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MCDM Assessment of a Healthy and Safe Built Environment According to Sustainable Development Principles: A Practical Neighborhood Approach in Vilnius

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Abstract: Urbanization has a massive effect on the environment, both locally and globally. With an ever-increasing scale of construction and manufacturing and misuse of energy resources come poorer air quality, growing mortality rates and more rapid climate change. For these reasons, a healthy and safe built environment is ever more in demand. Global debates focus on sustainable development of the built environment; a rational approach to its analysis is multiple criteria decision making (MCDM) methods. Alternative MCDM methods applied to the same problem often produce different results. In the search for a more reliable tool, this study proposes that a system of MCDM methods should be applied to a single problem. This article assesses 21 neighborhoods in Vilnius in the context of a healthy and safe built environment in view of the principles of sustainable development. MCDM methods were used for this purpose: entropy, Criterion Impact LOSs (CILOS) and Integrated Determination of Objective Criteria Weights (IDOCRIW) methods were used to determine the objective weights of the criteria, while expert judgement determined the subjective weights. With the overall weights determined, the Vilnius neighborhoods were assessed through the application of COmplex PRoportional ASsessment (COPRAS), Simple Additive Weighting (SAW), Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) and Evaluation based on Distance from Average Solution (EDAS) methods. The final results were then processed using the rank average method, Borda count and Copeland's method.

Keywords: healthy and safe built environment; sustainable development; MCDM methods; neighborhoods; Vilnius

1. Introduction

The built environment is responsible for significant use of final energy (62%) and is a major source of greenhouse gas emissions (55%) [1]. According to Joffe and Smith [2], cities contribute the vast majority of emissions, and a growing proportion of the world's population lives in cities. With the ever-increasing scale of construction and manufacturing and misuse of energy resources come poorer air quality, growing mortality rates, more rapid climate change and other issues. Many scientists look at a healthy and safe environment in terms of land use, transport, architectural design policies and strategies, strategic planning, collaborative design, etc. [2–6]. Sallis et al. [3] argue that there is growing evidence suggesting that healthy urban design and transport policies can have benefits beyond health for environmental sustainability and economic vitality. An article by Mohtashami et al. [4] determines policies and strategies for the architectural design of healthy buildings according to the health and safety conditions that influence the quality of the internal spaces and the external environments of cities.

A healthy and safe built environment should be developed with the principles of sustainable development at its heart. Sustainable development is often classified according to the definition by the World Commission on Environment and Development (WCED), where development meets "the needs of the present without compromising the ability of future generations to meet their own needs" [7]. The WCED defines the concept of sustainable development as a strategy towards sustainability by optimizing the link between global society and its natural environment, taking into account society's social, economic and environmental goals. In their investigations of the built environment, foreign scientists also consider the three basic principles of sustainable development [8–12]. Huang and Yin [8], for instance, carried out an empirical study using hedonic price models to examine a comprehensive set of environmental sustainability elements including green spaces, transit systems and central business districts (CBDs), which showed that environmental sustainability elements had the greatest impact on house prices. Barbosa and Almeida [9] proposed the Sustainability Panel tool, which was designed to reveal separately the status of the dimensions in sustainable development (environmental, social and economic).

Various MCDM methods, such as Analytical Hierarchy Process (AHP), Elimination and Choice Expressing the Reality (in french "ELimination Et Choix Traduisant la REalité") (ELECTRE), Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS), COmplex PRoportional ASsessment (COPRAS) and Analysis Network Process (ANP) [13–19], can be applied to analyze a sustainable built environment. Karaca et al. [13] applied the fuzzy AHP and ELECTRE methods for a sustainability analysis of a futuristic idea, "City-Blood". Mulliner et al. [14] integrated AHP, TOPSIS and COPRAS for sustainable housing affordability. Nilashi et al. [15] developed a knowledge-based expert system for assessing the performance level of green buildings by using the AHP method. In the analysis of a healthy and safe built environment, this article also applies the MCDM methods: COPRAS, Simple Additive Weighting (SAW), TOPSIS, Evaluation based on Distance from Average Solution (EDAS) [20–22].

Environmental sustainability must go hand-in-hand with other important goals, such as promoting economic development, decreasing poverty and improving quality of life. The green agenda is a necessary part of holistic, city-led strategies for economic, social and environmental sustainability [23].

2. Research Methodology

The aim of this article is to assess a healthy and safe built environment. To reach this aim, secondary objectives are: (1) to integrate the principles of sustainable development; (2) to integrate MCDM methods; (3) to assess 21 neighborhoods in Vilnius. Figure 1 presents the research methodology.

Sustainable urban development is an attempt to ensure the balanced development of cities and their subdivisions to safeguard their citizens' welfare now without compromising their quality of life in the future. Social, economic, environmental and other sciences offer various methods for that purpose. Sustainable urban development aims to reduce poverty, improve the quality of life and social connections and relationships in communities, meet fundamental human needs, promote sustainable economic and political development and prevent harm to natural resources [24,25].

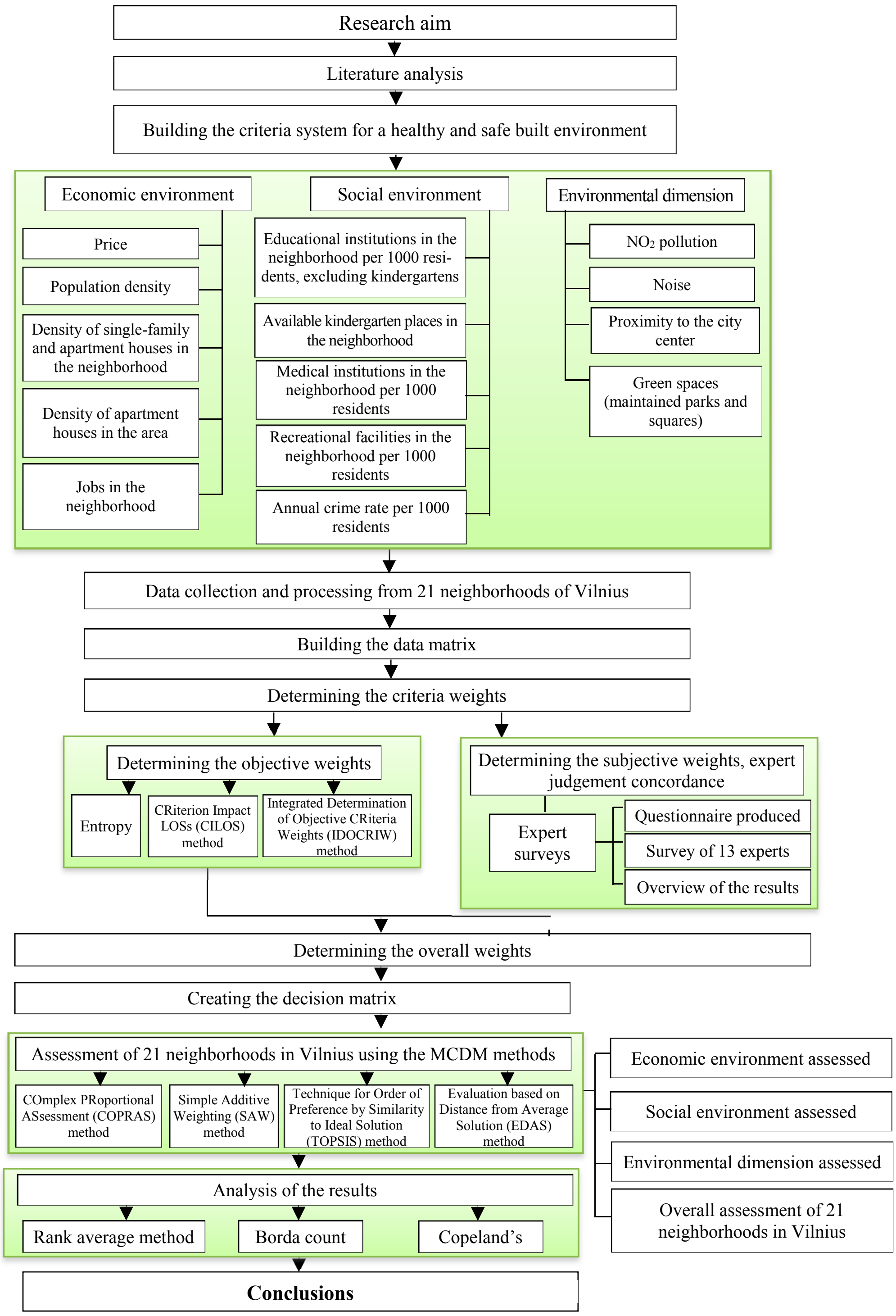

Figure 1. Research methodology.

Sustainable urban development can be seen as a yin-yang balance with contradicting goals [26–28]. Economic growth, for instance, is impossible without increasing the use of resources [29,30]. Therefore, some scientists propose lower consumption as a way of saving the environment. Sustainable economic development may not include the ecological, social and cultural dimensions of sustainable development. Debates are common in the scientific literature about whether a balance between the economic, environmental and social development of the built environment and cultural diversity is attainable in practice. Multiple criteria analysis methods are, therefore, perfect for the analysis of the sustainable development of cities and their subdivisions [31–34].

Many multiple criteria analysis methods are available [35–38]. The results they produce for the same problem with identical criteria, values and weights are often different. Therefore, the question is: which of these methods is the best option for specific problems [39–43]. Attempts to determine the superior multiple criteria analysis method have always been a source of many arguments and endless debates. Competing methods always exist. Often it is very difficult to establish whether the answer to a specific multiple criteria analysis method produced is right or wrong. To escape these issues, authors propose solving the same problem with an integrated set of multiple criteria analysis methods [44–46].

The integrated methodology of the multiple criteria analysis methods is presented below as a case analysis of 21 neighborhoods in Vilnius.

The literature analysis presented in Section 2 was the first step in the assessment of the healthy and safe built environment in the neighborhoods in Vilnius. Three key areas were identified in the criteria: the economic environment, the social environment and the environmental dimension. Based on the literature analysis, a criteria system for the assessment of a healthy and safe built environment was created. The data that were collected and processed are presented in a data matrix (Section 3). Data alone are not enough, however, for the assessment of the 21 neighborhoods in Vilnius. The objective criteria weights were determined using the entropy, CRiterion Impact LOSs (CILOS) and Integrated Determination of Objective CRiteria Weights (IDOCRIW) methods. The subjective weights were determined by expert judgement with 13 property experts surveyed using a questionnaire. Nine experts work for property companies, two for associations dealing with property, one for a construction company and one for an educational institution offering a property management study program. Of those involved in the assessment, 77% were female and 23% were male. All of the experts have university degrees. A look at the experience of the experts shows that 53.8% have been in property for 5–10 years, 38.5% have been in the field for less than five years and 7.7% have 10–15 years in the field. Section 4 outlines the theory of the computations behind the objective, subjective and overall weights. The COPRAS, SAW, TOPSIS and EDAS MCDM methods were applied in the assessment of the healthy and safe built environment in the neighborhoods in Vilnius. Section 5 deals with the theory of their computations. Section 6 presents the results, i.e., the computations of the objective, subjective and overall weights, the use of the MCDM methods in the neighborhood assessment according to each area (the economic environment, the social environment and the environmental dimension) alone and in the overall context. The overall results for the 21 neighborhoods in Vilnius were processed using the rank average, Borda count and Copeland's methods (Section 7). The discussion and conclusions follow in Section 8.

3. Criteria of a Sustainable Built Environment and the Assessment Criteria for a Healthy and Safe Built Environment

A built environment is developed in order to satisfy the residents' requirements. Human needs can be physiological or social and are related to security, respect and self-expression. People are interested in ecologically clean and almost noiseless environments with sufficient options for relaxation, shopping, easy access to work or other destinations and good relationships with neighbors [47].

Both indoor and outdoor built spaces affect human health. Buildings play a role in a person's quality of life, work and recreation, as well as health. Keall et al. [48], for instance, tested the safety benefits of home modifications. The results suggest that about 38% of the home injuries studied were potentially related to a structural aspect of the home environment [49]. Buildings are also a significant source of pollution. They account for almost half of sulfur dioxide emissions, 25% of nitrous oxide emissions, 10% of particulate matter emissions and about 35% of carbon emissions, all contributing to climate change [47].

According to the classical conception, sustainable development consists of social, economic and environmental components [50]. Urbanization and growing numbers of construction projects lead to greater building and population densities. Anderson et al.'s [1] detailed analysis shows that the influence of density on carbon dioxide is limited and can vary significantly between households in similar density locations due to socio-economic factors. High residential density is an important element of the compact city concept alongside mixed land use, well-connected urban layouts and easily accessible public transport networks [51]. Dempsey et al. [51] specifically makes reference to the relationship between density and aspects of social sustainability, specifically social equity, environmental equity and sustainability of community.

A sustainable built environment is, therefore, inseparable from attempts to build sustainable communities [14,51–58]. Maliene and Malys [52] developed a model of sustainable housing development for sustainable communities, which can be adapted to any town and which will help to create healthy and attractive communities. Sustainable housing is characterized as being available, good quality, economical, ecological, comfortable and cozy. For communities to be sustainable, they must provide hospitals, schools, shops, good public transport, open public spaces and a clean and safe environment. According to Maliene and Malys [52], most importantly, sustainable communities must provide decent homes at prices people can afford. According to Ceccato and Lukyte [53], a sustainable community is a place free from the fear of crime, where a feeling of security underpins a wider sense of place attachment and place attractiveness. Researchers propose that safety is a central dimension of the contemporary debate on urban sustainable development. Viteikiene and [50], Dempsey et al. [51], Lee et al. [54], Charoenkit, Kumar [59], Conejos et al. [60,61], Cozens [62] and others have also analyzed the criteria of safety. Cozens [62] claims that such issues as crime and the fear of crime are not effectively represented within most sustainability agendas and require explicit inclusion. He provides recommendations for integrating crime and the fear of crime within urban sustainability [62].

In terms of a healthy and safe environment, outdoor recreation is an inseparable assessment criteria for a sustainable built environment. Engaging in outdoor recreation contributes significantly to the better physical, mental and spiritual health of individuals [63]. Green spaces, including open water and parks, are a significant component in health promotion and play an important role in improving the health of cities and their residents [8].

A summary of previous research is shown in Table 1. A bibliometric analysis of the criteria subsystems and the criteria defining the assessment system of a healthy and safe built environment is presented in Table 2.

Table 1. Summary of previous research.

Authors	Assessment Criteria for a Sustainable Built Environment as a Building Block of a Healthy and Safe Environment
Anderson et al. [1]	Urban form, density (residential, job, neighborhoods), transportation, infrastructure, consumption.
Huang and Yin [8]	House prices, green spaces.
Mulliner et al. [14,57]	House prices in relation to incomes, rental costs in relation to incomes, interest rates and mortgage availability, availability of social and private rented accommodation, availability of affordable home ownership products, safety (crime level), access to employment opportunities, access to public transport services, access to good quality schools, access to shops, access to health services, access to childcare, access to leisure facilities, access to open green public spaces, quality of housing, energy efficiency of housing, availability of waste management facilities, desirability of the neighborhood area, deprivation in the area, environmental problems (e.g., litter, traffic).
Kaklauskas et al. [47]	Green spaces, infrastructure, transportation, unemployment, vandalism, education, neighborhood, air quality, social and recreational centers, ecologically-clean and almost noiseless environments.
Viteikiene and Zavadskas [50]	The city center is close, extensive supply of trade services, the schools are close, the kindergartens are close, extensive recreational opportunities, clean air, a nice environment, safe, good transport service to the city center, good transport service to the workplace, a well-attended environment, no noise, no drug addicts, the policlinics are close, the drugstores are close, good facilities for sports, lots of cultural institutions, no alcoholics in sight, no homeless people in sight, the workplace is close, pleasant architecture, well-attended parks.

Table 1. *Cont.*

Authors	Assessment Criteria for a Sustainable Built Environment as a Building Block of a Healthy and Safe Environment
Dempsey et al. [51]	Density, accessible public transport networks, access to services and facilities, safety, job opportunities, education, the neighborhood, green/open spaces, safety and security.
Maliene and Malys [52]	Hospitals, schools, shops, good public transport, clean and safe environment, open public spaces, affordability, technical and hygienic requirements, energy saving, ecological building materials.
Ceccato and Lukyte [53]	Crime level.
Lee et al. [54]	Housing, neighborhood facilities, childcare facilities, infrastructure, recreation and open space, health and safety, community safety, sport, leisure and recreation.
Sohn [58]	Density (residential crime, population, bus-stops, parks, streets, intersections), distance to the closest police station, median household income score, average number of building stories.
Charoenkit and Kumar [59]	Efficient use of land, walkability, access to public transport, safety, number of jobs/schools/amenities/parks, hospitals, etc., number of residential units, density.
Conejos et al. [60,61]	Density, accessibility, occupational health, safety and security, neighborhood and amenity.
Cozens [62]	Crime level.
Arni and Khairil [63]	Green spaces, recreation and leisure.
Chan and Lee [64]	Mass transport, houses, schools, care centers, hospitals, schools, leisure activities, availability of job opportunities, safety and security, density, open spaces and green areas, without traveling too far.
Deng and Quigley [65]	Average transaction price, housing stock.
El Asmar and Taki [66]	Air pollution, water pollution, building density, population, noise.
Fitzgerald et al. [67]	The criteria are grouped into the environment index (recycling, per capita waste volume, sewerage connections, forest areas within a 10-km radius, green energy interests, transport CO_2 emissions, level of wastewater treatment etc.), the Socio-Economic index (services index, population density, households with central heating, house price income ratio etc.), the Quality of Life index (health insurance cover, distance to the nearest hospital, community involvement, odor problems, noise problems, sports area satisfaction, green area satisfaction etc.), the Transport index (relative car use, work distance <8 km, work distance >24 km, public transport use, km to the nearest train station, traffic flow index, monthly distance travelled to shops, distance to work, etc.).
Lamķquiz and López-Domķnguez [68]	Mobility habits, population, job, neighborhood, accessibility.
Nuuter et al. [69]	General economic criteria (GDP per capital, unemployment rate, inflation rate), housing stock criteria (total dwelling stock, number of dwellings, private ownership rate etc.), housing affordability criteria (total housing costs in Purchasing Power Standards (PPS), share of housing costs in disposable incomes, harmonized consumer price in housing index, aggregated affordability index, normal house price index etc.), population and social conditions (inequality of income distribution, population at risk of poverty, population with severe housing deprivation, etc.), housing quality criteria (housing overcrowding rate, average household size, etc.), environmental quality criteria (healthcare index, traffic index, noise from neighbors and street, pollution, crime, quality of life index, etc.).
Oltean-Dumbrava et al. [70]	Noise level, pollution.
Sun et al. [71]	The criteria for economic development mainly reflect three aspects of the urban economy: overall economic strength, people's living standards and the industrial structure. The criteria for social progress mainly reflect three aspects of urban society: population quality, public services and living conditions. The criteria for the ecological infrastructure construction mainly include three perspectives of urban ecological infrastructure: the number of green spaces, land utilization and pollution control.
Xing et al. [72]	Environmental impact: energy, depletion of resource, climate changes: CO_2 emissions, land use, waste, air pollution, biodiversity, water pollution, noise, ground pollution. Social impact: health, quality of life, crime, transportation, leisure, social capital, security, high unemployment, social equity, cultural diversity. Economic impact: whole life cost, job creation, economic growth, unaffordable housing, socio-economic inequity, economic development, wealth, distribution of wealth, leakage from local economies, built facilities/service.
Yin et al. [73]	Population density, housing affordability, greenhouse gas emissions, protection of open spaces, environmentally sensitive habitats, road accessibility.

Table 2. Bibliometric analysis of the criteria subsystems and the criteria defining the Assessment System of a Healthy and Safe Built Environment.

	Science Direct, Publications	Google Scholar, Results
Subsystem of economic environment criteria		
"Healthy and safe" "built environment" "cost"	13,110	16,000
2017 (45), 2016 (1065), 2015 (987), 2014 (901), 2013 (781), 2012 (730), 2011 (513), 2010 (536), 2009 (487), 2008 (549), 2007 (488), 2006 (472), 2005 (461), 2004 (341), 2003 (350), 2002 (312), 2001 (310), 2000 (264), 1999 (238), 1998 (222), 1997 and earlier (3058)		
"Healthy and safe" "built environment" "density"	4546	6770
2017 (20), 2016 (418), 2015 (355), 2014 (314), 2013 (291), 2012 (291), 2011 (178), 2010 (183), 2009 (146), 2008 (162), 2007 (141), 2006 (127), 2005 (172), 2004 (100), 2003 (124), 2002 (99), 2001 (98), 2000 (79), 1999 (70), 1998 (59), 1997 and earlier (1119)		
"Healthy and safe" "built environment" "jobs"	6966	7470
2017 (24), 2016 (515), 2015 (523), 2014 (453), 2013 (425), 2012 (363), 2011 (271), 2010 (315), 2009 (256), 2008 (329), 2007 (263), 2006 (282), 2005 (256), 2004 (191), 2003 (210), 2002 (157), 2001 (142), 2000 (147), 1999 (142), 1998 (119), 1997 and earlier (1583)		
Subsystem of social environment criteria		
"Healthy and safe" "built environment" "schools"	7239	8660
2017 (21), 2016 (633), 2015 (574), 2014 (547), 2013 (494), 2012 (413), 2011 (307), 2010 (325), 2009 (303), 2008 (353), 2007 (272), 2006 (288), 2005 (247), 2004 (156), 2003 (161), 2002 (138), 2001 (136), 2000 (133), 1999 (98), 1998 (85), 1997 and earlier (1555)		
"Healthy and safe" "built environment" "pre-school"	324	409
2016 (11), 2015 (12), 2014 (15), 2013 (20), 2012 (6), 2011 (9), 2010 (11), 2009 (8), 2008 (16), 2007 (10), 2006 (4), 2005 (6), 2004 (3), 2003 (3), 2002 (2), 2001 (4), 2000 (3), 1999 (7), 1998 (7), 1997 (3), 1996 and earlier (24)		
"Healthy and safe" "built environment" "hospitals"	3990	4290
2017 (13), 2016 (248), 2015 (274), 2014 (276), 2013 (208), 2012 (197), 2011 (147), 2010 (185), 2009 (172), 2008 (198), 2007 (163), 2006 (190), 2005 (144), 2004 (92), 2003 (96), 2002 (110), 2001 (68), 2000 (93), 1999 (58), 1998 (43), 1997 and earlier (1015)		
"Healthy and safe" "built environment" "leisure"	1282	4340
2017 (3), 2016 (60), 2015 (59), 2014 (62), 2013 (62), 2012 (57), 2011 (43), 2010 (63), 2009 (58), 2008 (82), 2007 (71), 2006 (78), 2005 (63), 2004 (42), 2003 (39), 2002 (41), 2001 (29), 2000 (20), 1999 (30), 1998 (28), 1997 and earlier (292)		
"Healthy and safe" "built environment" "crime"	1310	4290
2017 (4), 2016 (109), 2015 (92), 2014 (85), 2013 (109), 2012 (63), 2011 (54), 2010 (58), 2009 (50), 2008 (71), 2007 (53), 2006 (66), 2005 (56), 2004 (26), 2003 (34), 2002 (28), 2001 (32), 2000 (28), 1999 (15), 1998 (17), 1997 and earlier (260)		
Subsystem of environmental criteria		
"Healthy and safe" "built environment" "pollution"	5574	8490
2017 (11), 2016 (447), 2015 (355), 2014 (353), 2013 (290), 2012 (301), 2011 (213), 2010 (179), 2009 (191), 2008 (204), 2007 (155), 2006 (166), 2005 (202), 2004 (127), 2003 (131), 2002 (143), 2001 (138), 2000 (121), 1999 (102), 1998 (106), 1997 and earlier (1639)		
"Healthy and safe" "built environment" "noise"	3594	6170
2017 (13), 2016 (266), 2015 (228), 2014 (242), 2013 (208), 2012 (196), 2011 (142), 2010 (125), 2009 (126), 2008 (150), 2007 (118), 2006 (116), 2005 (125), 2004 (70), 2003 (115), 2002 (99), 2001 (64), 2000 (67), 1999 (66), 1998 (57), 1997 and earlier (1001)		

Table 2. *Cont.*

	Science Direct, Publications	Google Scholar, Results
"Healthy and safe" "built environment" "distance"	5639	7490
2017 (24), 2016 (472), 2015 (438), 2014 (369), 2013 (360), 2012 (341), 2011 (229), 2010 (255), 2009 (198), 2008 (236), 2007 (208), 2006 (178), 2005 (190), 2004 (136), 2003 (166), 2002 (126), 2001 (114), 2000 (110), 1999 (86), 1998 (90), 1997 and earlier (1313)		
"Healthy and safe" "built environment" "parks"	4002	5510
2017 (9), 2016 (290), 2015 (240), 2014 (246), 2013 (232), 2012 (202), 2011 (151), 2010 (166), 2009 (167), 2008 (194), 2007 (157), 2006 (158), 2005 (157), 2004 (89), 2003 (88), 2002 (98), 2001 (83), 2000 (77), 1999 (64), 1998 (56), 1997 and earlier (1078)		

This article aims to assess the built environment in view of the principles of sustainable development with a focus on a healthy and safe environment. Analysis shows that, although researchers integrate different assessment criteria, the criteria are sorted under three labels of key sustainable development principles: economic, social and environmental. An analysis of the worldwide literature suggests that authors use different criteria systems in their assessments of a healthy and safe environment (Table 1). Table 3 summarizes the results. It lists the overall prevailing criteria and presents the system of criteria against which a healthy and safe environment is assessed. The number of sustainable built environment criteria analyzed during the project "Construction and Real Estate—Developing Indicators for Transparency" was in the hundreds [74]. In view of the results summarized in Tables 1–3, the authors have drawn up an assessment system for a sustainable built environment with a focus on the principles of health and safety from a holistic perspective. The assessment criteria for a healthy and safe built environment based on the principles of sustainability are as follows:

- Economic environment factors:
    - housing prices;
    - population density;
    - density of single-family and two-family houses;
    - density of blocks of flats;
    - number of jobs.
- Social environment factors:
    - number of educational institutions (except for kindergartens);
    - number of places in kindergartens;
    - number of healthcare institutions;
    - number of recreational facilities;
    - crime rates.
- Environmental factors:
    - air pollution;
    - noise;
    - distance to the city center;
    - green spaces (maintained large parks and small green urban spaces).

Table 3. Drawing up the system of the assessment criteria for a healthy and safe built environment based on the principles of sustainability.

	Economic Environment Factors					Social Environment Factors					Environmental Factors				
	Housing Prices	Population Density	Density of Single-Family and Two-Family Houses	Density of Blocks of Flats	Number of Jobs	Number of Educational Institutions (Except for Kindergartens)	Number of Places in Kindergartens	Number of Healthcare Institutions	Number of Recreational Facilities	Crime Rates	Air Pollution NO_2	Noise	Distance to the City Centre	Green Spaces (Maintained Large Parks and Small Green Urban Spaces)	% [1]
Anderson et al. [1]		+	+	+	+								+		35.71
Huang and Yin [8]	+				+								+	+	28.57
Mulliner et al. [14,57]	+				+	+	+	+	+	+			+	+	64.29
Kaklauskas et al. [47]					+	+		+	+	+	+	+	+	+	64.29
Viteikiene and Zavadskas [50]		+			+	+	+	+	+	+	+	+	+	+	78.57
Dempsey et al. [51]		+	+	+	+					+	+		+	+	57.14
Maliene and Malys [52]	+					+	+	+	+	+	+			+	57.14
Ceccato and Lukyte [53]		+			+					+					21.43
Lee et al. [54]		+					+	+	+	+				+	42.86
Sohn [58]		+								+			+	+	28.57
Charoenkit and Kumar [59]			+	+	+	+	+	+	+	+			+	+	71.43
Conejos et al. [60,61]		+						+		+			+		28.57
Cozens [62]		+								+					14.29
Arni and Khairil [63]									+					+	14.29
Chan and Lee [64]		+	+	+	+	+	+	+	+	+			+	+	78.57
Deng and Quigley [65]	+		+	+											21.43
El Asmar and Taki [66]		+	+	+							+	+			35.71
Fitzgerald et al. [67]	+	+			+	+		+	+		+	+	+	+	71.43
Lamķquiz and López-Domķnguez [68]		+			+								+		21.43
Nuuter et al. [69]	+	+	+	+				+		+	+	+			57.14
Oltean-Dumbrava et al. [70]											+	+			14.29
Sun et al. [71]	+	+						+			+			+	35.71
Xing et al. [72]	+				+	+	+	+	+	+	+	+			64.29
Yin et al. [73]	+	+											+	+	28.57
% [2]	38.46	61.54	26.92	26.92	50.00	34.62	30.77	53.85	42.31	61.54	38.46	26.92	57.69	57.69	

[1] Calculations were made to determine the percentage proportion of the criteria proposed by the authors of this article made in articles by other authors. [2] Calculations were made to determine the percentage proportion of the criteria proposed by the authors of this article made in the literature review.

4. Selection of the Survey Object

Vilnius is the capital of Lithuania. It is leader over the other cities in the country with the biggest population concentration and the largest economic potential. Its future is connected to ongoing urbanization processes, open market changes and evolution (Vilniaus miesto savivaldybė 2007). For this reason, Vilnius is the focus of this research.

Vilnius comprises 21 neighborhoods: Verkiai, Antakalnis, Pašilaičiai, Fabijoniškės, Pilaitė, Justiniškės, Viršuliškės, Šeškinė, Šnipiškės, Žirmūnai, Karoliniškės, Žvėrynas, Grigiškės, Lazdynai, Vilkpėdė, Naujamiestis, Senamiestis, Naujoji Vilnia, Paneriai, Naujininkai and Rasos. A healthy and safe built environment was assessed within the boundaries of these neighborhoods. The data were collected and processed from various sources, such as Statistics Lithuania, the Vilnius City Municipality, the Vilnius City Social Support Centre, the property portal Aruodas. It, the online portal Kurgyvenu. It run by CodeIn, the National Public Health Surveillance Laboratory and Google Maps. Table 4 presents the input data matrix for the alternatives that are assessed.

Table 4. The input data matrix for the assessment of the neighborhoods in Vilnius.

		Matavimo Vnt	**Min/ Max ***	**Antakalnis**	**Fabijoniškės**	**Grigiškės**	**Justiniškės**	**Karoliniškės**	**Lazdynai**	**Naujamiestis**	**Naujininkai**	**Naujoji Vilnia**	**Paneriai**
Economic environment factors	Housing prices	Eur/m^2	-	1888.34	1154.10	676.10	1080.61	1222.06	1190.30	1711.44	967.13	854.64	950.14
	Population density	Residents number/km^2	-	504.40	9697.32	1580.99	9215.44	6817.50	3019.13	4840.00	758.42	793.16	91.12
	Density of single-family and two-family houses	Number/km^2	+	44.62	106.59	76.90	39.26	11.50	54.66	116.04	40.54	89.03	19.11
	Density of blocks of flats	Number /km^2	-	3.60	42.20	14.79	86.58	12.75	14.17	33.54	6.18	8.22	1.04
	Number of jobs per 1000 residents	Number	+	18.20	9.30	2.00	4.60	7.20	7.20	94.60	21.50	11.00	41.70
Social environment factors	Number of educational institutions (except for kindergartens)	Institutions 1000 residents	+	0.4366	0.2515	0.3563	0.2549	0.3667	0.2894	0.5596	0.1925	0.5454	0.3876
	Number of places in kindergartens	Number	+	1630	1567	634	1731	1541	2104	1507	1371	1250	318
	Number of healthcare institutions per 1000 residents	Institutions 1000 residents	+	0.4622	0.1006	0.0891	0.1821	0.1100	0.0965	0.3444	0.1283	0.0962	0.2584
	Recreational facilities in the neighborhood per 1000 residents	Institutions 1000 residents	+	0.0770	0.1006	0.5345	0.1457	0.1834	0.0965	0.3874	0.2566	0.1283	0.3876
	Annual crime rate per 1000 residents	Number	-	5.6497	6.2627	5.7907	4.843	5.6105	4.7395	13.1284	15.2385	8.9562	13.6951
Environmental factors	Air pollution NO_2	μg/m^3	-	16.5	18.4	12.8	8.9	19.89	33.4	16.87	11.6	19.92	15.15
	Noise	dB	-	69.4	62.93	64.49	44.2	55.57	56.22	56.94	54.37	52.05	53.29
	Distance to the city center	km	-	4.3	5.4	19.8	6.6	6.9	7.1	1.6	4.1	12.6	14.3
	Green spaces (maintained large parks and small green urban spaces)	%	+	7.20	11.15	1.14	1.34	7.39	2.69	1.83	1.22	3.43	1.22

Table 4. *Cont.*

		Matavimo Vnt	Min/ Max *	Pašilaičiai	Pilaitė	Rasos	Senamiestis	Šeškinė	Verkiai	Vilk-pėdė	Viršu-liškės	Žirmūnai	Žvėrynas	Šnipiškės
Economic environment factors	Housing prices	Eur/m^2	-	1136.80	1243.52	1601.00	2221.89	1055.02	1481.19	1205.37	1175.03	1582.93	2153.47	1612.65
	Population density	Residents number/km^2	-	4031.22	1472.46	834.41	4321.56	7121.14	757.93	2072.43	5893.20	5455.29	4103.33	4917.31
	Density of single-family and two-family houses	Number/km^2	+	74.88	48.84	97.48	186.22	55.00	70.87	38.54	22.80	23.18	256.30	188.78
	Density of blocks of flats	Number /km^2	-	13.29	7.68	9.37	40.67	41.36	5.03	11.55	31.60	27.65	72.59	56.09
	Number of jobs (per 1000 residents)	Number	+	10.70	6.00	7.70	49.20	9.20	22.30	9.50	7.30	37.90	10.40	21.50
Social environment factors	Number of educational institutions (except for kindergartens)	Institutions 1000 residents	+	0.1513	0.1969	0.2831	0.9256	0.2553	0.1897	0.2811	0.5430	0.2588	0.5416	0.2607
	Number of places in kindergartens	Number	+	1679	551	513	1015	2067	1787	1009	897	1479	1002	746
	Number of healthcare institutions per 1000 residents	Institutions 1000 residents	+	0.1513	0.1476	0.1887	0.4628	0.0638	0.3319	0.4685	0.0679	0.2804	0.2708	0.0652
	Recreational facilities in the neighborhood per 1000 residents	Institutions 1000 residents	+	0.0908	0.3445	0.0944	0.8227	0.1596	0.0948	0.0937	0.4751	0.2157	0.7221	0.3911
	Annual crime rate per 1000 residents	Number	-	5.9595	4.5276	13.7775	13.421	5.9681	5.9983	11.1965	6.7195	5.9737	7.2207	13.9486
Environmental factors	Air pollution NO_2	μg/m^3	-	11.00	11.20	29.16	15.36	13.47	11.07	11.90	10.07	26.37	23.92	33.72
	Noise	dB	-	48.34	49.55	52.43	54.96	52.68	31.82	53.72	45.64	57.69	49.17	41.56
	Distance to the city center	Km	-	5.9	7.1	2.5	1.6	3.7	4.9	2.9	5.7	5.6	1.2	2.3
	Green spaces (maintained large parks and small green urban spaces)	%	+	4.48	0.04	7.37	21.66	8.67	20.03	17.80	10.75	2.78	1.77	0.21

* The sign + (−) indicates that a greater (lesser) criterion value corresponds to a greater (lesser) significance for stakeholders.

5. The Criteria Weights' Determination Methods

The MCDM methods involve the decision matrix $R = \|r_{ij}\|$, statistical data on the criteria or expert judgements, and the vector of criteria significances (weights) $\Omega = (\omega_j)$, where $i = 1, 2, \ldots, n$; $j = 1, 2, \ldots, m$; m denote the number of criteria; n is the number of the compared alternatives.

Criteria weights may be objective or subjective. As the criteria are assessed, the data structure can be evaluated, and the real prevalence, or the objective weight, of each criteria is determined. Combination weighting is based on the integration of subjective weighting and objective weighting [20,75,76]. In this research, we use such methods as entropy, the Criterion Impact Loss (CILOS) and the Integrated Determination of Objective Criteria Weights (IDOCRIW) (Section 5.1). Subjective weights based on expert judgement are, however, more common in practice [77]. Subjective criteria weights, as overall averages of expert opinions, may be applied in a multiple criteria assessment if the expert opinions are in concordance. Section 5.2 presents how the subjective weights were determined.

5.1. Determining the Objective Criteria Weights

5.1.1. The Entropy Method

The entropy method was offered by Shannon [78]. Entropy weights are defined as follows [20,76,79]:

The criteria values are normalized using Equation (1):

$$\widetilde{r}_{ij} = \frac{r_{ij}}{\sum_{i=1}^{n} r_{ij}} \tag{1}$$

The entropy level of each criteria is calculated as follows:

$$E_j = -\frac{1}{\ln n}\sum_{i=1}^{n} \widetilde{r}_{ij} \cdot \ln \widetilde{r}_{ij}, (j = 1, 2, \ldots, m; 0 \leq E_j \leq 1), \tag{2}$$

The degree of diversification of each criteria j is calculated:

$$d_j = 1 - E_j, \tag{3}$$

The entropy weights are calculated as d_j normalized values:

$$W_j = \frac{d_j}{\sum_{j=1}^{m} d_j} \tag{4}$$

The entropy weights reflect the structure of the data and the degree of their non-homogeneity. The weight of the homogeneous data (when the criteria values do not differ considerably), which is obtained by the entropy method (4), is about zero and does not have a strong influence on the evaluation. The largest weight of the criteria obtained by using the entropy method corresponds to the criteria with the highest weight ratio.

5.1.2. The Criteria Impact Loss: CILOS Method

This is another promising criteria impact loss method and a determination of objective weights [80]. This method evaluates the loss of each criteria, until one of the remaining criteria reaches the optimum. This method's algorithm, formalization, description and application are presented [76]. The logic of this method, the basic ideas, stages and a calculation algorithm are executed by the procedure that is given below.

The criteria that are minimized are transformed into maximizing ones, according to the following equation:

$$\bar{r}_{ij} = \frac{\min_i r_{ij}}{r_{ij}} \tag{5}$$

The new matrix is denoted as $X = \|x_{ij}\|$. The maximum values of each column (i.e., every criteria) are calculated: $x_j = \max_i x_{ij} = x_{k_j j}$ where the k_j j-th lines of the column with the largest element number.

A square matrix $A = \|a_{ij}\|$ is formed from the k_j-th rows values of matrix X; $a_{jj} = x_j$ ($i, j = 1, 2, \ldots, m$; m, number of criteria).

Matrix $P = \|p_{ij}\|$ of the relative losses is given below:

$$p_{ij} = \frac{x_j - a_{ij}}{x_j} (p_{ii} = 0; i, j = 1, 2, \ldots, m) \tag{6}$$

Elements p_{ij} of the P matrix show what the relative loss of the j-th criterion will be, if the i-th criterion is selected to be the best.

Weights $q = (q_1, q_2, \ldots, q_m)$ can be found from the system:

$$Fq = 0, \tag{7}$$

where matrix F is as follows:

$$F = \begin{pmatrix} -\sum_{i=1}^{m} p_{i1} & p_{12} & \cdots & p_{1m} \\ p_{21} & -\sum_{i=1}^{m} p_{i2} & & p_{2m} \\ & \cdots & & \\ p_{m1} & p_{m2} & \cdots & -\sum_{i=1}^{m} p_{im} \end{pmatrix} \tag{8}$$

The method based on the criteria significance loss offsets the drawback of the entropy method. Thus, when the values of the criteria do not differ considerably, elements p_{ij} of matrix P of the relative loss of the criteria's impact (6) approach zero, while the respective criteria weight increases and has a great impact on the evaluation. In the case of homogeneity, when the values of one of the criteria are the same in all of the alternatives, all of the relative losses of the criteria, as well as their total loss, are equal to zero. Therefore, the linear system of Equation (7) makes no sense because one column of elements in matrix P is equal to zero.

5.1.3. Aggregate Objective Weights: The IDOCRIW Method

Using the idea of the different significance weights to connect to a single overall weight [20], it is possible to connect entropy weights W_j and weights q_j of the criteria impact loss methods to the common objective criteria for the assessment of the structure of the array weights ω_j [76]:

$$\omega_j = \frac{q_j W_j}{\sum_{j=1}^{m} q_j W_j} \tag{9}$$

These weights will emphasize the separation of the particular values of the criteria (entropy characteristic), but the impact of these criteria decreases due the higher loss in the other criteria.

The calculated weights of the entropy and criteria loss of impact are combined into aggregated weights and are then used in the multi-criteria assessment to rank the options and select the best alternative.

5.2. Determining the Subjective Criteria Weights Based on an Expert Survey

Most of the currently-known methods applied when determining criteria weights in multiple criteria assessment are based on expert judgement. Assessments by professional experts form the basis for subjective criteria weights. The assessments depend on the experts' qualifications, job specifics, interests, work experience, and so on. The method of direct criteria weight determination is applied in research where the sum of the weights of all assessments c_{jk} by each expert must be equal to one (or 100%).

The direct basis weights of the j-th criteria are calculated using the following equation:

$$w_j = \frac{\sum_{k=1}^{r} c_{jk}}{\sum_{j=1}^{m} \sum_{k=1}^{r} c_{jk}} \tag{10}$$

where $j = 1, 2, \ldots, m$; m is the number of criteria, and r is the number of experts.

Table 7 (in the last column) lists the weights of each environment and criteria.

5.3. Overall Objective and Subjective Weights

Once the entropy, CILOS and IDOCRIW methods have produced the objective weights and the expert judgement has produced the subjective weights, the overall weights that make calculations more reliable can be determined.

The overall weights are calculated using Equation (11), which combines subjective weights w_j and objective weights ω_j:

$$\alpha_j = \frac{w_j \omega_j}{\sum_{j=1}^{m} w_j \omega_j} \tag{11}$$

Once the criteria weights are known, the multiple criteria assessment using COPRAS, SAW, TOPSIS and EDAS is performed.

6. The Methods Applied

6.1. The COPRAS Method

The criteria of the COPRAS (Complex Proportional Assessment) method) [22] Z_i were calculated as follows:

$$Z_i = S_{+i} + \frac{\sum\limits_{i=1}^{n} S_{-i}}{S_{-i} \sum\limits_{i=1}^{n} \frac{1}{S_{-i}}} \tag{12}$$

$S_{+i} = \sum\limits_{j=1}^{m} \omega_j \widetilde{r}_{+ij}$ is the sum of the weighted values of the maximized criteria $\widetilde{r}_{+ij}$,

$S_{-i} = \sum\limits_{j=1}^{m} \omega_j \widetilde{r}_{-ij}$ is same for the minimized criteria, where ω_j is the weight of the j-th criteria, and $\widetilde{r}_{ij}$ is normalized by using Equation (1), the value of the j-th criteria for the i-th alternative.

6.2. The SAW Method

The basic idea behind the MCDM methods is to combine the criteria values and weights to obtain a single point of reference for evaluation, i.e., the method's criteria. A common example is SAW [81], where the method's evaluation criteria S_i are calculated by using Equation (13):

$$S_i = \sum_{j=1}^{m} \omega_j \widetilde{r}_{ij}, \tag{13}$$

where ω_j is the weight of the j-th criteria and $\widetilde{r}_{ij}$ is normalized by using Equation (1), the value of the j-th criteria for the i-th alternative.

6.3. The TOPSIS Method

The TOPSIS method [20] is based on vector normalization:

$$\widetilde{r}_{ij} = \frac{r_{ij}}{\sqrt{\sum_{i=1}^{n} r_{ij}^2}} (i = 1, \ldots, n; j = 1, \ldots, m) \tag{14}$$

where $\widetilde{r}_{ij}$ is the normalized value of the j-th criteria for the i-th alternative.

The best alternative V^* and the worst alternative V^- were calculated by:

$$V* = \{V_1^*, V_2^*, \ldots, V_m^*\} = \left\{(\max_i \omega_j \widetilde{r}_{ij} / j \in J_1), (\min_i \omega_j \widetilde{r}_{ij} / j \in J_2)\right\}, \tag{15}$$

$$V^- = \left\{V_1^-, V_2^-, \ldots, V_m^-\right\} = \left\{((\min_i \omega_j \widetilde{r}_{ij} / j \in J_1), ((\max_i \omega_j \widetilde{r}_{ij} / j \in J_2)\right\}, \tag{16}$$

where J_1 is a set of indices of the maximized criteria and J_2 is a set of indices of the minimized criteria.

Distance D_i^* of every considered alternative to the ideal (best) solutions and its distance D_i^- to the worst solutions were calculated by:

$$D_i^* = \sqrt{\sum_{j=1}^{m} (\omega_j \widetilde{r}_{ij} - V_j^*)^2} \tag{17}$$

$$D_i^- = \sqrt{\sum_{j=1}^{m} (\omega_j \widetilde{r}_{ij} - V_j^-)^2} \tag{18}$$

Criteria C_i^* of the method *TOPSIS* were calculated by:

$$C_i^* = \frac{D_i^-}{D_i^* + D_i^-} (i = 1, \ldots, n) \tag{19}$$

$(0 \leq C_i^* \leq 1)$.

6.4. The EDAS Method

The EDAS (Evaluation Based on Distance from Average Solution) method is similar to the TOPSIS method. In the EDAS method, the best alternative is related to the distance from the average solution [21]. In this method, the authors have two measures dealing with the desirability of the alternatives. The first measure is the Positive Distance from the average (PD), and the second is the Negative Distance from the average (ND). The evaluation of the alternatives is made according to higher values of PD and lower values of ND. The steps for using the EDAS method are presented as follows:

Step 1: Construct the decisions matrix (R):

$$R = \| r_{ij} \|, \tag{20}$$

and the criteria weights vector:

$$\Omega = (\omega_j), \tag{21}$$

Step 2: Calculate the average of all of the criteria:

$$AV_j = \sum_{i=1}^{n} r_{ij} / n \tag{22}$$

Step 3: Calculate the positive distance (*PD*) and the negative distance (*ND*) from the average:

$$PD_{ij} = \frac{\max(0, (r_{ij} - AV_j))}{AV_j} \quad (23)$$

$$ND_{ij} = \frac{\max(0, (AV_j - r_{ij}))}{AV_j} \quad (24)$$

The *j*-th criteria are maximized, and:

$$PD_{ij} = \frac{\max(0, (AV_j - r_{ij}))}{AV_j} \quad (25)$$

$$ND_{ij} = \frac{\max(0, (r_{ij} - AV_j))}{AV_j} \quad (26)$$

The *j*-th criteria are minimized.

Step 4: Determine the weighted sum of *PD* and *ND* for all of the alternatives:

$$SP_i = \sum_{j=1}^{m} \omega_j PD_{ij} \quad (27)$$

$$SN_i = \sum_{j=1}^{m} \omega_j ND_{ij} \quad (28)$$

Step 5: Normalize the values of *SP* and *SN* for all of the alternatives:

$$NSP_i = \frac{SP_i}{\max_i SP_i} \quad (29)$$

$$NSN_i = 1 - \frac{SN_i}{\max_i SN_i} \quad (30)$$

Step 6: Calculate the appraisal score (*AS*) for all of the alternatives:

$$AS_i = \frac{1}{2}(NSP_i + NSN_i) \quad (31)$$

where $0 \leq AS_i \leq 1$.

6.5. Borda Count and Copeland's Methods

Different MCDM methods usually produce different assessment results (ranks). The Borda count [82,83] and Copeland's method [84,85] can be used as tools for the ranking of alternatives based on all MCDM assessments. The two methods use the following calculation algorithm:

1. A matrix for the assessment (ranking) S_{ij} ($i = \overline{1,n}; j = \overline{1,k}$) of alternatives ($a_1, a_2, \ldots, a_n$) is built with the methods $M_1, M_2, \ldots, M_k$ applied (Table 5). The average ranking $S_1, S_2, \ldots, S_n$ for each alternative is calculated.
2. The average rankings are then used for paired comparison of the rationality of all alternatives to determine which alternative has the lower average. Matrix B for the comparison of alternatives is built (Table 6). The alternatives compared in the matrix score either one or zero, where one signifies that the alternative in that row is more rational than the alternative in that column, and zero signifies that the alternative is not more rational or they both are equally rational.
3. The relative rationality values of each alternative (neighborhood) are added together horizontally (P_i).

4. The relative rationality values of each alternative (neighborhood) are added together vertically (N_j), and the alternative's "losses" are calculated.
5. The rational alternative:
   - Is the one that corresponds to the largest term of the last column in Matrix B in the case of the Borda method [82,83];
   - Is the alternative that produces the largest value when the "losses" (N_j) are subtracted from the sum of its rationalities (P_i) in case of Copeland's method [84,85].

Table 5. The ranks and their averages produced by different MCDM methods.

Methods / Alternatives	$\mathbf{M_1}$	$\mathbf{M_2}$	...	$\mathbf{M_k}$	Average Ranking
a_1	S_{11}	S_{12}	...	S_{1k}	S_1
a_2	S_{21}	S_{22}	...	S_{2k}	S_2
...	...	...	...	...	...
a_n	S_{n1}	S_{n2}	...	S_{nk}	S_n

Table 6. An example of Matrix B.

Alternative (Neighborhood)	Alternative (Neighborhood)				P_i
	a_1	a_2	...	a_n	
a_1	-	a_{12}	...	a_{1n}	P_1
a_2	a_{21}	-	...	a_{2n}	P_2
...	...	...	...	...	...
a_n	a_{n1}	a_{n2}	...	-	P_n
N_j	N_1	N_2	...	N_n	

7. Results Produced by the MCDM Methods

The questionnaire comprised four stages: an overall assessment of sustainable development areas (the economic environment, the social environment and the environmental dimension), an assessment of the individual factors of the economic environment, an assessment of the individual factors of the social environment and an assessment of the individual factors of the environmental dimension. The criteria were ranked according to their importance for assessment purposes. Table 7 presents the results of the expert judgement. Experts have applied the weights-direct-determination method. Each expert judgment totals 100%. The methodology is described in Section 5.2. The authors use Equation (10).

The Kendall [86] rank correlation theory was applied to verify the concordance of the expert judgement. The assessment was performed using the table of the expert rankings of the criteria. The opinions were in concordance in all of the assessments. The concordance coefficient $W = 0.285$ for the assessments of the economic environment and the respective value $\chi^2 = 14.83$ of criteria χ^2 is above the critical value $\chi^2_{kr} = 9.488$ taken from the χ^2 distribution table with $\nu = 5 - 1 = 4$ degrees of freedom, and the significance $\alpha = 0.05$; thus, the concordance of the expert judgement was assumed statistically. For the social environment, the values are $W = 0.625, \chi^2 = 36.55$ ($\chi^2_{kr} = 9.488$), and for the environmental dimension, the values are $W = 0.346, \chi^2 = 13.50$ ($\chi^2_{kr} = 7.815; \nu = 3$). The impact of each environment compared shows $W = 0.290, \chi^2 = 7.538$ ($\chi^2_{kr} = 5.991; \nu = 2$). To determine the criteria weights, the experts made a direct assessment of their importance, i.e., the sum total of the weights of all assessments c_{jk} by each expert must be equal to one, or 100%. The assessments of the individual criteria may repeat. Tables 8–13 present the results of the objective, subjective and overall weights determined for each area of sustainable development (economic, social and environmental).

Table 7. Expert judgement.

	Expert	1	2	3	4	5	6	7	8	9	10	11	12	13	Subjective Weight
	Judgement	%	%	%	%	%	%	%	%	%	%	%	%	%	
Areas of sustainable development	Economic environment factors	50	45	50	40	35	25	35	45	50	50	50	45	30	**0.4231**
	Social environment factors	30	30	25	25	25	40	20	20	20	30	15	20	50	**0.2692**
	Environmental factors	20	25	25	35	40	35	45	35	30	20	35	35	20	**0.3077**
Economic environment factors	Housing price (Eur/m^2)	10	15	50	40	55	10	35	40	40	25	30	35	35	**0.3231**
	Population density	30	25	20	25	12	26	20	15	25	15	10	15	18	**0.1969**
	Density of single-family and two-family houses	20	10	5	5	8	19	5	10	5	10	30	20	12	**0.1223**
	Density of blocks of flats	25	20	20	20	15	31	15	20	20	20	25	20	10	**0.2008**
	Number of jobs	15	30	5	10	10	14	25	15	10	30	5	10	25	**0.1569**
Social environment factors	Number of educational institutions (except for kindergartens)	9	30	30	20	15	30	20	15	25	20	20	20	16	**0.2077**
	Number of places in kindergartens	20	25	30	25	20	15	15	15	15	22	15	25	14	**0.1969**
	Number of healthcare institutions	30	16	5	15	25	20	25	10	15	18	5	5	10	**0.1531**
	Number of recreational facilities	1	9	5	10	5	10	10	10	10	15	10	10	20	**0.0962**
	Annual crime rates	40	20	30	30	35	25	30	50	35	25	50	40	40	**0.3462**
Environmental dimension factors	Air pollution NO_2	14	20	10	17	20	35	10	15	20	20	30	25	15	**0.2238**
	Noise	16	35	20	25	30	21	15	30	20	35	30	35	35	**0.2669**
	Distance to the city center	50	15	50	23	22	19	35	20	30	20	10	10	20	**0.2415**
	Green spaces (maintained large parks and small green urban spaces)	20	30	20	35	28	25	40	35	30	25	30	30	30	**0.2677**

Table 8. Determining the weights of the economic environment criteria.

	Entropy	CILOS	IDOCRIW	Subjective Weights	Overall Weights
Housing prices	0.1879	0.2132	0.2304	0.3231	0.3478
Population density	0.2970	0.1933	0.3303	0.1969	0.3039
Density of single-family and two-family houses	0.0308	0.3188	0.0564	0.1223	0.0322
Density of blocks of flats	0.2196	0.1369	0.1729	0.2008	0.1622
Number of jobs	0.2648	0.1378	0.2099	0.1569	0.1539

In Tables 8, 10 and 12, the weight was calculated using the following equations: entropy (1)–(4), CILOS (5)–(8), IDOCRIW (9), subjective weights (10) and overall weights (11). The overall ranking in Tables 9, 11 and 13 was determined by using the "sum of ranks" (the lower the sum of ranks is, the better ranking the neighborhood has).

For the economic environment, price (0.3478) and population density (0.3039) have the biggest impact on the assessments of a healthy and safe built environment (Table 8). The density of single-family and apartment buildings has the lowest impact (0.0322).

The Vilnius neighborhoods were assessed with the MCDM methods (TOPSIS, COPRAS, SAW and EDAS) using the overall weights. Table 9 sums up the assessment results of the economic environment in the Vilnius neighborhoods for all four MCDM methods. There are minor variations in the priority rankings for TOPSIS, COPRAS, SAW and EDAS. The overall rankings were calculated by adding together the rankings produced by each method. The results were verified using the rank average, Borda count and Copeland's methods [20,82–85]. Notably, all of the assessments produced by these methods matched. The calculations suggest that in terms of the economic environment, Naujamiestis is seen as being the best alternative, followed by Senamiestis and then Paneriai.

The objective, subjective and overall weights of the social environment criteria show that the number of medical institutions has the biggest impact (0.3424), followed by the number of crimes (0.3069) (Table 10). It follows that these criteria are directly related to the assessment of a healthy and safe environment.

After the multiple criteria assessment of 21 neighborhoods in Vilnius using COPRAS, SAW, TOPSIS and EDAS and the verification of the results using the rank average, Borda count and Copeland's methods (Table 11), the priority rankings looked similar. In terms of the social criteria, Senamiestis came first, followed by Antakalnis and then Žvėrynas.

The objective and subjective criteria weights determined for the environmental dimension show some differences (Table 12). The weights determined using the entropy, CILOS and IDOCRIW methods identify different key criteria from those that are compared. When using the entropy method, for instance, proximity to the city center has the biggest weight, while when using the CILOS method, green spaces come on top. The subjective weights determined by the expert judgement are all very similar. Presumably, the experts believe that all of the criteria are important in the assessment of a healthy and safe environment. The overall weights highlight two key criteria that affect the assessment of a healthy and safe built environment; green spaces (0.4976) and air pollution (0.3179).

In terms of the environmental dimension, Senamiestis again ranked best out of the other neighborhoods (Table 13). Senamiestis has plenty of green spaces (Kalnai Park, Bernardinai Garden, Cvirka Square, Kūdros Park and many others), and few other neighborhoods are closer to the city center. The Verkiai neighborhood comes second, followed by Vilkpėdė.

Table 9. The assessment of the economic environment using the MCDM methods.

	COPRAS		SAW		TOPSIS		EDAS		Sum of Ranks	Overall Ranking	Rank Average Ranking	Borda Count Ranking	Cope-Land Ranking
	The Values of the Assessment Criteria	Rank	The Values of the Assessment Criteria	Rank	The Values of the Assessment Criteria	Rank	The Values of the Assessment Criteria	Rank					
1. Antakalnis	0.0545	8	0.0551	7	0.3260	10	0.5107	10	35	9	9	9	9
2. Fabijoniškės	0.0332	15	0.0330	12	0.2611	17	0.2910	17	61	15	15	15	15
3. Grigiškės	0.0338	13	0.0291	14	0.2930	12	0.4257	13	52	13	13	13	13
4. Justiniškės	0.0146	21	0.0149	21	0.0739	21	0.0023	21	84	21	21	21	21
5. Karoliniškės	0.0147	20	0.0151	19	0.2139	18	0.2217	19	76	19	19	19	19
6. Lazdynai	0.0283	17	0.0251	17	0.2682	16	0.3908	16	66	17	17	17	17
7. Naujamiestis	0.1008	2	0.0990	2	0.6708	1	0.9485	1	6	1	1	1	1
8. Naujininkai	0.0546	7	0.0458	8	0.3282	9	0.5235	8	32	7–8	7–8	7–8	7–8
9. Naujoji Vilnia	0.0538	9	0.0456	9	0.3400	7	0.5423	7	32	7–8	7–8	7–8	7–8
10. Paneriai	0.1200	1	0.1753	1	0.3984	5	0.6175	3	10	2–3	2–3	2–3	2–3
11. Pašilaičiai	0.0336	14	0.0316	13	0.2900	13	0.4462	11	51	12	12	12	12
12. Pilaitė	0.0348	12	0.0290	15	0.2850	14	0.4082	14	55	14	14	14	14
13. Rasos	0.0476	10	0.0425	10	0.3391	8	0.5201	9	37	10	10	10	10
14. Senamiestis	0.0813	3	0.0796	3	0.5864	2	0.7827	2	10	2–3	2–3	2–3	2–3
15. Šeškinė	0.0232	18	0.0226	18	0.1906	19	0.2514	18	73	18	18	18	18
16. Verkiai	0.0599	6	0.0543	5	0.3596	6	0.5917	4	21	6	6	6	6
17. Vilkpėdė	0.0300	16	0.0254	16	0.2731	15	0.3947	15	62	16	16	16	16
18. Viršuliškės	0.0161	19	0.0150	20	0.1862	20	0.2209	20	79	20	20	20	20
19. Žirmūnai	0.0394	11	0.0377	11	0.3208	11	0.4402	12	45	11	11	11	11
20. Žvėrynas	0.0656	4	0.0649	4	0.4774	3	0.5652	6	17	4	4	4	4
21. Šnipiškės	0.0603	5	0.0592	6	0.4416	4	0.5737	5	20	5	5	5	5

Table 10. Determining the weights of the social environment criteria.

	Entropy	CILOS	IDOCRIW	Subjective Weights	Overall Weights
Number of educational institutions (except for kindergartens)	0.1185	0.1924	0.1180	0.2077	0.1342
Number of places in kindergartens	0.1439	0.1277	0.0951	0.1969	0.1025
Number of healthcare institutions	0.2638	0.2993	0.4085	0.1531	0.3424
Number of recreational facilities	0.3546	0.1180	0.2165	0.0962	0.1140
Annual crime rate per 1000 residents	0.1192	0.2626	0.1619	0.3462	0.3069

Table 11. The assessment of the social environment using the MCDM methods.

	COPRAS		SAW		TOPSIS		EDAS		Sum of Ranks	Overall Ranking	Rank Average Ranking	Borda Count Ranking	Cope-land Ranking
	The Values of the Assessment Criteria	Rank	The Values of the Assessment Criteria	Rank	The Values of the Assessment Criteria	Rank	The Values of the Assessment Criteria	Rank					
1. Antakalnis	0.0706	2	0.0706	2	0.6994	1	0.7816	2	7	2	2	2	2
2. Fabijoniškės	0.0381	17	0.0381	16	0.3556	17	0.2984	17	67	17	17	17–18	17
3. Grigiškės	0.0437	12	0.0437	12	0.3816	13	0.3710	11	48	12	12	13–14	12–13
4. Justiniškės	0.0511	8	0.0511	8	0.4556	8	0.4906	8	32	8	8	8	8
5. Karoliniškės	0.0438	11	0.0438	11	0.3862	12	0.3908	10	44	11	11	11	11
6. Lazdynai	0.0463	10	0.0463	10	0.4006	10	0.3703	12	42	10	10	10	10
7. Naujamiestis	0.0579	4	0.0579	4	0.5358	7	0.5575	6	21	5	5	5	5
8. Naujininkai	0.0316	19	0.0316	19	0.1872	20	0.0895	20	78	19–20	19–20	19–20	19–20
9. Naujoji Vilnia	0.0356	18	0.0356	18	0.2984	18	0.2782	18	72	18	18	17–18	18
10. Paneriai	0.0425	13	0.0425	13	0.3752	14	0.3054	15	55	14	14	13–14	14
11. Pašilaičiai	0.0419	15	0.0419	15	0.3970	11	0.3620	13	54	13	13	12	12–13
12. Pilaitė	0.0471	9	0.0471	9	0.4205	9	0.3914	9	36	9	9	9	9
13. Rasos	0.0307	20	0.0307	20	0.2363	19	0.1129	19	78	19–20	19–20	19–20	19–20
14. Senamiestis	0.0781	1	0.0781	1	0.6718	2	0.8023	1	5	1	1	1	1
15. Šeškinė	0.0397	16	0.0357	17	0.3613	15	0.3038	16	64	16	16	16	16
16. Verkiai	0.0571	5	0.0571	5	0.5810	5	0.5977	4	19	4	4	4	4
17. Vilkpėdė	0.0569	6	0.0569	6	0.6043	3	0.5507	7	22	6	6	6	6
18. Viršuliškės	0.0423	14	0.0423	14	0.3593	16	0.3617	14	58	15	15	15	15
19. Žirmūnai	0.0549	7	0.0549	7	0.5422	6	0.5931	5	25	7	7	7	7
20. Žvėrynas	0.0625	3	0.0625	3	0.5862	4	0.7127	3	13	3	3	3	3
21. Šnipiškės	0.0277	21	0.0277	21	0.1507	21	0.0293	21	84	21	21	21	21

Table 12. Determining the weights of the environmental criteria.

	Entropy	CILOS	IDOCRIW	Subjective Weights	Overall Weights
Air pollution NO_2	0.2470	0.2934	0.3520	0.2238	0.3179
Noise	0.2517	0.0147	0.0180	0.2669	0.0194
Distance to the city center	0.3403	0.1026	0.1695	0.2415	0.1652
Green spaces (maintained large parks and small green urban spaces)	0.1609	0.5894	0.1606	0.2677	0.4976

Table 13. The assessment of the environmental dimension using the MCDM methods.

	COPRAS		SAW		TOPSIS		EDAS		Sum of Ranks	Overall Ranking	Rank Average Ranking	Borda Count Ranking	Cope-Land Ranking
	The Values of the Assessment Criteria	Rank	The Values of the Assessment Criteria	Rank	The Values of the Assessment Criteria	Rank	The Values of the Assessment Criteria	Rank					
1. Antakalnis	0.0518	7	0.0476	10	0.4717	8	0.5524	7	32	8	8	8	8
2. Fabijoniškės	0.0626	5	0.0589	5	0.5891	4	0.6357	5	19	5	5	5	5
3. Grigiškės	0.0128	21	0.0171	21	0.1214	21	0.0159	21	84	21	21	21	21
4. Justiniškės	0.0277	15	0.0279	15	0.3467	16	0.3344	15	61	16	16	16	16
5. Karoliniškės	0.0453	10	0.0423	11	0.4556	9	0.4972	9	39	9	9	9	9
6. Lazdynai	0.0244	16–17	0.0222	18	0.3385	17	0.2738	17	68.5	17	17	17	17
7. Naujamiestis	0.0456	9	0.0495	9	0.4208	11	0.4126	11	40	10	10	10–11	10
8. Naujininkai	0.0341	13	0.0293	14	0.3815	14	0.3657	13	54	13	13	13	13
9. Naujoji Vilnia	0.0244	16–17	0.0240	17	0.2527	19	0.2359	19	71.5	18	19	19	19
10. Paneriai	0.0157	20	0.0172	20	0.1882	20	0.1360	20	80	20	20	20	12
11. Pašilaičiai	0.0402	11	0.0379	12	0.4093	12	0.4553	10	45	12	12	12	30
12. Pilaitė	0.0206	19	0.0196	19	0.3209	18	0.2682	16	72	19	18	18	18
13. Rasos	0.0514	8	0.0546	8	0.5101	7	0.5369	8	31	7	7	7	7
14. Senamiestis	0.1214	1	0.1238	1	0.9604	1	0.9997	1	4	1	1	1	1
15. Šeškinė	0.0621	6	0.0570	6	0.5407	6	0.6152	6	24	6	6	6	6
16. Verkiai	0.1016	3	0.0979	2	0.8758	2	0.9158	2	9	2	2	2	2
17. Vilkpėdė	0.1019	2	0.0961	3	0.8446	3	0.8835	3	11	3	3	3	3
18. Viršuliškės	0.0646	4	0.0625	4	0.5787	5	0.6500	4	17	4	4	4	4
19. Žirmūnai	0.0284	14	0.0256	16	0.3700	15	0.3385	11	56	14–15	14–15	14–15	15
20. Žvėrynas	0.0400	12	0.0590	7	0.4212	10	0.3887	14	43	11	11	10–11	11
21. Šnipiškės	0.0234	18	0.0297	13	0.3830	13	0.2725	12	56	14–15	14–15	14–15	14

Calculations suggest that 21 neighborhoods in Vilnius rank very differently according to the economic, social and environmental criteria. This is only natural. The Antakalnis neighborhood, for instance, ranks ninth according to its economic environment, second according to its social environment and eighth according to its environmental dimension. The impact of each environment on the overall assessment varies. The overall weight given by 13 experts to the economic environment is ω_1 = 0.4231. The value is ω_2 = 0.2692 for the social environment and ω_3 = 0.3077 for the environmental dimension. With subjective weights, the individual MCDM methods are combined for neighborhood assessments. This time, the decision matrixes contain the criteria values produced by the individual MCDM methods for the economic environment, the social environment and the environmental dimension. All of the methods in this research rank the highest value as the best, which means that all of the criteria are maximizing. Hence, the rankings produced by SAW and COPRAS match. Next, the economic environment, the social environment and the environmental dimension were assessed and the overall ranking produced using COPRAS, SAW, TOPSIS and EDAS. Now let us look at the results produced by the EDAS methods as an example (Table 14). Using COPRAS, SAW and TOPSIS, the results were calculated likewise.

Table 14. EDAS assessments for the economic environment, the social environment, the environmental dimension and the overall rankings.

	Economic Environment Factors ω_1 = 0.4231	Social Environment Factors ω_2 = 0.2692	Environmental Factors ω_3 = 0.3077	EDASThe Overall Values of the Assessment Criteria	Overall Rank
1. Antakalnis	0.5107	0.7816	0.5524	0.6888	4
2. Fabijoniškės	0.2910	0.2984	0.6357	0.3339	10
3. Grigiškės	0.4257	0.3710	0.0159	0.1469	20
4. Justiniškės	0.0023	0.4906	0.3344	0.0266	21
5. Karoliniškės	0.2217	0.3908	0.4972	0.2790	17
6. Lazdynai	0.3908	0.3703	0.2738	0.2826	16
7. Naujamiestis	0.9485	0.5575	0.4126	0.7658	3
8. Naujininkai	0.5235	0.0895	0.3657	0.2590	18
9. Naujoji Vilnia	0.5423	0.2782	0.2359	0.3042	13
10. Paneriai	0.6175	0.3054	0.1360	0.2951	14
11. Pašilaičiai	0.4462	0.3620	0.4553	0.4454	8
12. Pilaitė	0.4082	0.3914	0.2682	0.3081	12
13. Rasos	0.5201	0.1129	0.5369	0.3634	9
14. Senamiestis	0.7827	0.8023	0.9997	1.0000	1
15. Šeškinė	0.2514	0.3038	0.6152	0.2940	15
16. Verkiai	0.5917	0.5977	0.9158	0.7978	2
17. Vilkpėdė	0.3947	0.5507	0.8835	0.6423	5
18. Viršuliškės	0.2209	0.3617	0.6500	0.3160	11
19. Žirmūnai	0.4402	0.5931	0.3385	0.4623	7
20. Žvėrynas	0.5652	0.7127	0.3887	0.6099	6
21. Šnipiškės	0.5737	0.0293	0.2725	0.1858	19

Based on the EDAS results, overall, the Senamiestis neighborhood comes first, followed by Verkiai and then Naujamiestis. The analysis of the rankings according to different environments, however, shows that Naujamiestis ranked first according to the economic criteria, tenth according to the social criteria and fifth according to the environmental criteria. The MCDM methods are a way of assessing the impact of each environment on the overall result.

8. The Assessment Results of the Vilnius Neighborhoods

The application of multiple criteria assessment with COPRAS, SAW, TOPSIS and EDAS produces different priority rankings. The overall results were calculated using the rank average, Borda count and Copeland's methods [20,82–85]. Table 15 shows the priority rankings determined by COPRAS, SAW, TOPSIS and EDAS, plus the rank average, Borda count and Copeland's methods.

Table 15. The priority rankings compared.

	COPRAS Priority Ranking	SAW Priority Ranking	TOPSIS Priority Ranking	EDAS Priority Ranking	Rank Average Priority Ranking	Borda Count Priority Ranking	Copeland's Priority Ranking
Antakalnis	5	5	6	4	4	4	4
Fabijoniškės	9	9	11	10	10	10	10
Grigiškės	20	20	20	20	20–21	20–21	20–21
Justiniškės	19	19	21	21	20–21	20–21	20–21
Karoliniškės	17	17	19	17	18	18	18
Lazdynai	19	19	17	16	19	19	19
Naujamiestis	3	3	2	3	2	2	2
Naujininkai	13	13	13	18	14–15	14–15	14–15
Naujoji Vilnia	15	15	14	13	14–15	14–15	14–15
Paneriai	2	2	10	14	7	6–7	6–7
Pašilaičiai	16	16	12	8	13	13	13
Pilaitė	18	18	15	12	17	17	17
Rasos	8	8	9	9	8	8	8
Senamiestis	1	1	1	1	1	1	1
Šeškinė	14	14	18	15	16	16	16
Verkiai	4	4	3	2	3	3	3
Vilkpėdė	6	6	5	5	5	5	5
Viršuliškės	12	12	16	11	12	12	12
Žirmūnai	11	11	8	7	9	9	9
Žvėrynas	7	7	4	6	6	6–7	6–7
Šnipiškės	10	10	7	19	11	11	11

The calculations of the overall results show that the rank average, Borda count and Copeland's methods produce matching results. The assessment of 21 neighborhoods in Vilnius using COPRAS, SAW, TOPSIS and EDAS suggests that Senamiestis is the healthiest and safest neighborhood compared to the others with reference to the principles of sustainable development.

9. Discussion and Conclusions

This article aims to assess the built environment in view of the principles of sustainable development with a focus on a healthy and safe environment. Many multiple criteria analysis methods such as AHP, ELECTRE, TOPSIS, COPRAS and ANP can be applied to analyze a sustainable built environment. However, the results they produce for the same problem with identical criteria, values and weights are often different. In search of a more reliable tool, this study proposes that a system of MCDM methods should be applied to a single problem. COPRAS, SAW, TOPSIS and EDAS were used for the assessment of 21 neighborhoods in Vilnius. Their priority was ranked, and the results differed. The overall results were calculated using the rank average, Borda count and Copeland's method. The results for all three methods are identical, so the proposed system of MCDM methods could be applied for the assessment of a sustainable built environment. For future discussion, a developed criteria system of sustainable development with a focus on a healthy and safe environment could be extended by integrating cultural, ethical, psychological, religious, emotional and other dimensions, which are important for the creation of a sustainable community.

The assessment of a healthy and safe built environment leads to the following conclusions:

1. The literature analysis determined that the development of a healthy and safe built environment must rest on the key principles of sustainable development, i.e., the integration of the economic environment, the social environment and the environmental dimension.
2. A sustainable built environment is an inseparable component of sustainable community building. Communities should have hospitals, schools, green spaces, public transport and other facilities within easy reach. The community must feel safe and healthy.

3. The assessment criteria for a healthy and safe built environment were classified according to the key principles of sustainable development. The economic environment and the social environment were assessed against five criteria; the environmental dimension was assessed against four criteria.
4. The objective weights of the criteria for a healthy and safe built environment were determined using the entropy, CILOS and IDOCRIW methods. The subjective weights were determined based on expert judgement, with 13 experts involved. All of the assessments produced concordance of opinion. The objective and subjective weights were integrated to produce the overall weights that ensure a more reliable assessment of the significance the criteria have in the context of sustainable development. According to overall criteria weights, price and population density play the biggest role in the assessment of a healthy and safe built environment in the economic environment. Out of the social environment criteria, the number of medical institutions and the crime rate have the biggest impact. An analysis of the environmental dimension criteria shows that green spaces and air pollution have the biggest impact on the assessments.
5. The Vilnius neighborhoods were assessed using the MCDM methods such as COPRAS, SAW, TOPSIS and EDAS. The calculations were a two-stage process. The Vilnius neighborhoods were assessed for each environment, and then, an overall assessment was made in the context of a healthy and safe built environment. The calculations show that the assessments of 21 neighborhoods in Vilnius based on economic, social and environmental criteria differ due to the different impact each environment has on the overall assessment results. In terms of the economic environment, Naujamiestis ranked the highest. In terms of the social environment and environmental protection, Senamiestis was rated the best.
6. The results for all three methods (the rank average, Borda count and Copeland's) are identical. It follows that Senamiestis is the healthiest and safest neighborhood compared to the others with reference to the principles of sustainable development.

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