількість	Примітка
Вид будівництва - реконструкція				
Ступень вогнестійкості - II				
1.	Площа ділянки	га		
2.	Площа забудови	$м^2$	450	
3.	Поверховість	поверх	8	
4.	Загальна кількість квартир у будинку, в т.ч.	кв.	25	
	• 1-кімн.	кв.	10	
	• 2-кімн.	кв.	1	
	• 3-кімн.	кв.	13	
	• 5-кімн.		1	
5.	Площа житлового будинку	$м^2$	3200,7	
6.	Площа квартир у будинку	$м^2$	1860,6	
7.	Площа літніх приміщень	$м^2$	68,7	
8.	Загальна площа квартир у будинку	$м^2$	1929,3	
9.	Площа вбудованих нежитлових приміщень, в т.ч.	$м^2$	347,8	
	• цокольного поверху		95,3	
	• 1-го поверху		252,5	
10.	Загальний будівельний об'єм, в т.ч.	$м^3$	12768,5	
	• вище відм. 0.000		11335	
	• нижче відм. 0.000		1433	
11.	Кількість створених робочих місць	осіб	35	
12.	Річна потреба			
	• вода	тис. $м^3$	9994,9	
	• електрична енергія	тис.кВт*год	863,9	
	• теплова енергія	Гкал	405,2	
13.	Тривалість будівництва	місяць	10	

Головний архітектор проекту Бахарєва М. М.

Замовник КП «Спецжитлофонд»

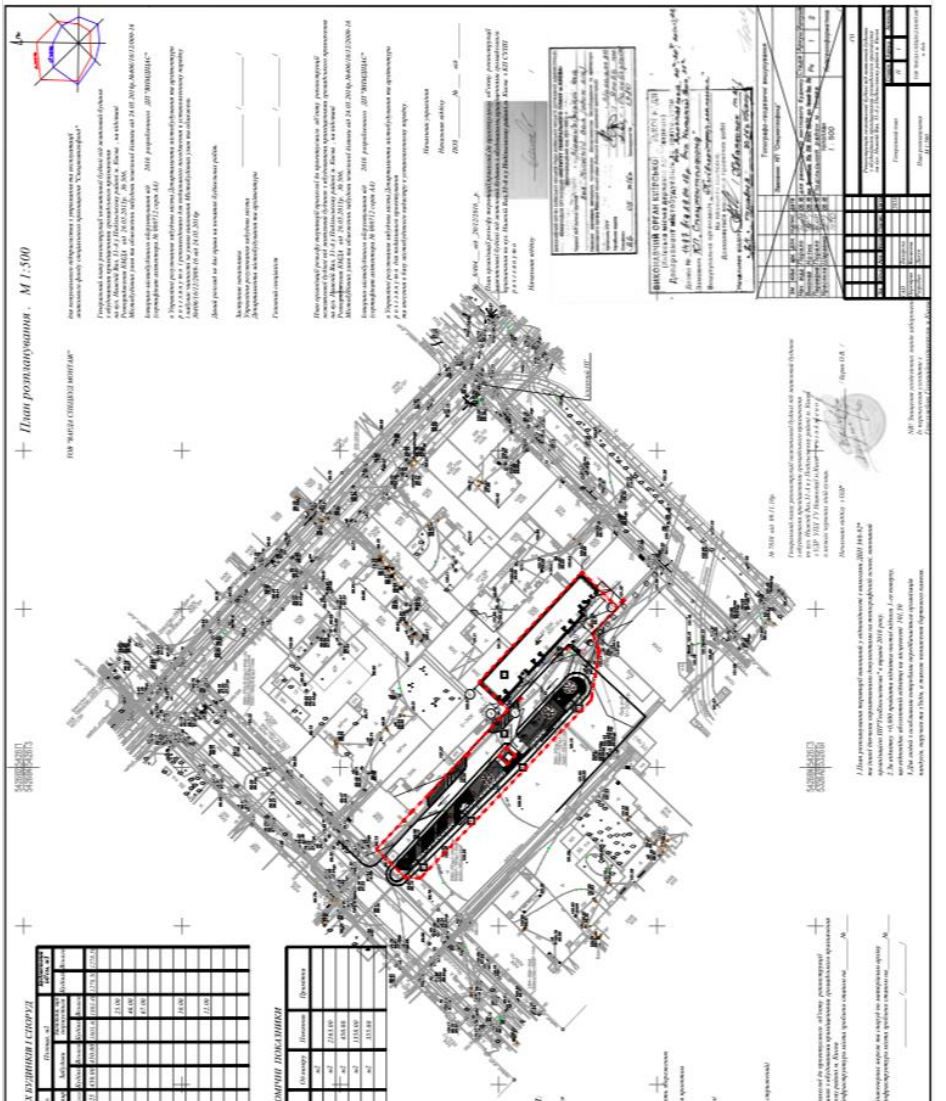
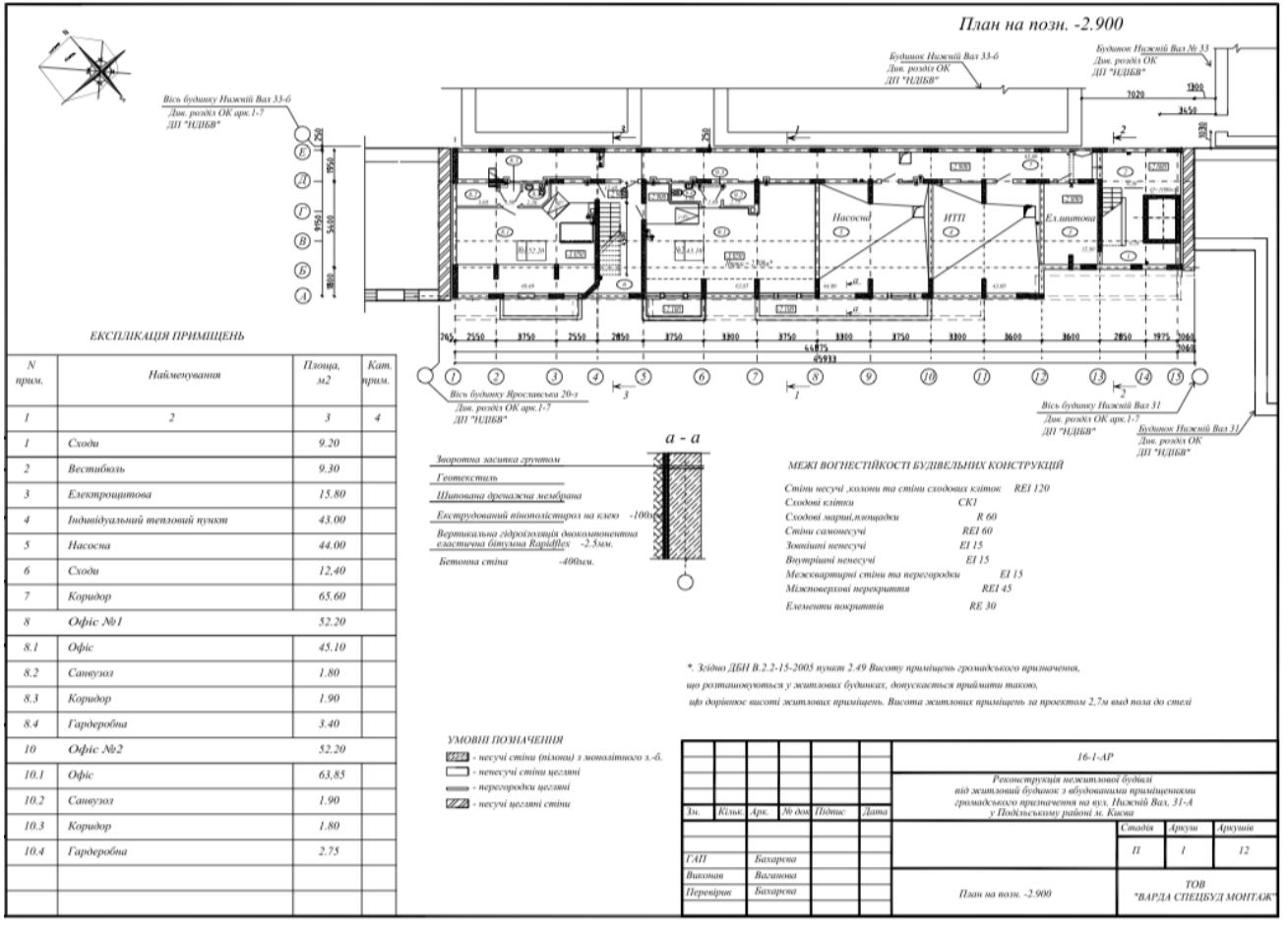


Fig. B2. Cross section of the research building under construction

Fig. B3. Plan of the research building on the mark 2.900



ЕКСПЛІКАЦІЯ ПРИМІЩЕНЬ

N прим.	Найменування	Площа, м2	Кат. прим.
1	2	3	4
1	Сходи	9.20	
2	Вестибюль	9.30	
3	Електрощитова	15.80	
4	Індивідуальний тепловий пункт	43.00	
5	Насосна	44.00	
6	Сходи	12,40	
7	Коридор	65.60	
8	Офіс №1	52.20	
8.1	Офіс	45.10	
8.2	Санвузол	1.80	
8.3	Коридор	1.90	
8.4	Гардеробна	3.40	
10	Офіс №2	52.20	
10.1	Офіс	63,85	
10.2	Санвузол	1.90	
10.3	Коридор	1.80	
10.4	Гардеробна	2.75	

МЕЖІ ВОГНЕСТІЙКОСТІ БУДІВЕЛЬНИХ КОНСТРУКЦІЙ

Стіни несучі ,колони та стіни сходових кліток	REI 120
Сходові клітки	СК1
Сходові марші,площадки	R 60
Стіни самонесучі	REI 60
Зовнішні ненесучі	EI 15
Внутрішні ненесучі	EI 15
Міжквартирні стіни та перегородки	EI 15
Міжповерхові перекриття	REI 45
Елементи покриттів	RE 30

*. Згідно ДБН В.2.2-15-2005 пункт 2.49 Висоту приміщень громадського призначення, що розташовуються у житлових будинках, допускається приймати такою, що дорівнює висоті житлових приміщень. Висота житлових приміщень за проектом 2,7м від пола до стелі

УМОВНІ ПОЗНАЧЕННЯ

- несучі стіни (пілони) з монолітного з.-б.
- ненесучі стіни цегляні
- перегородки цегляні
- несучі цегляні стіни

Зм.	Кільк.	Арк.	№ док.	Підпис	Дата
ГАП		Бахарєва			
Виконав		Вагапова			
Перевірив		Бахарєва			

16-1-АР

Реконструкція нежитлової будівлі під житловий будинок з вбудованими приміщеннями громадського призначення на вул. Нижній Вал, 31-А у Подільському районі м. Києва

Стадія	Аркуш	Аркушів
П	1	12

План на позн. -2.900

ТОВ "ВАРДА СПЕЦБУД МОНТАЖ"

Fig. B4. Roof plan of the research under the reconstruction

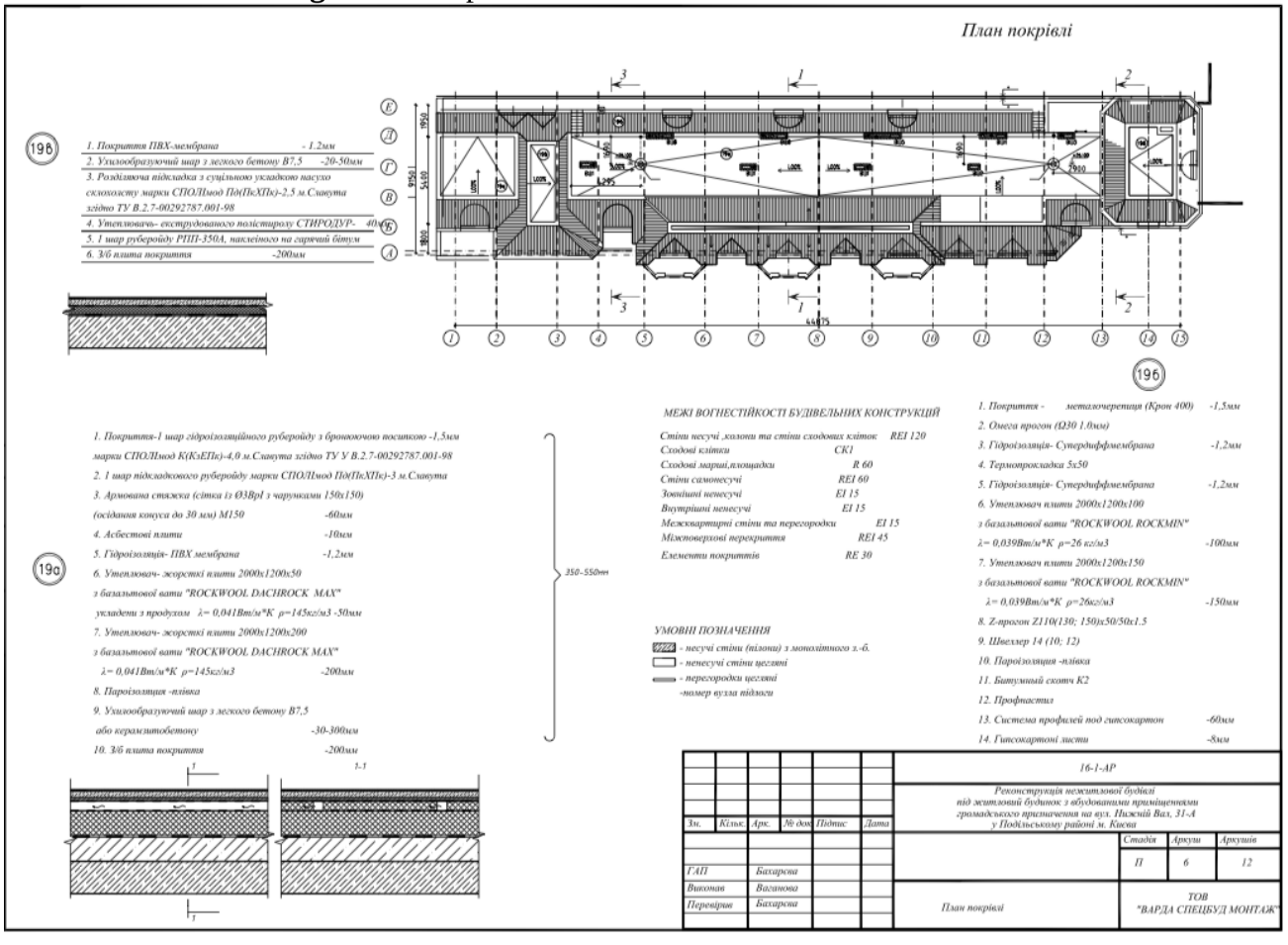
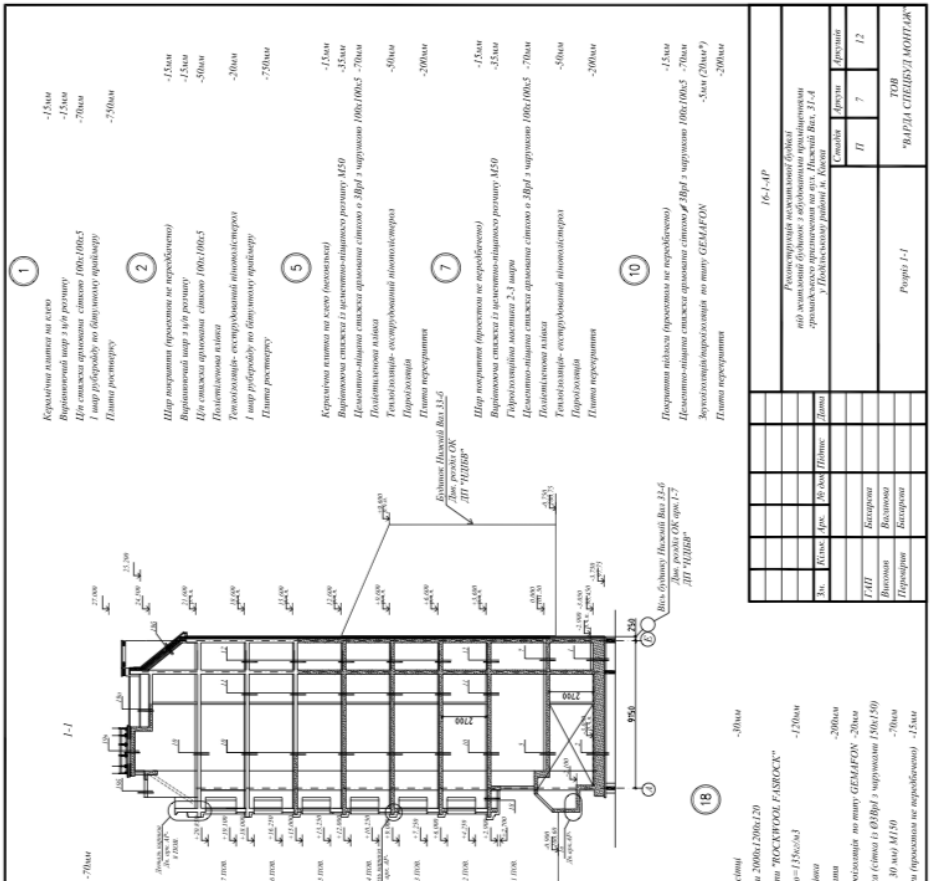


Fig. B5. Cross section of the research building



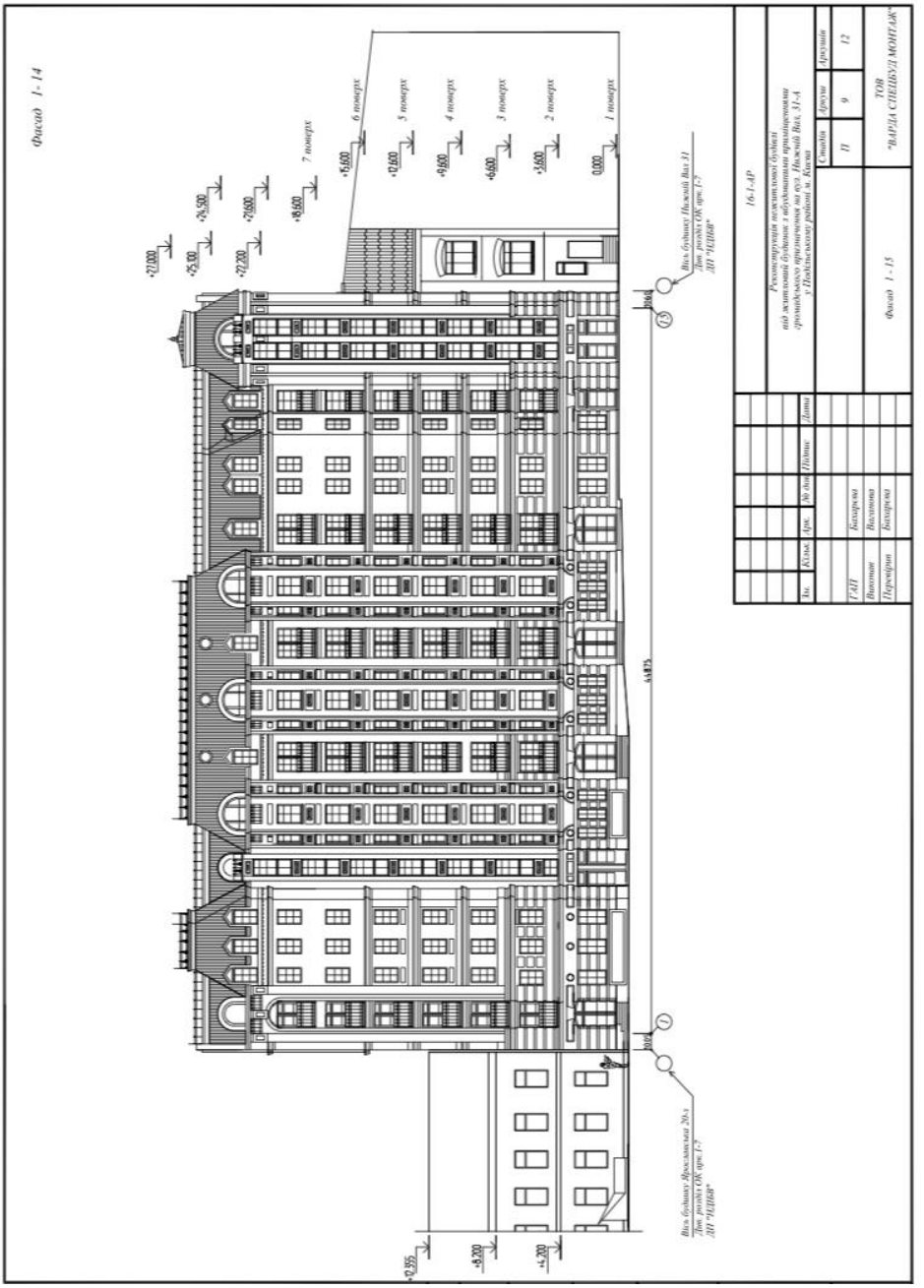


Fig. B6. Façade plan of research building (1-15)

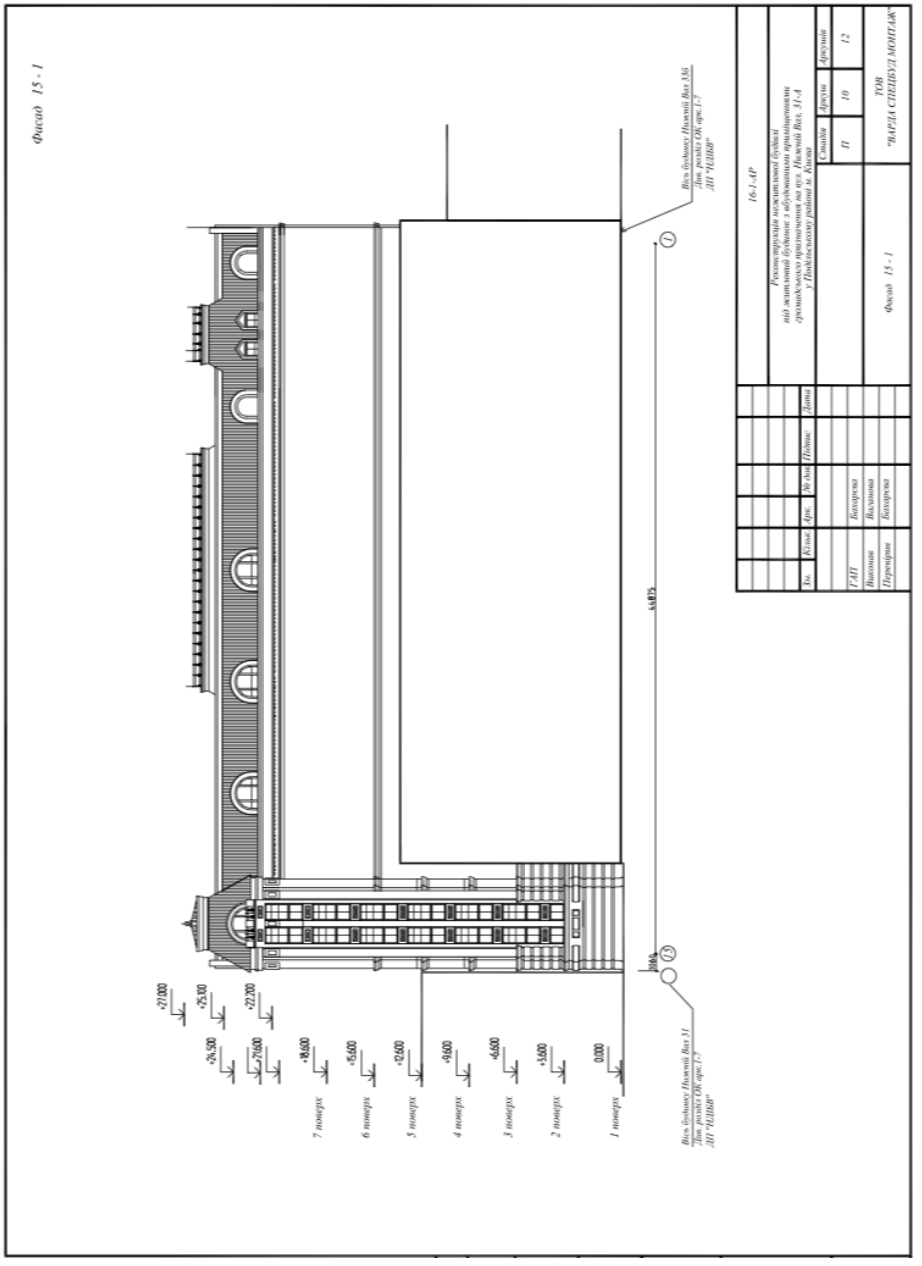


Fig. B7. Façade plan of research building (15-1)

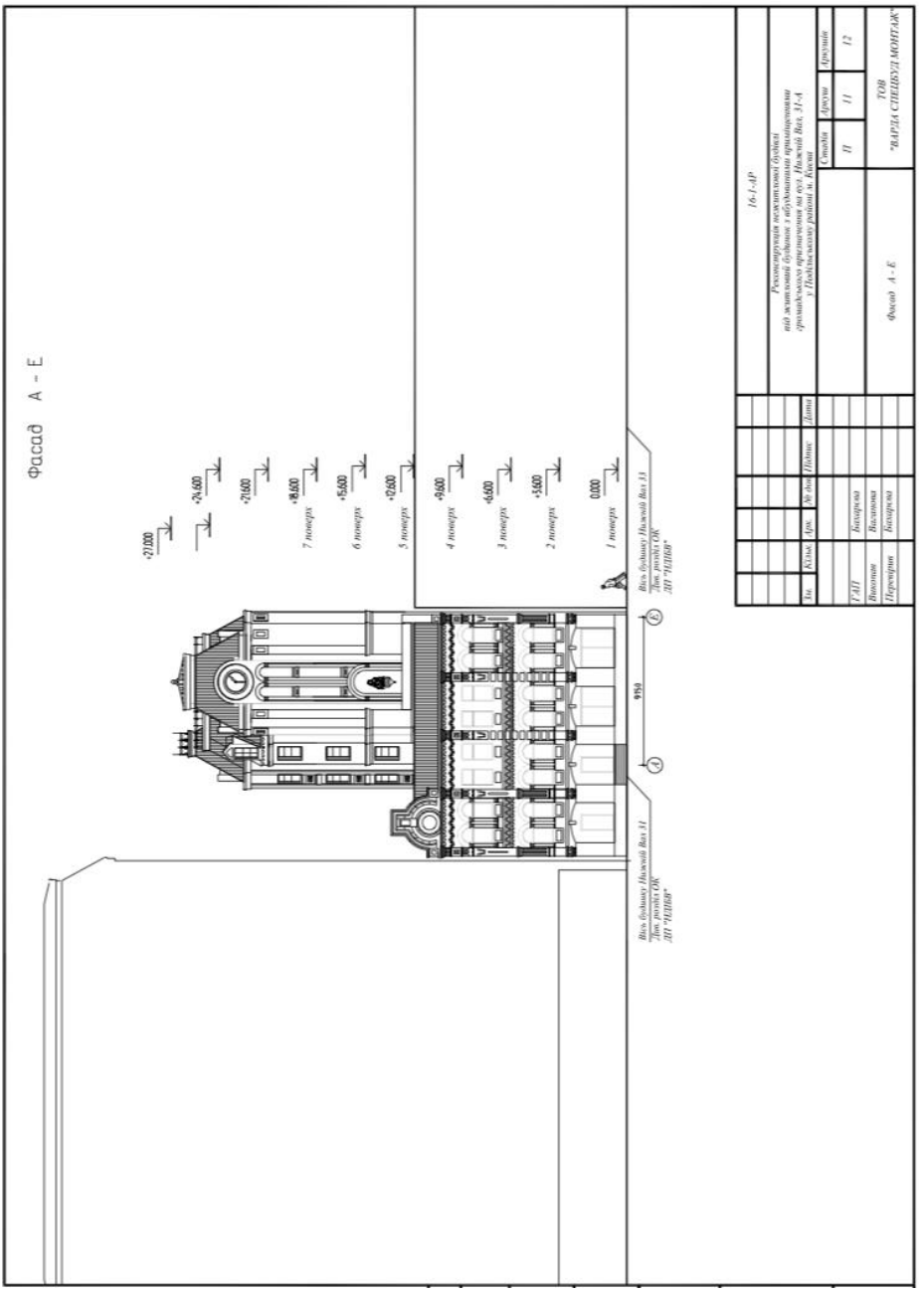


Fig. B8. Façade plan of research building (A-E)

Annex C. Automation process in Intelligent data-base and model base management system

Availability and requirements
Project name: MCDM_automation
Source code: https://github.com/anaveland/MCDM_automation/blob/main/excel_proj.py
Documentation: https://github.com/anaveland/MCDM_automation/blob/main/README
Operating system: MacOS
Programming language: Python
Other requirements: pandas==1.3.2; openpyxl==3.0.9

Steps for the first-time setup:

- Open Terminal and write the directions to the file

cd ~/Desktop/excel_proj

- Install additional Python virtual environments

python3 -m venv ./venv
source venv/bin/activate
pip install -r requirements.txt

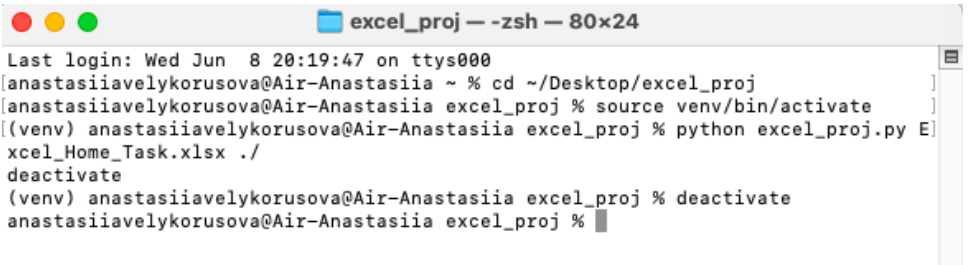


Fig. C.1. Set-up Python virtual environments – usage (created by author)

Code to reproduce the simulated datasets analyzed within the case study:

```
import pandas as pd
from argparse import ArgumentParser
from pathlib import Path

if __name__ == '__main__':
    parser = ArgumentParser()
    parser.add_argument(
        'source_table',
        type=lambda p: Path(p).resolve().expanduser(),
```

```
        help='Path to excel table to retrieve data from'
    )
    parser.add_argument(
        'save_to_dir',
        type=lambda p: Path(p).resolve().expanduser(),
        help='Directory to save results table to',
    )
    args = parser.parse_args()
    df = pd.read_excel(args.source_table, index_col=0)

    # Stage 1
    def stage_1_formula(row, criteria_num: int):
        the_sum = sum(row[f'Criteria {i}'] for i in range(1, 6))
        return row['Ultimate weights of criteria, qi'] * row[f'Criteria {criteria_num}'] /
the_sum

    for i in range(1, 6):
        df[f'Criteria {i}'] = df.apply(stage_1_formula, axis=1, criteria_num=i)

    # Stage 2
    name = 'The sums of weighted normalized maximizing indices of the windows, '

    results_plus = [df[df['*']][f'Criteria {i}'].sum() for i in range(1, 6)]
    results_minus = [df[~df['*']][f'Criteria {i}'].sum() for i in range(1, 6)]

    df.loc[name + 'S+j'] = [None, None, None, *results_plus]
    df.loc[name + 'S-j'] = [None, None, None, *results_minus]

    # Stage 3
    row_plus = df.loc[name + 'S+j']
    row_minus = df.loc[name + 'S-j']
    row_minus_sum = sum(row_minus[f'Criteria {i}'] for i in range(1, 6))

    def calculate_for_criteria(criteria_num: int):
        numerator = row_minus[f'Criteria {criteria_num}'] * row_minus_sum

        right_part_denom = sum(
            row_minus[f'Criteria {criteria_num}'] / row_minus[f'Criteria {i}']
            for i in range(1, 6)
        )
        denominator = row_minus[f'Criteria {criteria_num}'] * right_part_denom
        return row_plus[f'Criteria {criteria_num}'] + numerator / denominator

    significance = [calculate_for_criteria(i) for i in range(1, 6)]
```

```
df.loc['Windows significance, Qj'] = [None, None, None, *significance]

# Stage 4
rating = []
significance.sort(reverse=True)
windows_significance_row = df.loc['Windows significance, Qj']

for i in range(1, 6):
    value = windows_significance_row[f'Criteria {i}']
    rating.append(significance.index(value) + 1)

df.loc['Priority of the alternative'] = [None, None, None, *rating]

# Stage 5
highest_rating_sig = windows_significance_row[f'Criteria {rating.index(1) + 1}']
degree = []

for i in range(1, 6):
    value = windows_significance_row[f'Criteria {i}']
    percent = (value / highest_rating_sig) * 100
    degree.append(percent)

df.loc['Utility degree of the alternative (%)'] = [None, None, None, *degree]
df.to_excel(args.save_to_dir / 'table_test.xlsx')
```

Additionally, each of the above steps can either be run using individual shell scripts or the user can run a single shell script (run_ snp_stage*1.sh) that will carry out all steps. The addition of new samples is very straightforward, and result files from previous portions of the analysis that do not need to be re-generated are re-used. This greatly reduces the computational time when adding new samples as the mapping and pileup steps are not re-executed.

Anastasiia VELYKORUSOVA

DEVELOPMENT OF A METHOD AND INTELLIGENT DECISION SUPPORT SYSTEM FOR SUSTAINABLE RENOVATION OF A BUILT ENVIRONMENT

Doctoral Dissertation

Technological Sciences,
Civil Engineering (T 002)

TVARIOS UŽSTATYTOS APLINKOS ATNAUJINIMO METODAS IR INTELEKTINĖ SPRENDIMŲ PALAIKYMO SISTEMA

Daktaro disertacija

Technologijos mokslai,
statybos inžinerija (T 002)

Anglų kalbos redaktorė Jūratė Griškėnaitė
Lietuvių kalbos redaktorė Rita Malikėnienė

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